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RESEARCH PAPER

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Zooplankton Biodiversity in the Golden Horn Estuary after the Opening of the Water Channel from the Strait of Istanbul, Turkey

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Abstract

This paper examines spatial and temporal variations of zooplankton abundance and community structure from December 2014 to November 2015 after the opening of the water channel. So, this is the first zooplankton study after the opening of the water channel from the Istanbul Strait to the Golden Horn Estuary. It is thought that this study will be an important database for future studies in the region. A total of 40 species were identified during in this study. Nine species (*Daphnia curvirostris, Daphnia hyalina, Bosmina (Eubosmina) coregoni, Cyclops abyssorum, Mnemiopsis leidyi, Pleurobrachia pileus, Beroe ovata,* and *Aurelia aurita*) are first recorded in the Golden Horn and one of these (*Bosmina (Eubosmina) coregoni)* is also first records for the Turkish coasts. Furthermore, it has been observed that marine zooplankton abundance and diversity have increased in the estuary after the opening of the water channel.

Introduction

The zooplankton is also an important intermediate component in estuarine food webs, acting as a trophic link between small organic particles (e.g. detritus and microalgae) and planktivorous fishes (McLusky and Elliott, 2004). Besides, in order to control phytoplankton production and shape the pelagic ecosystem, zooplankton play an important role in the pelagic nutrient network. Additionally, because zooplankton is an important nutrient for fish larvae, its populations, dynamics, breeding and development cycles and survival rates are one of the most important factors affecting fish stocks (Lenz, 2000). Since many zooplankton species have a short life cycle and high growth potential, they react to changes in the environmental conditions in terms of biodiversity and abundance (Gajbhiye, 2002). The larvae of commercially important fish, shrimp and crab species are also part of the zooplankton community (Morgan, 1990). Zooplankton species play an important role in determining ecosystem quality and can be measured quantitatively (Day *et al*, 1989). In this respect, zooplankton should also be followed closely besides other biological parameters to gain information about the ecosystem's status.

Estuaries are transition zones between riverine and maritime environments, and they are known as highly productive ecosystems. When natural interactions of physical, chemical and biological factors combine with the effect of human use, they challenge our ability to understand and manage this natural resource. Knowledge of the variability of the estuarine zooplankton composition and abundance at different temporal scales is a prerequisite to the understanding of the ecosystem dynamics. In estuaries the temporal

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variation in environmental conditions strongly affects the distribution of zooplankton species (Dauvin, Thiébaut, & Wang, 1998).

The Golden Horn Estuary is located at the south west of the Strait of Istanbul, with approximately 7.5 km long and 700 m wide. The maximum depth is 40 m at the lower estuary and the depth decreases towards the upper part. The pollution particularly due to pharmaceutical, detergent, dye and leather industries, and domestic wastewater discharge had been severely increased by the rise in the industry and urban development in the Golden Horn Estuary since 1950s (Yüksek, Okuş, Yilmaz, Aslan-Yilmaz, & Taş, 2006). By the end of 1990s, the estuary became anoxic towards the upper parts and prevailed throughout the year (Tas, Okus, & Aslan-Yılmaz, 2006). As a result, the ecosystem of the Golden Horn was greatly influenced and the ecosystem of Golden Horn Estuary was dominated by *Polidora ciliata, Mytillus galloprovincialis, Podon polyphemoides* and *Noctiluca scintillans*, highly tolerant to organic pollution (Yüksek, Okuş, Yilmaz, Aslan-Yilmaz, & Taş, 2006; Dorak and Albay, 2016). While the aquatic life in the lower regions of the estuary was limited by pollution, it completely disappeared in the upper regions (Güvengiriş, 1977). By the end of 1990s, the Golden Horn Rehabilitation Project was initiated. One of the greatest projects of environmental protection of last years in Turkey namely “Golden Horn Estuary Environmental Protection Project” was started by the Greater Municipality of Istanbul and ISKI (Istanbul Water and Sewerage Administration) in 1995. As a part of this project, industrial plants were taken away, a number of wastewater collectors and wastewater collection tunnels were made on both sides of Golden Horn Estuary, through this way a wastewater was enabled to pump into Yenikapi and Baltalimani Wastewater Pre-Treatment Plant, five million cubic meters of sludge was removed from the sediment and along the coastline landscaping works were carried out. After the initiation of rehabilitation studies, dissolved oxygen (DO) concentrations increased significantly across the estuary, and the minimum values increased from 3 mg in 1998 to 5 mg in 2000. In addition, H2S formation detected at the beginning of the study was lost in the following years (Kiratli and Balkis, 2001). Via one of the final stages of the Golden Horn Estuary Environmental Protection Project water flow from the Strait of Istanbul to the Golden Horn Estuary, it was aimed to ensure permanent water flow to Kağithane branch for renewal of branch water and to clean water into the Golden Horn. Within the scope of the Project, seawater was collected from Sarıyer Çayırbaşı and transmitted to Ayazağa through a tunnel of 5 km long by this project which aims at renovating the waters of the Golden Horn and raise biological diversity. The waters from the Strait that emerged to the surface at that point were transferred to Kağıthane Stream by 23 km long accession. Seawater was transported to the Golden Horn after 9 km long travel in the Stream and the system is planned to be operated in the summer months when the stream flows are less than winter months.

Although there have been several studies on the phytoplankton community, pollution, physical and chemical characteristics of the estuary (e.g. Alpar, Yüce, & Türker, 2003; Aslan-Yılmaz, Okuş, & Övez, 2004; Taş, 2017), there have been a few studies about zooplankton structure (Dorak and Temel, 2015, Dorak and Albay, 2016). There are however no data on the annual zooplankton abundance, diversity and species composition, after the opening of the water channel from the Strait of Istanbul. The aim of the present study is to examine the zooplankton annual cycle in Golden Horn estuary, as shown by the seasonal evolution of zooplankton community structure, as well as to evaluate the influence of environmental parameters on them after opening water channel from the Strait of Istanbul to the Golden Horn Estuary.

