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# THE ZOOPLANKTON COMMUNITY AND ITS RELATIONSHIP WITH ENVIRONMENTAL VARIABLES IN A HIGHLY POLLUTED SYSTEM, GOLDEN HORN, TURKEY

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This study is a part of master thesis of Zeynep DORAK entitled "Seasonal Changes of the Density and Composition of in Istanbul Haliç".

## Abstract:

The Golden Horn Estuary (İstanbul) nutrient-rich, eutrophic and turbid at the inner part based on discharges from Alibeyköy and Kağıthane creeks. The pollution had been drastically increased by the accretion in the industry and urban development around the estuary since 1950s. The Golden Horn rehabilitation project was carried out during the 1998-2002 period. The present study was conducted following the rehabilitation process between November 2002-October 2003 at selected four stations, three at the inner part and one at the middle part of estuary. This is the first study on zooplankton community in the Golden Horn Estuary. The seasonal variation of zooplankton composition and density and 14 environmental variables (temperature, salinity, Secchi disc depth, turbidity, pH, dissolved oxygen, carbonate, bicarbonate, calcium, magnesium, total hardness, $NO_2$-N, $NO_3$-N, o-$PO_4$) and Chlorophyll-*a* concentration, which indicates the intensity of life in the Golden Horn Estuary have been studied, monthly. A total of 29 taxa was identified. Zooplankton composition was characterized by freshwater, estuarine and marine species. Zooplankton of Golden Horn Estuary was composed mainly by holoplanktonic organisms (53% of the total), with Copepoda as the most abundant group and a high number of taxa. Diversity were higher at all stations. A distinct relationship between zooplankton taxa composition and their environment, determined by a redundancy analysis, indicated that the measured environmental variables contributed to the variations in the zooplankton community structure to some extent. Four environmental variables and Chlorophyll-*a* explained 73.7% of the variation in the taxonomic structure. The results showed, that distribution of zooplankton was significantly associated total hardness, $NO_2$-N, $NO_3$-N, temperature and Chlorophyll-*a* ($p<0.05$).

**Keywords:** Golden Horn Estuary, Redundancy analysis, Water quality, Zooplankton

## Introduction

Estuaries as transition areas between land and sea form aquatic ecosystems that are characterized as one of the most dynamic ecosystems by a variety of inter-related biotic and abiotic structural components and intensive chemical, physical and biological processes which influence species density and diversity (Aslan-Yılmaz et al., 2004; Telesh, 2004; Yüksek et al., 2006; Sterza and Fernandes, 2006; Sun et al., 2009).

Because of the unusual dynamic conditions experienced in estuaries zooplankton distribution is spatially and temporally heterogeneous, more so than in other aquatic ecosystems (Kibirige and Perissinotto, 2003; Sterza and Fernandes, 2006). High primary production levels make estuarine zooplankton very abundant, however some other biological factors, like environmental variables, may restrict the variety of the zooplankton species when compared to that of the marine areas.

Golden Horn lies to Sarayburnu-Tophane in northwest-southeast direction in the junction of Istanbul Bosphorus and Marmara Sea as a meander. Golden Horn formed by the invasion of sea with the junction of Alibeykoy and Kagıthane streams. The length of coasts on both sides are approximately 7.5 km. (Baştürk et al., 2001). The maximum depth of the estuary is around 15 m in mid-estuary and 4-5 m in the upper parts. The main source of the freshwater flowing into the Golden Horn is rainfall (Sur et al., 2002).

The Golden Horn Estuary has been polluted by wastewater of pharmaceutical, detergent, dye, leather industries and domestic discharges since the 1950s (Yüksek et al., 2006). The building of dam on the Alibeyköy stream weakened freshwater input. Furthermore, bridges, floating on large buoys and shipyards with large buoyant dry docks blocked circulation of upper layer and strengthen the pollution effect. Poor renewal of estuarine water and heavy nutrient load including numerous types of organic and inorganic effluents resulted in low diversity, with planktonic organisms (Taş and Okuş, 2003) at the outer part of the estuary. The inner part had only anaerobic life characterised by hydrogen sulfide formation (Doğan et al., 2001). The anthropogenic pollution at the estuary not only adversely affected the communities living in the estuary but also human life, giving a heavy odor of hydrogen sulfide and an unaesthetic appearance of this once recreational area (Aslan-Yılmaz et al., 2004).

Hence, life cycles of zooplankters are related to environmental factors. The study of the spatial and temporal variability of the Golden Horn Estuary zooplankton communities becomes important for a better understanding of the functioning of estuary ecosystems. For this reason, present study carried out throughout a year to estimate the zooplankton composition, the abundance and distribution of zoo-fauna and their relationships with environmental variables and Chlorophyll-*a* properties.

## Materials and Methods

### Study area and stations

The Golden Horn Estuary is in conjunction with Bosphorus and Marmara Sea covers an area of approximately $2.5x10^6$ $m^2$. Golden Horn is between 28º 42' and 29º 01' East Longitudes and 41º 01' and 41º 15' North latitudes.

### Sampling

Three sampling stations were selected at the inner part of the Golden Horn Estuary (St.1, St.2, and St.3), determined mainly by their proximity to freshwater inputs, and one station was selected at the mid-estuary (St.4), is defined by proximity to the sea (Fig.1). Physicochemical and biological variables including Chlorophyll-*a* and zooplankton community structure and diversity were investigated monthly intervals from November 2002 to October 2003 (except February 2003). Water samples were collected vertically using 1.5 L Nansen bottle. Water salinity and pH were measured by pIONneer 65 Portable Multiparameter Instrument and light permeability with a 20 cm diameter Secchi disc onboard at each station. Turbidity was measured spectrophotometrically (Palin, 1955). Samples for nutrient analysis were pre-filtered. Nitrite was analyzed by colorimetric method (Parsons et al., 1984) and $NO_2$+$NO_3$ was detected by cadmium reduction method. o-$PO_4$ was detected spectrophotometrically following procedures of ADD Parsons et al. (1984). For Chlorophyll-*a* analysis, 1000 ml of seawater was filtered through GF/C filters and deep-frozen. Chlorophyll-*a* analyses were performed by acetone extraction method (Parsons et al., 1984). Dissolved oxygen (Winkler method) was measured following procedures of APHA (1989). Calcium, magnesium, total hardness, carbonate and bicarbonate were analyzed by titration methods following procedures of Boyd (1992).

### Zooplankton community structure and diversity

The samples were collected with a plankton net (mesh size 55 µm), taking vertically. All zooplankton samples were immediately preserved in 4% borax-buffered formaldehyde. In the laboratory, organisms were identified to species level, when possible, and counted; all the densities are presented as number of individuals per cubic meter (ind. $m^{-3}$). The following references were reviewed to identify the specimens: Rose (1938), Rose and Tregouboff (1957), Boubee (1969), Mozdukhay (1969), and Pontin (1978).

