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Summer distribution and community structure of surface water mesozooplankton from the eastern Mediterranean Sea

by

Melek Isinibilir[1,]*, Vedat Aker[2],
Ezgi E. Türkeri[1]

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[1]*Department of Marine Biology, Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey*

[2]*Department of Marine Biology, Faculty of Fisheries, Ege University, Izmir, Turkey*

* Corresponding author: melekis@istanbul.edu.tr

Abstract

The zooplankton community structure and its relationship with environmental parameters were evaluated in the surface waters (0–50 m) of the eastern Mediterranean (the Aegean Sea's coastal waters and the Levanine Sea's coastal and offshore waters), from coastal waters to open sea waters, during the summer for two years. A total of 157 species/groups were registered in the study area. Copepods, cladocerans, doliolids, meroplankton and appendicularians represented the most important zooplankton groups. Five copepod species (*Corycaeus* [*Onychocorycaeus*] *ovalis*, *Goniopsyllus clausi*, *Oncaea scottodicarloi*, *Sapphirina bicuspidata* and *Scaphocalanus curtus*) have been recorded for the first time in Turkish coastal regions; three species (*Centropages bradyi*, *Goniopsyllus clausi* and *Oncaea scottodicarloi*) had not previously been found in the Aegean Sea; and one species (*Goniopsyllus clausi*) has been added for the first time to the eastern Mediterranean fauna. Moreover, *Pleopis schmackeri* was already found to be present in both the Aegean Sea and Mediterranean coasts of Turkey in August 2006. Dominant species varied from the coastal waters to open waters. A small number of species belonging to the coastal community (e.g. *Penilia avirostris*, *Pseudevadne tergestina*, *Oithona plumifera*, *Paracalanus parvus* and *Centropages kroyeri*) dominated all coastal areas. In contrast, the open water stations were characterised by the presence of typically epipelagic species of the Mediterranean Sea (e.g. *Calocalanus* spp., *Clausocalanus furcatus*, *Lucicutia flavicornis*, *Mecynocera clausi*, *Farranula rostrata*, *Oncaea scottodicarloi* and *Oncaea mediterranea*).

Key words: eastern Mediterranean Sea, zooplankton, species diversity, abundance, first species record

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1. Introduction

The eastern Mediterranean basin is one of the most oligotrophic regions in the world, and has been described as a 'marine desert' due to its very low chlorophyll concentrations (Azov 1991, Krom et al. 1991, Antoine et al. 1995). Nutrient content, phytoplankton and zooplankton biomass, primary production and fish stocks are known to be higher in the northern Aegean Sea (Stergiou et al. 1997, Siokou-Frangou et al. 2002). Moreover, the composition of the mesozooplankton community was found to significantly differ between the northern and southern parts of the Aegean Sea (Sever 2009, Mazzocchi et al. 2014). The open marine areas of the Aegean and Levantine Seas (Siokou-Frangou et al. 2002, Aktan 2011), the two largest basins surrounding Turkey, have also been documented as oligotrophic. Although the Aegean Sea, which is one of the important basins of the Mediterranean, has an oligotrophic structure in general, it shows important biochemical differences between its north and south. Biodiversity, nutrient content and fishing activities were found to be higher in the northern Aegean Sea than in the southern Aegean Sea (Stergiou et al. 1997, Mazzocchi et al. 2014, Sever 2009). Furthermore, coastal domestic and industrial waste from major cities (such as Muğla, Antalya or Adana) as well as freshwater inputs from numerous small rivers results in local increases in biological production (Polat 2002, Kontas et al. 2004, Polat-Beken et al. 2009).

Basic knowledge of the structure of the zooplankton community and changes in species composition in different marine environments is still needed to better understand the ecological functioning of this basin. In general, although there have been various local studies on zooplankton communities, including information regarding their spatial and temporal variations along the eastern Mediterranean coastline (Benli et al. 2001, Isinibilir 2009, Isari et al. 2006, Protopapa et al. 2020, Sever 2009, Siokou-Frangou et al. 2009, Tarkan 2000, Terbıyık Kurt and Polat 2013, Toklu-Alıçlı and Sarıhan 2016, Uysal and Shmeleva 2012, Zervoudaki et al. 2006), there is limited data from large-scale investigations in open waters (Mazzocchi et al. 1997, 2007, 2014; Molinero et al. 2009; Siokou-Frangou et al. 1997).

The fact that the area in question included various coastal areas as well as open sea made it ideal for studying the regional variation of zooplankton community composition. The aim of this research is to determine the main zooplankton distribution patterns and dominant species compositions in the eastern Mediterranean, especially Turkish coastal areas, and to expand our knowledge about the pelagic ecosystem.

2. Materials and methods

2.1. Sampling and analysis

The study was carried out at 70 stations between 11 August and 4 September 2006 and between 10 July and 13 August 2008 in the Mediterranean Sea around the Turkish peninsula with the help of R/V YUNUS-S (Figure 1, Table 1). The northern Aegean Sea (NA) group was represented by 11 stations, the southern Aegean Sea (SA) by 19 stations, the coastal waters of the Levantine Sea (LSC) by 31 stations and the open waters of the Levantine Sea (LSO) by 9 stations. Temperature and salinity were also measured at each station with a SEABIRD CTD probe. Chlorophyll-*a* concentrations were measured synchronously with zooplankton sampling by Altuğ et al. (2007) and Aktan (2011). All samples were vertically collected by using a WP2 net (mesh size: 200 μm) from a depth of 50 m to the surface of the water column or from near the bottom to the surface if the station depth was less than 50 m. The filtered volume was measured with a Hydro-Bios flowmeter. After the tow, the net was carefully washed, and the sample was split into two with a Folsom splitter. The first half was used fresh for biomass measurements as the wet weight; the other half of each sample was fixed and preserved in a seawater-buffered formaldehyde solution (4% final concentration) for later determination of composition and abundance. Specimens were identified under a dissecting microscope. Quantitative analyses of commonly found species were performed on subsamples taken with a 1 ml Stempel pipette (at least three times). Rare species were identified from the whole sample. Cladocerans and copepods were identified at the species or genus level. All other taxa were identified to the lowest possible taxa. The pIONeer 65 multi-probe was used to assess water temperature, salinity and dissolved oxygen using the practical salinity scale. Seawater was filtered via Whatman GF/C glass fiber filters for chlorophyll analysis and then frozen until spectrophotometric examination took place after acetone extraction.

2.2. Data analysis

Species diversity and dominance were estimated using the Shannon–Weaver formula (Zar 1984). The differences in physical and biological data (total zooplankton abundance and biomass) between areas were evaluated with ANOVA (SPSS v. 22). Differences in the zooplankton community were evaluated for spatial variation with similarities and multidimensional scaling (MDS) analysis by calculating log (x + 1)-transformed

