# SPECIES COMPOSITION AND SEASONAL VARIATION OF PERACARIDS (CRUSTACEA: PERACARIDA) OF THE ISTANBUL STRAIT (TURKEY)

MÜLAYİM, A.

*Department of Biology, Faculty of Science, Istanbul University, 34134 Vezneciler, Istanbul, Turkey*
*(e-mail: aysegulm@istanbul.edu.tr; phone: +90-532-597-8093)*

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**Abstract.** The Istanbul Strait connects the Black Sea with the Sea of Marmara and it has a two-layered water system. In this study, we determined the diversity of the Peracarid Crustacean fauna and the ecological characteristics of the area. The data produced in this study revealed 76 peracarid species in the Istanbul Strait, of which five species (*Animoceradocus semiserratus* (Spence Bate.1862), *Echinogammarus stocki* G. Karaman, 1973, *Leptocheirus bispinosus* Norman, 1908, *Cymodoce spinosa* (Risso, 1816), *Gnathia dentata* (G. O. Sars, 1872)) were reported for the first time in the Sea of Marmara. The physicochemical properties of the seawater as well as total organic and inorganic carbon, and mud percentages of the sediment were analyzed at the sampling stations. In these stations, no significant relationship was determined between temperature, salinity, dissolved oxygen parameters and species or individual numbers. However, a positive relationship was found between the mud percentage and species and individual numbers. In contrast, at the hard bottom stations the number of individuals was positively associated with temperature and negatively with dissolved oxygen.

**Keywords:** *Crustacea, species diversity, hard and soft bottom habitats, ecology, Sea of Marmara*

## Introduction

The Istanbul Strait (also known as the Bosphorus) connects the Black Sea with the Sea of Marmara. This strait and the Dardanelles are located at opposite ends in the Sea of Marmara. These straits create a series of passages connecting the Aegean and Mediterranean (via the Dardanelles) to the Sea of Marmara, and ultimately the Black Sea via the Istanbul Strait (Beşiktepe et al., 1995). The Istanbul Strait, like the Sea of Marmara has a two-layered water system. The low-salinity waters of the Black Sea (17.86 PSU) are transported to the Mediterranean Sea through the straits, while the salty Mediterranean waters (37.3 PSU) move as underflow toward the Black Sea (Ünlüata et al., 1990; Orhon, 1995).

The Istanbul Strait has long coastal sides, which are both residential and social facilities are highly concentrated (Usluer and Alkan, 2016). Moreover, the Istanbul Strait is the narrowest strait used for international navigation in the world and the maritime traffic is dense (Birpınar et al., 2009). This means that pollution by sea is visible in the strait. In addition, as a large metropolis, Istanbul is a focal point of terrestrial pollution (Orhon, 1995). Therefore, monitoring of marine fauna and flora of this region is of critical importance.

The superorder Peracarida is a major component of marine benthic ecosystems and has a regionally high population density (Thiel and Hinojosa, 2009). They also dominate other groups of organisms in terms of individual number and species diversity (Guerra-García et al., 2009). Some species are highly sensitive indicators due to their predominance and sensitivity to pollutants and are frequently used as bioindicators in biological monitoring studies (Chintiroglou et al., 2004; Dauvin and Ruellet, 2007).

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Therefore, the monitoring of peracarid fauna is useful for understanding the effects of ecological changes on benthic fauna (Moreira et al., 2008).

Studies involving peracarids in the Istanbul Strait begin with Sowinsky (1897). Subsequent studies were conducted by Demir (1952), Caspers (1968), Băcescu (1982), Topaloğlu and Kihara (1993), Balkıs et al. (2002), Uysal et al. (2002), Kalkan et al. (2006), Kalkan et al. (2007), Aslan-Cihangir and Panucci-Papadopolou (2011), Öktener, Trilles (2004) and Bakır et al. (2016). Balkıs et al. (2016) conducted an extensive review of studies on Malacostraca crustaceans in the Turkish Strait System in which they listed 274 species of peracarid crustacean.

This study determined peracarid species diversity in the Istanbul Strait and explored its relationship with several environmental variables. Moreover, this study will elucidate the seasonal variation of peracarid biodiversity.

## Materials and methods

### *Sampling*

Sampling was performed seasonally between 22 and 23 July 2015, 27 and 28 October 2015, 1-4 February 2016 and 1-9 May 2016 at 34 stations (*Table 1; Fig. 1*). Peracarid samples were collected from the hard bottom with a 20 × 20 cm quadrat using a spatula, and a Van Veen Grab with 0.1 $m^2$ sampling capacity from the soft bottom. Three replicates were collected from each station. Benthic samples were sieved with 0.5 mm mesh and stored in a 4% formaldehyde solution prepared with seawater. Hard bottom sampling was performed at 13 stations (0.5 m) near the shores of the Istanbul Strait at sites unaltered by shore filling. Appropriate stations for sampling are difficult to find due to the extensive coastal filling of the strait. Soft bottom samples were collected from 21 stations at 11 localities in the Istanbul Strait and samples were taken from two depths (18.2 m and 36.4 m). As mentioned in the introduction, there is a two-layered water system in the Sea of Marmara. The upper water layer is the Black Sea (low salinity) and the lower water layer is the Mediterranean Sea (high salinity) and this two layer don't with each other due to different densities of salinity, but form a salinity intermediate water (halocline) at 25 m depth of the Sea of Marmara (Beşiktepe et al., 1995). Depths (18.2 m and 36.4 m) were chosen to ensure sampling captured faunal differences between the Black Sea and Mediterranean waters. These two depths have different salinity and dissolved oxygen conditions.

### *The physicochemical parameters*

Temperature, dissolved oxygen, and salinity values of the seawater were measured using a YSI brand multiparameter device. Sediment samples were collected with a plastic spoon from the upper layer of sediment at the depths specified above, placed into nylon bags and stored at -20 °C in a deep freezer. Since hard bottom samples were taken from algae and mussel rocks, mud samples were not available for total organic carbon (TOC) and total inorganic carbon (TIC) analyses. Thus, TOC, TIC and mud percentage values were obtained only for soft bottom surface sediment samples. TOC and TIC analyses were performed according to the Walkey-Blake method (Gaudette et al., 1974; Loring and Rantala, 1992). The mud percentage of sediment samples for the stations studied were determined according to the Galehouse (1971) and Mc Manus (1991) methods.

***Table 1.*** *Stations, coordinates, depth, and biotope properties of the sampling stations in the Istanbul Strait*

| Station | Station area | Latitude | Longitude | Depth (m) | Substrate type | Sampling device |
|---|---|---|---|---|---|---|
| 1 | Garipçe Shore | 41°12’799” | 29°06’564” | 0.5 | Hard Bottom | Quadrat |
| 2 | Rumeli Kavağı Shore | 41°10’670” | 29°04’451” | 0.5 | Hard Bottom | Quadrat |
| 3 | Sarıyer Shore | 41°09’792” | 29°02’935” | 0.5 | Hard Bottom | Quadrat |
| 4 | Tarabya Shore | 41°08’202” | 29°03’524” | 0.5 | Hard Bottom | Quadrat |
| 5 | Baltalimanı Shore | 41°05’820” | 29°03’246” | 0.5 | Hard Bottom | Quadrat |
| 6 | Beşiktaş Shore | 41°02’499” | 29º00’623” | 0.5 | Hard Bottom | Quadrat |
| 7 | Anadolufeneri Shore | 41°12’878” | 29º09’131” | 0.5 | Hard Bottom | Quadrat |
| 8 | Poyraz Shore | 41°12’296” | 29°07’903” | 0.5 | Hard Bottom | Quadrat |
| 9 | Anadolukavağı Shore | 41°10’3491” | 29°05’308” | 0.5 | Hard Bottom | Quadrat |
| 10 | Paşabahçe Shore | 41°07’302” | 29°05’846” | 0.5 | Hard Bottom | Quadrat |
| 11 | Anadoluhisarı Shore | 41°04’788” | 29°03’899” | 0.5 | Hard Bottom | Quadrat |
| 12 | Kuleli Shore | 41°03’613” | 29°03’164” | 0.5 | Hard Bottom | Quadrat |
| 13 | Kuzguncuk Shore | 41°02’283” | 29°01’873” | 0.5 | Hard Bottom | Quadrat |
| 14 | Garipçe 1 | 41°12’828” | 29°06’771” | 18.2 | Soft Bottom | Van Veen Grab |
| 15 | Garipçe 2 | 41°12’663” | 29°06’907” | 36.4 | Soft Bottom | Van Veen Grab |
| 16 | İstinye 1 | 41°06’766” | 29°03’619” | 18.2 | Soft Bottom | Van Veen Grab |
| 17 | İstinye 2 | 41°06’670” | 29°03’772” | 36.4 | Soft Bottom | Van Veen Grab |
| 18 | Bebek 1 | 41°04’676” | 29°02’941” | 18.2 | Soft Bottom | Van Veen Grab |
| 19 | Bebek 2 | 41°04’717” | 29°03’056” | 36.4 | Soft Bottom | Van Veen Grab |
| 20 | Ortaköy 1 | 41°02’824” | 29°01’557” | 18.2 | Soft Bottom | Van Veen Grab |
| 21 | Ortaköy 2 | 41°02’795” | 29°01’609” | 36.4 | Soft Bottom | Van Veen Grab |
| 22 | Karaköy 1 | 41°01’428” | 28°58’822” | 18.2 | Soft Bottom | Van Veen Grab |
| 23 | Karaköy 2 | 41°01’420” | 28°58’835” | 36.4 | Soft Bottom | Van Veen Grab |
| 24 | Salacak | 41°01’020” | 29°00’202” | 18.2 | Soft Bottom | Van Veen Grab |
| 25 | Çengelköy 1 | 41°02’962” | 29°03’051” | 18.2 | Soft Bottom | Van Veen Grab |
| 26 | Çengelköy 2 | 41°03’015” | 29°03’027” | 36.4 | Soft Bottom | Van Veen Grab |
| 27 | Anadoluhisarı 1 | 41°04’760” | 29°03’844” | 18.2 | Soft Bottom | Van Veen Grab |
| 28 | Anadoluhisarı 2 | 41°04’736” | 29°03’803” | 36.4 | Soft Bottom | Van Veen Grab |
| 29 | Paşabahçe 1 | 41°07’255” | 29°05’598” | 18.2 | Soft Bottom | Van Veen Grab |
| 30 | Paşabahçe 2 | 41°07’216” | 29°05’322” | 36.4 | Soft Bottom | Van Veen Grab |
| 31 | Anadolukavağı 1 | 41°10’375” | 29°05’273” | 18.2 | Soft Bottom | Van Veen Grab |
| 32 | Anadolukavağı 2 | 41°10’288” | 29°05’222” | 36.4 | Soft Bottom | Van Veen Grab |
| 33 | Keçilik 1 | 41°11’841” | 29°07’102” | 18.2 | Soft Bottom | Van Veen Grab |
| 34 | Keçilik 2 | 41°11’846” | 29°07’037” | 36.4 | Soft Bottom | Van Veen Grab |