### Data analysis

Shannon-Wiener diversity index (*H'*) (Shannon-Weaver, 1949) were calculated for each zooplankton sample.

Spearman's correlation analysis was used to count the matrix of correlation coefficients among environmental factors completed using the SPSS 16.0 for Windows (Renner, 1970).

The mean values with a 95% confidence interval were presented in all and mean ± standard deviation described. Analysis of variance (ANOVA) was applied to the physicochemical variables and Chlorophyll-*a* in order to test differences between samples (temporal patterns/ seasonally (4 season x 4 stations x 3 replicate)) and sampling stations (spatial patterns (11 months x 4 stations x 3 replicate)). Towards equalizing the variance and normalize distribution, all data used in the ANOVA were log transformed ln(*x*+1). Where significant differences in the ANOVA were detected, a Tukey's Honestly Significant Different (HSD) test was applied to identify sources of variation. Measurements (physicochemical variables and Chlorophyll-*a)* were conducted in triplicate for each station at each month (except February 2003) during the study period.

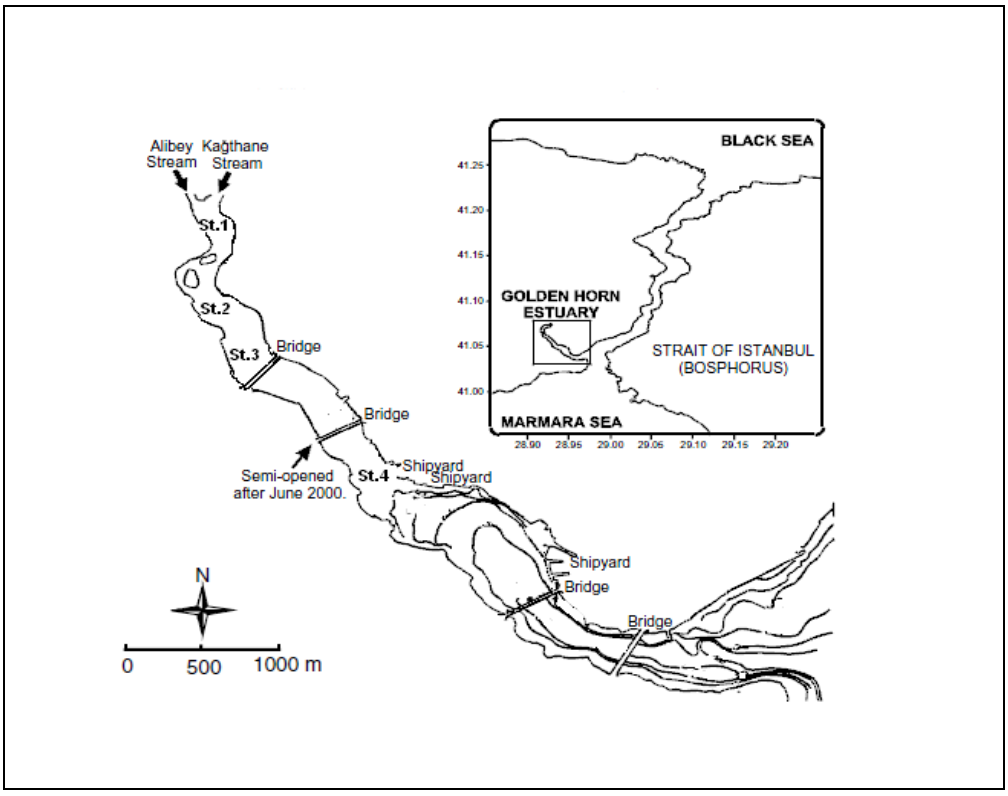


**Figure 1.** Golden Horn Estuary with the sampling stations.

Cluster analysis was carried out with biological data (zooplankton taxa abundances (ln(*x*+1)) using the Bray-Curtis similarity index, applying squared root data transformation). In this study, two sets of explanatory variables were built: biotic (zooplankton community and Chlorophyll-*a*) and abiotic (physicochemical factors). The abiotic matrix contained all measured physicochemical variables (including turbidity, salinity, dissolved oxygen, water temperature, pH, Secchi depth, calcium, magnesium, total hardness, bicarbonate, carbonate, nitrite, nitrate, orthophosfate). Principal Components Analysis (PCA) was used to determine the importance of environmental variables and Chlorophyll-*a*. To evaluate the association between zooplankton taxa

composition and their environment, we opted for a linear model of ordination instead of unimodal since preliminary Detrended Correspondence Analysis (DCA) showed a short gradient length on the biological data (SD=gradient length <2) (ter Braak and Šmilauer, 2002). In principle, environmental variables are displayed by their weights in an ordination diagram. In this study, there were 14 measured environmental variables and Chlorophyll-*a* (Table 1.) and 11 samples. To abstain from multicollinearity among the environmental variables, Forward Selection Method was used to reduce the number of environmental variables. The biological data in RDA were log($x$+1)-transformed so as to downweight large values. To guard against interpretation of spurious axes, the statistical significance of the first and all the ordination axes was tested by Monte Carlo permutation test (999 unrestricted permutations). DCA, PCA and RDA were performed by the computer program Canoco 4.5 for Windows.

**Table 1.** Physicochemical characteristics of water quality and Chlorophyll-*a* concentrations in Golden Horn, during the study period.