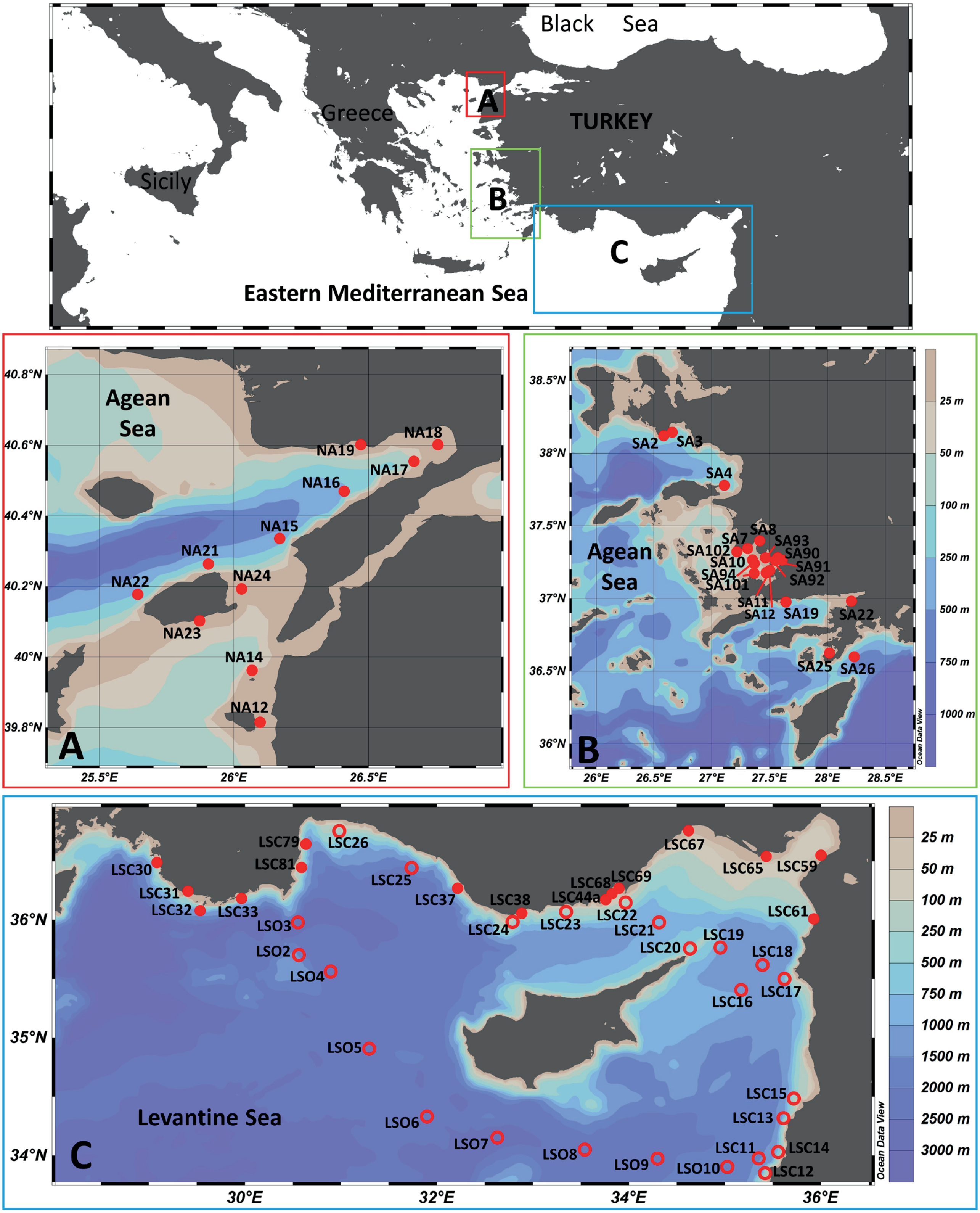

Figure 1

Mesozooplankton stations sampled in the eastern Mediterranean Sea

Table 1

Stations data from the R/V YUNUS-S cruise in the eastern Mediterranean Sea

Station Number	Station Name	Region	Date	Latitude (N)	Longitude (E)	Total Depth (m)
1	NA12	NA	09.07.2006	39°48.534	26°05.552	21
2	NA14	NA	09.07.2006	39°57.309	26°04.095	18
3	NA15	NA	14.07.2006	40°20.166	26°11.921	210
4	NA16	NA	13.07.2006	40°28.113	26°25.471	500
5	NA17	NA	13.07.2006	40°32.624	26°40.386	100
6	NA18	NA	13.07.2006	40°35.344	26°46.041	66
7	NA19	NA	13.07.2006	40°35.259	26°28.501	47
8	NA21	NA	14.07.2006	40°15.223	25°54.840	69
9	NA22	NA	10.07.2006	40°09.890	25°39.306	80
10	NA23	NA	09.07.2006	40°05.774	25°51.762	33
11	NA24	NA	14.07.2006	40°10.954	26°01.935	37
12	SA2	SA	13.08.2006	38°08.154	26°33.985	29
13	SA3	SA	13.08.2006	38°08.244	26°36.985	48
14	SA4	SA	13.08.2006	37°45.866	27°03.787	175
15	SA7	SA	14.08.2006	37°20.167	27°19.735	35
16	SA8	SA	14.08.2006	37°23.148	27°25.281	10
17	SA10	SA	14.08.2006	37°16.121	27°22.479	57
18	SA11	SA	14.08.2006	37°09.935	27°30.949	40
19	SA12	SA	14.08.2006	37°09.456	27°30.705	30
20	SA19	SA	16.08.2006	36°59.901	27°43.143	42
21	SA22	SA	16.08.2006	36°57.650	28°12.234	28
22	SA25	SA	17.08.2006	36°37.123	28°01.498	30
23	SA26	SA	17.08.2006	36°33.041	28°12.594	35
24	SA90	SA	30.08.2006	37°15.916	27°36.263	9
25	SA91	SA	30.08.2006	37°16.197	27°34.244	12
26	SA92	SA	30.08.2006	37°15.045	27°33.695	16
27	SA93	SA	30.08.2006	37°15.968	27°29.061	20
28	SA94	SA	30.08.2006	37°14.461	27°22.980	57
29	SA101	SA	03.09.2006	37°09.697	27°22.617	30
30	SA102	SA	03.09.2006	37°19.104	27°13.245	49
31	LSC30	LSC	17.08.2006	36°31.608	29°07.381	28
32	LSC31	LSC	18.08.2006	36°15.583	29°24.560	40
33	LSC32	LSC	18.08.2006	36°01.141	29°30.148	1600
34	LSC33	LSC	18.08.2006	36°07.500	29°57.000	1009
35	LSC37	LSC	19.08.2006	36°13.200	32°18.537	38
36	LSC38	LSC	17.08.2006	36°03.573	32°52.445	15
37	LSC44a	LSC	20.08.2006	36°11722	33°45643	14
38	LSC59	LSC	22.08.2006	36°31.350	36°01.456	10
39	LSC61	LSC	22.08.2006	35°57.679	35°55.627	70
40	LSC65	LSC	23.08.2006	36°31.350	35°25.333	64
41	LSC67	LSC	24.08.2006	36°46.399	34°38.348	13
42	LSC68	LSC	24.08.2006	36°15.175	33°48.802	24
43	LSC69	LSC	24.08.2006	36°18.135	33°51.746	22
44	LSC79	LSC	26.08.2006	36°37.041	30°36.041	64
45	LSC81	LSC	26.08.2006	36°27.440	30°33.091	65
46	LSC11	LSC	16.07.2008	33°58.390	35°26.400	1430
47	LSC12	LSC	16.07.2008	33°49.593	35°27.400	500
48	LSC13	LSC	17.07.2008	34°14.900	35°36.188	210
49	LSC14	LSC	17.07.2008	34°01.295	35°35.487	512
50	LSC15	LSC	19.07.2008	34°26.603	35°43.626	264
51	LSC16	LSC	19.07.2008	35°12.823	35°09.197	1500
52	LSC17	LSC	21.07.2008	35°26.729	35°31.128	1397
53	LSC18	LSC	22.07.2008	35°35.023	35°19.122	1200
54	LSC19	LSC	22.07.2008	35°39.582	34°54.051	1050
55	LSC20	LSC	22.07.2008	35°42.463	34°35.265	160
56	LSC21	LSC	22.07.2008	35°55.443	34°17.898	840
57	LSC22	LSC	22.07.2008	36°09.117	33°58.340	74
58	LSC23	LSC	23.07.2008	36°03.743	33°19.479	214
59	LSC24	LSC	23.07.2008	35°57.718	32°47.352	65
60	LSC25	LSC	23.07.2008	36°24.649	31°40.371	2000
61	LSC26	LSC	23.07.2008	36°43.412	30°58.711	350
62	LSO2	LSO	12.07.2008	35°40.9854	30°30.1947	1430
63	LSO3	LSO	13.07.2008	35°57.133	30°30.396	1200
64	LSO4	LSO	13.07.2008	35°26.2102	30°1.7999	2500
65	LSO5	LSO	13.07.2008	34°56.215	31°17.754	2500
66	LSO6	LSO	13.07.2008	34°22.300	31°49.50	2500
67	LSO7	LSO	14.07.2008	34°17.513	32°35.914	2500
68	LSO8	LSO	14.07.2008	34°08.555	33°25.751	2500
69	LSO9	LSO	14.07.2008	34°03.068	34°12.465	2500
70	LSO10	LSO	14.07.2008	33°58.571	34°58.046	2500

NA: northern Aegean Sea; SA: southern Aegean Sea; LSC: coastal waters of the Levantine Sea; LSO: open waters of the Levantine Sea abundance data on the basis of the Bray–Curtis similarity index. The differences between the samples were assessed by a one-way analysis of similarities (ANOSIM) permutation test. Using the similarities percentage procedure according to SIMPER was performed to determine the dominant species that contributed to the spatial differences in community structure. The MDS, ANOSIM and SIMPER procedures were performed using the software package PRIMER 6 (Clarke and Warwick, 1994).

