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Diurnal vertical distribution of zooplankton in a newly formed reservoir (Tahtalı Reservoir, Kocaeli): the role of abiotic factors and chlorophyll *a*

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Abstract: Although water level fluctuations and related environmental variations occurring within reservoirs have a considerable effect on the zooplankton community, studies on zooplankton dynamics of reservoirs are very limited. In the present study, we aimed to elucidate the diurnal vertical migration of zooplankton in relation to the concentration of physicochemical factors and chlorophyll *a* content in a recently formed water reservoir (Tahtalı Reservoir, Kocaeli, northwestern Turkey). During the sampling period 20 zooplankton taxa were identified, which were mostly indicative of eutrophic waters, as confirmed by the physicochemical factors of the water in the reservoir. Rotifera was the most abundant group, followed by Copepoda and Cladocera. Statistical analyses indicated that all the zooplankton species showed a similar distribution pattern throughout the study. They declined in abundance in the water column from the surface to a depth of 6 m, and then increased relatively again towards the deepest part of the water (9 m). Abiotic factors, chlorophyll *a*, time of the day, and depth significantly impacted the abundance of zooplankton, whereas they jointly had no effect. The results suggested that abiotic factors and chlorophyll *a* were controlling factors on the vertical distribution pattern of the zooplankton in the Tahtalı Reservoir.

Key words: Diel vertical migration, freshwater zooplankton, rotifers, crustaceans, physicochemical factors, Tahtalı Reservoir

1. Introduction

Zooplankton is one of the most important groups in aquatic ecosystems. It has a major role in transferring primary producers through trophic levels, i.e. from the phytoplankton to the fish. Diel migration of zooplankton might have a significant impact on the vertical distribution of nutrients in the water column (e.g., Kitchell et al., 1979). Hence, they provide economically exploitable fish stocks, while ecologically they control small phytoplankton species (<20 µm), which could be very disturbing for a recipient environment if they become too abundant. As they are strongly influenced by climatic variations, zooplankton species have also been used as indicators to monitor global changes in aquatic systems (Beaugrand et al., 2001).

Zooplankton distribution is dependent on several factors such as light, temperature, food, oxygen saturation, and the presence of invertebrate and fish predation (McLaren, 1974; Enright, 1977; Stich and Lampert, 1981; Dagg, 1985). Vertical diel migration behavior of zooplankton, on the other hand, is well documented and known as the most common behavior of zooplankton (Lampert, 1993), especially in deep lakes where a strong stratification exists (Lauridsen and Buenk, 1996). Since many zooplankton species are phototaxic (Buchanan and Haney, 1980), light intensity appears to be a primary factor in the migration. However, selective predation by visually orienting planktivorous fish, larger zooplankton, and invertebrates, as well as other abiotic factors, cannot be ruled out.

Although vertical migration by zooplankton has been documented in many studies in various kinds of environments, it is poorly documented in newly created reservoirs (Bozkurt and Dural, 2005; Guevara et al., 2009), which have recently become very common for irrigation and drinking water purposes all over the world, as well as in Turkey. Most of the limnoecological studies in these kinds of reservoirs focus on the determination of water quality, or the flora and fauna of several aquatic groups (e.g., phytoplankton, zooplankton, fish). Newly formed reservoirs are usually considered as ecological disasters for their recipient environment, since they are largely responsible for water course changes, sediment transport,

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water quality and temperature variations, and introductions of nonnative species, and they are unstable environments often suffering from eutrophication problems a short time after they are built (Ward and Stanford, 1995). In this respect, an understanding of the ecological structure of these artificial water bodies, and their role in the dynamics of biotic communities, is of a great importance (Guevara et al., 2009). As well as in other natural water bodies, the zooplankton community of a reservoir is a major resource of energy and nutrient flow in the food web (Bonecker et. al., 2007). Despite extensive study of the diurnal vertical migration of zooplankton, there are still many questions that remain unanswered about the dynamics of zooplankton movements in man-made artificial reservoirs. Although water level fluctuations and related environmental variations occurring within reservoirs have a considerable effect on the zooplankton community, studies on the zooplankton dynamics of reservoirs are very limited. In the present study, we aimed to understand the diurnal vertical migration of zooplankton in relation to several selected physical and chemical variables in a recently established water reservoir (Tahtalı Reservoir, Kocaeli, northwestern Turkey) used for irrigation.