### *Statistical methods*

The Soyer (1970) frequency index (Fi) and the dominance index (Di) formula of Bellan-Santini (1969), respectively, were used to determine the frequency and dominance of peracarid species in the study area. The species were classified into three groups: Constant (Fi ≥ 50%), Common ($50\% > F_i \geq 25\%$), and Rare ($F_i < 25\%$), according to their frequency indexes. The Bray-Curtis similarity index and multi-dimensional scaling (MDS) methods were used to determine similarities between sampling stations and to resolve regional distribution models, respectively. R value was calculated by using ANOSIM (similarity analysis) in order to test the significant differences between the groups formed in each season for both substrates. After bulk analysis, the similarities or differences within each group and the percentage contribution of each species to the similarities and differences among the resulting groups were identified using SIMPER analysis. We used Primer 6 program for these analyses (Clarke and Warwick, 2001). Relationships with abiotic parameters were revealed using the Spearman rank correlation coefficient method with IBM Statistics Version 21 (Siegel, 1956). We calculated the Shannon-Weaver Diversity Index (*H'*) using a composite of number of species and individuals at the sampling stations (Zar, 1984).

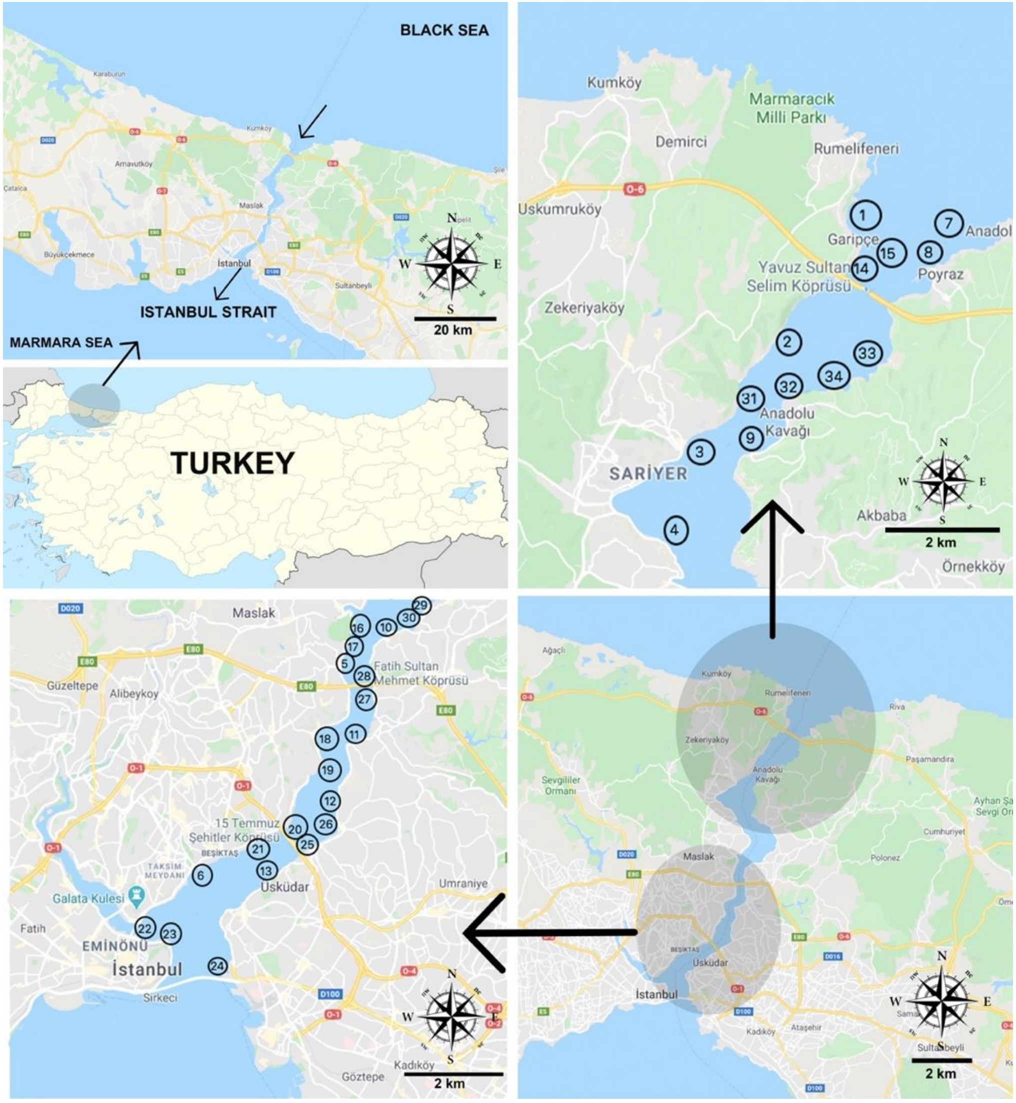

***Figure 1.*** *Map of the sampling stations. Hard bottom station: 1. Garipçe Shore 2. Rumeli Kavağı Shore 3. Sarıyer Shore 4. Tarabya Shore 5. Baltalimanı Shore 6. Beşiktaş Shore 7. Tarabya Shore 8. Poyraz Shore 9. Anadolukavağı Shore 10. Paşabahçe Shore 11. Anadoluhisarı Shore 12. Kuleli Shore 13. Kuzguncuk Shore. Soft bottom station: 14. Garipçe 1 15. Garipçe 2 16. İstinye 1 17. İstinye 2 18. Bebek 1 19. Bebek 2 20. Ortaköy 1 21. Ortaköy 2 22. Karaköy 1 23. Karaköy 2 24. Salacak 25. Çengelköy 1 26. Çengelköy 2 27. Anadoluhisarı 1 28. Anadoluhisarı 2 29. Paşabahçe 1 30. Paşabahçe 2. 31. Anadolukavağı 1 32. Anadolukavağı 2 33. Keçilik 1 34. Keçilik 2*

## Results

This study identified 76 peracarid crustacean species representing five orders (*Table 2*). *Animoceradocus semiserratus* (Spence Bate, 1862), *Echinogammarus stocki* G. Karaman, 1970, *Leptocheirus bispinosus* Norman, 1908, *Cymodoce spinosa* (Risso, 1816), and *Gnathia dentata* (G. O. Sars, 1872) were new records for the Sea of Marmara. Examining the taxonomic distribution, we observed that most of the species obtained across all samples belong to the order Amphipoda (*Fig. 2*). Species belonging to the orders Amphipoda, Isopoda, and Tanaidacea were found in hard bottom samples, but not species belonging to the orders Mysidacea or Cumacea. Amphipod species are dominant on the soft bottom, but peracarid species of Isopoda, Cumacea, Tanaidacea, and Mysidacea were also found, in order of decreasing occurrence.