3. Results

3.1. Environmental conditions

The data were collected over two summers from the Aegean and Levantine Seas. The overall means of the environmental parameters are presented in Table 2. The among-region differences were clear for temperature ($F_{3;69}$ = 137.29, $p < 0.05$) and salinity ($F_{3;69}$ = 35.22, $p < 0.05$). The highest temperatures were recorded in the coastal waters of the Levantine Sea, with an average of 27.21 ± 1.63°C. Surface salinity showed a north–south gradient, with mean values ranging from 37.38 ± 1.28 to 39.15 ± 0.08 PSU. The highest salinity value (39.6 ppm) was recorded in the Antalya Bay (in Station LSC37) in the coastal waters of the Levantine Sea. While lower chlorophyll-*a* levels were recorded in the northern Aegean Sea (0.23 ± 0.17 μg l^{-1}), chlorophyll-*a* levels were higher in the coastal waters of the southern Aegean Sea (0.89 ± 0.76 μg l^{-1}).

3.2. Zooplankton abundance and group and species composition

Taking all sampling stations into account, the zooplankton abundance values ranged between 123 and 23,931 ind m^{-3}, while biomass values ranged between 80 and 3200 mg m^{-3} (Figure 2). The highest mean abundance (4562 ind m^{-3}) and biomass (748 mg m^{-3}) values were detected in the southern Aegean

Table 2

Mean values and standard deviations of environmental parameters in each sub-region of the eastern Mediterranean Sea

Sea	Region	Water temperature (°C)	Water Salinity (PSU)	Total Chlorophyll-*a* (μg.l^{-1})
Aegean Sea	Northern Aegean Sea (NA)	17.09 ± 1.37	37.38 ± 1.28	0.23 ± 0.16[a]
	Southern Aegean Sea (SA)	24.50 ± 1.88	39.09 ± 0.18	0.89 ± 0.76[b]
Levantine Sea	Coastal Waters of the Levantine Sea (LSC)	27.21 ± 1.61	39.36 ± 0.14	0.87 ± 0.69[b]
	Open Waters of the Levantine Sea (LSO)	22.26 ± 0.76	39.15 ± 0.08	0.56 ± 0.40[b]

[a] Altuğ et al. 2007, [b] Aktan 2011

Table 3

Species first recorded in the present study.

Species	Aegean Sea	Levantine Sea	Stations
Calocalanus elegans Shmeleva, 1965	*, A	TL, L	NA12, NA24
Candacia giesbrechti Grice & Lawson, 1977	*, M, A	-	NA15
Centropages bradyi Wheeler, 1901	+ , *	TL, L	SA26
Clausocalanus jobei Frost & Fleminger, 1968	*, M, A	TL, L	NA12, NA15, NA16, NA17, NA18, NA19, NA21, NA24, SA10, SA101, SA102, SA11, SA12, SA2, SA3, SA4, SA7, SA22, SA26, SA94
Clausocalanus mastigophorus (Claus, 1863)	*, M, A	TL, L	SA102, SA25, SA26
Clausocalanus parapergens Frost & Fleminger, 1968	*, M, A	TL, L	NA19, SA4
Clausocalanus pergens Farran, 1926	*, M, A	TL, L	NA15, NA16, NA17, NA18, NA19, NA21
Corycaeus (Onychocorycaeus) latus Dana, 1849	TA, A	#, L	LSC11, LSC12, LSC16, LSC17, LSC19, LSC20, LSC21, LSC22, LSC24, LSC25, LSC26, LSO2, LSO3, LSO4, LSO5, LSO6, LSO7, LSO8, LSO9,
Corycaeus (Onychocorycaeus) ovalis Claus, 1863	*, A	#, L	NA16, NA22, SA4, SA25, SA102, LSC33, LSC79, LSO9
Goniopsyllus clausi Huys & Conroy-Dalton, 2000	+, *	#, μ	NA14, NA15, NA17, NA21, NA22, NA24, SA10, LSC11, LSC22, LSC30, LSC79, LSC81, LSO6
Oithona tenuis Rosendorn, 1917	*, M, A	TL, L	SA19, SA25, SA26
Oithona vivida Farran, 1913	*, A	TL, L	NA12, NA21, SA101
Oncaea curta Sars, 1916	*, M, A	TL, L	NA12, NA14, NA15, NA16, NA17, NA18, NA21, NA22, NA23, NA24, SA3, SA4, SA7,SA10, SA11, SA12, SA22, SA26, SA92, SA93, SA94, SA101, SA102
Oncaea scottodicarloi Heron & Bradford-Grieve, 1995	+ , *	#, L	LSC12, LSC14, LSC16, LSC17, LSC18, LSC19, LSC20, LSC22, LSC31, LSC33, LSC65, LSC79, LSC81, LSO2, LSO3, LSO4, LSO5, LSO6, LSO7, LSO8, LSO10 NA12, NA15, NA17, NA18, NA19, NA21, NA23, NA24, SA10, SA101, SA2, SA3, SA4, SA11, SA19
Pareucalanus sewelli (Fleminger, 1973)	*, A	TL, L	NA19, NA22, NA24, SA2, SA3, SA25, SA94
Sapphirina auronitens Claus, 1863	TA, A	#, L	LSC12, LSC18, LSC79, LSO7, LSO10
Sapphirina bicuspidata Giesbrecht, 1891	-	#, L	LSC11, LSC13, LSC61, LSC65, LSC81
Scaphocalanus curtus (Farran, 1926)	*, A	#, L	NA18, LSC79, LSO6, LSO7
Scolecithricella dentata (Giesbrecht, 1892)	TA, A	#, L	LSC79, LSO6

'+': first records for the Aegean Sea; '*': first records for Turkey's Aegean coast; '#': first records for the Turkish Levantine coasts; 'μ': first records for the Levantine Sea; '-': not found in that location. Previous records of the species in the Marmara Sea, the Turkish Aegean coasts, the Aegean Sea, the Turkish Levantine coasts and the Levantine Basin are indicated with 'B', 'M', 'TA', 'A', 'TL' and 'L', respectively (Hajderi 1995, Gücü et al. 2000, Ünal et al. 2000, Özel and Aker 2001, Aker 2002, Uysal et al. 2002, Isari et al. 2006, Uysal and Shmeleva 2012, Bakır et al. 2014, Razouls et al. 2005–2022)