2. Material and methods

2.1. Study area

The Tahtalı Reservoir is located 30 km from the city of Kocaeli in the district of Derince (Figure 1). It was built with the aim of flood control and irrigation, and it has surface area of 1.6 km^2. Its average depth is quite variable because of frequent water level fluctuations varying between approximately 1 and 5 m. There are 2 relatively large streams and a couple of small seasonal streams, which empty into the reservoir. Agriculture is quite common around the reservoir and, because of its deep draft, it is a very unpredictable environment in terms of ecological stability.

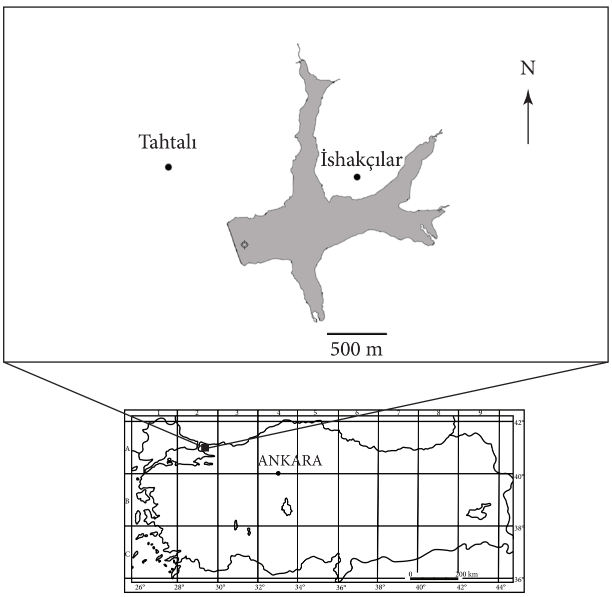

Figure 1. Study area and sampling station.

2.2. Zooplankton and water sampling

Samples were taken from the deepest part of the reservoir (9 m) on 22 and 23 May 2010. This part of the reservoir was the only suitable location available throughout the year in the reservoir allowing vertical migration of zooplankton. The sampling time was chosen as May because that was the only time the reservoir could possibly achieve its maximum water level. Zooplankton samples were collected vertically with a plankton net (closing net, mesh size 55 µm). The samples were collected throughout a 24-h period at 4-h intervals starting from 1100 hours on 22 May 2010 and were preserved in 4% formaldehyde. Sampling covered the entire water column, from the surface to the deepest part (9 m), and was repeated at 1.5-m intervals. Zooplankton count was enumerated under an inverted microscope and species were identified with the aid of a binocular. Zooplankton densities are presented as the number of individuals per liter (ind./L). The following references were reviewed to identify the species: Dussart (1967, 1969), Koste (1978), and Margaritora (1983).

Water samples for analysis of environmental variables were taken simultaneously with zooplankton samples from each sampling point. Water samples were collected vertically using a 1.5-L Nansen bottle. Conductivity, water temperature, turbidity, and pH measurements were recorded in situ with a digital portable multiparametric analyzer (Radiometer Pioneer 65) while dissolved oxygen was measured with a digital oxygen meter (WTW 330). Water transparency was determined using a Secchi disk and was used for the calculation of the euphotic zone (Parsons et al., 1977). To determine chlorophyll *a* content, water samples were filtered and extracted through ethanol. After centrifugation, absorbance was measured before and after acidification in a spectrophotometer and then calculated (Nusch, 1980).

2.3. Statistical analyses

In order to approximate better to normal distributions, biotic and abiotic variables were log-transformed ($\log(x + 1)$). Pearson's correlation factor was used to test the relationships among environmental factors, chlorophyll *a*, and zooplankton (Zar, 1999). To determine the effects of spatial (depth) and temporal (time of the day) variations on environmental factors and zooplankton communities, multivariate analysis of variance (MANOVA) was conducted. Spatial and temporal variations of zooplankton species were tested by analysis of variance (ANOVA). All statistical analyses were performed using SPSS 19.0.