Materials and Methods

Study Area and Sampling Procedure

Samples were collected from four stations in the Golden Horn Estuary. GH4 (40 m) and G3 (35 m) were located at the lower estuary receiving salty waters of the Strait of Istanbul. G2 (10 m) was located at the mid-estuary and GH1 (5 m) was close to the semi-opened bridge (Figure 1).

All samples were collected between December 2014 and November 2015 by vertical tows a WP2 closing net (200 µm mesh, 0.57 m diameter) to the surface from the bottom or from the predefined upper layer. The net was rinsed gently and samples were transferred into plastic containers, and fixed by addition of borax-buffered formaldehyde to a final concentration of 4%. Identification of specimens was carried out under a stereomicroscope using a Bogorov–Rass counting chamber. Cladocerans, Copepods, Ctenophora and Cnidaria were identified to species or genus level. All other taxa were identified to the lowest possible taxa. The main references used for the identification of the major zooplanktonic groups were Rose (1938), Tregouboff and Rose (1957), and Pontin (1978). Systematic classification and the nomenclature of zooplankton species were according to WoRMS Editorial Board (2018). Water temperature, salinity and dissolved oxygen were measured by pIONeer 65 multi-probe, using the practical salinity scale. For chlorophyll *a* analysis, seawater was filtered through Whatman GF/C glass fibre filters that were then kept frozen until analysis spectrophotometrically after extraction by acetone (APHA, 1985).

Statistical Analysis

The zooplankton community was analysed in terms of Shannon index of diversity (H'), and number of species (S) (Shannon and Weaver, 1949). Spearman's rank-correlation coefficient was used to detect any correlation among biotic and abiotic variables (Siegel, 1956). In addition, Multidimensional scaling (MDS) analyses of similarity between sampling months were computed on the basis of the Bray–Curtis similarity index using log (x + 1) transformed abundance data and Primer v. 6 software (Clarke and Warwick, 1994). Spatio-temporal patterns in zooplankton community structure and physical (salinity) and biological (Noctiluca, chlorophyll *a*) data were investigated among stations and months by ANOVA. Prior to analysis of variance, biological and physical data were normalized by logarithmic transformations.

Results

Environmental Variables

The temperature ranged from 5.7 °C (April, GH4) to 25.4 (August, GH2). Generally, the GH4 had lower temperature values than the other stations. In contrast to temperature, salinity values were always higher in the GH4. Surface salinities varied between 14 ‰ (January, GH1) and 22 ‰ (December, GH4). Dissolved oxygen values ranged from 1.5 $mg.L^{-1}$ (in October, GH1) to 20.6 mgL^{-1} (in November, GH4). Chlorophyll *a* concentrations, an indication of primary production, increased considerably in summer-early autumn and reached the highest level (67.4 $\mu g.L^{-1}$, September) in the GH1 (Figure 2). The seasonality is clear for temperature ($F_{11,47}$ = 48.5, $p < 0.05$), salinity ($F_{11,47}$ = 6.1, $p < 0.05$) and chlorophyll *a* ($F_{11,47}$ = 6.7, $p < 0.05$) (Figure 2). However, dissolved oxygen ($F_{3,47}$ = 4.9, $p < 0.05$) and salinity ($F_{3,47}$ = 4.6, $p < 0.05$) have varied significantly among stations. The chlorophyll *a* concentration was significantly positive correlated to temperature ($r = 0.37$, $p < 0.01$) and weakly correlated with salinity ($r = -0.20$, $p < 0.001$), while dissolved oxygen was positively influenced by the increase in salinity ($r = 0.34$, $p < 0.05$).

Species Composition and Diversity

A total of 40 species/groups were registered in the study area, of which 13 were from Copepoda and of which 8 were from Cladocera (Table 1). Five species (*Daphnia curvirostris, Daphnia hyalina, Bosmina (Eubosmina) coregoni, Cyclops abyssorum, Eudiaptomus*

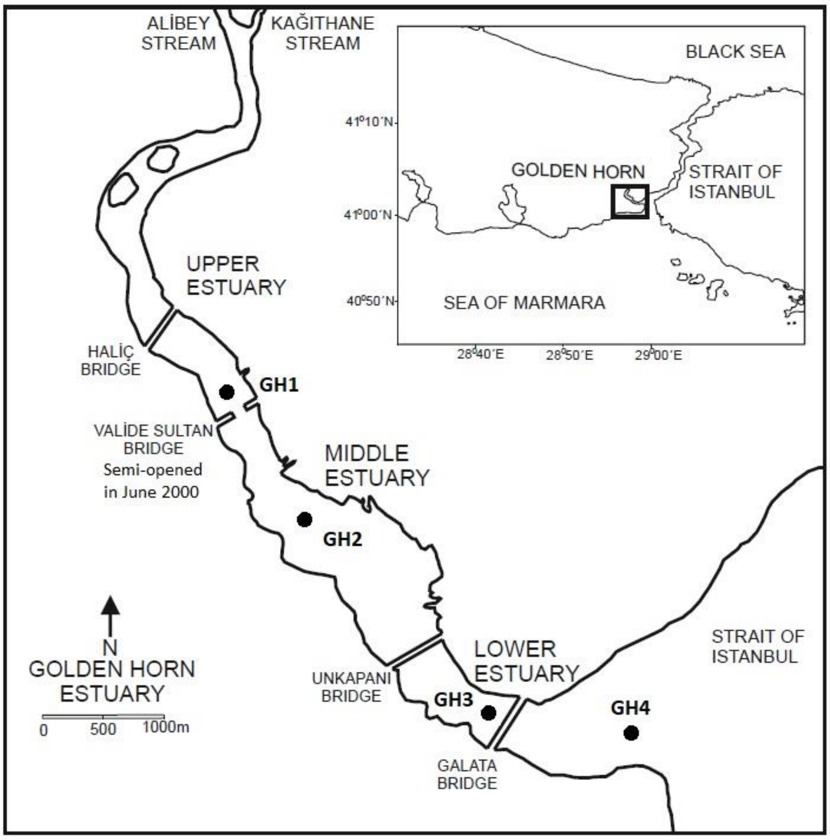

Figure 1. Positions of the Sampling Stations in the Golden Horn.

gracilis) are recorded for the first time in the Golden Horn estuary. *Bosmina (Eubosmina) coregoni* is also first records for the Turkish coasts. Furthermore, four jellyfish species (*Mnemiopsis leidyi, Beroe ovata*, *Pleurobrachia pileus* and *Aurelia aurita*) are recorded for the first time in the Golden Horn estuary.