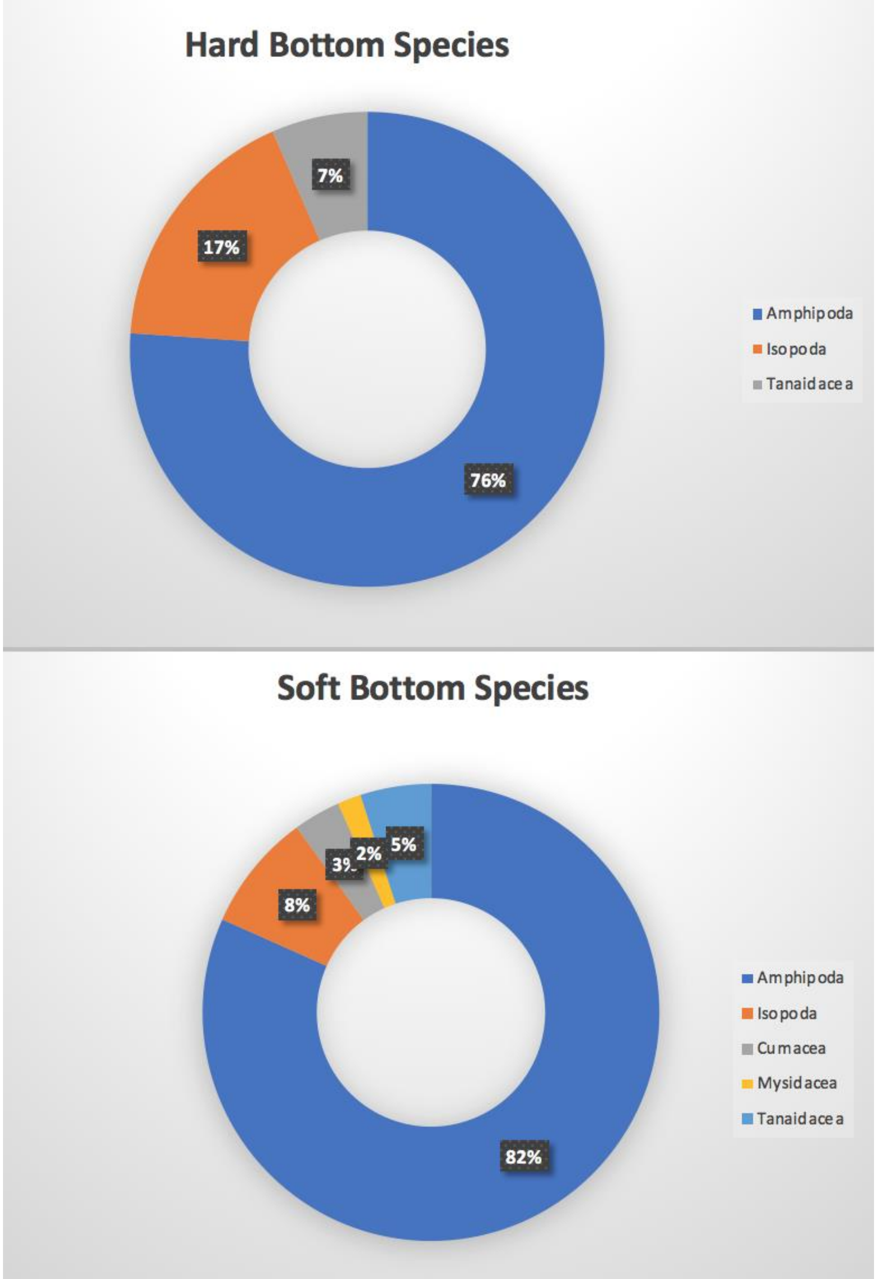

***Figure 2.*** *The distribution of species by orders*

***Table 2.*** *Peracarid Crustacean species of the Istanbul Strait and average individual numbers. Habitat type: Hs: Hard substratum, Mytilus with algae Ss: Soft substratum*

| SPECIES | SUMMER | AUTUMN | WINTER | SPRING |
|---|---|---|---|---|
| AMPHIPODA | | | | |
| *Ampelisca diadema* (Costa. 1853) | Ss:7 | | | Ss:3 |
| *Ampelisca multispinosa* Bellan-Santini & Kaim-Malka. 1977 | | | | Ss:3 |
| *Ampelisca pseudosarsi* Bellan-Santini & Kaim-Malka. 1977 | Ss:3 | | | |
| *Amphilochus brunneus* Della Valle. 1893 | | Ss:33 | Ss:23.3 | Ss: 43 |
| *Ampithoe ramondi* Audouin. 1826 | Hs:75039.9 | Hs: 586.7 | Hs:46.7<br>Ss:6.6 | Hs:540 |
| **Animoceradocus semiserratus* (Spence Bate.1862) | Ss:27 | | | |
| *Aora gracilis* (Spence Bate. 1857) | Hs:6.7 | | Hs:6.7 | |
| *Apherusa chiereghinii* Giordani- Soika. 1949 | | | | Hs:200 |
| *Apherusa mediterranea* Chevreux. 1911 | | | | Hs:106.7 |
| *Apocorophium acutum* (Chevreux. 1908) | Hs:3853.3<br>Ss:319 | Hs:13.3<br>Ss:2094 | Hs:6<br>Ss:263.2 | Hs:286.7<br>Ss: 339 |
| *Apolochus picadurus* (J.L. Barnard. 1962) | Ss:10 | | | Ss:3 |
| *Caprella acanthifera* Leach. 1814 | Ss:67 | Hs:333.3 | | Hs:86.7<br>Ss:7 |
| *Caprella danilevskii* Czerniavski. 1868 | | Hs:6.7 | Ss:13.3 | |
| *Caprella rapax* Mayer. 1890 | | Hs:26.7 | | |
| *Centraloecetes dellavallei* (Stebbing. 1899) | Ss:10 | | | |
| *Chelura terebrans* Philippi. 1839 | | | | Ss:103 |
| *Colomastix pusilla* Grube. 1861 | Ss:17 | | | Ss:33 |
| *Cymadusa crassicornis (Costa. 1853)* | | | | H:13.3<br>Ss:87 |
| *Deflexilodes gibbosus* (Chevreux. 1888) | Ss:3 | | Ss:6.7 | |
| *Dexamine spiniventris* (Costa. 1853) | Ss:3 | | | Hs:566.6 |
| *Dexamine spinosa* (Montagu. 1813) | Hs:6.6<br>Ss:3 | Hs:60 | Ss:3.3 | Hs:513.3<br>Ss:3 |
| *Echinogammarus foxi* (Schellenberg. 1928) | Hs: 3080 | Hs:120 | Hs:20 | |
| *Echinogammarus olivii* (H. Milne Edwards. 1830) | Hs:58513.3<br>Ss: 7 | Hs:946.7 | Hs:493.3 | Hs:4366.7<br>Ss:6 |
| *Echinogammarus stocki* G. Karaman. 1970 | | | Hs:66.7 | |
| *Elasmopus brasiliensis (Dana. 1855)* | Hs:40 | | | |
| *Elasmopus pocillimanus* (Spence Bate. 1862) | Hs:58033.3<br>Ss:3 | | | |
| *Ericthonius brasiliensis* (Dana. 1853) | Ss:13 | Hs:13.3 | Hs:20 | Hs:40 |
| *Gammarella fucicola* (Leach. 1814) | Ss:16 | Ss:97 | Ss:10 | Ss:97 |
| *Gammarus aequicauda* (Martynov. 1931) | Hs:173.3 | | Hs:6.7 | Hs:13.3 |
| *Gammarus crinicornis Stock. 1966* | Ss: 7 | | | |
| *Gitana sarsi* Boeck. 1871 | | | | Ss:167 |
| *Protohyale (Protohyale) schmidtii* (Heller, 1866) | Hs:178600<br>Ss:36 | Hs:44206.7<br>Ss:6 | Hs:7246.7<br>Ss:6.6 | Hs:29260<br>Ss:3 |
| *Jassa marmorata* Holmes. 1905 | Hs:11319.8<br>Ss:460 | Hs:7826.7<br>Ss:3 | Hs:2853.4 | Hs:8753.2<br>Ss:20 |
| *Jassa ocia* (Spence Bate. 1862) | Hs:333.3<br>Ss:4363 | Ss:873 | Ss:113.3 | Ss:70 |
| **Leptocheirus bispinosus* Norman. 1908 | Ss:123 | Ss:146 | | |
| *Leptocheirus pilosus* Zaddach. 1844 | | | Ss:66.7 | |
| *Maera grossimana* (Montagu. 1808) | | | Ss:6.6 | |
| *Medicorophium rotundirostre* (Stephensen. 1915) | Ss:3 | Ss:3 | | |
| *Megamphopus brevidactylus Myers. 1976* | | Ss:7 | | |
| *Megamphopus cornutus* Norman. 1869 | Ss:7 | | | |
| *Melita palmata* (Montagu. 1804) | Hs:579.9<br>Ss:206 | Ss:103 | Hs:13.4<br>Ss:753.1 | Hs:280<br>Ss:558 |

| | | | | |
|---|---|---|---|---|
| *Microdeutopus algicola* Della Valle. 1893 | | Ss:3 | Ss:56.6 | Hs:26.7 |
| *Microdeutopus anomalus* (Rathke. 1843) | Ss:84 | Ss:359 | Ss:86.7 | Hs:6.7<br>Ss:873 |
| *Microdeutopus gryllotalpa* Costa. 1853 | Hs:940<br>Ss:10 | Ss:20 | Ss:39.9 | Hs:246.7<br>Ss:127 |
| *Microdeutopus obtusatus* Myers. 1973 | | | Ss:3.3 | |
| *Microdeutopus versiculatus* (Spence Bate. 1857) | Ss:580 | Ss:474 | Ss:213.3 | Hs:6.7<br>Ss:1823 |
| *Monocorophium acherusicum* (Costa. 1853) | Ss:7 | Hs:20<br>Ss:3 | Hs:13.3<br>Ss:6.7 | |
| *Monocorophium insidiosum* (Crawford. 1937) | Ss:1020 | Ss:23 | Ss:90 | Hs:6.7 |
| *Nototropis massiliensis* (Bellan-Santini. 1975) | | | Hs:6.7 | Hs:6.7 |
| *Perioculodes longimanus longimanus* (Spence Bate & Westwood. 1868) | Ss:17 | | Ss: 6.6 | Ss:7 |
| *Phtisica marina* Slabber. 1769 | Ss:676 | Hs:26.7<br>Ss:1587 | Ss:616.6 | Hs:26.7<br>Ss:1371 |
| *Pseudoprotella phasma (Montagu. 1804)* | Ss:3 | | | |
| *Stenothoe bosphorana* Sowinsky. 1898 | Ss:7 | | Hs:6.7 | |
| *Stenothoe cavimana* Chevreux. 1908 | Hs:13.3 | Hs:86.6 | Ss:3.3 | Hs:20<br>Ss:3 |
| *Stenothoe elachista Krapp-Schickel. 1975* | | Ss:3.3 | Ss:3.3 | Hs:80 |
| *Stenothoe monoculoides* (Montagu. 1815) | Hs:413.4<br>Ss:1 | | | Hs:2206.7 |
| *Stenothoe tergestina* (Nebeski. 1881) | Hs:266.7 | | | |
| ISOPODA | | | | |
| **Cymodoce spinosa* (Risso. 1816) | | Hs:6.7 | Hs:20 | |
| *Dynamene bidentata* (Adams. 1800) | Hs:673.4 | Hs:926.7 | Hs:20 | Hs:60 |
| *Dynamene bifida* Torelli. 1930 | | | Hs: 6.7 | |
| **Gnathia dentata* (Sars G.O. 1872) | Ss:0.7 | | | |
| *Gnathia maxillaris* (Montagu. 1804) | | Ss:187 | | Ss:16.7 |
| *Gnathia vorax* (Lucas. 1849) | Ss:0.6 | | | Ss:3 |
| *Idotea balthica* (Pallas. 1772) | Hs:81753.3 | Hs:966.8 | Hs:126.7 | Hs:4539.9 |
| *Idotea metallica* Bosc. 1802 | Hs:226.7 | Hs:6.7 | | Hs:1166.7 |
| *Jaera (Jaera) italica* Kesselyak. 1938 | Hs:153.4 | | | |
| *Limnoria lignorum* (Rathke. 1799) | | | | Ss:207 |
| *Paragnathia formica (Hesse. 1864)* | Ss:173 | | | |
| *Sphaeroma serratum* (Fabricius. 1787) | Hs:940 | Hs:546.6 | Hs:26.7 | Hs:133.3 |
| *Stenosoma capito* (Rathke. 1837) | Hs:13.3 | Hs:20 | | |
| CUMACEA | | | | |
| *Iphinoe trispinosa* (Goodsir. 1843) | | Ss:3 | | |
| *Vaunthompsonia cristata* Bate. 1858 | | | Ss:3.3 | |
| MYSIDA | | | | |
| *Haplostylus normani* (G.O. Sars. 1877) | | | Ss:3.3 | |
| TANAIDACEA | | | | |
| *Apseudopsis latreillii* (Milne Edwards. 1828) | Ss:203.8 | Ss:139<br>Hs: 20 | Ss:953.3 | Ss:67.9<br>Hs: 13.3 |
| *Chondrochelia savignyi* (Kroyer. 1842) | Hs: 306.7 | Ss:3 | Ss:3.3 | Hs: 6.7 |
| *Tanais dulongii* (Audouin. 1826) | Hs:33119.8<br>Ss:3 | Hs:2220 | Hs: 1466.6 | Hs: 2773.4 |