3. Results

3.1. Physical and chemical factors and chlorophyll *a* distribution

All examined abiotic factors varied within the expected range of an optimum freshwater system except dissolved oxygen, which dropped down to 3.9 mg/L (Figure 2). These values showed a similar pattern, i.e. a decrease from the surface to depths of 4.5–6.0 m and a rise from this point to the deepest part of the vertical water column (Figure 2). There were mostly significant correlations among abiotic factors and chlorophyll *a*, with the exception of the euphotic zone, which showed no significant correlations with the variables analyzed (Table 1). MANOVA indicated the significant effects of time of day and depth on abiotic factors and chlorophyll *a* ($P < 0.05$). However, the combined effects of time of day and depth did not show any significant impact on physicochemical parameters and chlorophyll *a* (MANOVA, $P > 0.05$, Table 2). Euphotic zone and Secchi disk values did not change according to the time of the sampling. It was between 3.26 m and 3.83 m for the euphotic zone and 1.21 m and 1.42 m for Secchi disk.

3.2. Zooplankton composition, abundance, and vertical distribution

During the sampling period 20 taxa were determined (Table 3) and Rotifera were the most abundant taxa (95%), followed by Copepoda (4%), and Cladocera (1%) (Figure 3). Within the Rotifera group the most observed species were *Keratella cochlearis* (Gosse, 1851), *Polyarthra vulgaris* Carlin, 1943, and *Pompholyx sulcata* Hudson, 1885, respectively. From Cladocera, *Bosmina longirostris* (Muller, 1776) was the dominant species while *Daphnia cucullata* Sars, 1862 was found in small numbers. As a predator of Rotifers, *Asplanchna* spp. was observed in low quantities.

