



## Zooplankton Seasonal Abundance and Vertical Distribution of Highly Alkaline Lake Burdur, Turkey

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### Abstract

During the period from December 2003 to November 2004 a study has been held to examine the water quality and zooplankton of highly alkaline Lake Burdur. The lake showed thermal stratification between June and October. Six zooplankton taxa were determined, *Hexarthra fennica*, *Brachionus plicatilis* from Rotifera and *Arctodiaptomus burduricus* from Copepoda were the dominant species. Average zooplankton density was 399,074 ind.m<sup>-3</sup> and they were 51% *H. fennica*, 9% *B. plicatilis* and 40% *A. burduricus*. In addition, vertical zooplankton distributions have been investigated in this study. Generally, zooplankton groups were concentrated between 5-20 m. However, rotifers and *A. burduricus* were determined to have the highest density at 5 and 15 m, respectively.

**Keywords:** Saline lake, *Arctodiaptomus burduricus*, zooplankton, vertical distribution.

### Alkali Özellikli Burdur Gölü Zooplanktonunun Mevsimsel Bolluğu ve Dikey Dağılımı

#### Özet

Aralık 2003-Kasım 2004 tarihleri arasında yürütülen bu çalışmada, yüksek alkali özellikteki Burdur Gölü'nün su kalitesi ve zooplanktonu incelenmiştir. Haziran-Ekim ayları arasında termal tabakalaşma gösteren gölde zooplanktonu temsilen 6 takson belirlenmiş olup, Rotiferadan *Hexarthra fennica* ve *Brachionus plicatilis* ile Copepoda'dan *Arctodiaptomus burduricus* baskın bulunan türlerdir. Ortalama yoğunluğu 399.074 birey m<sup>-3</sup> olan zooplanktonunun %51'ini *H. fennica*, %9'unu *B. plicatilis* ve %40'ını *A. burduricus* oluşturmuştur. Zooplanktonun dikey dağılımının da incelendiği bu çalışmada, genel olarak, toplam zooplankton 5-20 m derinlikler arasında yoğunlaşmasına karşılık, rotiferler ve *A. burduricus* sırasıyla 5. ve 15. m derinliklerde en yüksek yoğunluk değerinde saptanmıştır.

**Anahtar Kelimeler:** Tuzlu göl, *Arctodiaptomus burduricus*, zooplankton, dikey dağılımı.

#### Introduction

Despite the worldwide simplicity of highly saline lakes, in terms of biological diversity, ecosystem structure and habitat homogeneity, no complete picture of the ecology of any salt lake has yet been produced (Williams, 1996). Euryhaline invertebrates generally include cosmopolitan species and those with wide distributions but presence only in certain habitats. The rotifer *Brachionus plicatilis* and the brine shrimp *Artemia* spp. are the examples of first category, while the calanoid copepod *D. salinus* may be the example of the latter (Cole, 1983).

Lake Burdur is one of the deepest lakes of Turkey. The aquatic plants are not observed in the lake because of the amount of sodium sulphate and

chlorine content (Anonymous, 1998). Since the lake does not freeze in winter, it serves as a winter refuge for the birds (Arcak and Altındağ, 2000). The ecosystem of the lake is threatened by the presence of an industrial complex (Isparta Organized Endustrial Region) and Süleyman Demirel Airport close to the northern shore. The decrease of water levels (because of construction of upstream dams and unknown causes), increasing of sedimentation (from catchment erosion), organic pollution (from food processing and Burdur City raw sewage waste) and inorganic effluent (from a sulphur mine) represent long-term threats to the integrity of the lake (Anonymous, 1993; Green *et al.*, 1996). The water level has decreased from 1975 to 2002 due to construction of dams and ponds in catchment basin, resulting in the loss of 27% of the

lake area during the period of 27 years (Şener *et al.*, 2005). Nowadays the estimated lake area ranges between 140 km<sup>2</sup> (Girgin *et al.*, 2004) or 153 km<sup>2</sup> (Şener *et al.*, 2005).

Lake Burdur has great ornithological importance harbouring numerous wintering bird species. It is the most important wintering site in the world for the white-headed duck *Oxyura leucocephala*, a globally threatened species. It has also served habitats to 10 other internationally important waterfowl species (Green *et al.*, 1996). Lake Burdur has been a Ramsar Site since 1993 and Wildlife Reserve since 1994 (Yarar and Magnin, 1997). *Aphanius anatoliae sureyanus* (Cyprinodontidae, Pisces) (the only fish species) and *A. burduricus* Kiefer, 1939 (Copepoda, Crustaceae) are endemic species of the lake (Altındağ and Yiğit, 2002; Girgin *et al.*, 2004). The lake show mesosaprobic levels (Girgin *et al.*, 2004) and *Nodularia spumigena* (Cyanobacteria) blooms occur during summer (Anonymous, 2000).

The previous studies on zooplankton and limnology of Lake Burdur were done by Numann (1958), Timur *et al.* (1988), Kazancı *et al.* (1998), Arcaç and Altındağ (2000), Altındağ and Yiğit (2002) and Girgin *et al.* (2004). These studies mainly dealt with the seasonal variation of zooplankton distribution, while vertical distributions were not included.

The aim of this study is to determine annual cycle and vertical distribution in thermal stratification period of the zooplankton, also the effective limnological parameters. Since the vertical distribution and monthly densities of zooplankton in Lake Burdur are firstly described in this study, it can contribute to related studies. Secondly, it is aimed at presenting a distribution model representative of zooplankton in saline-alkaline lakes of Turkey.

## Materials and Methods

Lake Burdur is among the largest and deepest lakes of Turkey, located at the Lake District Region in south-western Anatolia (37°43'351" N, 30°10'878" E), within a closed basin (Figure 1). Catchment area is 6150 km<sup>2</sup>. The average depth is 40 m and maximum depth 68 m. Maximum surface area is 140 km<sup>2</sup> at 854 m elevation (Girgin *et al.*, 2004). It is salty and highly alkaline (pH 9-9.60) and it never freezes.