*New records for Sea of Marmara

## Hard bottom

A total of 46 species were obtained from hard bottom samples. Analyzing the seasonal distribution of the species, we found that the greatest number of species are obtained in spring samples, followed by summer, autumn and final winter (*Fig. 3*). The number of individuals was positively associated with temperature (r: 0.384 $P < 0.001$). *Protohyale (Protohyale) schmidtii* (Heller, 1866) is the species recording the highest number of individuals throughout the year, with an individual count of up to 178.600 $m^2$ in the summer. Moreover, this species was a dominant and constant species across all seasons in the Strait, according to the dominance and frequency indices (*Fig. 4*).

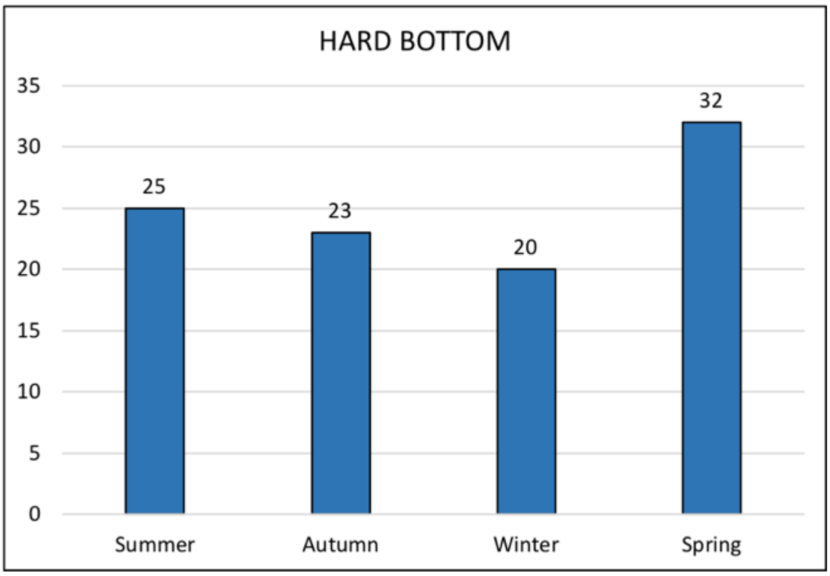

***Figure 3.*** *Seasonal changes of species numbers on the hard bottom*

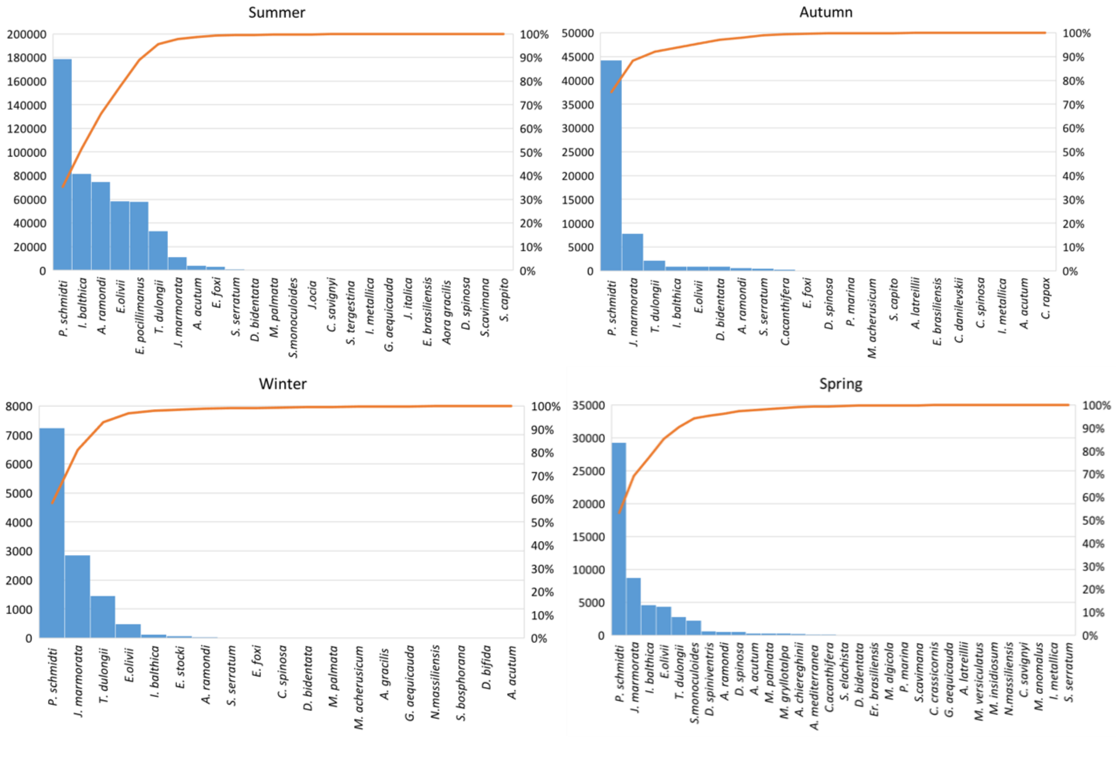

***Figure 4.*** *Seasonal variation of the Peracarid species and individual numbers at the hard bottom stations*

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According to the Frequency and Dominancy Index values, most of 24 species are rare in the summer. Of the remaining species, 4 (*E. pocillimanus*, *M. gryllotalpa*, *D. bidentata*, and *T. dulongii*) are common and another 4 (*E. olivii*, *P. schmidtii*, *J. marmorata* and *I. balthica*) are constant. Of the 22 species obtained in autumn, 15 are rare, 3 (*A. ramondi*, *E. olivii*, *S. serratum*) are common, and 4 (*P. schmidtii*, *J. marmorata*, *I. balthica*, *T. dulongii*) are constant species. In winter, 19 species were obtained, of which 15 were found to be rare species, while 2, *E. olivii* and *I. balthica*, were common, and another 2, *P. schmidtii* and *T. dulongii*, were constant. In the spring, the last season of the study, 24 of 31 species were rare, 2 (*A. acutum*, *A. ramondi*) were common, and 5 (*T. dulongii*, *I. balthica*, *P. schmidtii*, *E. olivii*, *J. marmorata*) were constant species.

*H'* index values are determined as 0 (Autumn station 2 and winter stations 8 and 9) in stations where peracarid species were not found, while the highest *H'* value was 2.42 (Spring station 7) (*Table 3*).

***Table 3.*** *Shannon-Weaver diversity index (H') values for hard and soft bottom stations*

| **HARD BOTTOM** | | | | |
|---|---|---|---|---|
| **Station** | **Summer** | **Autumn** | **Winter** | **Spring** |
| 1 | 1.44 | 0.67 | 2.1 | 0.68 |
| 2 | 0.002 | 0 | 0.68 | 0.42 |
| 3 | 0.72 | 0.45 | 0.93 | 0.11 |
| 4 | 1.73 | 0.37 | 1.0 | 0.70 |
| 5 | 1.04 | 0.60 | 0.69 | 0.75 |
| 6 | 0.69 | 1.33 | 0.32 | 0.73 |
| 7 | 0.28 | 0.26 | 0.54 | 2.42 |
| 8 | 1.45 | 1.03 | 1.08 | 1.51 |
| 9 | 0.52 | 0.003 | 0 | 1.21 |
| 10 | 1.27 | 0.98 | 0 | 0.45 |
| 11 | 1.35 | 0.79 | 1.02 | 1.21 |
| 12 | 1.51 | 1.16 | 0.66 | 0.81 |
| 13 | 1.75 | 0.8 | 0.33 | 0.65 |
| **SOFT BOTTOM** | | | | |
| **Station** | **Summer** | **Autumn** | **Winter** | **Spring** |
| 14 | 1.35 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0.69 |
| 16 | 1.07 | 1.07 | 1.56 | 0 |
| 17 | 1.84 | 1.38 | 1.06 | 1.51 |
| 18 | 0 | 1.1 | 2.17 | 0.58 |
| 19 | 1.01 | 0 | 0 | 0.59 |
| 20 | 1.27 | 2.13 | 1.31 | 1.6 |
| 21 | 2.07 | 0 | 0 | 0 |
| 22 | 2.58 | 2.11 | 0 | 2.45 |
| 23 | 2.55 | 0 | 0 | 0 |
| 24 | 2.74 | 1.80 | 2.03 | 0.87 |
| 25 | 0 | 0.97 | 2.08 | 2.18 |
| 26 | 0 | 1.34 | 2.39 | 1.98 |
| 27 | 0 | 0 | 0 | 0.69 |
| 28 | 0 | 0 | 1.46 | 1.25 |
| 29 | 0 | 0 | 0 | 0.87 |
| 30 | 0.66 | 0 | 1.54 | 0.53 |
| 31 | 0 | 0 | 1.6 | 0.84 |
| 32 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 |