| | | Station | | | |
|---|---|---|---|---|---|
| Variables | | 1 | 2 | 3 | 4 |
| Turbidity (nm) | min.-max. | 0.053-0.15 | 0.038-0.16 | 0.049-0.09 | 0.043-0.08 |
| | average-stdev. | 0.089±0.03 | 0.083±0.04 | 0.063±0.01 | 0.060±0.01 |
| Salinity (‰) | min.-max. | 7.45-19.15 | 14.6-19.15 | 14.4-19.55 | 17.1-21.45 |
| | average-stdev. | 15.94±3.29 | 17.21±1.67 | 17.35±1.71 | 18.59±1.39 |
| Dissolved oxygen (mg $L^{-1}$) | min.-max. | 1.65-3.52 | 1.6-4.24 | 1.38-5.5 | 1.82-4.9 |
| | average-stdev. | 2.36±1.01 | 2.91±0.87 | 3.33±1.18 | 3.55±0.88 |
| Water temperature (°C) | min.-max. | 8.0-21.3 | 7.9-21.1 | 6.7-21.3 | 6.7-21.5 |
| | average-stdev. | 14.0±4.8 | 14.1±4.8 | 13.9±5.0 | 13.3±5.2 |
| pH | min.-max. | 7.8-10.6 | 7.8-10.7 | 7.9-10.8 | 8.0-10.9 |
| | average-stdev. | 8.2±0.81 | 8.3±0.82 | 8.4±0.81 | 8.5±0.80 |
| Secchi-disc depth (m) | min.-max. | 0.5-2.21 | 0.75-2.57 | 1.0-4.8 | 1.5-7.2 |
| | average-stdev. | 1.33±0.51 | 1.56±0.53 | 2.22±1.04 | 2.9±1.6 |
| Calcium (mg $L^{-1}$) | min.-max. | 4.3-9.4 | 5.0-8.2 | 4.8-9.4 | 4.7-8.5 |
| | average-stdev. | 7.7±1.4 | 7.4±1.2 | 7.7±1.4 | 7.5±1.3 |
| Magnesium (mg $L^{-1}$) | min.-max. | 5.5-9.0 | 4.6-9.2 | 4.5-11.4 | 4.7-10.3 |
| | average-stdev. | 7.7±1.2 | 8.1±1.3 | 8.8±1.7 | 8.7±1.5 |
| Total Hardness (mg $L^{-1}$) | min.-max. | 10.5-18.3 | 9.8-19.2 | 9.8-21.5 | 10.2-20.1 |
| | average-stdev. | 16.2±2.5 | 17.0±2.6 | 17.4±2.8 | 17.5±2.7 |
| Bicarbonate (mg $L^{-1}$) | min.-max. | 451.4-658.8 | 396.5-652.7 | 353.8-640.5 | 366.0-640.5 |
| | average-stdev. | 502.97±62 | 493.55±66. | 466.37±83.7 | 448.63±75.5 |
| Carbonate (mg $L^{-1}$) | min.-max. | 2.44-2.75 | 3.05-6.71 | 3.36-5.2 | 1.22-4.88 |
| | average-stdev. | 2.59±0.22 | 4.37±2.03 | 4.27±0.9 | 3.38±1.37 |
| Nitrite (mg $L^{-1}$) | min.-max. | 0.71-3.03 | 0.49-3.26 | 0.3-2.48 | 0.15-3.1 |
| | average-stdev. | 1.68±0.73 | 1.76±0.85 | 1.59±0.72 | 1.4±1.04 |
| Nitrate (mg $L^{-1}$) | min.-max. | 0.51-15.48 | 0.29-12.13 | 0.18-13.05 | 0.11-11.53 |
| | average-stdev. | 5.04±4.87 | 5.59±4.35 | 5.47±4.1 | 4.88±4.02 |
| Orthophosfate (mg $L^{-1}$) | min.-max. | 0.27-5.09 | 0.40-4.6 | 0.2-5.29 | 0.12-1.73 |
| | average-stdev. | 1.78±1.49 | 1.44±1.39 | 1.45±1.45 | 0.86±0.64 |
| Chlorophyll-*a* (mg $L^{-1}$) | min.-max. | 1.33-65.49 | 0.67-39.29 | 0.44-12.21 | 0.67-10.43 |
| | average-stdev. | 15.24±20.82 | 12.51±14.01 | 5.65±5.1 | 4.2±3.76 |

## Results and Discussion

### Environmental variables

Physicochemical characteristics of water quality and Chlorophyll-*a* concentrations are summarized in Table 1.

Regarding sampling locations, significant differences occured for turbidity (ANOVA $F_{(3,128)}$=4.777, $p$= 0.003, p<0,05; η=0.32 p<0.5); for dissolved oxygen (ANOVA $F_{(3,128)}$=9.878, $p$= 0.000, p<0,05; η=0.43 p<0.5); for Secchi disc depth $F_{(3,128)}$=16.898, $p$= 0.000, p<0,05; η=0.53 p>0.5); for magnesium (ANOVA $F_{(3,128)}$=4.567, $p$= 0.000, p<0,05; η=0.31 p<0.5); for bicarbonate (ANOVA $F_{(3,128)}$=4.184, $p$= 0.007, p<0,05; η=0.30 p<0.5); for orthophosphate (ANOVA $F_{(3,128)}$=3.058, $p$= 0.031, p<0,05; η=0.26 p<0.5); for Chl.-*a* (ANOVA $F_{(3,128)}$=6.252, $p$= 0.001, p<0,05; η=0.36 p<0.5);

According to Tukey's HSD post hoc test these variables showed significant differences among the stations. Highest dissolved oxygen values and Secchi disc depths occured at the mid-estuary station (Station 4), whereas the lowest values occured in the inner estuary region. Tukey's HSD post hoc test showed that turbidity, magnesium, bicarbonate, orthophosphate, and Chl.-*a* values in inner part of the estuary (first three stations), were significantly different from those collected in the middle part of the estuary (4th station), during the study period.

Significant seasonal differences occured for all physicochemical variables and Chl.-*a* (for turbidity (ANOVA $F_{(3,44)}$=4.058, $p$= 0.012, p<0,05; η=0.45 p<0.5); for salinity (ANOVA $F_{(3,44)}$=5.402, $p$= 0.003, p<0,05; η=0.52 p>0.5); for dissolved oxygen (ANOVA $F_{(3,44)}$=2.928, $p$= 0.044, p<0,05; η=0.42 p<0.5); for temperature (ANOVA $F_{(3,44)}$=1816.874, $p$= 0.000, p<0,05; η=1.00 p>0.5); for pH (ANOVA $F_{(3,44)}$=208.635, $p$= 0.000, p<0,05; η=0.97 p>0.5); for Secchi disc depth (ANOVA $F_{(3,44)}$=5.540, $p$= 0.003, p<0,05; η=0.52 p>0.5); for carbonate (ANOVA $F_{(3,44)}$=37.249, $p$= 0.000, p<0,05; η=0.85 p>0.5); for bicarbonate (ANOVA $F_{(3,44)}$=27.392, $p$= 0.000, p<0,05; η=0.81 p>0.5); for nitrite (ANOVA $F_{(3,44)}$=117.145, $p$= 0.000, p<0,05; η=0.94 p>0.5); for nitrate (ANOVA $F_{(3,44)}$=69.446, $p$= 0.000, p<0,05; η=0.91 p>0.5); for orthophosphate (ANOVA $F_{(3,44)}$=56.832, $p$= 0.000, p<0,05; η=0.89 p>0.5); for Chl.-*a* (ANOVA $F_{(3,44)}$=19.635, $p$= 0.000, p<0,05; η=0.76 p>0.5); for calcium (ANOVA $F_{(3,44)}$=202.294, $p$= 0.000, p<0,05; η=0.97 p>0.5); for magnesium (ANOVA $F_{(3,44)}$=3.986, $p$= 0.013, p<0,05; η=0.46 p<0.5) and for total hardness (ANOVA $F_{(3,44)}$=11.569, $p$= 0.000, p<0,05; η=0.66 p>0.5)). Tukey's HSD post hoc test showed that nutrients ($NO_2$-N, $NO_3$-N, o-$PO_4$) were significantly higher in autumn than the other seasons. Salinity, dissolved oxygen, Chl.-*a*, temperature, turbidity, and pH samples determined in spring, which are closely related with each other, were significantly different from those determined in other seasons. According to Tukey's HSD post hoc test Ca, Mg and total hardness spring values were significantly different from the other seasons. Bicarbonate concentrations in winter were significantly difference from other seasons, where carbonate values were significantly different in summer.