Zooplankton abundance showed a seasonal distribution in the Golden Horn Estuary. The total zooplankton abundance (excluding the dinoflagellate *Noctiluca scintillans*) was characterized by two peaks, late autumn and spring (Figure 2). The highest zooplankton abundance was encountered at station GH1 in May 2015 (42837 ind.m^{-3}), particularly due to high *Pleopis polyphemoides* and *Synchaeta elsteri* abundance (14310 ind.m^{-3} and 11465 ind.m^{-3}, respectively) (Figure 3). Generally Copepods and Cladocerans were the most abundant groups, while contribution of meroplankton increased at innermost sections and dominated zooplankton (e.g. station GH1, May 2015). Copepods abundance ranged from 43 to 12395 ind.m^{-3} in all the samples combined, minimum and maximum values being recorded at station GH1 in

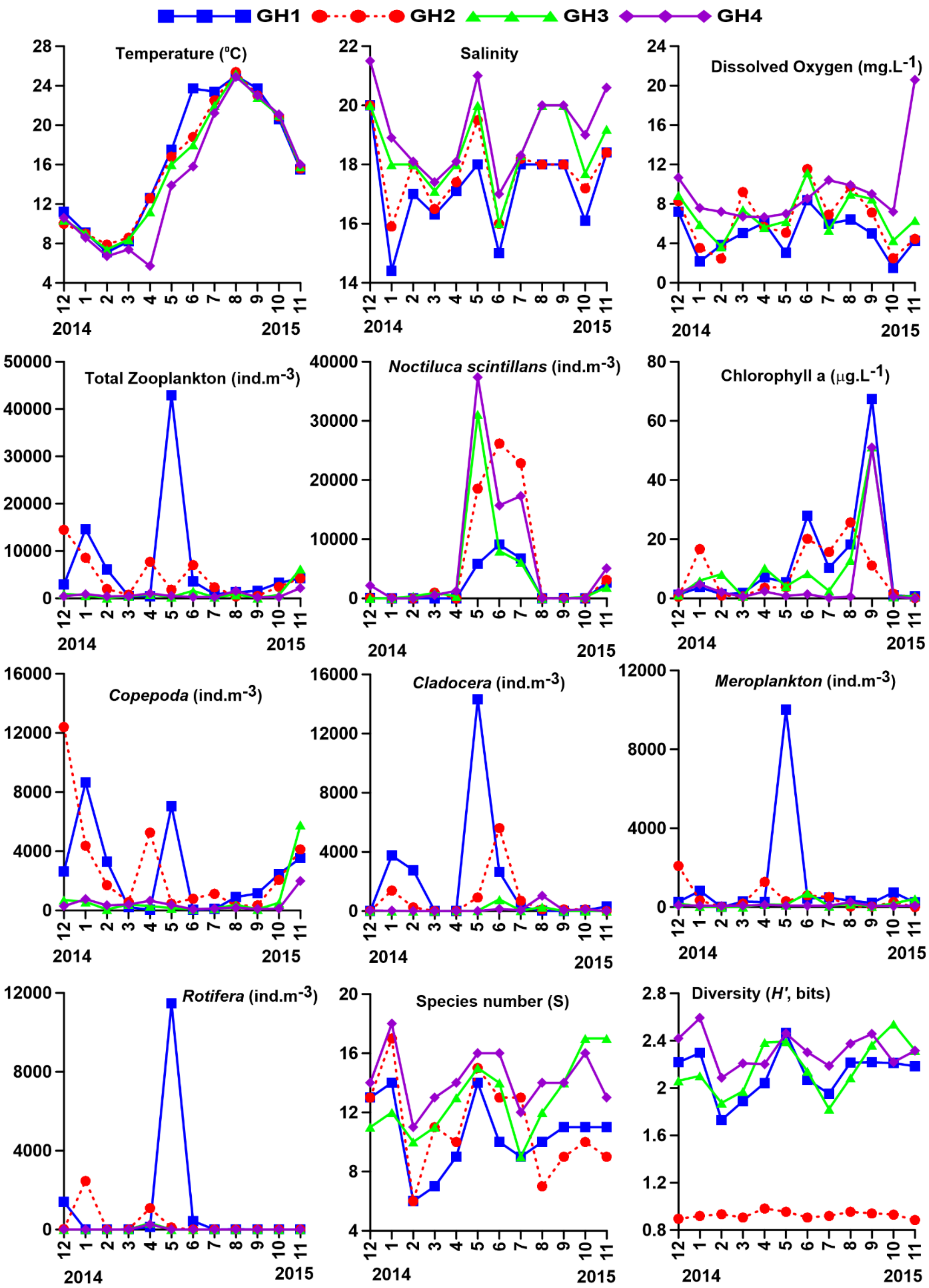

Figure 2. Fluctuations in biological and physico-chemical parameters in the Golden Horn Estuary.