Three stations were chosen from different parts of the lake (Figure 1): station I at 37°43'351" N, 30°10'878" E (depth: 60-65 m); station II at 37°46'849" N, 30°16'256" E (depth: 6-7 m), and station III at 37°44'517" N, 30°13'981" E (depth: 15-20 m).

The samples for water quality were collected at three stations (Figure 1), at surface water at depth of transparency by using Nansen bottles (1.7 L volume). The water quality parameters were analyzed using the methods described by Apha-Awwa-Wef (1998), Boyd and Tucker (1992) and Lind (1985). Transparency (Secchi disc depth), temperature, pH (WTW 330i pH meter), conductivity (YSI 30 model SCT meter) and dissolved oxygen (WTW Oxi 320 oximeter) were measured *in situ*. Nutrient analysis of water was done by filtering with GF/C filters in the Merck Spectroquant® test kits, and water is analyzed for NH<sub>4</sub>-N, NO<sub>3</sub>-N, and PO<sub>4</sub>-P. Turbidity and color were determined directly in Merck Nova 60 photometer. Chlorophyll *a* was determined according to Apha-Awwa-Wef (1998), Bartram and Balance (1996). Total non-filterable (suspended matter) and filterable residues were filtered through the filter paper (Whatman CF/C) and dried 1 h at 103-105°C (Apha-Awwa-Wef, 1998).

Zooplankton was sampled monthly during the

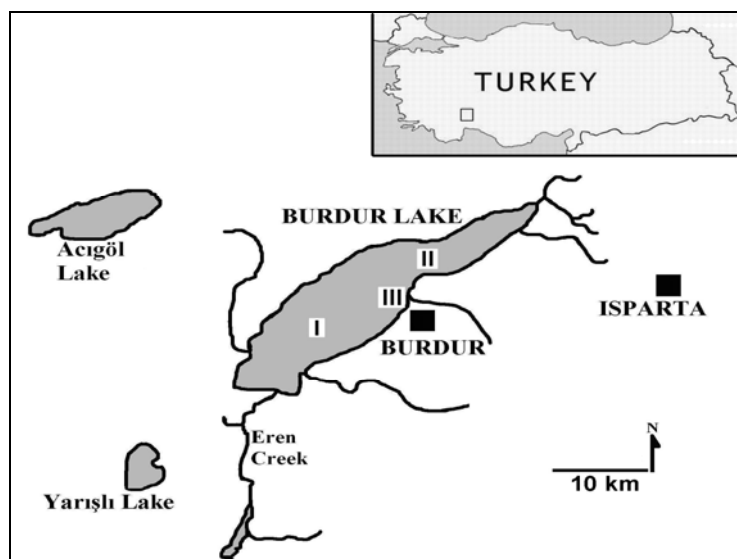


Figure 1. Map of Lake Burdur and sampling stations.

period from December 2003 to November 2004. Sampling was done with plankton net of 55µm mesh size equipped with mounted digital flow meter (Hydro-bios Kiel), as vertical hauls of 20, 10 and 5 m; of I<sup>st</sup>, III<sup>rd</sup> and II<sup>nd</sup> stations respectively (according to the depth of the lake). The net-selected samples were preserved in 4% formalin. Also, in July 2004, zooplankton samples were collected vertically from 0 to 60 m (at station I), in 5 meter intervals from bottom upwards and with 5 sampling from each depth in a 24 hours duration, by using a motor-pump. 20 litres of water samples taken from each sampling depth were filtered through net of 55 µm pore size. Zooplankton counts were carried out in Sedgwick-Rafter counting chambers under an inverted microscope (Nikon Eclipse TE-200). Zooplankton abundance was expressed as individuals per cubic meter.

Statistical analyses were done for zooplankton density and its vertical distribution using one-way ANOVA.

## Results

The mean surface water parameter values of Lake Burdur are shown below (Table 1).

Graphics for parameters of water quality are

shown in Figures 2 and 4. Differences between the mean for parameters of water quality were significant ( $P<0.05$ ), excluding colour and turbidity (Table 1). Variance of temperature, dissolved oxygen and pH are shown in Figure 2; transparency, chlorophyll *a* and salinity are shown in Figure 3; NH<sub>4</sub>-N, NO<sub>3</sub>-N and PO<sub>4</sub>-P are shown in Figure 4. The minimum and maximum temperatures were measured in February (6.3°C) and July (24.9°C), respectively. The minimum and maximum values of dissolved oxygen were found in December (6.8 mg L<sup>-1</sup>) and March (16.7 mg L<sup>-1</sup>), respectively (Figure 2).

Figure 3 shows that the salinity is low in February-June period and high in July-December period. The minimum and maximum values were determined in April (18.3 ppt) and November (19.5 ppt), respectively. The highest chlorophyll *a* values were recorded in spring (the maximum in February, 16.17 µg L<sup>-1</sup>) and the lowest ones in the other seasons (the minimum in August, 0.70 µg L<sup>-1</sup>). The chlorophyll *a* concentrations showed a dissimilar gradient of transparency (Secchi disc depth) (Figure 3) addition, differences of mean chlorophyll *a* contents were significant ( $P<0.05$ ) (Table 1).