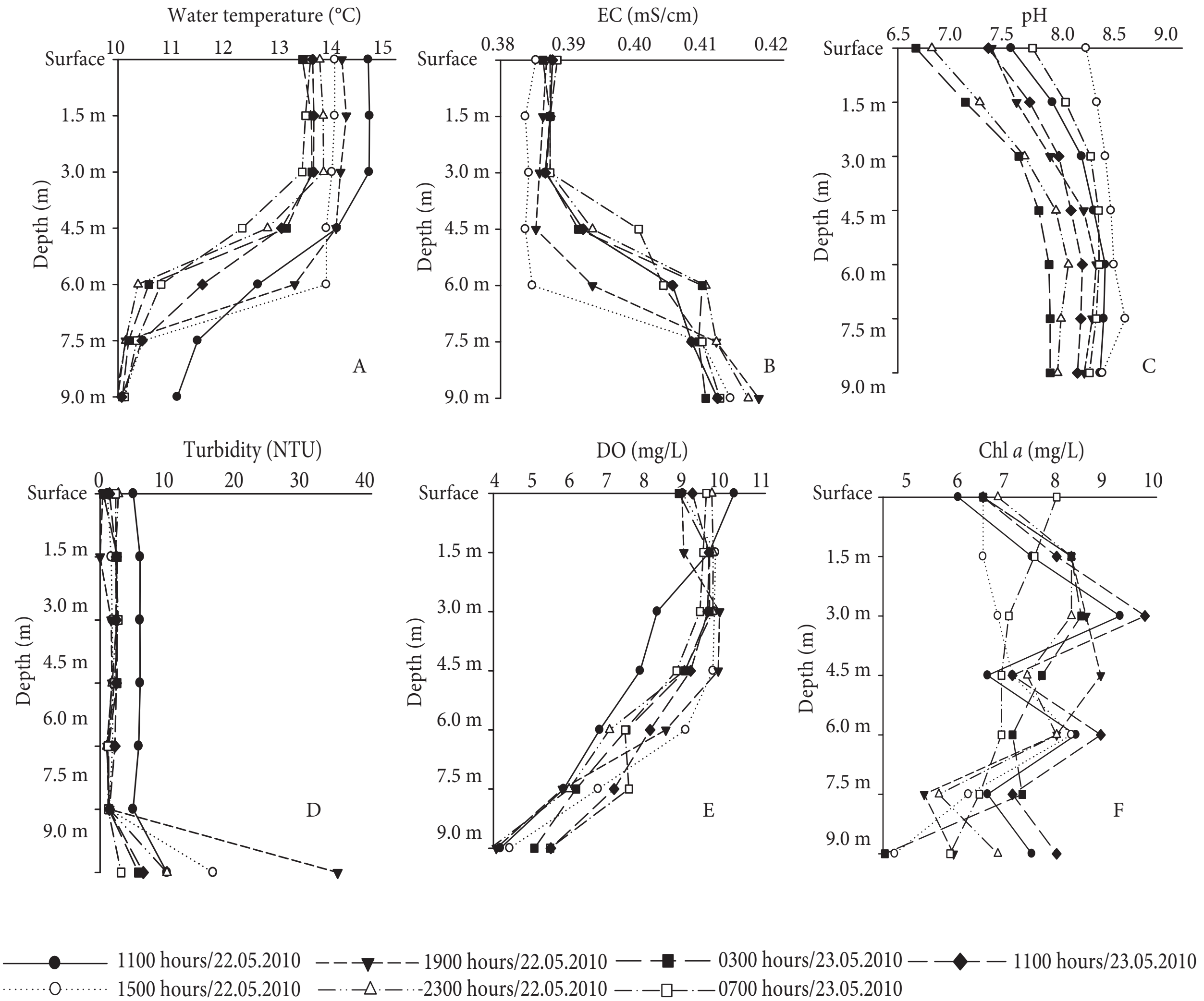

Figure 2. The vertical distribution of A) water temperature, B) electrical conductivity (EC), C) pH, D) turbidity, E) dissolved oxygen (DO), and F) chlorophyll a (Chl *a*), denoted by time of the sampling.

Table 1. Classifications of the zooplankton species living in the study area (Ustaoğlu, 2004).

Rotifera	**Rotifera**
Asplanchna girodi De Geurne, 1888	*Pompholyx sulcata* Hudson, 1885
Asplanchna priodonta Gosse, 1850	*Synchaeta oblonga* Ehrenberg, 1831
Brachionus angularis Gosse, 1851	*Trichocerca pusilla* (Jennings, 1903)
Brachionus budapestinensis Daday, 1885	**Cladocera**
Filinia terminalis (Plate, 1886)	*Bosmina longirostris* (Müller, 1776)
Keratella cochlearis (Gosse, 1851)	*Daphnia cucullata* Sars, 1862
Keratella quadrata (Müller, 1786)	**Copepoda**
Lecane lunaris (Ehrenberg, 1832)	*Cyclops abyssorum* Sars, 1863
Lecane flexilis (Gosse,1886)	*Metacyclops gracilis* Lilljeborg, 1853
Polyarthra vulgaris Carlin, 1943	*Metacyclops stammeri* Kiefer, 1938

Table 2. Correlation matrix for electrical conductivity (EC), water temperature, pH, turbidity, dissolved oxygen (DO), chlorophyll *a* (Chl *a*) and euphotic zone in the Tahtalı Reservoir. Bold type shows significant differences between relative conditions at 95% confidence limits.

Pearson's correlation; **P < 0.01, *P < 0.05; n = 42							
	EC	Water temperature	pH	Turbidity	DO	Chl *a*	Euphotic zone
EC	1	–0.981**	0.362*	0.437**	–0.938**	–0.519**	–0.068
Water temperature		1	–0.356*	–0.365*	0.918**	0.560**	0.074
pH			1	0.152	–0.335*	–0.149	0.558**
Turbidity				1	–0.554**	–0.293	–0.028
DO					1	0.567**	0.064
Chl *a*						1	–0.106
Euphotic zone							1

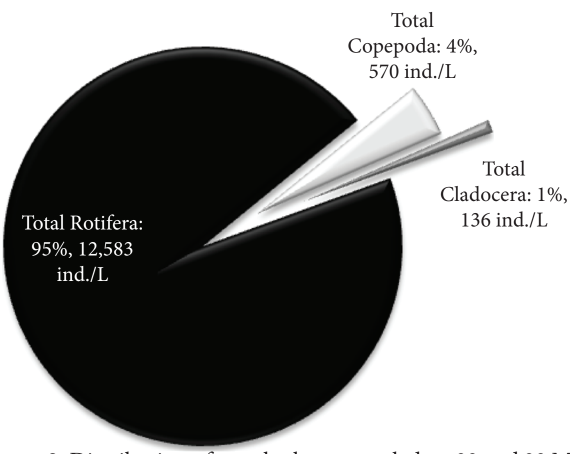

Figure 3. Distribution of zooplankton sampled on 22 and 23 May 2010 from the Tahtalı Reservoir.