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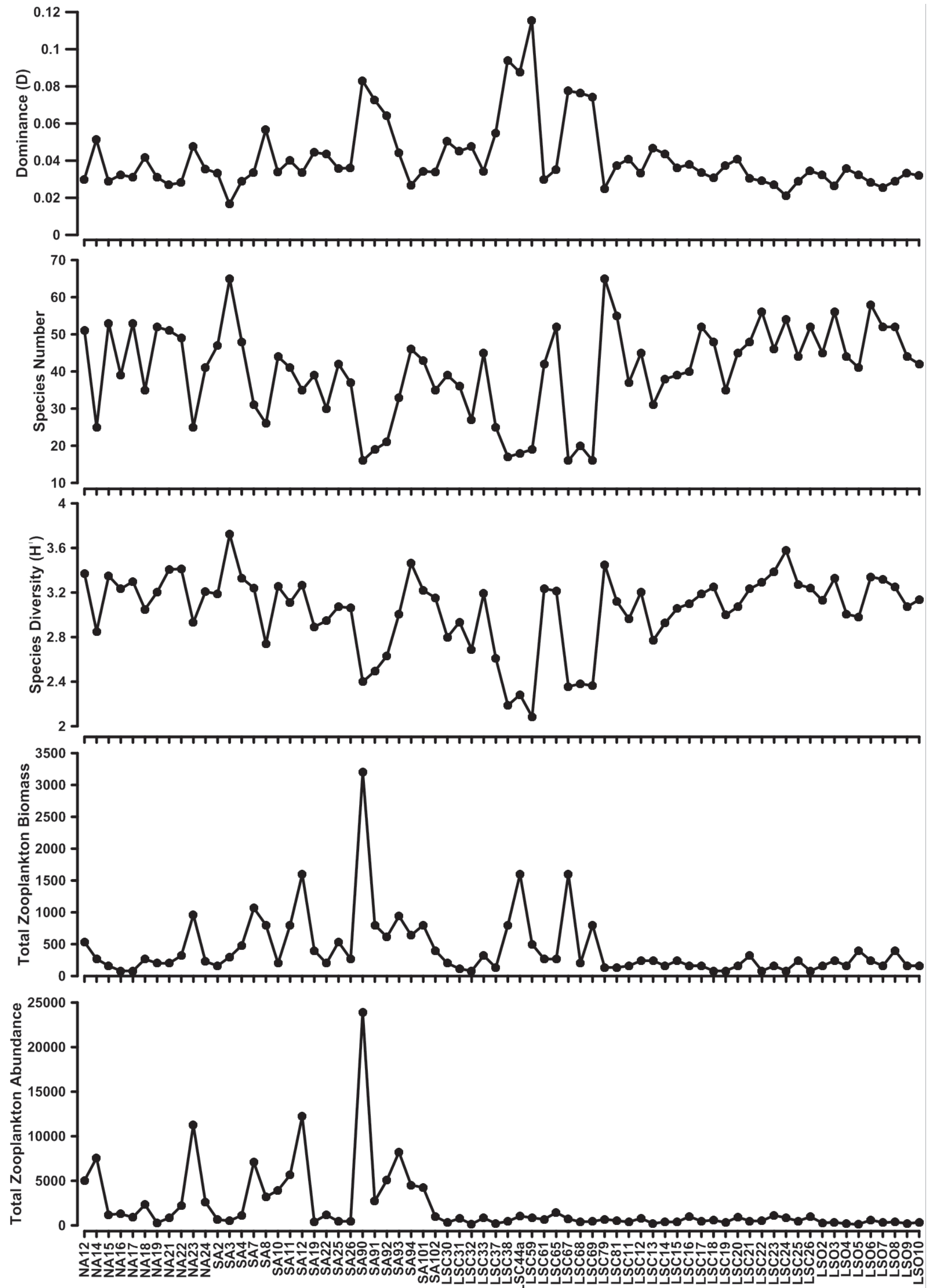

Figure 2

Fluctuations in zooplankton abundance (ind m^{-3}), biomass (mg m^{-3}), number of species and dominance (D)

Sea (SA), especially in Station SA90, particularly due to *Penilia avirostris* and *Centropages kroyeri*, whereas the lowest mean abundance (307 ind m^{-3}) and biomass (231 mg m^{-3}) values were observed in the LSO (Table 4). A total of 157 taxa were registered in the study area, of which 112 were in Copepoda and 7 were in Cladocera. Copepods, cladocerans, doliolids, meroplankton and appendicularians represented the most important zooplankton groups in all stations. Among meroplankton, the most important groups were larvae of Decapoda, Polychaeta, Mollusca and Cirripedia, together comprising 2.7% of the total abundance. Salps and siphonophores were also abundant in some areas, especially in the Aegean Sea; however, their relative abundance never exceeded 5%.

Generally, Copepoda was the most abundant group in the LSO area (Table 4), but the maximum abundance (11,757 ind m^{-3}; Station SA90) was recorded in the southern Aegean Sea (Figure 3). *Paracalanus parvus*, *Acartia clausi*, *Centropages kroyeri* and *Temora stylifera* were very important in the Aegean Sea; *Clausocalanus furcatus*, *Oithona plumifera*, *Calocalanus pavoninus*, *Farranula rostrata* and *Calanopia elliptica* were dominant in the stations of the Levantine Sea (Table 4). *Candacia giesbrechti* (Station NA15) and *Acartia* (*Hypoacartia*) *adriatica* (Stations NA17, SA2 and SA3) were found only in the Aegean Sea, while *Sapphirina bicuspidata* was recorded only on the eastern coasts of the Levantine Sea (Stations LSC11, LSC13, LSC61, LSC65 and LSC81). *Calonopia elliptica* and *Parvocalanus elegans* were only present in the coastal waters of the Levantine Sea, where *Calonopia elliptica* reached extremely high abundance (506 ind m^{-3}) at Station LSC59. A total of 19 copepod species were recorded for the first time in the Aegean (15 species) and Levantine (8 species) coasts of Turkey. Five copepod species (*Corycaeus* (*Onychocorycaeus*) *ovalis*, *Goniopsyllus clausi*, *Oncaea scottodicarloi*, *Sapphirina bicuspidate* and *Scaphocalanus curtus*) were recorded for the first time in the Turkish coastal region, three (*Centropages bradyi*, *Goniopsyllus clausi* and *Oncaea scottodicarloi*) for the Aegean Sea and one (*Goniopsyllus clausi*) among the eastern Mediterranean fauna (Table 3).

Cladocera, with maximum abundance of 11,757 ind.m^{-3} at Station SA90, had a higher percentage of mesozooplankton at the NA and SA stations (Table 4), but a much lower mean relative abundance was observed at the LSC and LSO stations (Figure 3). A total of 7 Cladocera species (*Penilia avirostris*, *Pseudevadne tergestina*, *Evadne spinifera*, *Evadne nordmanni*, *Pleopis polyphemoides*, *Podon intermedius* and *Pleopis schmackeri*) were identified in the present study. Among Cladocera *Penilia avirostris* was the dominant species, especially in coastal bays and areas in the sub regions of the study area, with a maximum abundance of 8778 ind m^{-3} (at Station NA23) and of 8203 ind m^{-3} (at Station SA90). Other Cladocera (in order of importance) followed: *Pseudevadne tergestina* and *Evadne spinifera*. *Pleopis schmackeri* was observed at both the SA and LSC stations, with a maximum abundance of 5.3 ind m^{-3} (at Station SA101).

Although Doliolida species were also occasionally observed (a 50% occurrence), they did not significantly contribute to the total zooplankton abundance (Table

Table 4

Mean relative abundance (%), total abundance (ind m^{-3}) and biomass (mg m^{-3}) of dominant taxa within the total zooplankton in the Eastern Mediterranean Sea ('-': not found). Only taxa with a general contribution of >0.5% to the total zooplankton abundance are reported here.