In generally, PO<sub>4</sub>-P values were moderate to high. Its concentrations ranged from 0.02 to 0.26 mg

**Table 1.** Chemical and physical features of the water in Lake Burdur, December 2003-November 2004

Months	Temperature (°C)	pH	Dissolved oxygen (mg L <sup>-1</sup> )	Conductivity (mS cm <sup>-1</sup> )	Salinity (ppt)	Suspended Matter (mg L <sup>-1</sup> )	Secchi disc depth (m)
Dec. 03	11.2 <sup>h</sup>	9.29 <sup>c</sup>	6.8 <sup>d</sup>	31.1 <sup>b</sup>	19.3 <sup>bc</sup>	12.60 <sup>e</sup>	5.2 <sup>ab</sup>
Feb. 04	6.3 <sup>i</sup>	9.43 <sup>a</sup>	12.3 <sup>b</sup>	30.6 <sup>d</sup>	18.8 <sup>e</sup>	15.39 <sup>cd</sup>	2.2 <sup>de</sup>
Mar. 04	10.7 <sup>h</sup>	9.39 <sup>ab</sup>	16.7 <sup>a</sup>	29.7 <sup>f</sup>	18.4 <sup>h</sup>	15.65 <sup>c</sup>	1.1 <sup>e</sup>
Apr. 04	15.6 <sup>f</sup>	9.39 <sup>abc</sup>	9.7 <sup>bc</sup>	29.6 <sup>f</sup>	18.3 <sup>h</sup>	16.30 <sup>bc</sup>	2.4 <sup>de</sup>
May 04	20.2 <sup>d</sup>	9.34 <sup>bc</sup>	8.1 <sup>d</sup>	29.7 <sup>f</sup>	18.5 <sup>g</sup>	15.33 <sup>cd</sup>	3.4 <sup>cd</sup>
June 04	23.8 <sup>b</sup>	9.10 <sup>d</sup>	8.9 <sup>bc</sup>	30.1 <sup>e</sup>	18.6 <sup>f</sup>	15.00 <sup>cd</sup>	3.6 <sup>cd</sup>
Jul. 04	24.9 <sup>a</sup>	9.10 <sup>d</sup>	9.3 <sup>bc</sup>	30.6 <sup>cd</sup>	19.0 <sup>d</sup>	18.69 <sup>a</sup>	2.9 <sup>cd</sup>
Aug. 04	24.1 <sup>b</sup>	9.14 <sup>d</sup>	7.8 <sup>d</sup>	30.8 <sup>c</sup>	19.2 <sup>c</sup>	18.18 <sup>ab</sup>	3.5 <sup>cd</sup>
Sept. 04	21.2 <sup>c</sup>	9.10 <sup>d</sup>	7.1 <sup>d</sup>	31.0 <sup>b</sup>	19.4 <sup>b</sup>	18.54 <sup>a</sup>	4.4 <sup>bc</sup>
Oct. 04	18.8 <sup>e</sup>	9.18 <sup>d</sup>	7.8 <sup>d</sup>	31.1 <sup>b</sup>	19.4 <sup>ab</sup>	13.45 <sup>de</sup>	5.7 <sup>ab</sup>
Nov. 04	12.7 <sup>g</sup>	9.17 <sup>d</sup>	6.8 <sup>d</sup>	31.4 <sup>a</sup>	19.5 <sup>a</sup>	8.42 <sup>f</sup>	6.1 <sup>a</sup>
Mean ±S.E (min-max) n=33	17.2±1.1 (6.0-25.3)	9.2±0.02 (9.0-9.5)	9.2±0.6 (6.1-24.4)	30.5±0.1 (29.5-31.4)	19.0±0.1 (18.3-9.6)	15.2±0.53 (8.3-20.5)	3.7±0.29 (1-8)
Months	Color (Pt/Co)	Turbidity (NTU)	Chl. <i>a</i> (µg L <sup>-1</sup> )	PO <sub>4</sub> -P (mg L <sup>-1</sup> )	NO <sub>3</sub> -N (mg L <sup>-1</sup> )	NH <sub>4</sub> -N (mg L <sup>-1</sup> )	Tot. filt. Residue (g L <sup>-1</sup> )
Dec. 03	-	-	0.84 <sup>c</sup>	0.03 <sup>de</sup>	2.10 <sup>a</sup>	0.19 <sup>b</sup>	30.27 <sup>b</sup>
Feb. 04	-	-	16.17 <sup>a</sup>	0.04 <sup>de</sup>	0.28 <sup>cd</sup>	0.22 <sup>b</sup>	27.67 <sup>d</sup>
Mar. 04	26 <sup>a</sup>	7 <sup>a</sup>	12.12 <sup>a</sup>	0.08 <sup>c</sup>	0.35 <sup>cd</sup>	0.00 <sup>b</sup>	27.86 <sup>d</sup>
Apr. 04	14 <sup>a</sup>	5 <sup>a</sup>	6.66 <sup>b</sup>	0.06 <sup>cd</sup>	0.41 <sup>bc</sup>	0.02 <sup>b</sup>	27.04 <sup>d</sup>
May 04	12 <sup>a</sup>	2 <sup>a</sup>	1.54 <sup>bc</sup>	0.04 <sup>de</sup>	0.13 <sup>cd</sup>	0.00 <sup>b</sup>	27.69 <sup>d</sup>
June 04	13 <sup>a</sup>	2 <sup>a</sup>	1.15 <sup>bc</sup>	0.15 <sup>b</sup>	0.16 <sup>cd</sup>	0.16 <sup>b</sup>	27.60 <sup>d</sup>
Jul. 04	20 <sup>a</sup>	4 <sup>a</sup>	1.60 <sup>bc</sup>	0.08 <sup>c</sup>	0.76 <sup>b</sup>	0.00 <sup>b</sup>	27.91 <sup>d</sup>
Aug. 04	18 <sup>a</sup>	3 <sup>a</sup>	0.70 <sup>c</sup>	0.08 <sup>c</sup>	0.45 <sup>bc</sup>	1.45 <sup>a</sup>	34.29 <sup>a</sup>
Sept. 04	15 <sup>a</sup>	2 <sup>a</sup>	1.30 <sup>bc</sup>	0.24 <sup>a</sup>	0.48 <sup>bc</sup>	0.27 <sup>b</sup>	30.12 <sup>bc</sup>
Oct. 04	12 <sup>a</sup>	2 <sup>a</sup>	1.82 <sup>bc</sup>	0.03 <sup>de</sup>	0.16 <sup>cd</sup>	0.04 <sup>b</sup>	28.65 <sup>bcd</sup>
Nov. 04	12 <sup>a</sup>	1 <sup>a</sup>	0.99 <sup>c</sup>	0.02 <sup>e</sup>	0.03 <sup>d</sup>	0.01 <sup>b</sup>	28.30 <sup>cd</sup>
Mean ±S.E. (min-max) n=33	16±0.95 (9-31) n=27	3.07±0.35 (1-8) n=27	4.09±0.99 (0.50-22)	0.077±0.01 (0.02-0.26)	0.49±0.10 (0-2.4)	0.18±0.10 (0-3.1)	28.85±0.38 (26.5-35.7)