April 2015 and at station GH2 in December 2014, respectively (Figure 2). Thirteen copepod species were identified in this study (Table 1). Thermophilic *Acartia tonsa*, found only station GH1, was observed only for a limited period of the year; from June till end of November. On the other hand, eurytermal *Acartia clausi* was present all year, reaching higher densities in November 2014 (Figure 3). While *Paracalanus parvus, Pseudocalanus elongates* and *Oithona similis* were the most important contributors to the Copepod community from November 2014 to end of May 2015, *Oithona davisae* was observed from August to November 2015. *Oithona nana* was observed maximum values in January and October 2015. The highest value of cladocerans (14310 ind.m^{-3}) were recorded in station GH1 in May 2015. Eight cladoceran species were

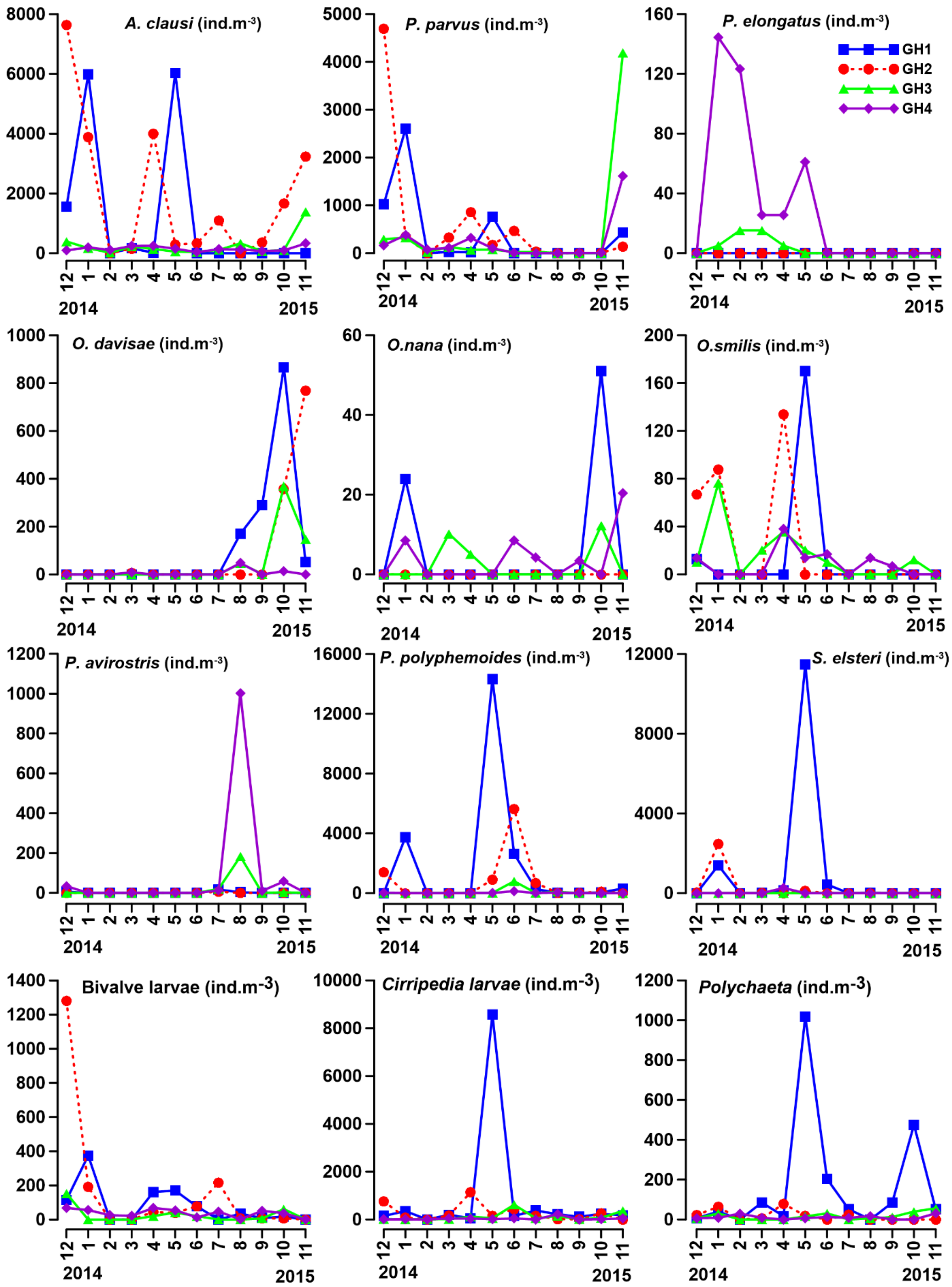

Figure 3. Fluctuations in abundance of major zooplankton species and groups in the Golden Horn Estuary.

Table 1. The regional mean abundance (ind.m^{-3}) of total zooplankton taxa and *Noctiluca scintillans* in the Golden Horn estuary. Species marked with "*" are first records for the Golden Horn Estuaries, and "+" are first records for the Turkish coasts