All zooplankton species declined in abundance in the water column until the depth of 6 m and then relatively increased again towards the deepest part of the water (9 m) (Figure 4). Likewise, abiotic factors and chlorophyll *a*, time of day, and depth significantly impacted the abundance of zooplankton (MANOVA, $P < 0.05$, Table 4), whereas they jointly had no effect on zooplankton abundances (MANOVA, $P > 0.05$, Table 4).

3.3. Physicochemical and biological association

Significant correlations were detected between zooplankton groups, abiotic factors, and chlorophyll *a* except for turbidity, which showed an insignificant correlation with zooplankton species (Table 5). ANOVA results showed that the time of day and depth had significant effects on selected zooplankton species ($P < 0.05$, Table 6).

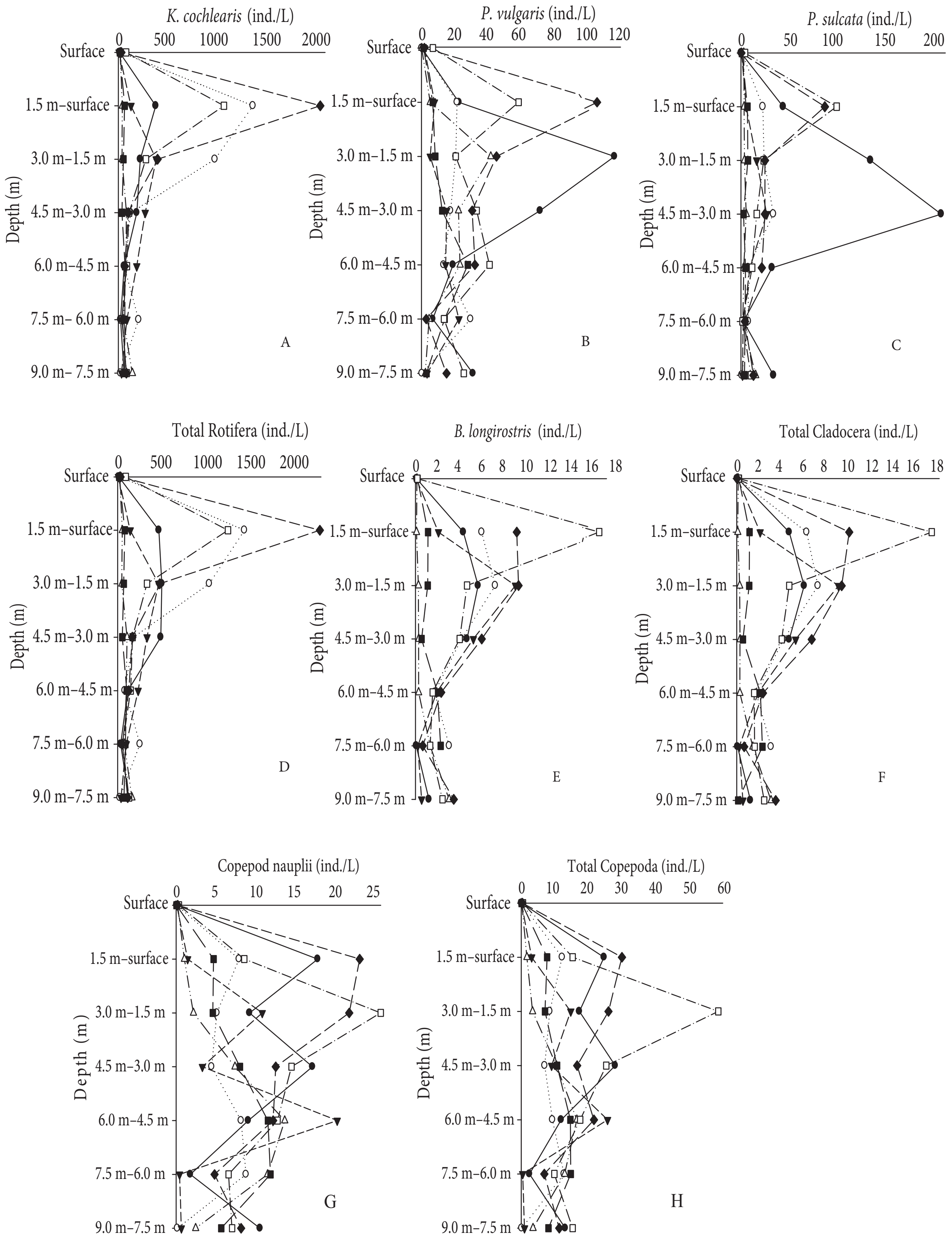

Figure 4. The vertical distribution of A) *K. cochlearis*, B) *P. vulgaris*, C) *P. sulcata*, D) total Rotifera, E) *B. longirostris*, F) total Cladocera, G) copepod nauplii, and H) total Copepoda, denoted by the time of sampling.