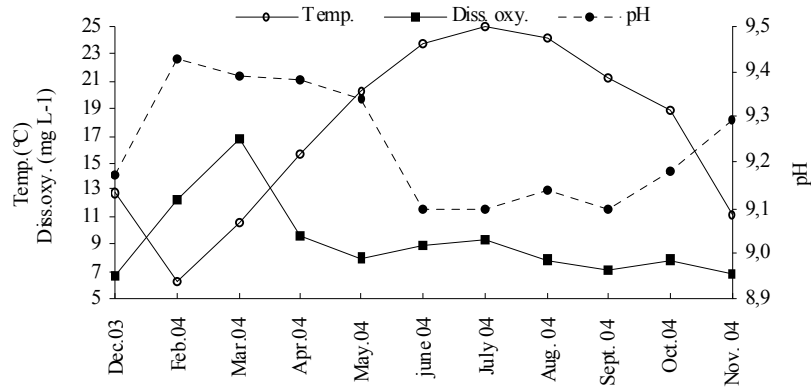


Figure 2. Variation of temperature (°C), dissolved oxygen (ppm) and pH.

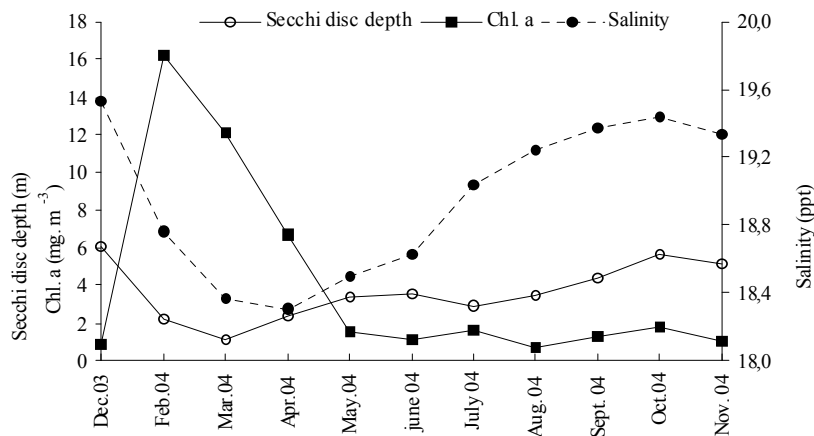


Figure 3. Variation of Secchi disc depth (m), chlorophyll *a* ( $\mu\text{g L}^{-1}$ ) and salinity (ppt).

$\text{L}^{-1}$ .  $\text{NO}_3\text{-N}$  values were found as 0.03-2.10  $\text{mg L}^{-1}$  and  $\text{NH}_4\text{-N}$  values were measured up to 1.45  $\text{mg L}^{-1}$  (Figure 4).

Temperature and dissolved oxygen profiles are presented in Table 2, at the surface layer and deep waters (downward to 30 m). Temperature and dissolved oxygen concentration in between layers are statistically different from each other ( $P < 0.05$ ).

Dissolved oxygen profile is clinograde type and similar to the temperature profile. This graph indicates the existence of thermocline between 10 and 16 m depth. Surface water (1-14 m) is rich for dissolved oxygen however, deep water is (from 18<sup>th</sup> m to depth) poor in dissolved oxygen (Figure 5).

The seasonal maximal density of zooplankton was observed in June as 1,144,559  $\text{ind. m}^{-3}$ , and minimum density in February as 129,765  $\text{ind. m}^{-3}$ , thus seasonal fluctuation in the zooplankton community was important ( $P < 0.05$ ). The maximum density of *A. burduricus* was 437,915  $\text{ind. m}^{-3}$  in March. In general, two periods were detected in zooplankton density: one with the lesser density (between September-February) and the other with the higher density (between March-August) (Figure 6, Figure 7).

A total of 6 zooplankton taxa were recorded: 3 rotifers, and 3 copepods. Cladoceran species were not observed.

#### Rotifera

Order: Monogononta

Family: Brachionidae

*Brachionus plicatilis* Müller, 1786

Family: Colurellidae

*Colurella adriatica* Ehrenberg, 1831

Family: Hexarthriidae

*Hexarthra fennica* (Levander, 1892)

#### Copepoda

Order: Calanoida

Family: Diaptomidae

*Arctodiaptomus burduricus* Kiefer, 1939

Order: Cyclopoida

Family: Cyclopidae

*Cyclops* sp.

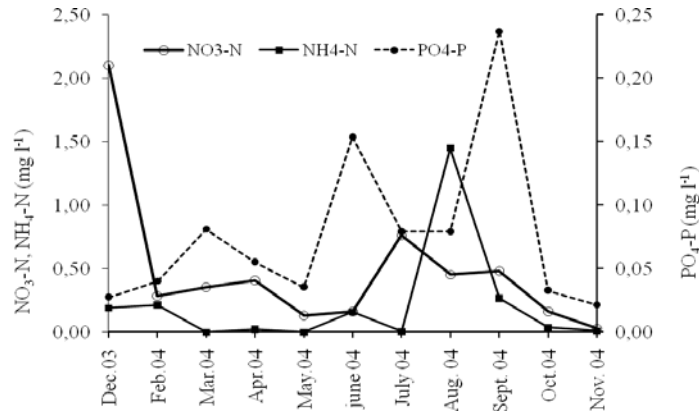
Order: Harpacticoida

Family: Canthocamptidae

*Canthocamptus* sp.