	Species	GH1	GH2	GH3	GH4
Appendicularia	*Oikopleura (Vexillaria) dioica* Fol, 1872	14.1 ± 63	19.4 ± 39	13.8 ± 24	16 ± 34
Ascidiacea	*Ascidia asperca* (Müller, 1776)	0	2.6 ± 0	0	0
Copepoda	*Acartia (Acartiura) clausi* Giesbrecht, 1889	1146.3 ± 3034	1913.0 ± 2375	253.2 ± 376	152.0 ± 84
	Acartia (Acanthacartia) tonsa Dana, 1849	455.7 ± 1168	0	0	0
	Calanus euxinus Hulsemann,1991	4.0 ± 2 9	0.3 ± 0.7	0.4 ± 1.1	1.5 ± 2
	*Cyclops abyssorum** Sars G.O., 1863	89.0 ± 0	109.1 ± 0	0	0
	*Eudiaptomus gracilis** (Sars G.O., 1863)	186.0 ± 0	33.0 ± 0	0	0
	Euterpina acutifrons (Dana, 1847)	2.1 ± 6	2.0 ± 0	1.7 ± 0	1.6 ± 1
	Metridia lucens Boeck, 1865	0	0	2 ± 0	0
	Oithona davisae Ferrari F.D. & Orsi, 1984	114.7 ± 361	94.3 ± 381	47.1 ± 164	5.8 ± 21
	Oithona nana Giesbrecht, 1893	6.2 ± 19	0	2.3 ± 4	3.7 ± 7
	Oithona similis Claus, 1866	15.2 ± 111	24.0 ± 34	15.4 ± 24	9.0 ± 11
	Paracalanus parvus (Claus, 1863)	405.7 ± 964	586.0 ± 1489	430.1 ± 1362	232.1 ± 485
	Pseudocalanus elongates (Boeck,1865)	0	0	3.4 ± 5	32.6 ± 58
	Unidentified copepod	81.0 ± 226	37.2 ± 109	8.5 ± 13	14.0 ± 11
Cladocera	*Daphnia curvirostris** Eylmann, 1887	29.2 ± 0	3.6 ± 0	0	0
	*Daphnia hyalina** Leydig, 1860	188.4 ± 0	17.5 ± 0	0	0
	*Bosmina (Eubosmina) coregoni**+ Baird, 1857	12 ± 0	0.4 ± 0	0	0
	Evadne nordmanni Lovén, 1836	2.1 ± 0	1.4 ± 3	0.4 ± 0	11.2 ± 10
	Evadne spinifera P.E. Müller, 1867	0	0	0	0.8 ± 0
	Penilia avirostris Dana, 1849	2.2 ± 7	0.5 ± 0	17.2 ± 99	93.1 ± 435
	Pleopis polyphemoides (Leuckart,1859)	1778.2 ±4913	728.0 ±1996	78.4 ±275	18.2 ±47
	Pseudoevadne tergestina (Claus, 1877)	0	17.8 ± 56	0.2 ± 0	0
Chaetognatha	*Parasagitta setosa* (Müller, 1847)	0.8 ± 0	1.1 ± 2	2.8 ± 04	10. 1 ± 029
Ciliophora	*Tintinnopsis sp.*	17.6 ± 0	0	0	0
Cnidaria	*Aurelia aurita** (Linnaeus, 1758)	0.3 ± 0.7	2.1 ± 2.7	0.4 ± 0.7	0.1 ± 9
	Unidentified Hydromedusae (sp.)	0	0	5.1 ± 0	0
Ctenophora	*Beroe ovata** Bruguière, 1789	0.4 ± 1.2	1.3 ± 8.5	0.2 ± 0.3	0.3 ± 0.3
	*Mnemiopsis leidyi** A. Agassiz, 1865	1.1 ± 2.8	0.7 ± 0.8	0.9 ± 1.1	2.1 ± 0.8
	*Pleurobrachia pileus** (O. F. Müller, 1776)	0.2 ± 0	0.4 ± 1.5	0.4 ± 1.4	0.4 ± 0.7
Rotifera	*Keratella sp.*	0	90.1 ± 0	28.0 ± 230	0
	Synchaeta elsteri Hauer, 1963	1121.1 ± 4548	218.0 ± 1210	0	21.5 ± 0
Meroplankton	Bivalve larvae	79.6 ± 120	156.1 ± 410	25.1 ± 53	36.7 ± 22
	Cirripedia larvae	882.9 ± 2527	264.3 ± 365	122.9 ± 189	35.5 ± 66
	Decapoda larvae	0.5 ± 0	2.0 ± 7	0.6 ± 1	1.0 ± 4
	Fish egg and larvae	2.8 ± 21	1.8 ± 7	0.4 ± 1	0.5 ± 1
	Gastropoda larvae	36.5 ± 69	24.5 ± 42	4.8 ± 18	2.6 ± 2
	Polychaeta larvae	169.5 ± 318	17.9 ± 28	16 ± 18	10.7 ± 9
	Total zooplankton	6846.1 ± 2030	4367.3 ± 1075	1075 ± 368	712 ± 152
Dinoflagellate	*Noctiuca scintillans* (Macartney) Kofoid & Swezy, 1921	2034.2 ± 3673	5983.9 ± 11751	4081.3 ± 9632	6625.6 ± 12610

identified in the present study (Table 1). The fine particle filter feeder *Penilia avirostris* dominated the zooplankton community in August 2015, while *Pleopis polyphemoides* was one of the important species in January, May and June 2015. Rotifera species *Synchaeta elsteri* dominated the zooplankton community in January and May 2015. Seven meroplankton groups were identified in the Golden Horn Estuary in the present study (Table 1) and these meroplanktonic forms also contributed notably to the zooplankton abundance during May 2015. The maximum abundance of meroplankton (10009 ind.m^{-3}) was seen in station GH1 in May 2015 (Figure 2) due to Cirripedia and Polychaete larvae. Bivalve larvae reached high concentrations in December 2014, particularly in station GH2 (1282 ind.m^{-3}) (Figure 3). Polychaeta was observed maximum values in station GH1 in May (1019 ind.m^{-3}) and October 2015 (476 ind.m^{-3}) and Cirripedia larvae was one of the important species in station GH1 in May 2015 (8578 ind.m^{-3}).

A total of 5 jellyfish species (*Mnemiopsis leidyi, Pleurobrachia pileus, Beroe ovata*, *Aurelia aurita*, and unidentified hydromedusae) were recorded throughout the study period (Table 1). Maximum jellyfish abundance (Cnidaria and Ctenophora) observed in the station GH2 in November 2015 (16 ind. m^{-3}) was due to *Beroe ovata*, but in the lower part (in st. GH4, 11 ind. m^{-3}), the maximum jellyfish abundance (in August 2008) was due to *Mnemiopsis leidyi*.

Species number (S) and diversity (H') varied significantly through the year ($F_{11,47} = 2.74$ and $F_{11,47} = 2.51$, $p < 0.001$, respectively). Species number (S) and diversity index values dropped to their lowest values in the station GH2 in February 2015 due to the numerical dominance of five species (*Daphnia curvirostris, Daphnia hyalina, Bosmina (Eubosmina) coregoni, Cyclops abyssorum, Eudiaptomus gracilis*). Both S and H' were positively influenced by the increase in salinity ($r = 0.33$ and $r = 0.34$, $p < 0.51$, respectively).