	Eastern Mediterranean Sea			
	Aegean Sea		Levantine Sea	
	Northern Aegean Sea (NA)	Southern Aegean Sea (SA)	Coastal Waters of the Levantine Sea (LSC)	Open Waters of the Levantine Sea (LSO)
Copepods	28.7	44.3	77.0	86.8
Acartia clausi	7.82	0.43	0.10	-
Acartia negligens	-	0.08	0.81	3.43
Calocalanus pavo	0.01	0.18	0.68	1.25
Calocalanus pavoninus	0.01	0.19	6.16	9.08
Calocalanus styliremis	1.67	0.11	0.30	3.76
Calonopia elliptica	-	-	4.35	-
Centropages kroyeri	0.41	13.70	2.06	0.01
Centropages typicus	2.55	0.09	0.00	0.00
Clausocalanus furcatus	0.00	0.55	20.92	28.80
Farranula rostrata	0.43	0.44	0.71	12.03
Lucicutia flavicornis	0.01	0.00	0.08	1.56
Mecynocera clausi	0.22	0.10	0.35	0.51
Paracalanus denudatus	0.04	0.11	0.10	1.83
Paracalanus nanus	0.04	0.09	0.10	2.64
Paracalanus parvus	6.60	19.03	16.08	0.59
Temora stylifera	0.53	5.38	2.88	2.51
Parvocalanus elegans	-	-	0.60	-
Oithona nana	0.34	0.50	1.29	0.21
Oithona plumifera	2.93	1.45	15.23	9.37
Oithona similis	1.51	0.05	0.53	2.31
Oithona tenuis	-	0.03	0.68	0.41
Oncaea mediterranea	0.21	0.03	0.03	1.37
Oncaea media	0.17	0.33	0.53	0.02
Oncaea scottodicarloi	0.20	0.03	0.10	2.64
Cladocera	63.6	43.4	12.4	0.9
Penilia avirostris	58.65	33.07	4.60	-
Pseudevadne tergestina	3.10	6.95	3.05	0.11
Evadne spinifera	1.53	2.67	4.77	0.69
Appendicularians	2.1	3.6	2.8	1.4
Doliolida	3.2	5.8	2.6	0.0
Chaetognaths	0.7	0.5	1.2	2.6
Meroplankton	1.5	2.9	5.4	3.2
Total abundance (ind m^{-3})	3231	4562	628	307
Total biomass (mg m^{-3})	300	748	316	231

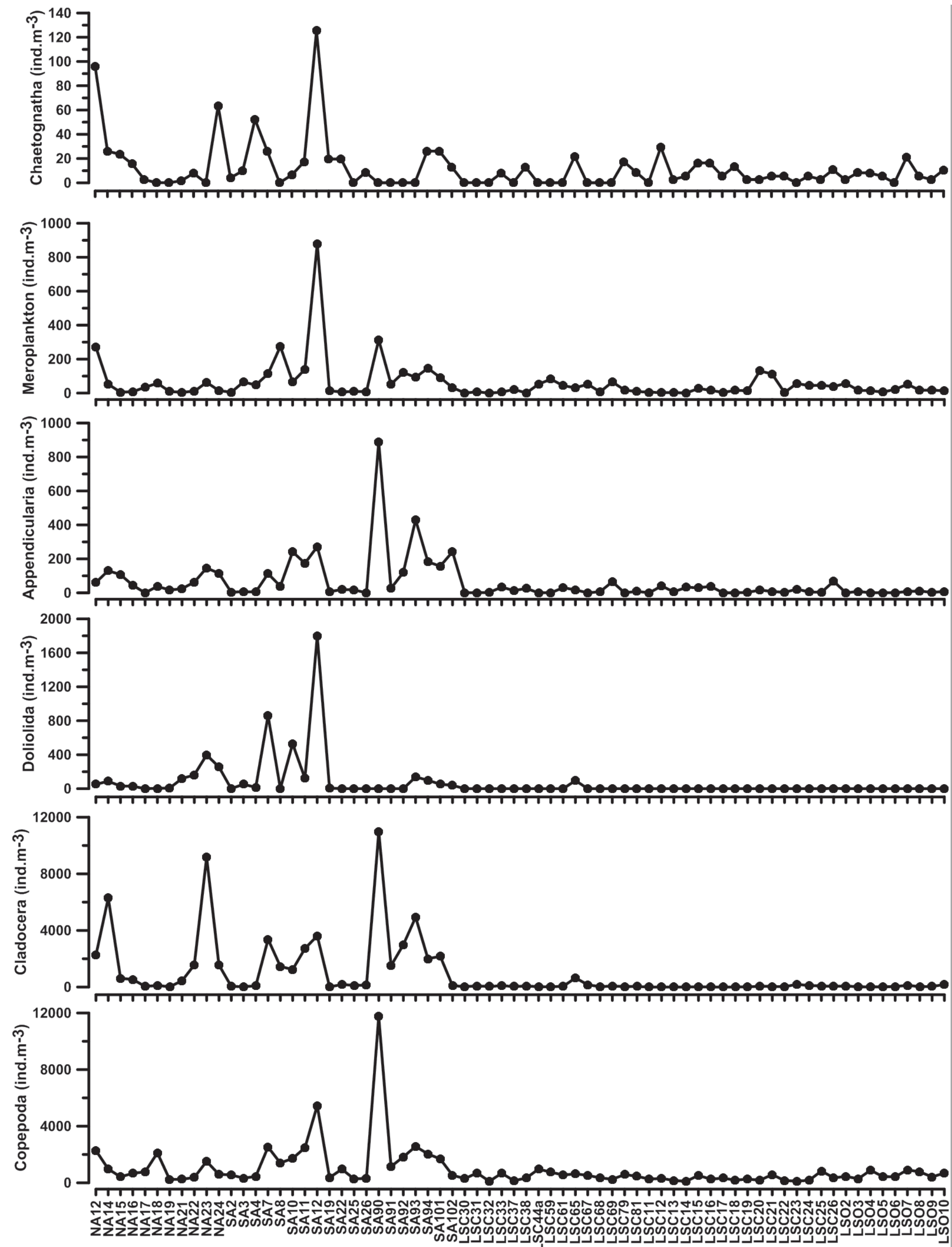

Figure 3

Fluctuations in dominant zooplankton groups in the sampling area

4, Figure 3). The abundance of meroplanktonic groups, including larvae of Bivalvia, Gastropoda, Polychaeta and Echinodermata, were higher in the gulfs and the coastal stations, whereas Appendicularia were an important group in SA, with a maximum abundance of 888 ind m^{-3} at Station SA90 (Figure 3).

With regard to regions, 96 species were found in the NA, 98 in the SA, 124 in the LSC and 91 in the LSO. The increasing number of species from NA to LSC was more evident, except in LSO. The variability in the number of species within areas was greater in the SA and LSC regions. The most species (65 species) was recorded at Stations SA3 and LSC79 (Figure 2). The diversity index values varied between 3.7 bits (Station SA3) and 2.1 bits (Station LSC59) (Figure 2). The dominant species from the coastal waters differed from those in open waters.