As for similarities between stations, the station groups showing the highest similarity in summer were S4, S7, and S12, as well as S5 and S9 (*Fig. 5*). R values calculated using ANOSIM (similarity analysis) in the hard substratum and we found significant values. R values respectively for summer (R = 0.638, P < 0.01); autumn (R = 0.797, P < 0.01); winter (R = 0.917, P < 0.01); spring (R = 0.813, P < 0.01). The species *P. schmidtii*, *E. olivii* and *I. balthica* contributed greatly to the similarity of the first group, while *P. schmidtii*, *T. dulongii* and *I. balthica* contributed most to that of the of the second. Similarity percentages increased between stations in autumn, when the most similar group consisted of stations A6 and A12, the second most similar was A3, A4, and A5, and the third was A1, A8, and A9. *P. schmidtii*, *J. marmorata* and *T. dulongii* contributed most to this similarity. The highest similarity in winter was between stations W2, W4, W5, W1, and W12. The second most similar group was W3 and W7. Similar to other seasons, the resemblance was heavily influenced by *P. schmidtii*, *T. dulongii*, *J. marmorata* and *I. balthica*. The highest similarity in spring was between stations SP11, SP12, and SP13, followed by a group consisting of stations SP2, SP3, SP4, and SP5. Unlike other seasons, *H. normani*, *J. italica*, *S. tergestina* and *E. foxi* contributed most to the similarity in spring *P. schmidtii* was the species that contributed most to similarities across all seasons, except in spring at hard bottom stations.

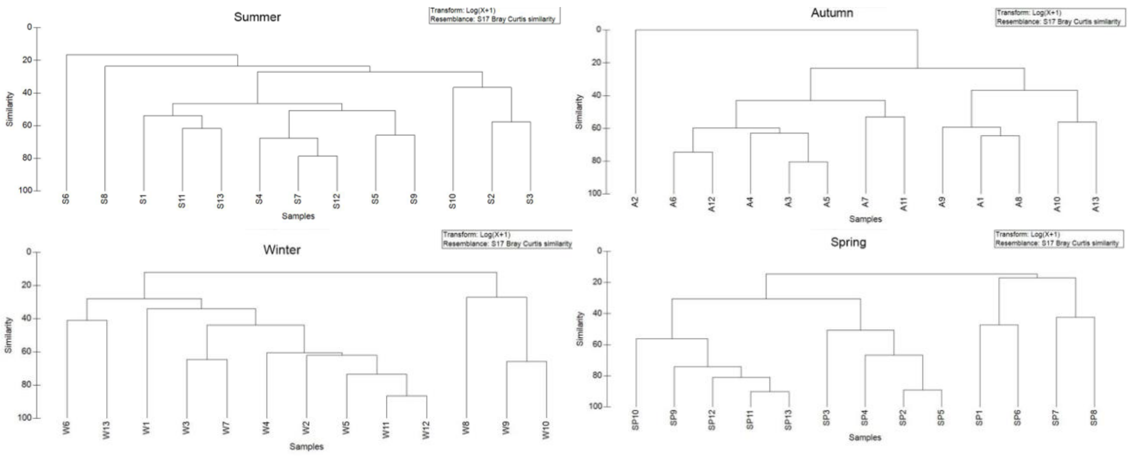


***Figure 5.*** *The similarity of the hard bottom stations. S: Summer A: Autumn W: Winter SP: Spring*

### *Soft bottom*

Sixty peracarid species were obtained in soft bottom sampling. Most species (38) were obtained in the summer, followed by spring (27). The number of species obtained in autumn (23) and winter (24) was nearly equal (*Fig. 6*). In analyzing frequency and dominancy index values for species in soft bottom samples, we see that the only common species is *A. acutum*, and only in spring. In all other seasons, all species were rarely obtained (*Fig. 7*).

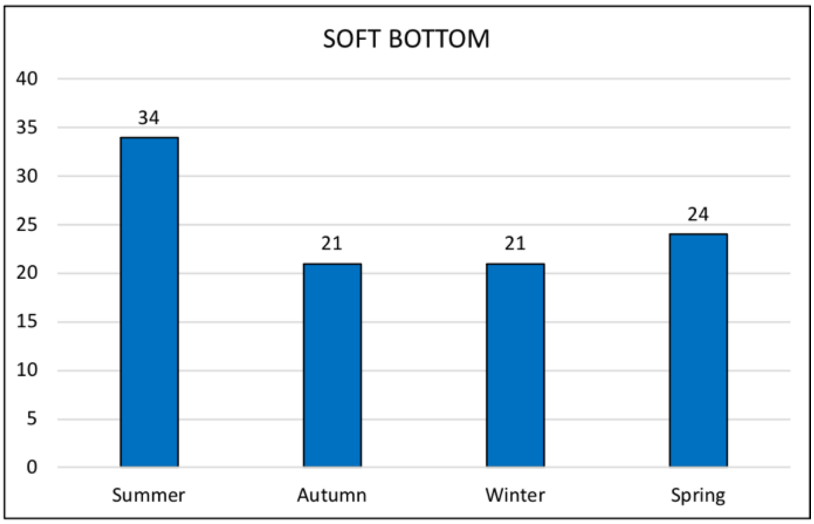


***Figure 6.*** *Seasonal changes of species numbers on the soft bottom*

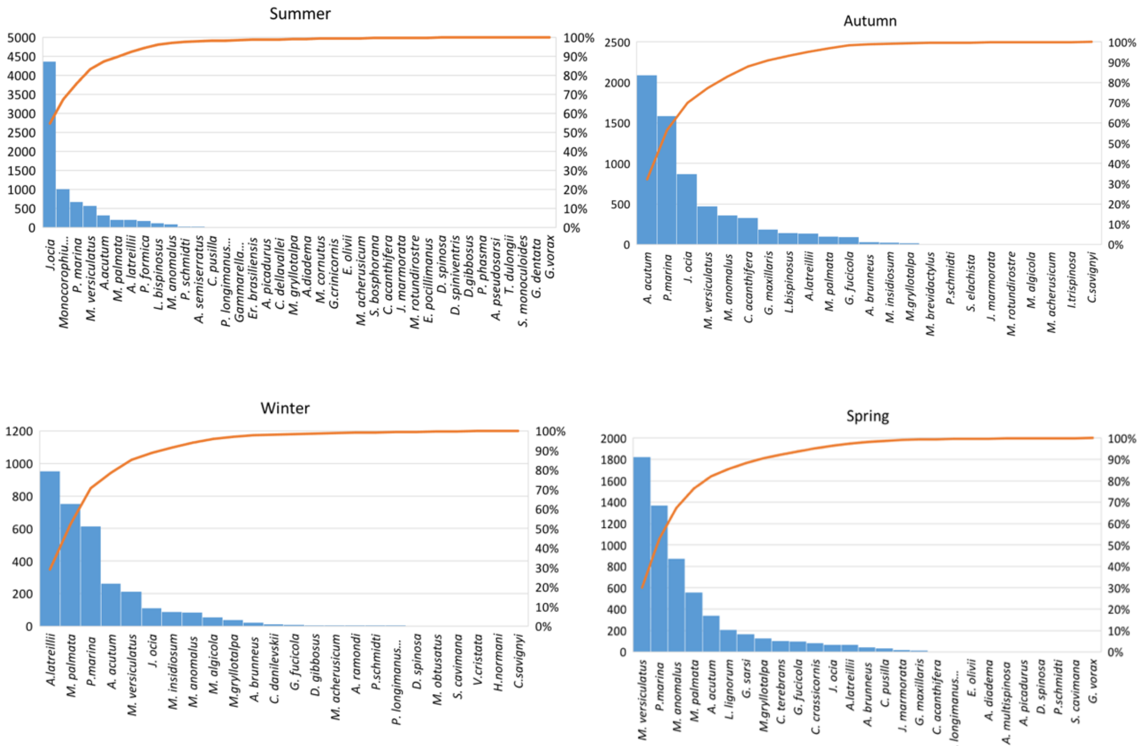


***Figure 7.*** *Seasonal variation of the Peracarid species and individual numbers at the soft bottom stations*

*H'* index values range from 0 to 2.7. Peracarids could not be obtained throughout the year at some stations (32, 33 and 34) and the *H'* value of these stations is zero. The highest *H'* values were found at 24th (Salacak) and 23rd (Karaköy) stations (*H'* = 2.7 and *H'* = 2.5) in the summer (*Table 3*).