Table 3. MANOVA assessing the effects of depth and time of day on physicochemical parameters.

MANOVA				
Physicochemical parameters				
	DF	Pillai's trace	Wilks' lambda	P < 0.05
Depth	36	2.373	0.004	0.000
Time of day	6	0.691	0.309	0.000
Depth × time of day	36	1.020	0.294	0.546

Table 4. MANOVA assessing the effects of depth and time of day on the diversity of zooplankton.

MANOVA				
Zooplankton				
	DF	Pillai's trace	Wilks' Lambda	P < 0.05
Depth	54	2.581	0.007	0.001
Time of day	9	0.860	0.140	0.000
Depth × time of day	54	2.092	0.016	0.075

Table 5. Correlation matrix for the mean depth distribution of zooplankton, physicochemical parameters, and chlorophyll *a* for 24 h of sampling in early summer in the Tahtalı Reservoir. Bold type shows significant differences between relative conditions at 95% confidence limits. **P < 0.01, *P < 0.05.

	K. cochlearis	*P. vulgaris*	*P. sulcata*	Total Rotifera	*B. longirostris*	Total Cladocera	Nauplii	Total Copepoda
EC	**−0.346***	−0.138	−0.263	**−0.347***	−0.269	−0.285	0.027	−0.039
Water temperature	**0.332***	0.164	0.302	**0.339***	0.259	0.280	−0.020	0.038
pH	0.196	**0.309***	0.203	0.216	0.277	0.278	**0.381***	**0.363***
Turbidity	−0.095	−0.145	−0.028	−0.099	−0.057	−0.065	−0.192	−0.168
DO	**0.328***	0.197	0.223	**0.331***	0.247	0.270	0.076	0.124
Chl *a*	0.093	**0.360***	0.262	0.127	0.207	0.234	0.248	0.197
Euphotic zone	**0.335***	**0.377***	**0.396****	**0.362***	**0.338***	**0.356***	0.218	0.273

4. Discussion

Recorded zooplankton species such as *K. cochlearis*, *P. vulgaris*, *P. sulcata*, *Asplanchna* spp., *B. longirostris*, and *D. cucullata* in the Tahtalı Reservoir are common species encountered in temperate reservoirs in Turkey (Bozkurt and Dural, 2005; Demir, 2005; Bozkurt and Sagat, 2008). These species are usually considered as indicators of eutrophic waters (Kolisko, 1974) and this was supported by the measured physicochemical features of the water in the Tahtalı Reservoir, especially with its higher chlorophyll *a* production (Figure 2). The observed dominancy of rotifers and cladocerans in the reservoir is also consistent with previous studies, which demonstrated that copepods were the dominant zooplankton group in oligotrophic waters whereas eutrophic waters were dominated by Rotifera and cladocerans (Guevara et al., 2009). Reservoirs, as unpredictable and unstable environments, tend to have a eutrophic character and hence in the majority of reservoirs, rotifers are the predominant group, composing more than 60% of the total zooplankton (Marneffe et al., 1988; Rodriguez and Matsumura-Tundisi, 2000).

Table 6. ANOVA results for the effect of time of day and depth on zooplankton species. All variables were significant at 95% confidence intervals.

Taxon	One-way ANOVA (P < 0.05)			
	Time of day		Depth	
K. cochlearis	$F_{(1,26)} = 23.07$	P = 0.000	$F_{(6,26)} = 14.86$	P = 0.000
P. vulgaris	$F_{(1,26)} = 10.66$	P = 0.003	$F_{(6,26)} = 2.47$	P = 0.049
P. sulcata	$F_{(1,26)} = 10.67$	P = 0.003	$F_{(6,26)} = 2.46$	P = 0.049
Total Rotifera	$F_{(1,26)} = 32.75$	P = 0.000	$F_{(6,26)} = 17.40$	P = 0.000
B. longirostris	$F_{(1,26)} = 7.55$	P = 0.011	$F_{(6,26)} = 3.83$	P = 0.007
Total Cladocera	$F_{(1,26)} = 8.23$	P = 0.008	$F_{(6,26)} = 4.06$	P = 0.005
Nauplii	$F_{(1,26)} = 5.40$	P = 0.028	$F_{(6,26)} = 4.30$	P = 0.004
Total Copepoda	$F_{(1,26)} = 6.49$	P = 0.017	$F_{(6,26)} = 2.96$	P = 0.024