Table 5

Species contributing to within-group similarity as defined by SIMPER

Group and Average Similarity	Species	Similarity-to-Standard Deviation Ratio	Per cent Contribution	Cumulative Per cent Contribution
NA, 56.96	*Paracalanus parvus*	7.59	10.11	10.11
	Penilia avirostris	2.55	10.09	20.20
	Oithona plumifera	3.17	7.64	27.84
	Appendicularia	2.06	6.73	34.57
	Centropages typicus	1.94	6.38	40.95
	Acartia (Acartiura) clausi	1.67	6.33	47.28
	Doliolida	1.64	5.75	53.03
	Pseudevadne tergestina	1.44	5.56	58.58
	Evadne spinifera	3.08	5.55	64.13
	Calocalanus styliremis	1.25	3.9	68.03
SA, 49.84	*Paracalanus parvus*	4.16	12.97	12.97
	Temora stylifera	6.28	10.39	23.37
	Penilia avirostris	1.39	8.88	32.25
	Oithona plumifera	1.95	7.24	39.49
	Evadne spinifera	1.67	7.19	46.68
	Appendicularia	1.96	7.16	53.84
	Pseudevadne tergestina	1.70	6.89	60.73
	Clausocalanus furcatus	0.81	3.5	64.23
	Farranula rostrata	0.91	3.14	67.38
	Chaetognatha	0.91	2.88	70.25
LSC, 50.03	*Oithona plumifera*	2.09	12.71	12.71
	Clausocalanus furcatus	1.81	12.30	25.01
	Paracalanus parvus	1.18	9.97	34.98
	Evadne spinifera	1.69	8.81	43.79
	Calocalanus pavoninus	1.75	8.77	52.56
	Pseudevadne tergestina	1.22	5.82	58.38
	Temora stylifera	1.06	4.88	63.27
	Appendicularia	0.91	4.29	67.55
LSO, 65.80	*Clausocalanus furcatus*	11.01	12.52	12.52
	Farranula rostrata	9.95	9.72	22.24
	Oithona plumifera	7.08	9.43	31.67
	Calocalanus pavoninus	4.70	8.69	40.36
	Calocalanus styliremis	7.16	6.88	47.24
	Oithona similis	3.70	5.48	52.71
	Chaetognatha	1.63	4.30	57.01
	Siphonophora	1.24	3.86	60.87
	Temora stylifera	1.2	3.86	64.73
	Paracalanus denudatus	1.85	3.84	68.57

3.3. Spatial patterns of zooplankton composition and diversity

Cluster analysis (Figure 4) and MDS ordination (Figure 5) of the combined data from the subregions showed that the samples were clearly differentiated by region. The among-region differences were stronger when zooplankton abundance ($F_{3;69} = 19.885$; $p < 0.05$) and biomass ($F_{3;69} = 7.629$; $p < 0.05$) were considered. The Tukey test indicated a difference in total biomass between the southern Aegean Sea and all other areas, while the zooplankton community structure in the subregions (NA and SA) of the Aegean Sea had significantly higher values than those of the Levantine Sea (LSC and LSO). While the highest zooplankton abundance value was recorded in the SA region, with an average of 4562 ± 5523 ind m^{-3}, lower values were recorded in LSO (307 ± 132 ind m^{-3}) and LSC (628 ± 300). ANOSIM analysis (global R value = 0.517, p = 0.1%) showed significant correlations between the study sites regarding the zooplankton communities. It was determined that the structure of the zooplankton community in the LSO region differed from that of the NA region (ANOSIM R = 0.946). The within-group similarity (using SIMPER; Table 5) depending on the dominant species revealed a higher average similarity (more than 60%) within the LSO group, with *Clausocalanus furcatus* significantly contributing along with *Farranula rostrata* and *Calocalanus pavoninus*, due to their higher abundance. The lowest average similarity (49.84) was observed in the SA region. *Paracalanus parvus*, *Temora stylifera* and *Penilia avirostris* were relatively consistent species within SA.

SIMPER analysis showed that Appendicularia, Doliolidae, some Copepoda (such as *Paracalanus parvus*, *Acartia clausi*, *Centropages kroyeri* and *Centropages typicus*) and Cladocera (such as *Penilia avirostris*, *Pseudevadne tergestina* and *Evadne spinifera*) mostly contributed to dissimilarity among groups (Table 6). The species contributing to the dissimilarities

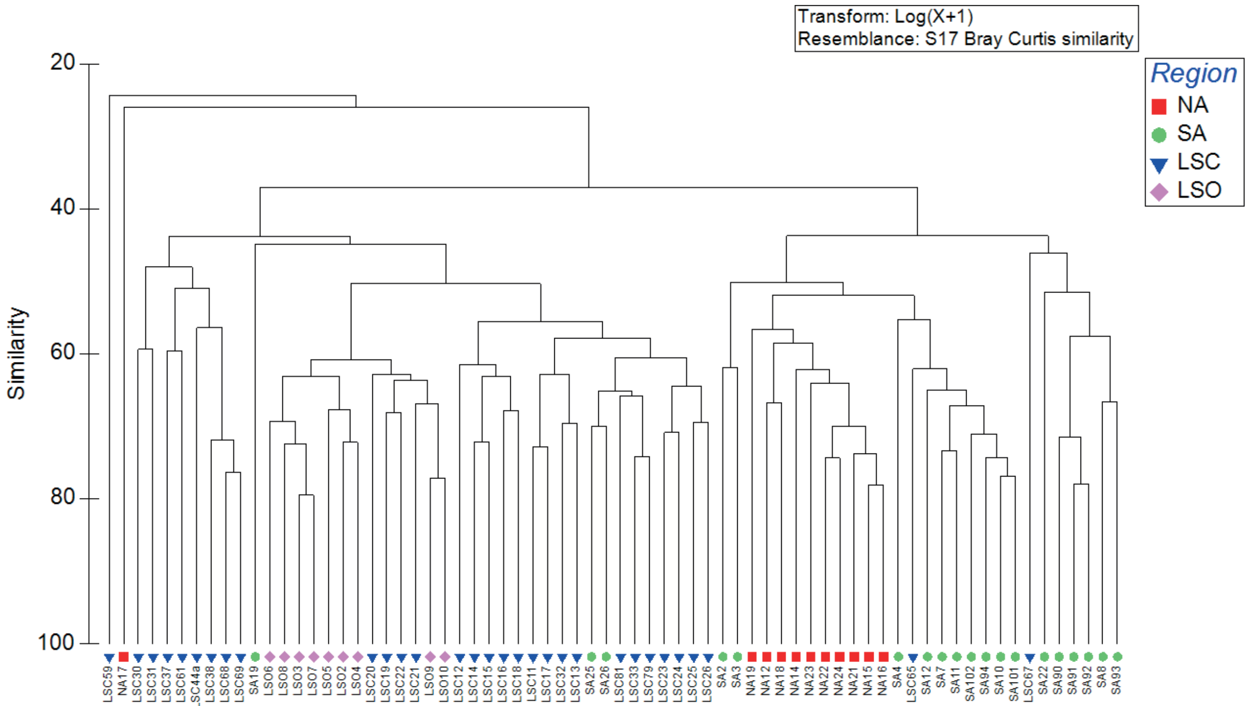

Figure 4

Dendogram for the hierarchical clustering of the 70 stations using group-average linking of Bray–Curtis similarities calculated on log-transformed abundance data. NA: northern Aegean Sea; SA: southern Aegean Sea; LSC: coastal waters of the Levantine Sea; LSO: open waters of the Levantine Sea