Similarity values between soft bottom stations were lower than between hard bottom stations (*Fig. 8*). For the soft bottom, there was a significant difference between the groups formed in all seasons (summer ($R = 0.791$, $P < 0.01$); autumn ($R = 0.960$, $P < 0.01$); winter ($R = 0.778$, $P < 0.01$); spring ($R = 0.958$, $P < 0.01$). The highest similarity in summer in stations with soft bottom sampling is between S14 and S16. This resemblance was caused by *P. schmidtii* and *A. acutum*. The stations A20 and A24, as well as a group of A16, A17, and A25 showed similarity in autumn. While *L. bispinosus*, *M. versiculatus* and *G. fucicola* greatly contributed to the similarity of the first group, *M. palmata* and *P. marina* contributed to the similarity of the second group. In winter, stations W16 and W17, and stations W24 and W25 were similar groups. *P. marina*, *M. gryllotalpa* and *M. palmata* contributed to the similarity of the first group and *P. marina*, *A. acutum*, *L. pilosus* and *M. algicola* contributed to the similarity of the second group. In the spring, stations SP14, SP19, 27 and stations SP24 and SP29 were similar. The species that most contributed to the first group were *A. acutum* and *P. marina*, while *M. versiculatus* and *M. palmata* contributed to the second group.

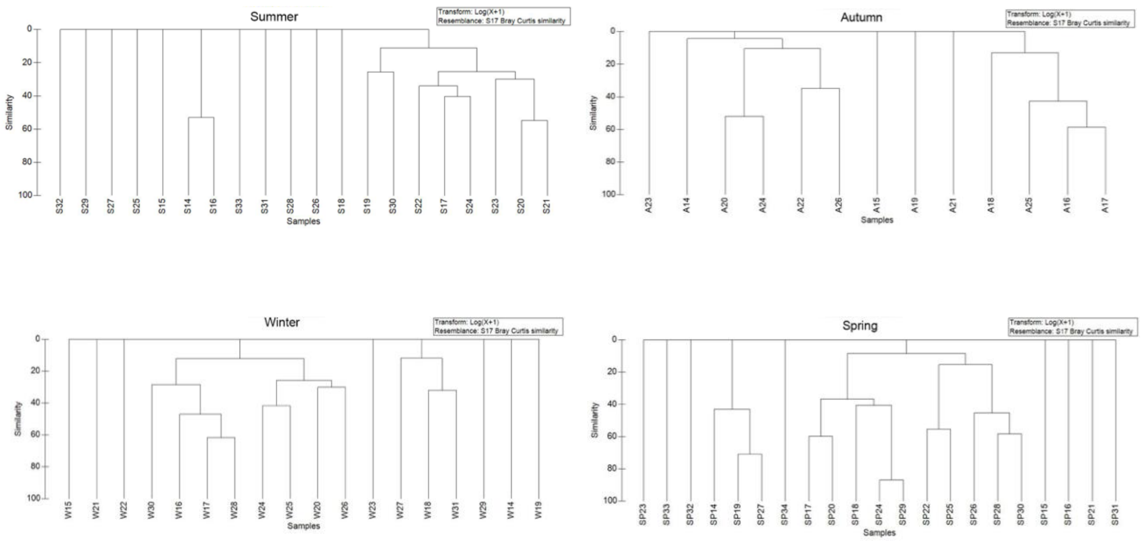


***Figure 8.*** *The similarity of the soft bottom stations. S: Summer A: Autumn W: Winter SP: Spring*

### *Physicochemical parameters*

At hard bottom stations, sea water temperature ranged from 7.17 °C (winter) to 24.6 °C (summer), dissolved oxygen from 7.64 (autumn) to 15.08 mg $l^{-1}$ (winter), dissolved oxygen percentage from 89.5% (autumn) to 156.6% (summer) and salinity content ranged from 14.10 (winter) to 24.43 PSU (practical salinity unit) (winter) (*Fig. 9*).

We conducted Spearman’s correlation analysis to elucidate the relationships between parameters. Accordingly, we found a negative relationship (r: - 0.702 $P < 0.001$) between temperature and dissolved oxygen. In contrast, there was a positive (r: 0.605 $P < 0.001$) relationship between species number and temperature. A negative (r: - 0.365 $P < 0.001$) relationship was observed between species number and both dissolved oxygen and number of individuals. The number of individuals was positively associated with temperature (r: 0.384 $P < 0.001$), and negatively with dissolved oxygen (r: - 0.346 $P < 0.001$).

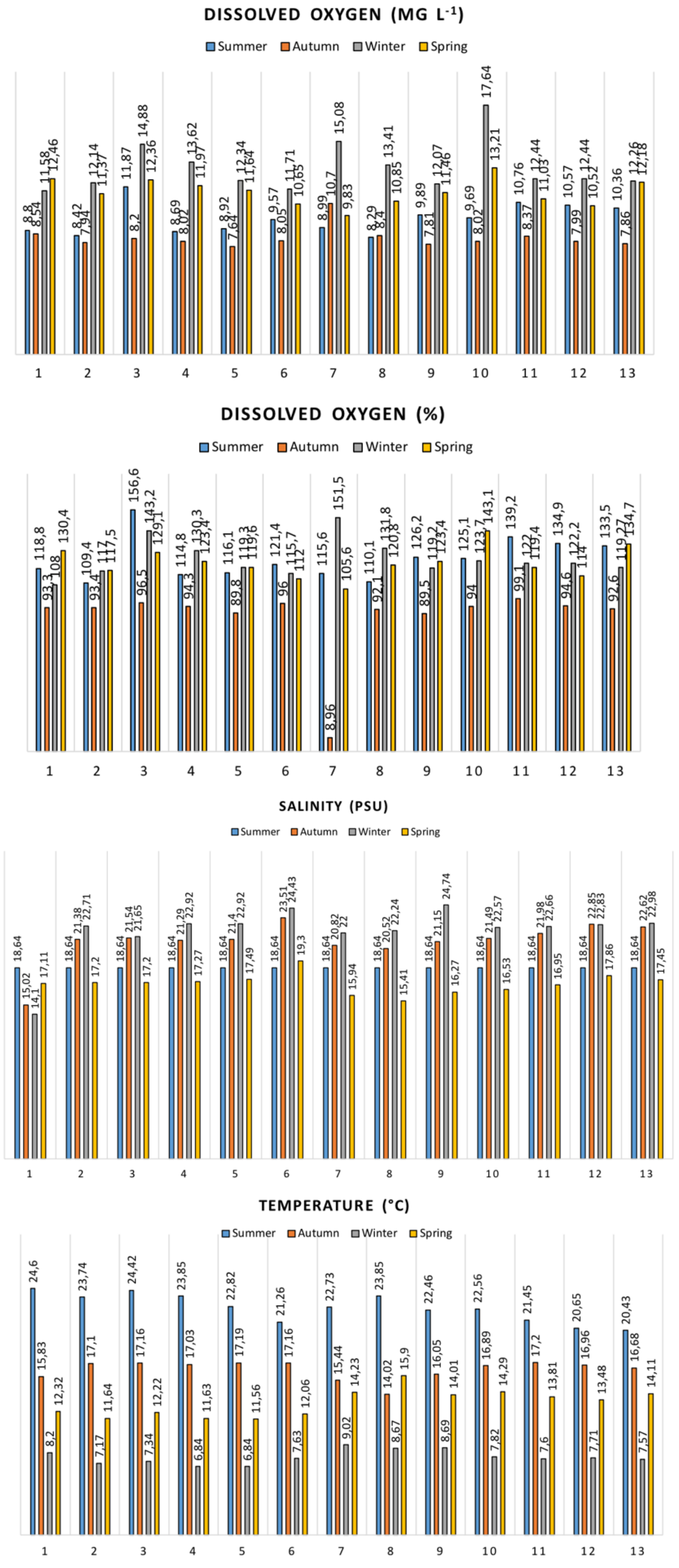
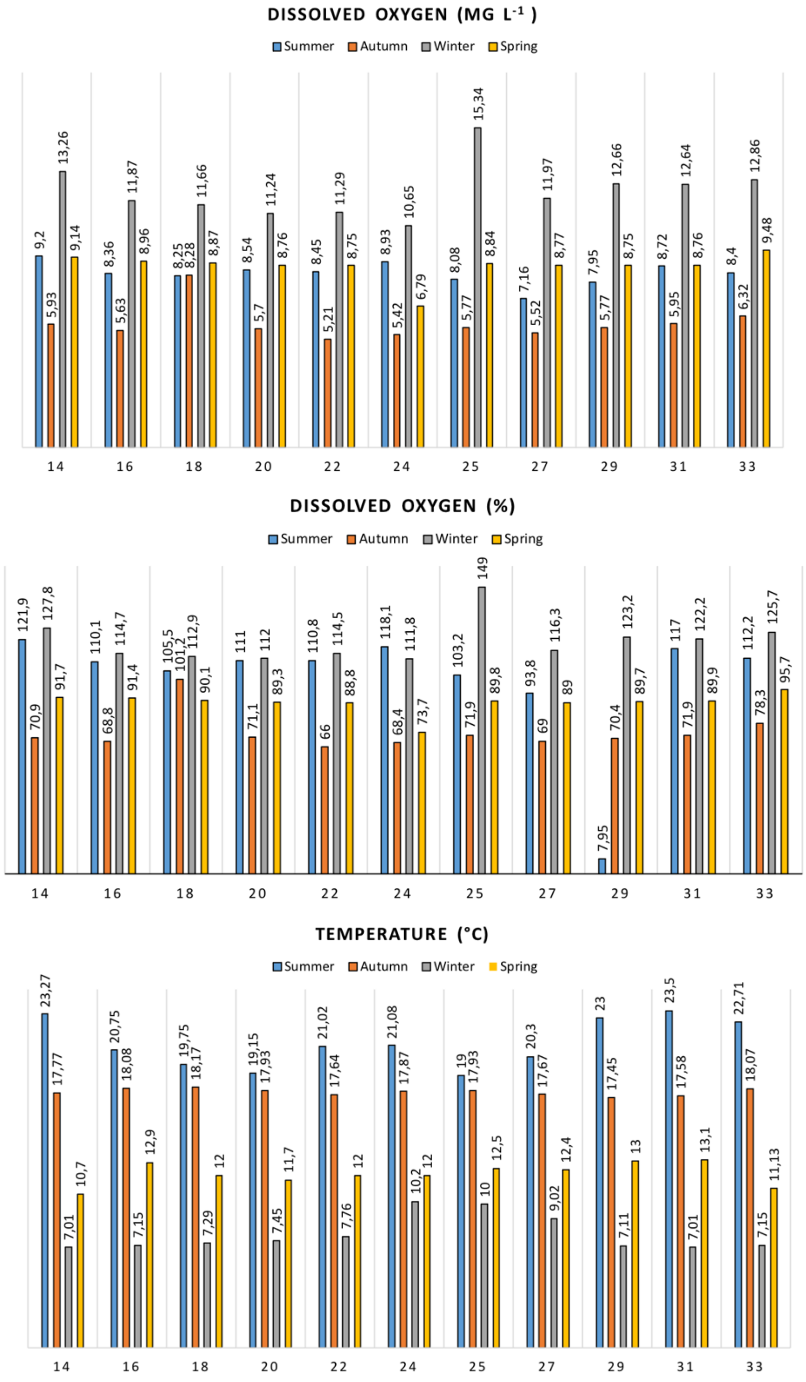