The heterotrophic dinoflagellate *Noctiluca scintillans*, as a major component of net samples in Golden Horn Estuary, followed a rather regular trend throughout the year (Figure 2), with highest value in May 2015 (37367 ind.m^{-3} in station GH4). In May, lower parts of the estuary had higher *Noctiluca scintillans* abundance, while in June and July upper parts had higher values. *Noctiluca scintillans* density dropped to minimum levels following May peak, and abundances were very low from August to October.

There was a high correlation between temperature and abundance of cladocerans, *P. parvus, P. poliphemoides, O. davisae*, *P. avirostris*, *M. leidyi* and negatively correlated with *E. nordmanni* (Table 2). Salinity was significantly positive correlated with abundance of chaetognaths, *P. avirostris, M. leidyi*, species number and the Shannon–Weaver diversity index, but negative correlated with *S. elsteri* and Bivalve larvae. Dissolved oxygen was significantly negative correlated with abundance of copepods, and positive correlated with *M. leidyi*. Chlorophyll *a* was significantly positive correlated with cladocerans and negatively correlated with abundance of chaetognaths.

Zooplankton Community Structure

MDS ordination was applied on abundance data in order to detect affinities between stations and seasons (Figure 4). Total zooplankton assemblage exhibited winter-spring (Group II) and summer-autumn (Group III) heterogeneity. Winter-spring community was characterized by high abundance of *Paracalanus parvus*, *Pseudocalanus elongates*, *Synchaeta elsteri* and Bivalve larvae (Group II). Summer-autumn communities were gathered in group III and samples were dominated *Penilia avirostris*, *Oithona davisae*, and Polychaeta larvae. Moreover, stations GH1 and GH2 in February (Group I) were clearly separated from other samplings by the dominance of fresh water species (e.g. *Daphnia curvirostris, Daphnia hyalina, Bosmina (Eubosmina) coregoni, Cyclops abyssorum, Eudiaptomus gracilis*) and low species richness, which was completely different from other months and stations.

Discussion

The present study provides information on the pelagic area of the Golden Horn Estuary by describing the main zooplankton species and their seasonality. In this study, the most widely distributed zooplankton species were also the most abundant ones, such as *Acartia clausi, Paracalanus parvus, Pleopis polyphemoides, Penilia avirostris*, *Oithona davisae*, and cirripedia and bivalve larvae. These species are similar to those reported for the Golden Horn Estuary (Dorak and Albay, 2016, Isinibilir, Svetlichny, & Hubareva, 2016) and Marmara Sea (Isinibilir, Kıdeys, Tarkan, & Yılmaz, 2008; Isinibilir *et al*., 2011) Nine species (*Daphnia curvirostris, Daphnia hyalina, Bosmina (Eubosmina) coregoni, Cyclops abyssorum, Eudiaptomus gracilis, Mnemiopsis leidyi, Pleurobrachia pileus, Beroe ovata,* and *Aurelia aurita*) are first recorded in the Golden Horn and one of these (*Bosmina (Eubosmina) coregoni*) is also first records for the Turkish coasts. Furthermore, it has been an increase in the marine zooplankton abundance and diversity. Some species found in the Black Sea and Marmara Sea such as *Acartia tonsa, Calanus euxinus,*

Table 2. Spearman's rank-correlation matrix (r_s) to correlate zooplankton assemblages and enviromental variables in the study area (**P<0,01, *P<0,05; N=48)

	Chlorophyll a (µgL^{-1})	Temperature (°C)	Salinity (‰)	Dissolved Oxygen (µg.L^{-1})
Copepoda	-0,257	-0,255	-0,034	-,404**
Cladocera	,349*	,400**	-0,238	-0,082
Chaetognatha	-,336*	0,052	,357*	,286*
Bivalvia	,094	,242	-,298*	-,141
Paracalanus parvus	-0,256	-,535**	0,132	0,003
Oithona davisae	-0,249	,328*	0,025	-0,204
Pleopis polyphemoides	,306*	,493**	-0,070	0,053
Penilia avirostris	-0,026	,488**	,393**	0,275
Evadne nordmanni	0,095	,302*	0,088	0,266
Synchaeta elsteri	,158	-,171	-,313*	-,214
Mnemiopsis leidyi	0,187	,643**	,289*	,425**
Beroe ovata	-,506**	-0,120	,297*	-0,004
Pleurobrachia pileus	0,057	-,509**	-0,039	-0,182
H'	0,006	0,055	,342*	0,118
Number of species (S)	-0,016	0,037	,329*	0,157

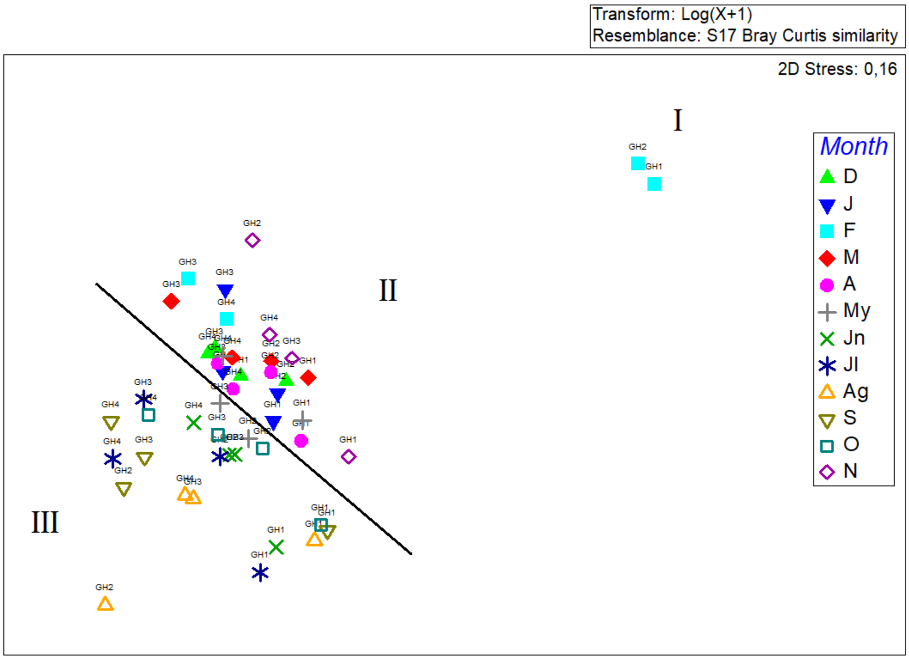

Figure 4. MDS ordination of the Golden Horn Estuary samples.