PCA was applied to 14 environmental variables and Chlorophyll *a*, first axis constituted 42.6% of the total variance. The highest positive values of the first axis were determined in Chl.-*a* (0.96) and temperature (0.81), and the highest negative value of the first axis was determined in Secchi disc depth (-0.20) (Fig. 2). Second axis constituted 22.5% of the total variance, o-$PO_4$ (0.42), pH (-0.03) and $NO_2$-N (-0.07) determined significant for the second axis (Fig. 2). The relationship of the environmental variables according to Spearman's rank correlation analysis is given in Table 2.

### Zooplankton

During the study a total of 29 taxa was observed, with 22 taxa of holoplankton and 7 taxa of meroplankton (Table 3). A total of 22 taxa of holoplankton, 7 taxa for Copepoda, 4 taxa for Cladocera, 6 taxa for Rotifera, 1 taxa for Dinophyta, 2 taxa for Chordata, 1 taxa for Ctenophora, 1 taxa for Chaetognatha and 1 taxa for Protozoa, was recorded in Golden Horn Estuary (Table 3). Zooplankton community was characterized by the presence of freshwater, estuarine and marine species. Zooplankton of the Golden Horn Estuary was composed mainly by holoplanktonic organisms (75% of the total), with Copepoda as the most abundant group and a higher number of taxa. Among them, the most abundant taxa were Copepoda nauplii and *Acartia clausi* Giesbrecht, 1889 (Copepoda) (Table 4). The protozoan specimen *Favella ehrenbergii* (Claparède ve Lachmann, 1858) comprised 21.04% of the community (Table 4). Among the Cladocerans *Podon polyphemoides* (Leuckart, 1859) was the most abun-

dant (1.95%, Table 4) particularly in summer. Among the Rotifera the most abundant taxa was *Asplanchna priodonta* Gosse, 1850 (11.47%, Table 4) and was followed by *Asplanchna sieboldi* (Leydig, 1854) (2.63%, Table 4). The meroplankton comprised 25%, with 15.65 being polychaeta larvae, they were increased especially in spring (Table 4). The greatest zooplankton number was determined at 3rd station, while the lowest number was recorded at 4th station (478226 and 151066 org. $m^{-3}$, respectively) (Fig. 3). Zooplankton community showed also seasonal variations. The maximum zooplankton number was recorded during summer (450134 org. $m^{-3}$), while the lowest number was recorded during winter (59516 org. $m^{-3}$).

The hierarchical classification of the 29 taxa, in a rank order of abundance, based on monthly averaged data from the total period, can be summarized the above mentioned (Figure 4). Those species can depict the zooplankton community and their main assemblages in the Golden Horn Estuary.

**Table 2.** Correlations among the 14 environmental variables and Chl.-*a* selected for multivariate analysis of the species-environment relationships (*n*=44)

| | Sal. | DO | Temp. | pH | SD | $Ca^{2+}$ | $Mg^{2+}$ | TH | $CO_3^{2-}$ | $HCO_3^-$ | $NO_2$-N | $NO_3$-N | o-$PO_4$ | Chl.-*a* | Turb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sal. | 1 | .307* | .457** | .443** | .300* | ns | ns | .502** | ns | ns | ns | ns | -.676** | .490** | ns |
| DO | | 1 | ns | .378* | .510** | .321* | ns | ns | .499** | -.301* | -.481** | ns | -.351* | ns | ns |
| Temp. | | | 1 | .595** | ns | ns | ns | .324* | ns | ns | -.590** | -.662** | -.587** | .721** | ns |
| pH | | | | 1 | .451** | .313* | .411** | .562** | ns | .398** | ns | -.479** | -.411** | ns | ns |
| SD | | | | | 1 | .403** | ns | ns | ns | -.445** | ns | ns | ns | ns | ns |
| $Ca^{2+}$ | | | | | | 1 | ns | .313* | ns | ns | ns | ns | ns | ns | ns |
| $Mg^{2+}$ | | | | | | | 1 | .679** | ns | -.344* | ns | ns | ns | ns | ns |
| TH | | | | | | | | 1 | ns | ns | ns | -.390** | ns | ns | ns |
| $CO_3^{2-}$ | | | | | | | | | 1 | -.576** | ns | -.344* | ns | ns | ns |
| $HCO_3^-$ | | | | | | | | | | 1 | ns | ns | ns | ns | ns |
| $NO_2$-N | | | | | | | | | | | 1 | .559** | .453** | -.472** | ns |
| $NO_3$-N | | | | | | | | | | | | 1 | ns | -.448** | ns |
| o-$PO_4$ | | | | | | | | | | | | | 1 | -.490** | ns |
| Chl.-*a* | | | | | | | | | | | | | | 1 | -.452** |
| Turb. | | | | | | | | | | | | | | | 1 |

*: Correlation is significant at the 0.05 level (2-tailed).
**:Correlation is significant at the 0.01 level (2-tailed).
ns: not significant.

**Table 3.** Zooplankton species composition in Golden Horn**.**

| **Holoplankton** | **Holoplankton** |
|---|---|
| **Copepoda** | **Dinophyta** |
| *Acartia clausi* Giesbrecht, 1889 | *Noctiluca scintillans* (Macartney, Kofoid et Swezy, 1921) |
| *Microsetella norvegica* (Boeck, 1865) | **Chordata** |
| *Oncaea mediterranea* Claus, 1863 | larvea of *Ascida aspersa* (O.F.Mueller, 1776) |
| *Oithona nana* Giesbrecht, 1892 | *Oikopleura dioica* Fol, 1872 |
| *Paracalanus parvus* (Claus, 1863) | **Ctenophora** |
| *Thermocyslos oithonoides* G.O. Sars, 1863 | larvea of Ctenophora |
| **Cladocera** | **Chaetognatha** |
| *Bosmina longirostris* (O.F. Müller, 1776) | *Parasagitta setosa* ( Mueller, 1847) |
| *Evadne normanni* Lovén, 1836 | **Protozoa** |
| *Penilia avirostris* Dana, 1849 | *Favella ehrenbergi* (Claparède ve Lachmann, 1858) |
| *Podon polyphemoides* (Leuckart, 1859) | **Meroplankton** |
| **Rotifera** | Cypris |
| *Asplanchna sieboldi* (Leydig,1854) | larvea of Bivalvia |
| *Asplanchna priodonta* Gosse, 1850 | larvea of Echinodermata |
| *Keratella cochlearis* (Gosse, 1851) | larvea of Gastrapoda |
| *Gastropus stylifer* Imhof, 1891 | larvea of Ostracoda |
| *Synchaeta litoralis* Rousselet, 1902 | larvea of Polychaeta |
| eggs of *Asplanchna* spp. | larvea of Zoea |

**Table 4.** The average number of the dominant zooplankton genera (org. $m^{-3}$) and their frequency to the total zooplankton number in Golden Horn Estuary.