Although the vertical distribution of zooplankton is well documented (Lampert, 1993; Lauridsen and Buenk, 1996) and reported to be regulated by both abiotic (light, temperature, oxygen, food availability) and biotic (predation, interspecific competition) factors (Buchanan and Haney, 1980; Dagg, 1985; Horppila, 1997), all zooplankton groups studied in the present study (i.e. Rotifera, Cladocera, and Copepoda) did not show any significant migrations and were distributed entirely throughout the water column with decreasing abundances from top to bottom. This pattern corroborated the findings from other reservoirs in Turkey and tropical lakes in South America (Bozkurt and Dural, 2005; López and Zoppi de Roa, 2005; Bozkurt and Sagat, 2008; Guevara et al., 2009). In contrast to common expectations of the migration behavior of zooplankton, many lakes do not have any migratory species or they have migratory and nonmigratory species at the same time and location (Gliwicz and Pijanowska, 1988). It was also observed that vertical migration can occur by the same species in one lake but not in another (Geller, 1986).

Migratory behavior of zooplankton largely depends on resource limitation (food) and predator avoidance (Gliwicz and Pijanowska, 1988); however, whether these factors are effective remains unexplained in the Tahtalı Reservoir because of inadequate data on the food of zooplankton and on their predators (i.e. mainly planktivorous fish). Rotifers particularly are preyed upon by many fish species, more intensively in their young stages, and compose the majority of food items in fish guts (Telesh, 1993). While initial evaluation of gut content analyses of fishes was indicative of zooplankton predation by some native (e.g., *Squalius pursakensis* (Hanko, 1925), *Leucaspius delineatus* (Heckel, 1843)) and nonnative fishes (e.g., *Carassius gibelio* (Bloch, 1782), *Pseudorasbora parva* (Temminck and Schlegel, 1846)) in the Tahtalı Reservoir, these fishes were not simultaneously caught during zooplankton sampling and found in the littoral zone of the reservoir. Food distribution, on the other hand, would be a more important factor for the observed distribution of zooplankton in the Tahtalı Reservoir, as all zooplankton groups and species were positively and significantly correlated with chlorophyll *a* distribution (Table 5 and 6), suggesting that the aggregation of these organisms may be dependent on food concentration. This positive relationship between Rotifera density and chlorophyll *a* concentration was also found by Weglenska et al. (1997) and Bonecker and Lansac-Tôha (1996). Since the Tahtalı Reservoir is a mesoeutrophic reservoir, phytoplankton production is expected to be high and sufficient for herbivorous zooplankton feeding. The sampling was also carried out in early spring, a time when edible phytoplankton peaked. It was reported earlier that cladocerans favor their nutrition and energetic costs at the expense of predator avoidance behavior (Dagg, 1985). This might be true for the dominant Cladocera species *B. longirostris* in the Tahtalı Reservoir, as it did not show any migration behavior and preferred the depths where chlorophyll *a* concentrations were higher (Figure 4).