Metridia lucens, Oithona similis, Pseudocalanus elongatus, Evadne spinifera, and Pseudoevadne tergestina were also recorded in the Golden Horn estuary in the present study.

While temperature, salinity and Chlorophyll *a* demonstrate a significant seasonal variation, Dissolved oxygen demonstrate spatial variation in the study area. The salinity, which was expected to decrease due to the lack of precipitation in summer months, did not change much due to probably the fresh water flowed through the channel opened from the Strait of Istanbul. Dissolved oxygen values were higher in the GH4, having a strong interaction with the Strait of Istanbul and were always lower in the GH1 than in the other parts. All environmental variables did not differ significantly from previous studies, but Chlorophyll values were lower (Taş and Yılmaz, 2015; 2017).

There are very few studies on zooplankton of the Golden Horn Estuary (Dorak, 2010; Dorak and Temel, 2015; Dorak and Albay, 2016), so we have compared our findings with these previous investigations. Dorak and Albay, (2016) reported 59 zooplankton species in the Golden Horn Estuary, consisting of 6 species of Cladocera, 35 species of Rotifera, 7 species of Copepoda and meroplankton such as larvae of Bivalvia and Polychaeta (Table 3). The species composition of zooplankton recorded in our investigation varied from those reported in previous studies (Dorak and Temel, 2015; Dorak and Albay, 2016). Possible reason for this change could be the fact that after the opening of the water channel from the Istanbul Strait, more marine species had the opportunity to penetrate the Golden Horn Estuary. Different sampling method may also be another important reason.

Dorak (2010) reported two zooplankton abundance maxima for the Golden Horn: one in early spring (March 2007) and a second peak in early autumn (September 2007). During the present study, a spring maximum was detected in May 2015, but a second peak was observed in January 2015 at almost all stations located in upper part of the estuary. The early spring maximum was related to the abundance of Cladocera and Rotifera, while the winter one is almost exclusively due to copepods. The early winter maximum could be associated with the phytoplankton peak; during the study period, chlorophyll *a* reached highest values in September 2015. Meroplankton is an important component of plankton in the Golden Horn Estuary and high abundance of meroplankton was in spring and autumn and mollusca larvae, cirripedia larvae and polychaeta larvae dominated in the estuary (Dorak and Albay, 2016). In present study, meroplankton were more abundant in spring. Bivalvia larvae dominated in winter, while Cirripedia and Bivalvia larvae caused the increase in the abundance values of meroplankton in spring.

The dinoflagellate *Noctiluca scintillans* is common in temperate to tropical neritic waters around the world and is known at times to form pronounced red tides (Cardoso, 2008; Turkoglu, 2013). Blooms have been reported from the Marmara Sea including the straits of Istanbul, and Dardanelles (Yılmaz, Okuş, & Yüksek, 2005; Turkoglu, 2013; Isinibilir, Hubareva & Svetlichny, 2014). *Noctiluca scintillans* observed high biomass in spring and summer periods in Golden Horn (Dorak and Albay, 2016) contributed largely to the decrease of Copepod importance at high salinity locations (in stations GH3 and GH4). The proliferation and accumulation of *Noctiluca scintillans* is associated with temperature

Table 3. Zooplankton species list and *Noctiluca scintillans* in the Golden Horn Estuary.

Species	2002-2003 (Dorak and Temel, 2015)	2006-2007 (Dorak and Albay, 2016)	2014-2015 (in this study)
Appendicularia	1	1	1
Oikopleura (Vexillaria) dioica	+	+	+
Ascidiacea	1	0	1
Ascidia asperca	+	-	+
Copepoda	6	7	13
Acartia clausi	+	+	+
Acartia tonsa	-	-	+
Calanus euxinus	-	-	+
Cyclops abyssorum	-	-	+
Clytemnestra rostrata	-	+	-
Eudiaptomus gracilis	-	-	+
Euterpina acutifrons	-	+	+
Microsetella norvegica	+	+	-
Metridia lucens	-	-	+
Oithona davisae	-	-	+
Oithana nana	+	+	+
Oithona similis	-	-	+
Oncaea mediterranea	+	+	-
Paracalanus parvus	+	+	+
Pseudocalanus elongatus	-	-	+
Thermocyslos oithonoides	+	-	-
Unidentified copepod	-	-	+
Cladocera	4	6	8
Bosmina longirostris	+	+	-
Daphnia curvirostris	-	-	+
Daphnia hyalina	-	-	+
Daphnia cucullata	-	+	-
Bosmina (Eubosmina) coregoni	-	-	+
Evadne nordmanni	+	+	+
Evadne spinifera	-	-	+
Moina macrocopa	-	+	-
Penilia avirostris	+	+	+
Pleopis polyphemoides	+	+	+
Pseudoevadne tergestina	-	-	+
Chaetognatha	1	0	1
Parasagitta setosa	+	-	+
Ciliophora	1	2	1
Favella ehrenbergi	+	+	-
Tintinnopsis sp.	-	+	+
Cnidaria	0	0	2
Aurelia aurita	-	-	+
Unidentified Hydromedusae (sp.)	-	-	+
Ctenophora	1	0	3
Beroe ovata	-	-	+
Ctenophora larvae	+	-	-
Mnemiopsis leidyi	-	-	+
Pleurobrachia pileus	-	-	+
Rotifera	5	35	2
Asplanchna priodonta	+	+	-
Keratella cochlearis	+	+	-
Keratella sp.	-	-	+
Synchaeta elsteri	-	+	+
Meroplankton	7	7	6
Fish egg and larvae	-	-	+
Bivalve larvae	+	+	+
Cirripedia larvae	+	+	+
Decapoda larvae	+	+	+
Echinodermata larvae	+	-	-
Gastropoda larvae	+	+	+
Ostracoda larvae	+	+	-
Nematoda larvae	-	+	-
Polychaete larvae	+	+	+
Σ Total zooplankton	27	58	38
Dinoflagellate	1	1	1
Noctiuca scintillans	+	+	+