***Figure 9.*** *Physicochemical parameters of the seawater of the hard bottom (0.5 m) stations. DO: dissolved oxygen (mg l$^{-1}$) DO: dissolved oxygen (%) S: salinity (PSU) T: temperature (°C)*

In soft bottom stations, seawater temperature values were between 6.55 °C (winter) and 23.5 °C (summer), dissolved oxygen values were between 1.84 (autumn) and 17.98 mg $l^{-1}$ (winter), dissolved oxygen percentage values were between 7.95% (summer) and 139% (summer) and salinity values were between 16.2 (spring) and 46.44 (autumn) PSU (practical salinity unit). The lowest measured oxygen values were obtained at stations 21 (Ortaköy) and 23 (Karaköy) at 36.4 m depth for all seasons. High oxygen values were obtained at station 15 (Garipçe) (*Figs. 10* and *11*). We also found a negative relationship between dissolved oxygen values and depth as expected. (r: -0.297 $P < 0.001$). Salinity increased as expected due to the Mediterranean water below (r: 0.439 $P < 0.001$).



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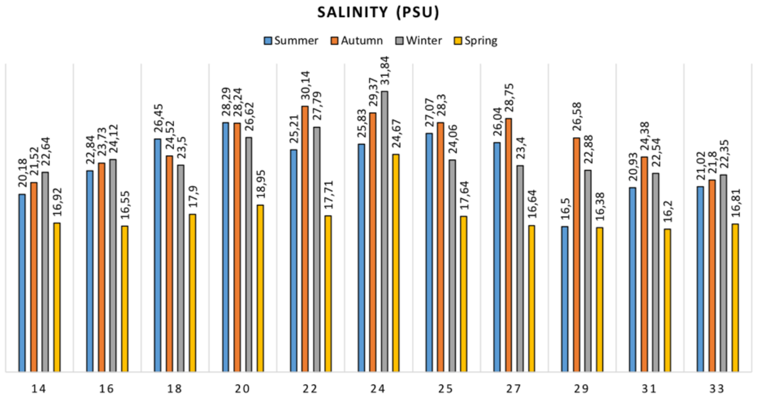

***Figure 10.*** *Physicochemical parameters of the seawater of the soft bottom (18.2 m) stations DO: Dissolved Oxygen (mg $l^{-1}$) DO: Dissolved Oxygen (%). T: Temperature (°C) S: Salinity (PSU)*

The lowest Total Organic Carbon (TOC) value (0.2%) was found at stations 14 (Garipçe), 27 (Anadoluhisarı) and 31 (Anadolukavağı), while the highest values were obtained at station 23 (Karaköy) (6.4 and 5.2%). Total inorganic carbon values were between 3.09% (Çengelköy, station 25) and 56.22% (Paşabahçe, station 30) (*Table 4*). We identified statistically significant but a weak negative relationship between TOC values and DO (r: - 0.186 $P < 0.001$). A positive relationship was observed between TOC and both salinity values (r: 0.324 $P < 0.001$) and mud percentage (r: 0.360 $P < 0.001$). The relationship between TIC and mud percentage was negative (r: - 0.244 $P < 0.001$).

In this study, no statistically significant relationship was found between TOC and TIC values.

***Table 4.*** *Physicochemical parameters determined in the soft bottom surface sediment samples of Istanbul Strait*

| | TOC (%) | | | | TIC (%) | | | | MUD PERCENTAGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| **STATION** | **SUMMER** | **AUTUMN** | **WINTER** | **SPRING** | **SUMMER** | **AUTUMN** | **WINTER** | **SPRING** | |
| 14 | 0.36 | 0.62 | 0.84 | 0.21 | 13.90 | 13.90 | 10.81 | 8.3 | 9.50 |
| 15 | 2.02 | 0.71 | 0.39 | 2.57 | 32.43 | 7.72 | 30.89 | 32.43 | 16.00 |
| 16 | 2 | 1.05 | 1.05 | 0.47 | 6.18 | 4.63 | 20.08 | 21.62 | 24.97 |
| 17 | 0.82 | 0.75 | 1.51 | 0.23 | 26.25 | 24.5 | 18.53 | 20.08 | 29.03 |
| 18 | 0.92 | 0.31 | 0.85 | 0.99 | 21.62 | 17 | 13.90 | 10.81 | 6.47 |
| 19 | 0.51 | 0.28 | 0.38 | 0.31 | 9.27 | 4.63 | 15.74 | 16.99 | 5.28 |
| 20 | 2.68 | 1.11 | 3.24 | 2.5 | 10.81 | 3.09 | 7.72 | 10.81 | 41.94 |
| 21 | 2.18 | 4.12 | 1.39 | 2.2 | 9.27 | 10.81 | 7.72 | 10.81 | 20.41 |
| 22 | 1.63 | 0.58 | 2.5 | 2.7 | 6.18 | 26.25 | 7.72 | 7.1 | 69.9 |
| 23 | 2.3 | 2.48 | 6.4 | 5.2 | 6.18 | 6.18 | 7.1 | 7.7 | 72.66 |
| 24 | 1.05 | 0.56 | 0.65 | 0.83 | 37.07 | 13.90 | 33.98 | 30.89 | 10.86 |
| 25 | 2.9 | 1.1 | 2.09 | 1.44 | 3.09 | 24.71 | 15.44 | 25.64 | 17.56 |
| 26 | 0.9 | 1.1 | 0.63 | 0.9 | 4.63 | 9.27 | 24.71 | 24.69 | 25.99 |
| 27 | 0.95 | 0.2 | 0.74 | 0.2 | 3.09 | 4.60 | 4.63 | 3.09 | 1.44 |
| 28 | 0.62 | 0.84 | 0.61 | 0.2 | 4.63 | 4.63 | 4.63 | 4.63 | 21.26 |
| 29 | 0.75 | 0.78 | 0.66 | 0.8 | 13.90 | 12.35 | 10.81 | 13.90 | 25.47 |
| 30 | 0.8 | 1.78 | 1 | 1.2 | 12.35 | 44.79 | 15.44 | 56.22 | 13.48 |
| 31 | 2.04 | 0.51 | 0.2 | 0.69 | 12.35 | 9.27 | 16.98 | 24.69 | 18.23 |
| 32 | 0.6 | 0.57 | 0.64 | 0.95 | 7.72 | 8.3 | 4.63 | 6.18 | 84.57 |
| 33 | 1.23 | 1.02 | 1.11 | 1.55 | 7.72 | 24.71 | 15.44 | 6.18 | 2.52 |
| 34 | 3.47 | 3.15 | 2.51 | 0.69 | 6.18 | 18.53 | 38.61 | 24.69 | 16.61 |