| Group | Dominant taxa | No. of org. $m^{-3}$ | % total zooplankton |
|---|---|---|---|
| Holoplankton | | | |
| Copepoda | *A.clausi* | 2453 | 3.03 |
| | Copepoda nauplii | 19146 | 23.67 |
| | Subtotal | 22093 | 27.31 |
| Cladocera | *P.polyphemoides* | 1561 | 1.93 |
| | Subtotal | 1738 | 2.15 |
| Rotifera | *A.priodonta* | 9280 | 11.47 |
| | *A.sieboldi* | 2130 | 2.63 |
| | Subtotal | 14521 | 17.95 |
| Dinophyta | *N.scintillans* | 4567 | 5.65 |
| | Subtotal | 4567 | 5.65 |
| Chordata | larvea of *A.aspersa* | 147 | 0.181 |
| | *O.dioica* | 117 | 0.145 |
| | Subtotal | 264 | 0.33 |
| Ctenophora | larvea of Ctenophora | 470 | 0.58 |
| | Subtotal | 470 | 0.58 |
| Chaetognatha | *S.setosa* | 1 | 0.001 |
| | Subtotal | 1 | 0.001 |
| Protozoa | *F.ehrenbergi* | 17015 | 21.04 |
| | Subtotal | 17015 | 21.04 |
| Meroplankton | larvea of Polychaeta | 12661 | 15.65 |
| | Subtotal | 20217 | 25.00 |
| | Grand total | 80885 | |

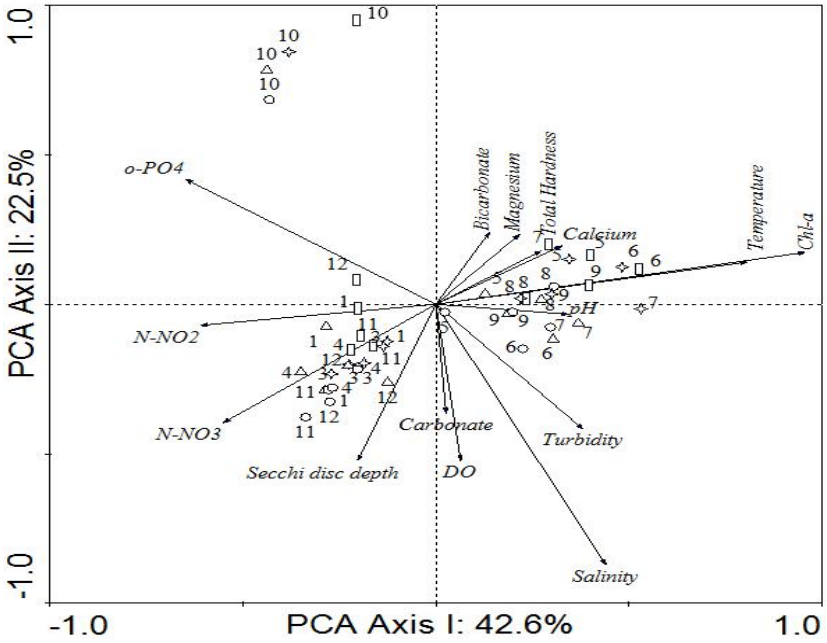


**Figure 2.** PCA on environmental variables. Numbers of 1–12 represented samples taken monthly. (11:November, 12:December, 1: January, 3: March, 4: April, 5: May, 6: June, 7: July, 8: August, 9: September, 10: October; rectangle: St.1, star: St.2, triangle: St.3, circle: St.4.)