(Turkoglu, 2013) and high concentration of diatoms that found high biomass in spring and summer (Tas 2017)

Jellyfish species in the Marmara Sea can influence the zooplankton community substantially (Shiganova, Tarkan, Dede, Cebeci, 1995). Jellyfish species, especially *Mnemiopsis leidyi*, are known to feed voraciously on zooplankton (Finenko, Abolmasova, Romanova, Datsyk, & Anninskii, 2013). In the Golden Horn, the invader species *Mnemiopsis leidyi* and the resident *Aurelia aurita* and *Pleurobrachia pileus,* which were not observed in the previous studies (Table 3), had high abundances and the highest population of jellyfish occurred in summer and at the end of autumn due to *Mnemiopsis leidyi*. This may suggest that jellyfish may be an important force in initiating summer and autumn decline in zooplankton in the Golden Horn.

The pelagic copepods *A. clausi* and *A. tonsa* characterize many coastal or estuarine environments where they can reach high population densities. In temperate regions, they sometimes co-exist at the same time (Lee and McAlice, 1979) but, most frequently, *A. tonsa* dominates during summer and *A. clausi* during winter (Gaudy, Cervetto, & Pagano, 2000), which contributes to reduce food competition. *Acartia clausi* is widely distributed in the Black Sea and the Mediterranean, where it reproduces all year round (Gubanova, Prusova, Niermann, Shadrin, & Palikarpov, 2001; Isinibilir *et al*., 2011). This species has a high tolerance to pollution and it usually dominates zooplankton in polluted areas (Gubanova, Prusova, Niermann, Shadrin, & Palikarpov, 2001). The results of the present work also support these findings and indicate a dominance and year-round occurrence of *A. clausi* in the Golden Horn which reflects the eutrophic characteristics of the area. *Acartia tonsa* is also a typical Mediterranean species and was found in the Marmara Sea (Isinibilir *et al*., 2011). This species was found only in the inner upper part of the Golden Horn estuary. This indicates that this species was transported from the upper layer water of Strait of Istanbul formed by the Black Sea water to the Golden Horn Estuary through the water channel.

Bosmina (Eubosmina) coregani is a small planktonic, freshwater cladoceran species. It was first described from England and it was seen that it spread from Northern Europe to Spain and Italy and even to North American (Geraldes and Alonso, 2014, Smits, Litt, Cordell, Kalata, & Bollens, 2013). Probably *Bosmina (Eubosmina) coregani* could be transported by several ways, especially by aquatic animals, ballast waters, recreational boats activity or by bird's feet (Geraldes and Alonso, 2014; Smits *et al*., 2013). The way of introduction of this species to the Golden Horn Estuary is also unknown. However, it is possible that human activities caused its presence in this estuary.

Oithona davisae inhabits eutrophic bays (Uye and Sano, 1995) and is indigenous to Japan and China Seas, and other coastal areas (Hirakawa, 1988). It is an invasive species along the west coast of the US (Ferrari and Orsi, 1984) and is established in the Mediterranean (Saiz, Calbet, & Broglio, 2003) and the Black Seas (Mihneva and Stefanova, 2013). *Oithona davisae* recorded as a new exotic species for the Marmara Sea (Doğan and Isinibilir, 2016) and was also found in the Golden Horn (Isinibilir *et al*., 2016). *O. davisae* probably penetrated into the Golden Horn Estuary and Marmara Sea from the Black Sea through the Strait of Istanbul current only several years ago (Isinibilir *et al*., 2016). The highest abundances of *O. davisae* was observed in October 2015 (with the maximum of 866 ind.m^{-3}) which is consistent with earlier findings in the Black Sea and Marmara Sea (Gubanova and Altukhov, 2007, Doğan and Isinibilir, 2016). *O. davisae* and *O. nana* were observed in the Golden Horn Estuary in same periods in the study area but the total abundance of *O. davisae* was higher than of *O. nana*. Isinibilir *et al*., (2016) informed that *O. davisae* had the high competitive ability of in comparison with *O. nana.*

The Shannon-Wiener index was calculated between 0.07 and 1.97 in present study, Dorak (2010) found these values between 0.57 and 3.55 in 2006-2007. In present study, we focused on the availability and abundance of marine species in the Golden Horn Estuary. Therefore, the method used for sampling zooplankton was not very suitable for freshwater and microzooplankton (Cilliata). For this reason, these species have been excluded from sampling, which may have reduced biodiversity. However, in our samples, high numbers of rotifer due to *Synchaeta elsteri* were found in the Golden Horn estuary in from winter till late spring (especially in May), while Dorak (2010) found 35 rotifer species in the Golden Horn estuary and the percentage distribution of them revealed from January to June with the highest numbers in February and March. Rotifer feeds on ciliate species at high rates (Dolan and Gallegos, 1992) and their distribution encountered same area and months in present study. The relationship between rotifers and ciliates in eutrophic estuaries and coastal waters needs further study.

It has been observed that the Golden Horn Estuary is a eutrophic structure and the zooplankton community structure changes seasonally and the physical parameters are markedly affect their change. As a result, the rehabilitation studies in the Golden Horn Estuary and the opening of the water channel to the Golden Horn Estuary from the Strait of Istanbul have already altered the very sensitive ecological balances and caused the increase of marine and alien species in the environment. For this reason, the long-term monitoring activities in the Golden Horn Estuary should be continued to see how biodiversity has changed and the newly joined species to the Golden Horn Estuary should be monitored for effects on the Golden Horn Estuary ecosystem.

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