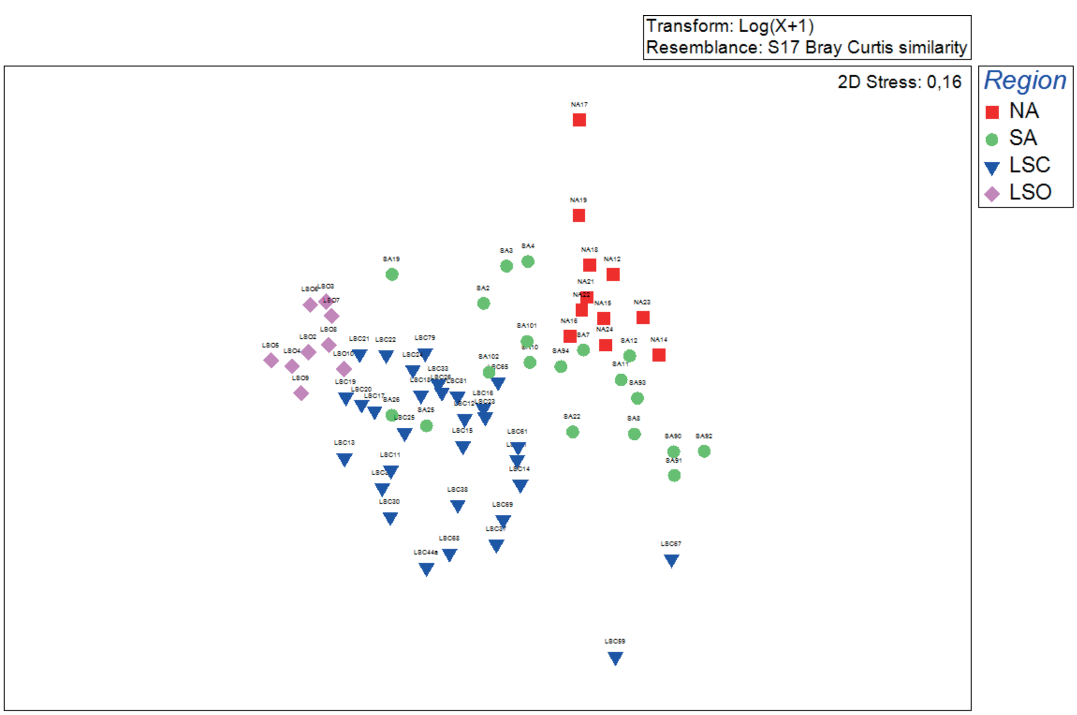

Figure 5

MDS ordination plot of 70 stations in the study area. NA: northern Aegean Sea; SA: southern Aegean Sea; LSC: coastal waters of the Levantine Sea; LSO: open waters of the Levantine Sea

Table 6

Zooplankton species characterising the station groups, identified by clustering, determined by similarity percentage analysis (SIMPER), based on log-transformed abundance data and the Bray–Curtis similarity measure

Groups and average dissimilarity	Species	Average dissimilarity	Dissimilarity to standard deviation ratio	Percent contribution	Cumulative percent contribution
SA vs NA 54.84	*Acartia (Acartiura) clausi*	2.23	1.57	4.07	4.07
	Centropages typicus	2.07	1.88	3.78	7.85
	Penilia avirostris	1.99	1.22	3.63	11.48
	Temora stylifera	1.92	1.71	3.5	14.98
	Doliolida	1.78	1.42	3.25	18.23
	Centropages kroyeri	1.71	0.82	3.11	21.35
	Oithona similis	1.58	1.27	2.88	24.22
	Pseudevadne tergestina	1.54	1.29	2.8	27.02
	Clausocalanus furcatus	1.5	1.27	2.74	29.76
	Calocalanus styliremis	1.45	1.33	2.64	32.41
	Pteropoda	1.27	1.07	2.32	34.73
SA vs LSC 58.01	*Penilia avirostris*	3.37	1.69	5.81	5.81
	Centropages kroyeri	2.13	0.88	3.67	9.48
	Temora stylifera	2.1	1.53	3.62	13.1
	Paracalanus parvus	2.1	1.33	3.62	16.72
	Appendicularia	1.96	1.51	3.37	20.09
	Clausocalanus furcatus	1.91	1.31	3.29	23.38
	Pseudevadne tergestina	1.89	1.14	3.25	26.63
	Doliolida	1.88	1.12	3.24	29.87
	Calocalanus pavoninus	1.82	1.59	3.13	33
	Pteropoda	1.53	1.09	2.63	35.63
SA vs LSO 67.05	*Paracalanus parvus*	4.13	3.5	6.15	6.15
	Penilia avirostris	4.09	1.89	6.1	12.25
	Pseudevadne tergestina	3	1.64	4.48	16.73
	Evadne spinifera	2.56	1.9	3.82	20.55
	Appendicularia	2.29	1.67	3.41	23.96
	Temora stylifera	2.27	2.1	3.39	27.35
	Centropages kroyeri	2.06	0.77	3.06	30.41
	Doliolida	1.89	1.11	2.83	33.24
LSC vs NA 64.20	*Penilia avirostris*	3.66	1.89	5.7	5.7
	Clausocalanus furcatus	3.13	2.42	4.87	10.57
	Acartia (Acartiura) clausi	3.06	1.88	4.77	15.34
	Centropages typicus	2.85	2.35	4.44	19.78
	Doliolida	2.75	1.97	4.29	24.07
	Calocalanus pavoninus	2.24	2.14	3.48	27.55
	Calocalanus styliremis	1.84	1.41	2.87	30.42
	Oithona similis	1.83	1.34	2.85	33.27
LSC vs LSO 56.67	*Paracalanus parvus*	3.23	1.73	5.69	5.69
	Evadne spinifera	2.42	1.74	4.27	9.96
	Farranula rostrata	2.39	1.7	4.21	14.17
	Pseudevadne tergestina	2.18	1.6	3.85	18.02
	Calocalanus styliremis	1.82	1.75	3.21	21.24
	Paracalanus nanus	1.68	1.8	2.96	24.2
	Gastropoda	1.64	1.32	2.89	27.08
	Appendicularia	1.6	1.3	2.82	29.91
NA vs LSO 72.61	*Penilia avirostris*	4.67	2.77	6.43	6.43
	Paracalanus parvus	3.43	4.13	4.72	11.15
	Clausocalanus furcatus	3.42	6.92	4.71	15.86
	Acartia (Acartiura) clausi	3.23	2	4.45	20.3
	Centropages typicus	2.9	2.41	3.99	24.3
	Doliolida	2.85	2.09	3.92	28.22
	Pseudevadne tergestina	2.72	1.9	3.75	31.97
	Calocalanus pavoninus	2.38	3.33	3.27	35.24

between pairs of station groups revealed that the LSO was significantly dissimilar to both the NA and SA (total average dissimilarity: 72.61% and 67.05%, respectively), due to the rarity and relative scarcity of some zooplankton species compared to those of other groups, including *Penilia avirostris*, *Pseudevadne tergestina*, *Paracalanus parvus*, *Clausocalanus furcatus*, *Acartia clausi*, *Centropages typicus*, *Calocalanus pavoninus* and Doliolidae. The average of the Bray–Curtis dissimilarities between all pairs of NA and SA groups was relatively lower (54.84%). The species that contributed the most to dissimilarity was *A. clausi* because of its high frequency (7.82%) and relatively higher abundance in the NA region, especially at stations NA23 (950 ind m^{-3}) and NA18 (707 ind m^{-3}). Additionally, the low-frequency species *Oithona setigera* (<1% occurrence in all regions) exhibited the highest abundance only in Station NA17 (154 ind m^{-3}) of the northern Aegean Sea and *Paracartia latisetosa* was found only at two stations in the coastal waters of Levantine Sea (52 ind m^{-3} at Station LSC67 and 13 ind m^{-3} at Station LSC68), but there was no significant contribution to the dissimilarity (<1%) between regions.

4. Discussion

This study provides information about the abundance and distribution of the main zooplankton species in the Aegean and Levantine Seas. In the study, *Paracalanus parvus*, *Acartia clausi*, *Centropages kroyeri*, *Oithona plumifera*, *Temora stylifera*, *Clausocalanus furcatus*, *Penilia avirostris*, *Evadne spinifera*, *Pseudevadne tergestina*, Doliolidae and Appendicularia represented the most common and most abundant zooplankton taxa. Moreover, a total of 15 species were recorded in the study area for the first time, including 3 for the Aegean Sea, 1 for the eastern Mediterranean and 5 for the Turkish coastal areas. *Corycaeus* (*Onychocorycaeus*) *ovalis*, *Goniopsyllus clausi*, *Oncaea scottodicarloi*, *Sapphirina bicuspidata* and *Scaphocalanus curtus* were recorded for the first time in Turkish coastal regions, while *Centropages bradyi*, *Goniopsyllus clausi* and *Oncaea scoottodicarloi* were recorded for the first time in the Aegean Sea with this study. *Goniopsyllus clausi* was the new species for the Eastern Mediterranean fauna.