The abundance levels of zooplankton in three sampling stations are different from each other (Figure 8).

At station I, which is the deepest of stations, A.

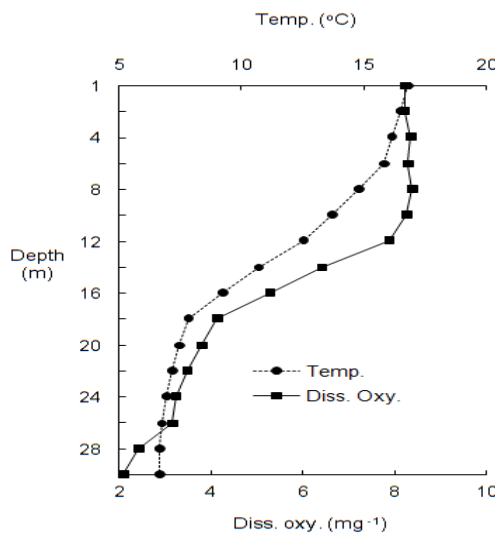


**Figure 4.** Variation of NO<sub>3</sub>-N, NH<sub>4</sub>-N and PO<sub>4</sub>-P.

**Table 2.** Monthly distribution of temperature and dissolved oxygen according to depth (0-30 m), during December 2003- November 2004, monthly

Depth	Temperature			Dissolved Oxygen		
	Mean ±SD (n=11)	Min	Max	Mean ±SD (n=11)	Min	Max
1	16.8±6.4 <sup>a</sup>	5.9	24.4	8.2±2.1 <sup>a</sup>	6.0	12.7
2	16.5±6.4 <sup>ab</sup>	5.6	24.3	8.2±2.1 <sup>a</sup>	6.0	12.5
4	16.2±6.4 <sup>ab</sup>	5.4	24.3	8.3±2.2 <sup>a</sup>	6.0	12.6
6	15.8±6.4 <sup>ab</sup>	5.4	24.1	8.3±2.0 <sup>a</sup>	5.9	11.7
8	14.8±6.0 <sup>ab</sup>	5.4	23.2	8.4±1.9 <sup>a</sup>	6.0	11.5
10	13.7±5.8 <sup>abc</sup>	5.4	21.6	8.3±1.8 <sup>a</sup>	6.4	11.0
12	12.6±5.2 <sup>bcd</sup>	5.4	20.2	7.9±1.4 <sup>a</sup>	6.5	10.5
14	10.7±4.5 <sup>cde</sup>	5.6	19.8	6.4±2.2 <sup>ab</sup>	3.0	10.2
16	9.2±2.9 <sup>de</sup>	5.8	15.7	5.3±3.0 <sup>bc</sup>	1.2	9.6
18	7.9±1.6 <sup>e</sup>	5.9	10.8	4.1±3.4 <sup>cd</sup>	0.0	9.5
20	7.4±1.4 <sup>e</sup>	5.9	10.1	3.8±3.3 <sup>cd</sup>	0.0	8.9
22	7.1±1.3 <sup>e</sup>	6.1	10.0	3.5±2.9 <sup>cd</sup>	0.0	8.0
24	6.9±1.0 <sup>e</sup>	6.2	9.7	3.3±2.6 <sup>cd</sup>	0.0	7.7
26	6.8±0.7 <sup>e</sup>	6.3	8.6	3.1±2.5 <sup>cd</sup>	0.2	7.6
28	6.6±0.4 <sup>e</sup>	6.3	7.7	2.4±2.0 <sup>cd</sup>	0.4	6.5
30	6.6±0.3 <sup>e</sup>	6.2	7.5	2.1±2.0 <sup>d</sup>	0.1	6.3

Statistical analysis was performed in order to observe the relation according to one tailed ANOVA Duncan test. Values in the same column with same superscript are not significantly different (P>0.05)



**Figure 5.** Water temperature and dissolved oxygen profile of Lake Burdur, according to average value of one year.

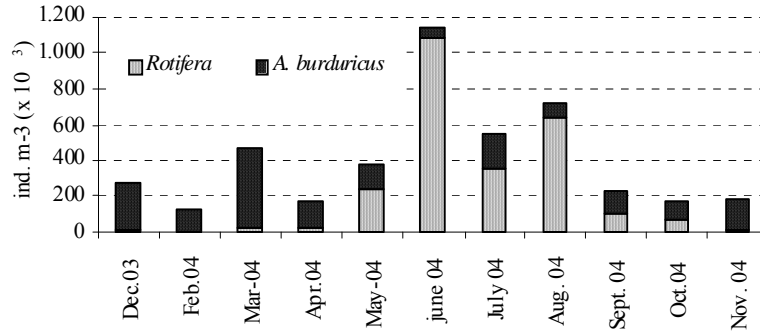


Figure 6. Monthly distribution of zooplankton groups density (ind. m<sup>-3</sup>).

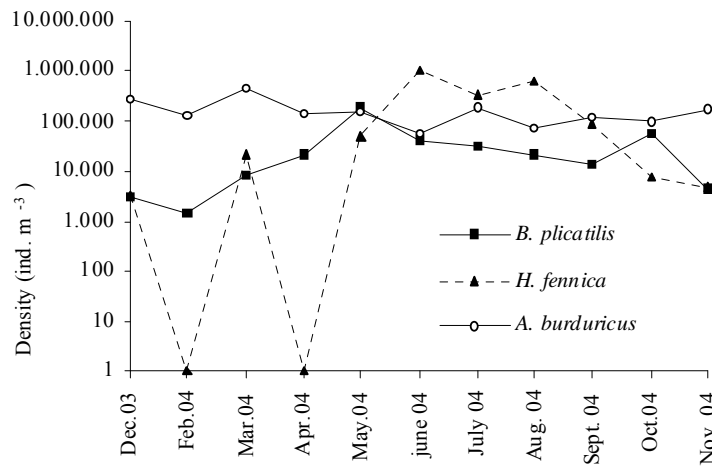


Figure 7. Monthly distribution of zooplankton species density (ind. m<sup>-3</sup>).