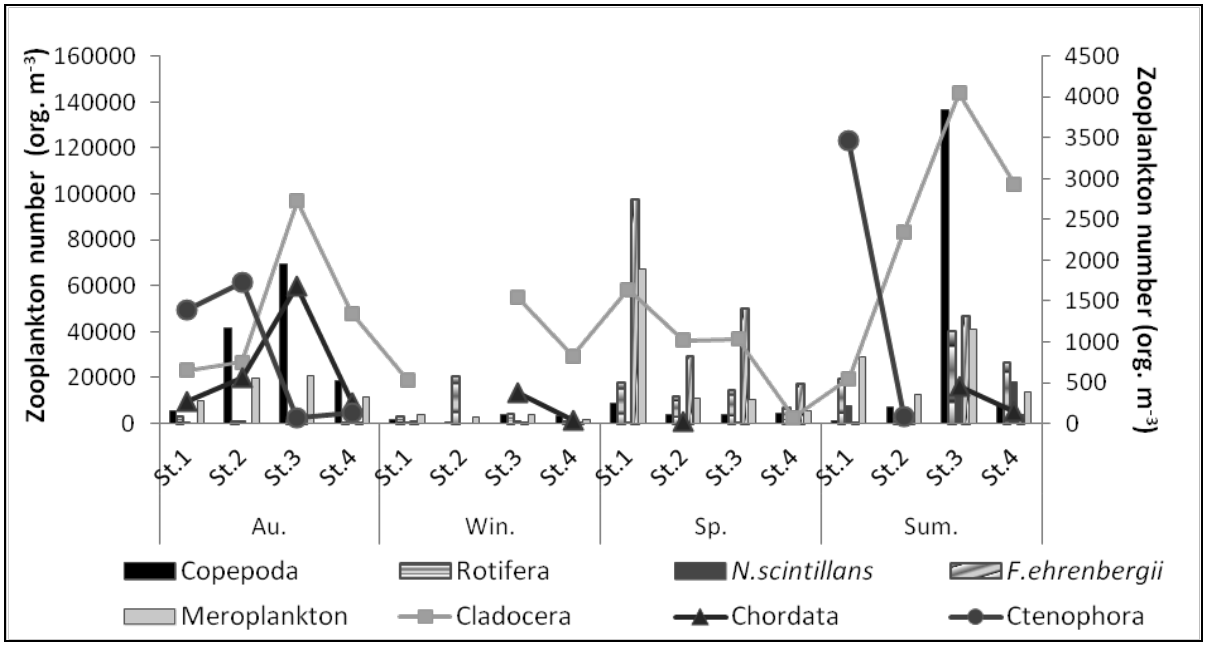


**Figure 3.** Distribution of numbers of zooplankton groups (org. $m^{-3}$) in Golden Horn Estuary during 2002/2003.

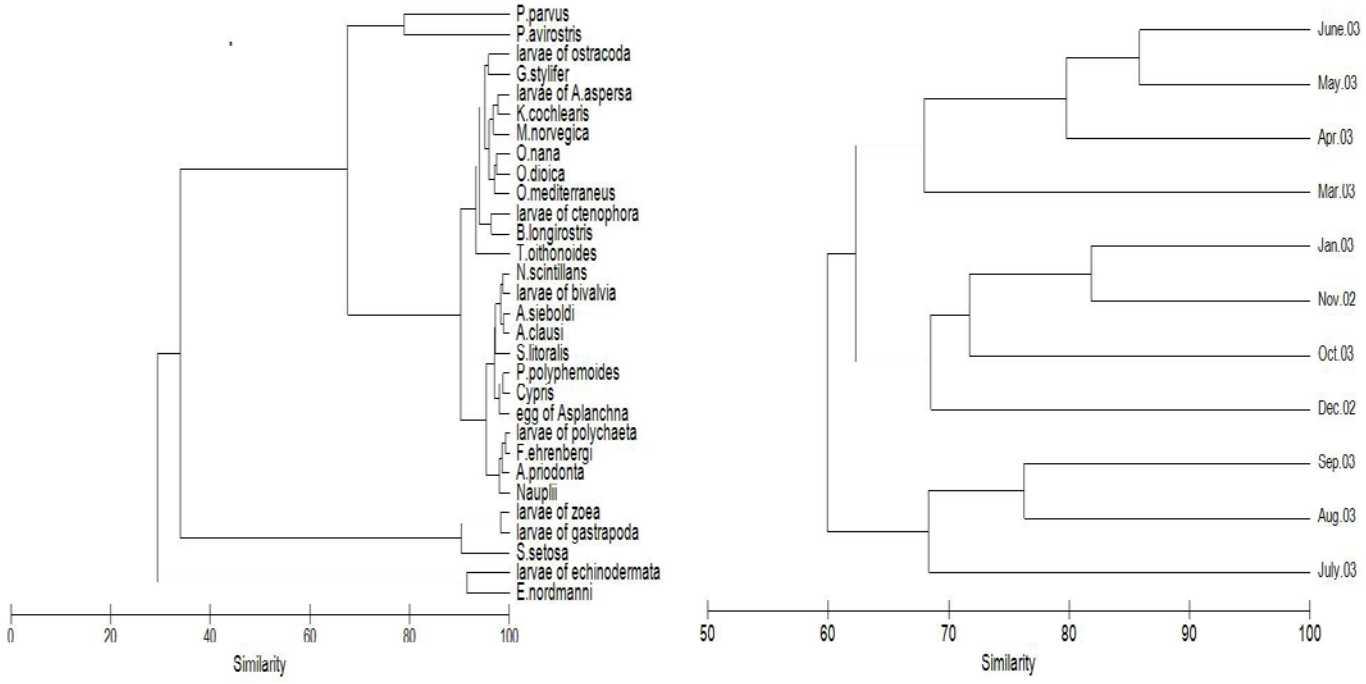


**Figure 4.** Dendogram using group average linking on Bray–Curtis similarity of the main species (variables) and months (samples) found from November 2002 to October.

There are three separate groups according to the dendogram. One large group is constituted by species showing a higher presence during the study period. Among these, *A. sieboldi, A. priodonto*, Cypris, *Noctiluca scintillans*, *P.polyphemoides* and Copepoda nauplii are the most abundant in summer, whereas larvae of bivalvia, *A. clausi*, eggs of *Asplanchna*, polychaeta larvae and *F. ehrenbe*rgi are more important in spring. Another large group includes the species *Gastropus stylifer, Keratella cochlearis, Microsetella norvegica, Oithona nana, Oikopleura dioica, Oncea mediterranea, Bosmina longirostris, Thermocyclops oithonoides*, larvae of ctenephora and larvae of ostracoda. Other three groups constituted by *Paracalanus parvus* and *Penilia avirostris*; *Parasagitta setosa*, larvae of zoea and larvae of gastrapoda; *Evadne nordmanni* and echinodermata larvae, respectively.

The cluster analysis of the mean monthly abundance of zooplankton taxa showed the three main assemblages, coinciding with the main annual environmental situations temporally (Figure 4).

Shannon–Wiener diversity index of the log-transformed means of zooplankton species density for the separate reaches of the estuary showed high values (2.3-4.1) during the study period for all stations. Generally, the lower reaches showed a higher zooplankton diversity index (Figure 5).

**Relationships between zooplankton and their environment**

With the submission of the first four synthetic gradients to RDA, the first two eigenvalues explained 26.3% of the cumulative variance of species data. Also, the species-environment correlations of axis 1 (0.900) and axis 2 (0.909) were high. The first four environmental variables explained 73.7% of the total variance in species data. The Monte Carlo permutation test was significant on the first axis (*F*-ratio = 6.034, *P*-value = 0.001) and on all axes (*F*- ratio = 3.920, *P*-value = 0.001) (Table 5).

In Figure 6a, the upper quadrant was completely confined to the distribution of zooplanktonic Crustaceans (Copepoda, Cladocera) and the lower one mainly to the distributions of two rotifers (*A. priodonta*, *A. sieboldi*). In Fig. 6b, the upper quadrant was restrict largely to the distribution of samples taken autumn and winter. Therefore, samples taken in autumn and winter were charecterized by more Crustaceans, while samples taken in spring and summer were characterized by more meroplankton, two rotifers and *N.scintillans*. According to the centroid principle and distance rule implied in RDA, in Fig. 6a $NO_2$-N and $NO_3$-N were both associated mainly with Crustaceans and two Rotifers (*A. priodonta*, *A. sieboldi*), while temperature, Chl.-*a* and total hardness mainly with meroplankton, two Rotifers and *N. scintillans.*

**Table 5.** Summary of the RDA analysis.

| Axes | | 1 | 2 |
|---|---|---|---|
| Eigenvalues | | 0.155 | 0.109 |
| Species-environment corrlations | | 0.900 | 0.909 |
| Cumulative percentage variance | | | |
| | of species data | 15.5% | 26.3% |
| | of species-environment relation | 41.5% | 70.7% |
| Total variance explained | | 73.7% | |
| The Monte Carlo permutation test | | *F*-ratio | *P*-value |
| | on the first axis | 6.034 | 0.001 |
| | on all axes | 3.920 | 0.001 |