Unlike in previous years (Sever 2009), a gradual increase in mesozooplankton abundance from the northern Aegean Sea towards the southern part was observed. Previous studies (Siokou-Frangou et al. 2002, Zervoudaki et al. 2006) found that the entry of Black Sea water into the Aegean Sea via the Dardanelles caused a significant increase in phytoplankton and mesozooplankton biomass and abundance in the region. However, aquaculture and terrestrial inputs make a significant contribution to higher picophytoplankton biomass and productivity in the coastal waters of the southern Aegean and Levantine Seas (Aktan 2011, Polat 2002, Polat and Terbıyık 2013). These factors are favourable for Cladocera, primarily *P. avirostris* (Isari et al. 2007). *Penilia avirostris* were found in very high numbers in these regions, often exceeding 2000 ind m^{-3}. Swarms of this species can be seen in the surface coastal waters and in shallow locations during the summer (Christou and Stergiou 1998, Gülşahin and Tarkan 2012, Killi and Sağdıç 2018). Some authors have suggested that temperature may play an important role in the population dynamics of *P. avirostris* (Atienza et al. 2007, Gieskes 1971, Onbé and Ikeda 1995). However, environmental conditions such as photoperiod, food availability, turbulence, crowding and predation seem to be key factors in population size (Stross and Hill 1968, Frey 1982, Fofonoff 1994). Also, Christou and Stergiou (1998) reported that salinity influences the amount and distribution of *P. avirostris*, despite its high salinity tolerance. Playing a different role in the pelagic food chain, *P. avirostris* is a species commonly found in tropical and subtropical seas that mostly feeds on nanoplankton (<15 μm) (Lipej et al. 1997). Therefore, *P. avirostris* plays an important role among bacterioplankton and higher level consumers. Lipej et al. (1997) reported that pico and nanoplanktonic autotrophs are abundant in the water column in the Adriatic Sea during the summer months, and that an increase in *P. avirostris* population occurs because it feeds effectively on these organisms. In addition, Turner et al. (1988) stated that this species feeds on heterotrophic microflagellates, small diatoms and autotrophic flagellates. The presence of these organisms in the study area (Aktan 2011) may have contributed positively to the dominance of *P. avirostris* in the environment. The other Cladocera species were found in much lower numbers when compared with *Penilia avirostris*. *E. spinifera*, *P. tergestina* and *E. nordmanni* were present all across the study area in low numbers. These three species have been found in both coastal and pelagic areas of the eastern Mediterranean (Mazzocchi et al. 1997, Christou and Stergiou 1998, Gülşahin and Tarkan 2012, Killi and Sağdıc 2018, Killi 2020). In this study, while *P. intermedius* and *P. schmackeri* were observed in both the Aegean Sea and the coastal regions of the eastern Mediterranean, *Podon polyphemoides* was found only in the Aegean Sea. However, *Pleopis polyphemoides* has been reported among the dominant Cladocera in the coastal areas of the

Mediterranean Sea (Siokou-Frangou 1996, Camatti et al. 2008, Gülşahin and Tarkan 2012, Terbiyik-Kurt and Yilmaz-Zenginer 2016, Killi and Sağdıc 2018, Killi 2020). *Pleopis schmackeri* was reported for the first time in İskenderun Bay, in the north-eastern Mediterranean in July 2012 (Terbıyık Kurt and Polat 2017) and later in August 2017 it was found in the entire Aegean coast of Turkey (Bariche et al. 2020). However, the present study demonstrates that *Pleopis schmackeri* (Poppe 1889) may have already existed in August 2006 along the coasts of both the Aegean Sea and the Mediterranean Sea of Turkey.

In the present study, a total of 112 copepod species were discovered, of which 97 were in the Levantine Sea and 88 in the Aegean Sea. The dominance of *Clausocalanus furcatus*, *Oithona plumifera* and *Paracalanus parvus* resulted in a comparable copepod species composition across practically the entire eastern Mediterranean. While *C. furcatus* has a global tropical/subtropical distribution (Frost and Fleminger 1968), *O. plumifera* is found mainly in warm waters as well as in temperate regions (Raymont 1983). *C. furcatus* and *O. plumifera* are the dominant species in a large area of the eastern Mediterranean (Toklu and Sarıhan 2003; Siokou-Frangou et al. 1997, 2004; Altuğ et al. 2011; Mazzocchi et al. 2014; Terbıyık Kurt and Yilmaz-Zenginer 2016). Furthermore, in late summer and autumn, *C. furcatus* and *O. plumifera* dominated in Mediterranean coastal areas, subjected to the influence of the open sea (Siokou-Frangou et al. 1998). They are thought to be typical of the Mediterranean epipelagic habitat, and populations have been found in both coastal and offshore regions (Siokou-Frangou et al. 1997, Ramfos et al. 2005, Altuğ et al. 2011, Aker 2015). These two species were found to be prevalent in a vast area between LSC and LSO, as well as in SA, according to our research. In temperate and warm seas, *Paracalanus parvus* has a remarkable range of distribution (Raymont 1983). The most important dominant species in the northern Aegean Sea are *Paracalanus parvus*, *Acartia clausi* and *Penilia avirostris* (Siokou-Frangou et al. 2009, Zervoudaki et al. 2006, Isari et al. 2005, Sever 2009, Isinibilir 2009, Altuğ et al. 2011, Aker 2015). These species are also found in high abundance and dominance in the Sea of Marmara (Isinibilir et al. 2008, 2011), and they could be transported into the northern Aegean Sea through the Black Sea outflow by the Çanakkale Strait (Altuğ et al. 2011).

The Aegean Sea, particularly the southern section, has larger relative abundances of Appendicularia, which are commonly linked with abundant particulate organic aggregates (Alldredge 1976), and thus play an essential role in pelagic food webs and carbon transfer downward (Gorsky et al. 1991). Their significant relative importance in the southern Aegean Sea suggests that the water column in these areas was richer in particulate organic material and, in general, smaller particles. The highest nutrient levels and the lowest transparency levels were found at several stations in the LSC region, due to local tourism, domestic sewage discharge, industrial wastewater and marina activities and marine traffic, as well as in the SA region, due to intensive aquaculture and limited water exchange with the sea (Aktan 2011).

Eutrophication may have an indirect effect on zooplankton species diversity through its effect on phytoplankton (Shiganova et al. 1998). The abundance of *Noctiluca scintillans* and herbivorous zooplankton species increases as phytoplankton biomass increases (Shiganova et al. 1998). Reduced chlorophyll-*a* and nutrients from inshore to open waters (Aktan, 2011) may have resulted in higher zooplankton species diversity in the research area. The coastal waters of the southern Aegean Sea and the Levantine Sea, which host mariculture and domestic inputs, had lower diversity values.

The cluster diagram (Figure 4) and MDS representation (Figure 5) showed that Stations NA17 and LSC59 were starkly different from the other sampling stations, mainly due to their low number of species and unique species composition. Both stations present very particular conditions, which most likely were responsible for their singularity in terms of the zooplankton. An interesting finding for Station NA17 was the registration of *Acartia* (*Hypoacartia*) *adriatica*, a species endemic to the Adriatic Sea and never recorded in other seas around the world (Belmonte and Potenza 2001). This species has also detected in the middle Aegean Sea (Aker 2002). LSC59 is located very close to the Iskenderun port, and it could be affected by high anthropogenic pressure; this seems to presuppose the existence of a relatively poor zooplankton community. Only some common and opportunistic taxa (for example, the well-known *Paracalanus parvus* or *Calonopia elliptica*) can form persistent populations in this disturbed environment. *Calanopia elliptica*, which is of Indo-Pacific origin, is present in the Levantine Sea (Lakkis 1976), but has not been observed in the western part of the Mediterranean Sea or the Atlantic Ocean (Uysal et al. 2002).

The current study provides information on broader forms of zooplankton community structure in the Eastern Mediterranean, ranging from coastal to open water areas. Detailed future investigations are required to better understand the impact of zooplankton on coastal ecosystems due to growing anthropogenic and climatic pressures. Furthermore, the ecological significance of zooplankton, both in the oligotrophic eastern Mediterranean Sea and in coastal environments with changing trophic status, should be investigated further.

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