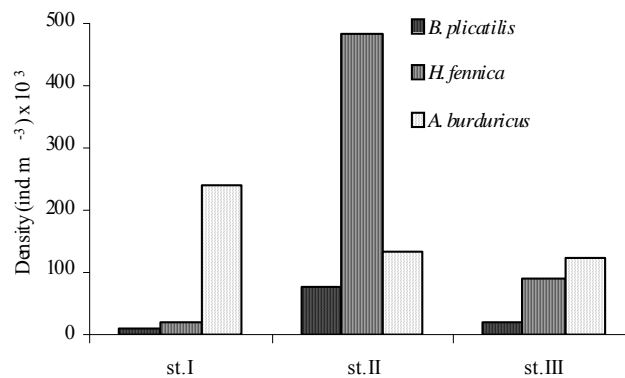


Figure 8. The densities of zooplankton taxa according to stations of the Lake Burdur.

*burduricus* is the dominant species ( $238,519 \pm 175,772$  ind.m<sup>-3</sup>), and stations II and III are alike in zooplankton density. All through the lake, the rotifers showed a widespread distribution (Figure 9).

The vertical distribution of zooplankton showed a clear correlation between zooplankton groups and water depth. The upwater was characterized by the presence of the rotifers and the lower depth by the Calanoid copepod, *A. burduricus*. Rotifers and

nauplius larvae colonized the surface layer (1-10 m), but *A. burduricus* inhabited in the mid layer of water (Figure 10b). Vertical temperature and dissolved oxygen profile of the lake were determined in same period (Figure 10a). The vertical distribution patterns of zooplankton were very similar to that of temperature and dissolved oxygen curves (Figures. 10a, b).

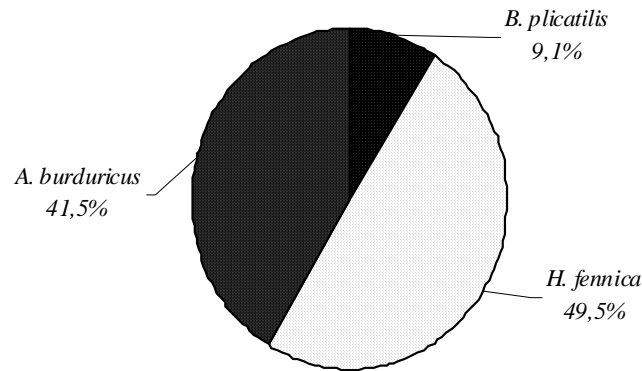


Figure 9. The distribution of zooplankton taxa in Lake Burdur.

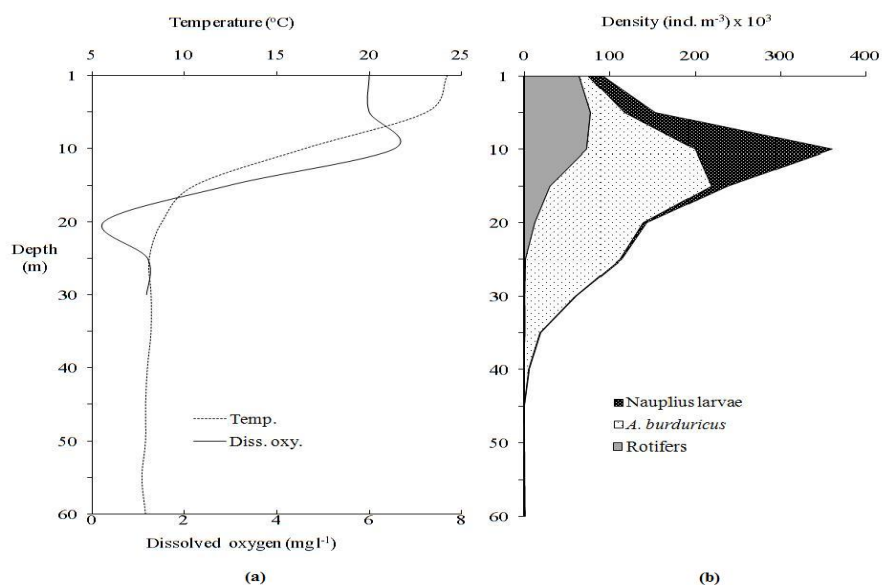


Figure 10. a) Vertical distributions of water temperature and dissolved oxygen b) Vertical distributions of zooplankton during the summer stratification period.

## Discussion and Conclusions

In order to determine the vertical distribution of zooplankton, the sampling was performed throughout the day (24 hours) in July, when thermal and chemical stratification could be observed. However, while observing the zooplankton distribution according to depth, the time periods of the day were neglected, so the repression by fish hunting could not have been determined. Additionally, the effects of the environmental factors on seasonal distribution of zooplankton were discussed.

The dissolved oxygen value of the surface level was generally sufficient for each season of the year (between 6.1-24.4 mg L<sup>-1</sup>). Similar results had been found in the previous studies that were performed on the lake (Altındağ and Yiğit, 2002; Arcaç and Altındağ, 2000; Kazancı *et al.*, 1998; Girgin *et al.*, 2004; Timur *et al.*, 1988).

Vertical water quality measurements of Lake Burdur between June and November presented a

thermal stratification. During the year, according to the vertical dissolved oxygen measurements, it was observed that this parameter was increasing from surface to 20 m depth, and anoxic conditions were present after 24 m in general. In the period of thermal stratification, the epilimnion layer occurred between 0-14 m; metalimnion layer occurred between 14-18 m; and hypolimnion layer (6-8°C) occurred after 18 m depth. In the lake, classified as warm monomictic due to thermal characteristics, the amount of dissolved oxygen has an instantaneous decline after 16 m depth. The vertical profile of dissolved oxygen is clinograde type which coincides with eutrophic lakes (Cole, 1983; Goldman and Horne, 1983).