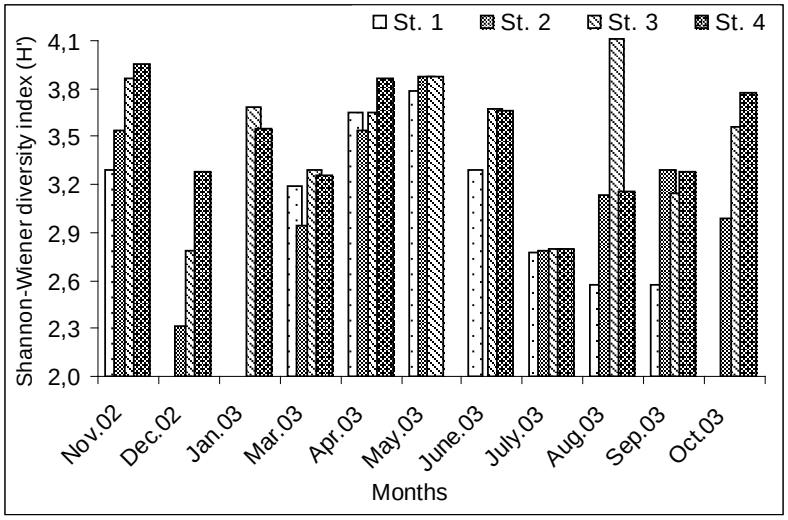


**Figure 5.** Shannon–Wiener diversity (*H'*) for the zooplankton community of the Golden Horn Estuary.

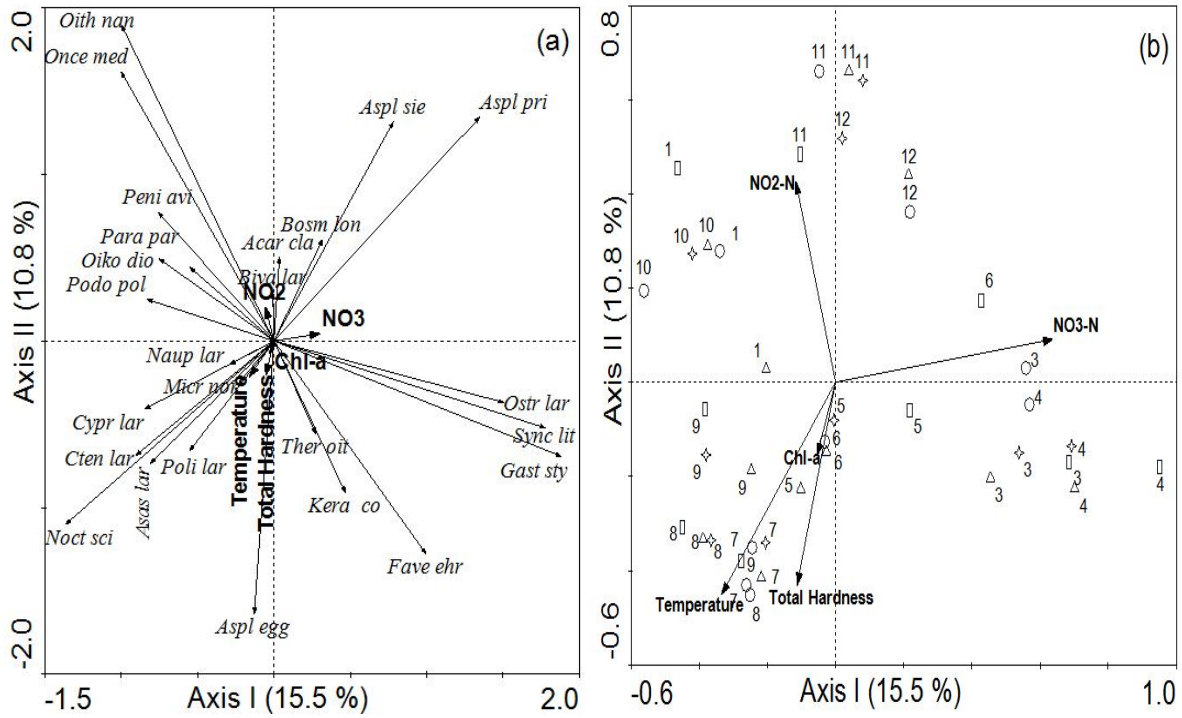


**Figure 6.** RDA ordination plots. (a) with species, Chl.-*a* and environmental variables. (b) with samples, Chl.-*a* and environmental variables. Numbers of 1–12 represented samples taken monthly. (11:November, 12:December, 1:January, 3:March, 4:April, 5:May, 6:June, 7:July, 8:August, 9:September, 10:October; rectangle: St.1, star: St.2, triangle: St.3, circle: St.4.)

This work characterize the variability of zooplanktonic species and their relationship with environmental variables in the inner- and middle part of the Golden Horn Estuary.

Study area characterized by a water mass with high salinity and low dissolved oxygen. Thus, low dissolved oxygen values might be related to organic matter decomposition processes, due to great input of two streams (Alibeyköy and Kağıthane) and sewages in the area. Rehabilitation workings in Golden Horn Estuary started in 1998, and the floating bridge (Valide Sultan Bridge) was opened partially. The semi-opening of the bridge enhanced of water circulation at the surface layer, relatively. The highest salinity values is the evidence of a strong input of Marmara Sea and reflecting homogenization of water mass throughout the surface waters of estuary.

Secchi disc depth increased to the sea direction, whereas turbidity decreased in this direction. These results correlates ascended depth and sea water circulation. Also, salinity values increased from the inner part to the middle part of the estuary, as a result of the impact of sea.

In the present study, the highest pH values were found in summer in general, and following heavy rains in the basin pH values dropped. The highest pH values recorded in summer can be controlled by decreasing rainfall and increasing phytoplankton production due to increasing temperature.

According to Yüksek et al. (2006), eukaryotic photosynthetic organisms dominated the plankton and succession of different species was observed in very small temporal scales following the opening of the bridge, and the heavily polluted upper layer began to show dense and frequent phytoplankton blooms. In this study, determined high dissolved oxygen concentration might depend on above-referred increasing photosynthetic activity.

Dissolved oxygen concentration and pH values ascended at the same period. There were significant positive correlations between pH-DO (Spearman's rho correlation, r=0.962, p= 0.378, p<0.05, *n*=44) and pH-temperature (Spearman's rho correlation, r=0.699, p= 0.595, p<0.01, *n*=44).

Free carbon dioxide, carbonate and bicarbonate are the three forms of carbon dioxide in melts. Bicarbonate-carbonate equation determines the alkalinity of the aquatic environments. Measured pH values can be used to determine to amount of the free $CO_2$, or the alkaline/asidic situation of the environment. Bicarbonate uptake is defined as indicator of algal activity (Currie and Kalff, 1984), because some plants use $CO_2$ in the structure of bicarbonate, when increased pH values. Because of bicarbonate concentration buffers the alteration of pH, its important variable in natural waters. According to the results, pH values and bicarbonate showed significant positive correlations (Spearman's rho correlation, r=0.398, p=0.008, p<0.01, *n*=44), similar to the literature. In the present study, the carbonate and bicarbonate values decreased from 1st Station to 4th Station. These members are more abundant in streams, and this case originate from pH balance, biological processess and the chemical structure of substratum. 4th Station is away from the impact of the creeks, so flow of the creeks, carrying the minerals in water, not attains to the middle part of the estuary.

Magnesium and calcium are the most important cations in aquatic environments, which constitute the total hardness of fresh water. Thus there was a significant correlation between total hardness-magnesium (Spearman's rho correlation, r=0.679, p= 0.000, p<0.01, *n*=44), and total hardness-calcium (Spearman's rho correlation, r=0.313, p= 0.039, p<0.05, *n*=44). On the other hand, they build up the salinity with other some cations and anions (eg. carbonate). Therefore, despite the first three stations are far from the sea, the salinity values were higher than in fresh water because of high anion and cation values. Magnesium is the important component of Chlorophyll, but according to Bohn et. al. (2004) Chlorophyll-bound Magnesium contributes a small and nutritionally insignificant part of total Magnesium intake in industrialized countries. Calcium can be used by some lime-stored plants to change to monocarbonate or shell forming animals (eg. Crutaceans).