TOC: total organic carbon, TIC: total inorganic carbon

DOI: http://dx.doi.org/10.15666/aeer/1806_83218342

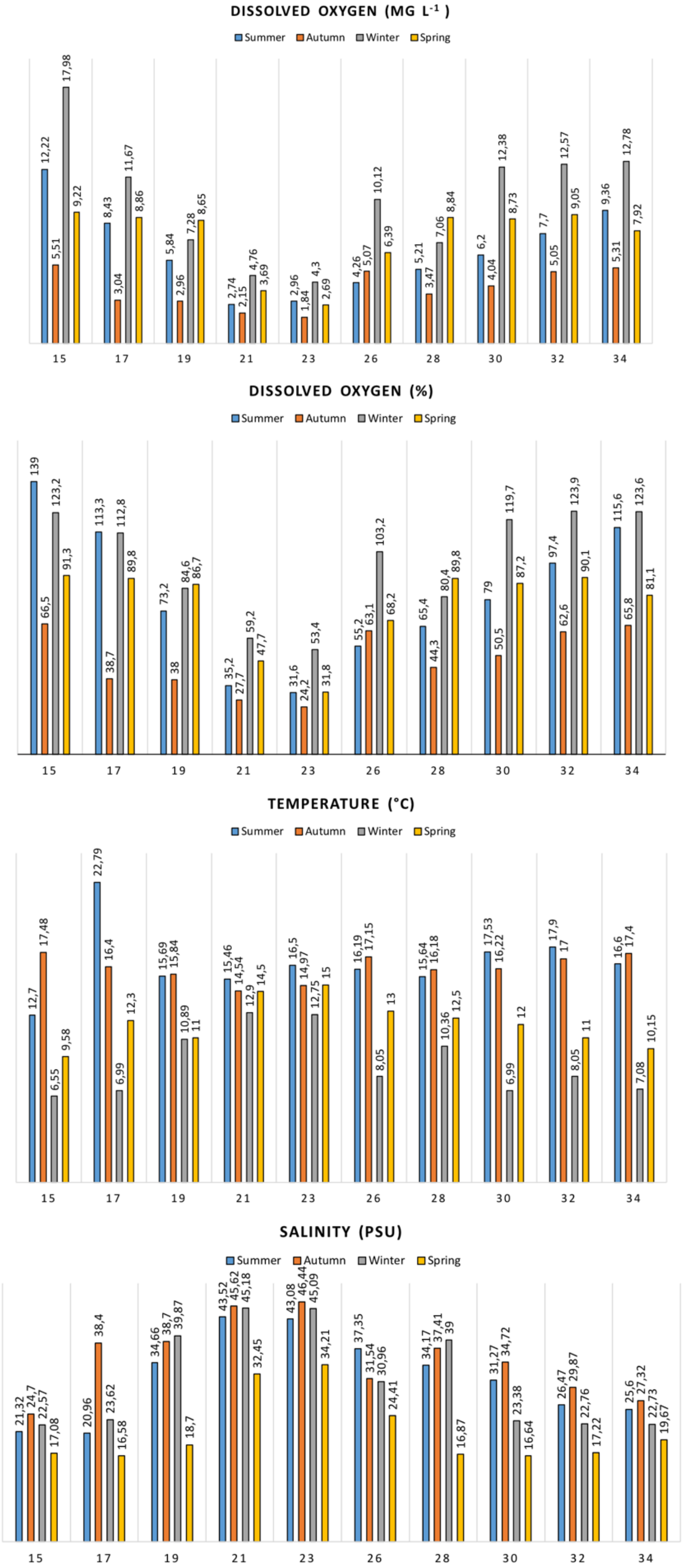

***Figure 11.*** *Physicochemical parameters of the seawater of the soft bottom (36.4 m) stations. DO: Dissolved Oxygen (mg $l^{-1}$) DO: Dissolved Oxygen (%) T: Temperature (°C) S:Salinity (PSU)*

## Discussion

In this study, we found 46 species in hard bottom and 58 in soft bottom stations. Coastal filling to create artificial areas for ports, parks, and recreation areas is common on the shores of the Istanbul Strait. It has been observed that natural areas are in decline as artificial areas gradually increase in the Istanbul Strait (Onuk et al., 2017). For this reason, we experienced difficulty in finding natural stations to sample. The limited number of hard bottom stations to be found were surrounded by restaurants, residential areas, and anchored boats. Hard bottom macrobenthos is heavily influenced by habitat type and the hydrodynamic processes are particularly effective in the distribution of macrobenthic fauna, especially in the Istanbul Strait (Uysal et al., 2002). Water movements directly affect benthic organisms living in the sediment on the soft bottom, causing the transport of sediment and organic matter. In addition, hydrodynamic conditions change the distribution of the macrobenthic community in that region by changing the grain size distribution (Foulquier et al., 2020). Uysal (2002) states in his study in the Istanbul Strait that only one of the stations in the lower layer current system consists of fine sand and silt-containing mud. This station is located at the Black Sea exit of the Istanbul Strait. Researcher says that the sediments of other stations contain coarse-grained shells due to their high flow rates.

During the study, we observed that the number of species increased seasonally with temperature, and most species were collected in spring. Peracarid biodiversity depends on many factors, such as vegetation, hydrodynamics, sedimentation carbonates, habitats, and combinations of all of these features, and it has been observed in previous studies that biodiversity increases especially in spring (Wang et al., 2010). In addition to the increase in algae and mussels, which form the hard bottom communities and hosts of peracarids, this increase can also be influenced by the rising reproduction rates in the spring months when the temperature is high. According to Izquierdo and Garcia et al. (2011), peracarids reproduce year-round in the Strait of Gibraltar, but they are most abundant in spring and summer. The researchers linked this situation to seasonal changes in sea meadows, but factors such as predation and competition should also be evaluated (Izquierdo and Garcia, 2011).

The primary reason for the lack of species from the Mysid and Cumacea orders is that these peracarids prefer soft bottom habitats. However, it may also be related to the flow system and quadrat sampling on the shore (Wang et al., 2010). In this study, sampling was performed with a quadrat on hard bottom, but some researchers use a hand scoop or plankton nets to collect mysids (Porter, 2016).

The dominance of the amphipod species *P. schmidtii* in hard bottom stations is remarkable. *Ampithoe ramondi, Protohyale (Protohyale) schmidtii* and *Elasmopus brasiliensis* species were found to be dominant in a rocky community study in Gökçeada (Aslan and İşmen, 2019). Species with high frequency and dominance in this study, such as *Hyale* and *Jassa,* are tolerant of pollution (Kalkan et al., 2007). In this study, *Tanais,* which was obtained predominantly on the shores of the Istanbul Strait, was widely obtained from clean waters and harbors by various researchers. (Chintiroglou et al., 2004). In a previous study in the Istanbul Strait, *Hyale perieri*, *E. olivii*, *J. marmorata* and *T. dulongii* were dominant in discharge areas (Kalkan et al., 2007). Similarly, in this study, these species show high dominance the Istanbul Strait coast, including Beşiktaş, Sarıyer, and Tarabya, where the settlement was intense.

In this study, Cumacea, Mysid, and Tanaid species were represented by many fewer species than other orders. Cumacea and Mysid species (*I. trispinosa, V. cristata, H.*

*normani*) obtained were distributed on only soft bottom stations. Only 3 tanaid obtained (A. *latreillei, C. savignyi and T. dulongi*). We obtained these tanaid species on both soft and hard bottom. However, *A. latreillei* has a high number of individuals on soft bottom and *T. dulongi* on hard bottom. Amphipods (195 species) make up the most 418 Malacostracan species in the Turkish Straits System. This is followed by decapoda (140), Isopoda (42), Cumacea (18), Mysidacea (12), Tanaidacea (7), Stomatopoda (2) and Leptostraca (1), respectively (Balkıs et al. 2016). In the studies performed in the Sea of Marmara and the Black Sea, it is seen that the Amphipods are dominant in the crustacean fauna (Sezgin et al. 2010; Bat et al., 2011; Bakır et al., 2012). This study reports the first record of the Atlanto-Mediterranean maerid amphipod *Animoceradocus semiserratus* in Sea of Marmara. This species is distributed throughout the Atlantic Ocean and Mediterranean Sea (Christodoulou et al., 2013). The existence of this species in Turkish seas was unknown until recently (Mutlu, 2020). However, considering the sampling date of the researcher, it is seen that it has been in our waters for a long time. Previous records of the species are from the Aegean and the Mediterranean Sea, and it is observed that Mediterranean origin species increase in the Sea of Marmara.

In sampling on soft bottom, stations were selected from two depths (18.2 m and 36.4 m) with a difference in salinity between them. However, according to the Spearman analysis, no significant relationship was found between depth differentiation and the number of species and individuals. While salinity is an important factor in lagoons, sediment type and amount of organic matter are more critical in the distribution of peracarids in marine ecosystems (Lourido et al., 2008; Zaabar et al., 2017). The strait's sediment has a coarse-grained structure (Uysal et al., 2002). In this study, the mud percentage values in the sampled soft bottom stations vary between 1.44% and 84.57% with an average value of 25.4%. Only a few stations had high mud percentages. A weak but positive correlation was found between the number of species and individuals and the mud percentage (r: 0.221 $P < 0.001$). The same relationship was also observed between the mud percentage and organic carbon. This can be explained by the fact that the amount of organic matter increases as the mud percentage increases. Fine grain sediments do not permit the entry of oxygen, increasing the absorption of organic matter. (Secrieru and Oaie, 2009). This organic material is an important parameter, especially for detritivore species, as it constitutes a food source. Two of the two stations which lack peracarids throughout the year (33 and 34) are located in Keçilik, which has vortex (Atasoy, 2008). The associated strong current is one reason why species were not collected in these stations. In the spring, high *H'* index values were obtained in the Ortaköy (Station 20), Karaköy (station 22), and Salacak (station 25) areas, which have low dissolved oxygen values and were observed to be discharge regions during sampling. This is due to the density of the species, which feed on detritus at these stations. The high organic carbon content, especially at Karaköy and Ortaköy stations supports this idea and indicates the organic contamination at these points. The strait's sediment samples show high organic carbon content values, especially in the summer. Anthropogenic organic pollution was remarkable at station 34 Keçilik (3.47%), station 20 Ortaköy (2.68%), and station 23 Karaköy (2.3%) stations, where the highest percentage of carbon was obtained. Low dissolved oxygen content in the same areas confirms this result. Again, the lowest dissolved oxygen values in seawater were measured at 36.4 m depths in Karaköy and Ortaköy in all seasons, and this is one of the results of oxygen deficiency in the bottom layers and organic pollution in the strait.

## Conclusion

As a result, with this study, we examined the Istanbul Strait peracarid fauna in detail in both hard and soft bottoms and reported species that were not observed in the Bosphorus and Sea of Marmara before. Thus, we ensured the update of macrozoobenthic fauna information. We have observed that most of the species we have obtained are of Atlanto-mediterranean origin, and a few species are Mediterranean endemic or cosmopolitan species. Considering that the Istanbul Strait creates a natural transition between the Mediterranean and the Black Sea, it is an expected result to obtain the species previously identified from the Mediterranean from the Istanbul Strait. We have observed that in the distribution of species in the strait, ground structure, temperature, organic carbon amount and current system are more effective than the salinity difference of Black Sea and Mediterranean waters. We think that the analysis of grain size in future studies will be useful for understanding the habitat structure and distribution. We stated that we had difficulty in finding natural coastal areas during the hard bottom sampling of the study. We think that the coastal filling creates negativity for distributing of macrozoobenthic organisms in the strait. The decrease in the amount of oxygen with depth and high carbon amount in certain areas can be considered as a warning for the pollution in the strait. However, since this study is not a pollution study, it was conducted to determine the diversity and distribution of peracarids, we recommend increasing pollution studies in the region. Moreover, this study cannot comment on the overall benthic ecological quality of the strait, since only peracarid species were examined. For this reason, the authors recommend following it up with studies on ecological quality in the future.

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