The measurements of pH, conductivity and salinity according to the depth were correlated well with thermal stratification. The values of pH increased distinctly from surface to depth, and had a maximum value (9.36) at 22-37.5 m and a minimum value (9.15) at 60 m. The conductivity and salinity values at the surface were 28.9 mS cm<sup>-1</sup> and 17.8 ppt

respectively; at the depth level (50 m) these values were between 30.86 mS cm<sup>-1</sup> and 19.6 ppt. These gradations are the general characteristics of salty lakes (Cole, 1983).

At the surface level of Lake Burdur, there is no dissolved oxygen deficiency, since average dissolved oxygen value was 9.2±0.6 mg L<sup>-1</sup> and saturation value was 103%. The maximum dissolved oxygen value (16.73 mg L<sup>-1</sup>) measured was in March. The maximum chlorophyll *a* (16.17 µg L<sup>-1</sup>) measurements coincide with those of minimum transparency values (1.1 m). This condition can be explained by an increase in photosynthesis of phytoplankton.

In the other studies that were performed in Lake Burdur, transparency values were measured as 3-6 m in 1993-1995 (Kazancı *et al.*, 1998), 1.3-5 m in 1997 (Girgin *et al.*, 2004), and 1.5-4.2 m in 1998 (Arcak and Altındağ, 2000). These results are in conformity with our results (with the range of 1.1-6.1 m, Figure 3).

In this study, the average chlorophyll *a* concentration was 4.09 µg L<sup>-1</sup>, with a range of 0.70-16.17 µg L<sup>-1</sup>. This parameter was determined as 0.006 µg L<sup>-1</sup> in 1993-1995 (Kazancı *et al.*, 1988), and 1.17-14.74 µg L<sup>-1</sup> (spring overturn) in 1997 (Girgin *et al.*, 2004). Chlorophyll *a* concentration peaked in late winter (February to April), but was low in summer and early winter in general (Figure 3). This figure can be explained as a result of thermal and chemical stratification; because in warm monomictic lakes, the highest values of chlorophyll *a* are available in spring, the mixing period (Cole, 1983; Wetzel, 2001). The increasing concentration of chlorophyll *a* displays an upward trend of the trophic level of the lake during this period.

In our research, average PO<sub>4</sub>-P value was measured as 0.106 mg L<sup>-1</sup>. This value is over the derigueur limit values for eutrophic lakes (Harper, 1992; Henderson-Sellers and Markland, 1987). In previous studies, PO<sub>4</sub>-P was measured as 0-0.013 mg L<sup>-1</sup> (Kazancı *et al.*, 1998), 0.03-0.09 mg L<sup>-1</sup> (Arcak and Altındağ, 2000) and 0-0.19 mg L<sup>-1</sup> (Girgin *et al.*, 2004). Consequently, a substantial increase in the nutrient level in the last decade can also be seen

Total hardness level is very high, with values between 4,750 and 6,250 mg L<sup>-1</sup> as CaCO<sub>3</sub> (Arcak and Altındağ, 2000; Kazancı *et al.*, 1998). In this case, the coprecipitation of phosphate and calcium is especially important in taking phosphate out of circulation. Phosphate adsorbs on calcium carbonate and they precipitate concurrently when the pH rises to values close to 9.0 (Cole, 1983). Also concentration of iron, on which phosphate is known to adsorb also, had been declared high (160 mg L<sup>-1</sup>) (Kazancı *et al.*, 1998). Considering the hardness levels, the striking upward trend of the phosphate concentration is considered an issue of concern for future of the lake.

In our study, 6 taxa of zooplankton (Rotifera 3 and Copepoda 3) were determined, while Kazancı *et al.* (1988) determined 9 (Rotifera 8 and Copepoda 1),

Arcak and Altındağ (2000) 18 (Rotifera 10, Cladocera 5 and Copepoda 3), Altındağ and Yiğit (2002) 17 (Rotifera 10, Cladocera 5 and Copepoda 2), Girgin *et al.* (2004) 7 (Rotifera 6 and Copepoda 1) zooplankton taxa. The higher number of cladoceran and rotifer species in contrast to lower numbers in the present study should be due to coverage of drifted material from the streams and other freshwater sources like Soğanlı Pond. In our study, intrusion from other environments was prevented by selection of stations at least 1 km off the coastline. But there are recordings from springs and mouths of streams in previous studies. Thus, indeed, the actual zooplankton of Lake Burdur is relatively poor as shown by our results.

Normally, increase in the trophic levels is characterized by increase in number and abundance of rotifers in zooplankton (Harper, 1992). But the saline (mesohaline) and highly alkaline structure of the lake hindered this change and only tolerant species remained in salty water of the lake. (Halse *et al.*, 1998; Williams, 1998). So the salinity is more determinative on zooplankton composition than the trophic levels (Hammer, 1986).

In general, the diversity of species is inversely correlated with salinity. There is only a limited list of species found in waters having excess of 10% salinity (Cole, 1983). So the zooplanktonic organisms that really represent the lake consist of the species that are suitable for brackish-salty lakes.

*A. burduricus*, an endemic of the lake, is the organism adapted most to the saline-alkaline character of the lake. Rotifera taxa have tolerance to salinity, pH, and hardness, although planktonic rotifer genus *Brachionus* is mainly calciphilic (Cole, 1983). According to Koste (1978), *C. adriatica* is euryhaline and found in waters with pH 5.5-10.5. The pH of the Lake Burdur ranges between 8.5-9.6 and according to Arcak and Altındağ (2000) and it is a suitable habitat for this species, which was mentioned to be 'frequent' in their study concerning the relative abundance of zooplankton. However, in this study, *C. adriatica* and copepod species other than *A. burduricus* were found as extremely rare and therefore density level for the species was not calculated.