The Golden Estuary was in eutrophic state and the main source of various nutrients were the discharges, as mentioned earlier. Also, its sediment has a fine-grain structure, and this type of sediment include high concentrations of soluble nitrogen and phosphorus (Fisher et al., 1982). Resuspension of sediments following disturbance generally causes rapid release of nutrients to the water column. For these reasons the nutrient values ($NO_2$, $NO_3$, o-$PO_4$) in the present study were determined in high concentrations. It was seen, that the values of nutrients were increased toward inner side of the estuary (from 4th station to 1st station), especially. Because 1st station is closer to the creeks, the quantity of pollution and sediment carried by creeks are higher in this region than the other three stations.

According to the results, the significant increase in Chl.-*a* content at the inner part of estuary may indicate an icrease in algal biomass. This was probably due to the decreased transparency and declined phosphorus levels. There were significant negative correlations between Chl.-*a* and phosphorus levels (Spearman's rho correlation, r=-0.490, p= 0.001, p<0.01, *n*=44) and Chl.-*a* and turbidity in the study (Spearman's rho correlation, r=-0.452, p= 0.002, p<0.01, *n*=44).

According to our results, some of the determined physicochemical variables (salinity, dissolved oxygen, water temperature, and pH) affect the distribution of zooplankton directly, whereas others indirectly.

Zooplankton community in Golden Horn Estuary was characterized by the presence of freshwater, estuarine and marine species. Zooplankton composition in Golden Horn Estuary is similar to other estuarine systems which holoplanktonic organisms, particularly Copepoda (Büyükateş and İnanmaz, 2010), dominated in this kind of environments. Copepoda nauplii, the most abundant taxon of Copepoda, have poor swimming ability, and therefore they can not change their habitat, until their size and swimming ability increase, after which they can then return to regions of preffered salinity (Chinnery and Williams, 2004). The other abundant Copepoda specimen *A. clausi* is known as non-migratory (Ergün, 1994). *A. clausi* population is often among the most abundant zooplankton specimen settled in many coastal and open water environments. Local populations of *Acartiidae* family may present according to highly variable temperature, salinity and available nutrient conditions (Hubareva et al., 2008). Cladocerans are not effective indicators to determine the level of pollution of estuaries (Uriarte and Villate, 2004), conversely *P.polyphemoides* (the abundant taxon of Cladocera in the present study) and *A. clausi* were reported as that they preffered highly polluted waters (Tarkan and Ergüven, 1988; Ünal et al., 2000; Benli et al., 2001). Determined abundant Rotifer species *Asplanchna* spp., noted by some authors that in general they are dominant zooplankton taxa in lotic areas, and are predatory (Bekleyen, 2001; Güher, 2003).

Also tintinnids (tintinnids represented in this study by *F.ehrenbergii*) are an important component in most marine environments (Cordeiro et al., 1997), and they can be important occasionally in estuarine environments (Dolan and Gallegos, 2001). Meroplanktonic forms, have also important components of plankton in this estuary, like the other estuary around the world (Tan et al., 2004; Ayón et al., 2008; Móderan et al., 2010).

Zooplankton community composition associates with trophic status of water body tightly, and the outcome of impacts like nutrient enrichment can be reflected in zooplankton community structure (Conde-Porcuna et al., 2002; Hietala et al., 2004). This can be illustrated by the RDA analysis in the context, which displayed a distinct relationship between zooplankton taxa composition and their environment. The first five determined variables explained 73.7% of the taxonomic structure. The zooplankton community structure responded rapidly to the environmental changes. As indicated by the RDA, temperature, $NO_2$-N, $NO_3$-N, Chl.-*a* and total hardness were significant variables that controlled species composition and temporal variations of abundance of the zooplankton assemblages.

According to the results, all the selected variables ($NO_2$-N, $NO_3$-N, Chl.-*a*, temperature and total hardness) associated with Rotifers and meroplankton, and $NO_2$-N, $NO_3$-N mainly with zooplanktonic Crustaceans.

The relation among zooplankton taxa, water temperature and high concentrations of nutrients has been detected by many authors (Park and Marshall, 2000). It is a consensus that an increase in the concentration of nutrients influences the top levels of a food web through a cascade of interactions (Anderson et al., 2002).

Rotifers are usually regarded as bio-indicators of water quality (Sládĕcek, 1983), and their abundance and population characteristics are used as effective indicators of environmental changes (Attayde and Bozelli, 1998). Rotifera species, we have identified in present study, are commonly found in eutrophic waters (Kolisko, 1974). The abundance of Rotifers decreased, while the density of zooplanktonic Crustaceans increased markedly. Increase in temperature during spring allowed the development of total Rotifers in high abundances up to 51106 ind. $m^{-3}$, while abundance of Crustacea was 24418 ind. $m^{-3}$. Inorganic nitrogen such $NO_2$-N and $NO_3$-N can help the increase of Rotifer density. According to the results $NO_3$-N concentration increased in spring.

Calcium is an essential structural component of crustacea carapaces (Korosi et al., 2008), and is an integral part of total hardness. Consequently has been shown to be important in influencing Crustacean assemblages in our study area.

Because zooplankton taxa are key components of aquatic ecosystems, this pattern may reflect the ability of larger Cladocera to competitively exclude smaller species when nutrients are limiting, as larger Cladocerans have lower limiting thresholds for nutrients (Brooks and Dodson, 1965). When nutrient levels are higher, competition pressures decrease and smaller individuals can proliferate. This situation could explain the relationship between nitrate and nitrite with Cladocerans. Copepoda affected indirectly by $NO_2$-N and $NO_3$-N. The presence of phytoplankton is controlled by utilizable nitrogen and phytoplank-

ton is an important diet for Copepoda (Lawrence et al., 2004).

## Conclusions

The Golden Horn, in the center of Istanbul city, has been the favourite settlement area of the city in 1970s, because of its clean water, and sheltered harbors (Eyice, 1975). Therefore, it was an important fishing and recreational area, and also had touristic value and for this reason the Golden Horn is among the most important ecosystems in Turkey. In conclusion, this study presents the relationship between zooplankton distribution and the spatio-temporal patterns of environmental variables at the inner- and middle part of the Golden Horn Estuary. Longitudinal gradient has also an importance on variation of zooplankton species and physicochemical variables. According to the Water Pollution Regulation by the Ministry of Forestry and Water Affairs (Anonymous, 2004), study area was found to have IVth class of water quality according to the nutrient concentrations. However, species richness was found very high in all stations as meroplanktonic and holoplanktonic species contributes highly to the total species numbers. This study revealed the zooplankton fauna of the Golden Horn Estuary for the first time.

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