Although a pronounced vertical migration of zooplankton was not observed in the Tahtalı Reservoir, all zooplankton species showed an unusual distribution pattern by declining in abundance down to the depth of 6 m and then increasing again towards the deepest part of the water column. This observed pattern is most probably due to water abstraction by a pipe located at the 6-m depth. All aquatic organisms drift out of the reservoir because of this water abstraction structure in the reservoir. Nonmigratory behavior of zooplankton in the present study indicates that they did not contribute to active nutrient transport; however, this distribution pattern (i.e. decreasing abundances from the surface towards deeper parts of the water column) can also be associated with environmental factors such as temperature and oxygen. Increase in temperature has been associated with a higher abundance and species diversity of zooplankton in lakes (Castro et. al., 2005; Buyurgan et. al., 2010). The positive correlation between temperature and zooplankton can be attributed to the increase of phytoplankton and algae providing food resources for zooplankton (Matsubara, 1993; Castro et. al., 2005). Indeed, in the current study, the abundance of rotifers, water temperature, and chlorophyll *a* were closely related. Significant relationships of oxygen and temperature, especially with rotifers, were evident in the Tahtalı Reservoir and showed that the deeper water column had less Rotifera abundances because of lower temperatures and oxygen concentrations, which supported earlier reports about the avoidance of poor oxygen levels by migratory crustaceans (Fisher et al., 1983; Horppila, 1997). Despite the fact that cladocerans were reported to tolerate dissolved oxygen concentrations below 1 mg/L (Murtaugh, 1985), their feeding is considerably reduced at oxygen levels below 3 mg/L (Heisey and Porter, 1977). The most abundant cladoceran species in the present study, *B. longirostris*, was found at a depth of 1.5 m, where oxygen levels were relatively higher (Figure 4). This can be attributed to the avoidance of lower oxygen levels and light in deeper water levels by this species, as shown by other studies (Rautio et al., 2003), as well as a positive significant correlation with euphotic zone depth found in the present study (Table 5). In spite of the relatively lower abundances of copepods determined in the present study, they were represented by abundant nauplii and followed a similar pattern to other zooplankton groups, i.e. avoiding lower oxygen concentrations in the water column sampled. This behavior is consistent with several previous observations stating that the nonmigratory behavior of copepods was due to limiting environmental factors, largely temperature and oxygen (Kurki et al., 1999; Zotina et al., 1999).

Most of the biological processes and biochemical reactions depend on pH, which therefore affects the distribution of zooplankton, and in terms of pH the alkaline limit was reported as 8.5 (Berzins and Pejler, 1987). According to our results, pH values were on the alkaline side. Bozkurt and Sagat (2008) reported the acceptable water conductivity value for aquatic organisms to be between 250 and 500 µmhos/cm (maximum: 2000 µmhos/cm). The conductivity variation can be an important regulator of the structure of zooplankton assemblages, especially for species diversity and richness (Williams, 1998). Our conductivity values varied between 380 and 420 µmhos/cm, and statistical analyses indicated that there was a negative significant correlation between conductivity and rotifer species ($P < 0.05$). This is because of the low tolerance of rotifer species for conductivity values higher than 400 µmhos/cm (Kaya et al., 2010).

The temperature preference of rotifers may play a major role in shaping their vertical distribution in the Tahtalı Reservoir. Some particular species can be highlighted to demonstrate the true pattern of this distribution. As the dominant species, *K. cochlearis* is known to chase phytoplankton and avoid low temperatures (Primicerio, 2000). It is also not a preferable prey species of Copepoda, because of its large spines and crusty lorica relative to other rotifer species (e.g., Gilbert and Hampton, 2001), although it is reported as one of the typical preys of *Asplanchna* (Miracle et al., 1993). However, neither *Asplanchna* spp. nor any Copepoda species were found in sufficiently high abundances to feed on *Keratella* species or other rotifer species found during the sampling. Thus, besides chlorophyll *a* and oxygen concentrations, temperature variations in the water column can explain the vertical distribution of zooplankton in the Tahtalı Reservoir, which is supported by a positive significant relationship between temperature and zooplankton groups and species in the present study (Table 5). Many other studies were also in agreement with the present study, emphasizing the importance of temperature, which controls the vertical mixing of plankton distribution (Pinel-Alloul et al., 1988; Pinel-Alloul and Pont, 1991).

In conclusion, the results of this study have indicated that the zooplankton species are typical for Turkish lakes in accordance with the climate regime of the region, and they showed no significant migration pattern throughout the water column. The dominant species detected in the Tahtalı Reservoir are indicators of eutrophic waters, confirmed by physicochemical factors of the water in the reservoir. The results also suggested that the distribution of the examined zooplankton groups and species was related to abiotic factors, such as water temperature, dissolved oxygen, conductivity, and pH, and also food concentrations represented by chlorophyll *a*. However, as reservoirs are usually used for irrigation and suffer from severe droughts in temperate climates, their physical structure is not uniform and temperature, oxygen levels, and nutrient composition showed unpredictable changes among different reservoirs. Hence, reservoir-specific studies should be conducted to understand the real pattern of variations in zooplankton dynamics and consequently trophic interactions.

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