Salinity is one of the important factors affecting the distribution of aquatic invertebrate species (Halse *et al.*, 1998). In hyposaline (3-20 ppt) and mesosaline (20-50 ppt) waters, halotolerant forms become much less and most of the biota comprises taxa adapted to inland saline waters (Hammer, 1986; Halse *et al.*, 1998). The occurrence and species compositions of cladoceran zooplankton are related to ambient Ca concentrations, pH, total phosphorus, chlorophyll *a* and predators. Ambient Ca concentrations appeared to influence the distribution of *Daphnia* species (Wærvågen *et al.*, 2002). There are several halotolerant groups among cladocerans (e.g. *Moina mongolica*, *Daphniopsis pusilla*) (Williams, 1998). But, although in our study hardness and the other



biotic–abiotic conditions were suitable, there was no cladoceran species in Lake Burdur, and this is explicable by high salinity (19 ppt) that limits the distribution of cladocerans.

Maximum conductivity value, measured as 22.5 (Merter *et al.*, 1986) and as 29.4 mS.cm<sup>-1</sup> in 2000 (Altinkale, 2001), was found as 30.5 mS.cm<sup>-1</sup> in this study. It is believed that the increase in conductivity is among the factors promoting productivity in freshwater systems (Harper, 1992) and it also correlates with density of the zooplankton, which indicates eutrophication (Radwan, 1984). Yet, sometimes, in lakes with high conductivity levels there can be low biological production, and thus zooplanktonic indication of eutrophy may not be present in such waters (Radwan, 1984).

The high values of zooplankton abundance in shallow lakes indicate their eutrophic and hypereutrophic condition (Echaniz *et al.*, 2006) but in such cases the diversity of plankton communities is also characteristically low (Wetzel, 2001). In the previous studies that were performed in Lake Burdur (Arcak and Altındağ, 2000; Girgin *et al.*, 2004; Kazancı *et al.*, 1988; Ongan *et al.*, 1972) and in the current study the recorded numbers of zooplankton species were relatively low, not as a result of low or high trophic level of the lake, but due to the fact that low number of species were able to tolerate high alkalinity, conductivity, and salinity. However, since the lake is mentioned as  $\alpha$ - $\beta$  mesosaprobic (Girgin *et al.*, 2004), it was expected to inhabit more species. As the current trophic level is to be classified as eutrophic according to the parameters analyzed (Table 1, Figures 3 and Figure 4), the low diversity among zooplanktons is explainable.

When we examine the distribution of zooplankton sampling stations: *A. burduricus* was observed as the most dominant species in the station I, which is very deep (approximately 70 m) (Figure 8). Although the depth of this station provides a refuge for *A. burduricus* from birds and fish, especially in thermal stratification period, the oxygen deficiency has an effect on keeping the fish away from this site. Additionally, Timur *et al.* (1988) mentioned that the H<sub>2</sub>S level limits the biological life in hypolimnion and deep mud in Lake Burdur.

Rotifers are consistently found in station II, which is very shallow (5-6 m), both *A. burduricus* and rotifers are found approximately at the same consistency in station III, which is of medium-depth (15-20 m) (Figure 8). Rotifers were found more consistently in stations II and III as these are shallow and consist high amounts of organic material. Harper (1992) and Radwan (1984) mentioned that the rotifers are dominant zooplankton groups in the environments rich in organic materials. According to our observations, in the station II there is high avian pressure and in the station III drainage water mixture is the source of organic material.

In our study, general zooplankton distribution in

Lake Burdur is found as follows; 50%; *H. fennica*, 41% *A. burduricus*, and 9% *B. plicatilis* (Figure 9). No relation could be found between densities of the rotifers and *A. burduricus* (Figure 6). As the first group inhabits shallow regions (stations I-II) and the latter is predominantly found in limnetic region (Fig. 10b), this distinctiveness is thought to be caused solely by ecological conditions.

In the previous studies, the rotifers were determined to be dominant (Kazancı *et al.*, 1998; Girgin *et al.*, 2004). In 1998, the 46.6% of total zooplankton were *A. burduricus* (104,000 ind. m<sup>-3</sup>) peaking in March and April, while rotifers peaked in June and July (Girgin *et al.*, 2004), and our findings are concordant with these results.

When the vertical distribution of *A. burduricus* was studied during the day; it was found to concentrate in 4 different regions (1-10 m; 10-25 m; 25-35 m and after 35. m), nevertheless the most concentrated region was between 10-25 m (P<0.05). But the nauplius larvae of the species concentrated in 10 m depth throughout the day (P<0.05). The vertical distributions of rotifers during the day was not flexible, and the organisms were found mostly in 0-10 m zone, epilimnion layer (P<0.05) (Figure 10b).

If we generalize the vertical distribution of the zooplankton, the distributions are limited mostly for rotifers and nauplius larvae at 20 m, while adult *A. burduricus* could be found even below 30 m in low numbers (P<0.05). But *A. burduricus* was not found in hypolimnion (Figure 10b) due to coldness (below 10°C in sampling date), anoxic conditions (Figure 10a) and possibly feed-feeding relations.

As a result of the long history of pollution (due to domestic, agricultural and industrial discharge) (Anonymous, 1998; Green *et al.*, 1996; Kazancı *et al.*, 1999; Timur *et al.*, 1988), trophic level of the lake gradually increased (Girgin *et al.*, 2004; Altındağ and Yiğit, 2002) to its eutrophic stage.

This study, along with the description of zooplankton population features, is unique in presentation of vertical distribution of zooplankton taxa of the lake for the first time. The zooplankton, generally dominated by halotolerant-euryhaline rotifers, show diversification in vertical distribution during thermal stratification period: rotifers concentrate in epilimnion, while *A. burduricus* is found mainly within thermocline.

The lake has been surviving dramatic changes in recent years and these changes would also affect zooplankton composition. But there is no concrete data on zooplankton history of the lake. Thus follow up studies are needed to understand actual effects of mentioned changes. Also in future zooplankton studies in the lake, determination of diel vertical migration patterns and vertical distribution effects of the fish predation, thermal stratification and chlorophyll *a* would contribute to further understanding of the dynamics of the lake zooplankton.

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