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Spatial and temporal characterization of the physicochemical parameters and phytoplankton assemblages in Dodurga Reservoir (Sinop, Turkey)

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Abstract: Physicochemical parameters and phytoplankton seasonal variation were investigated between August 2010 and July 2011 in Dodurga Reservoir. A total of 35 phytoplankton taxa were identified. Phytoplankton samples collected from surface samples in late winter, spring, and early and mid-summer were found to be influenced by nitrate, dissolved oxygen, pH, temperature, and phosphate. However, early winter and autumn assemblages of the samples were influenced by total hardness, silica, water transparency, conductivity, organic matter, and oxidation reduction potential. The phytoplankton samples collected from different depths in early and mid-summer were found to be influenced by only temperature. Early and middle spring assemblages of the samples were affected by pH, dissolved oxygen, and conductivity, while winter samples fluctuated according to conductivity and oxidation reduction potential. The phytoplankton abundance increased in the spring and early summer. High phytoplankton abundance was recorded in the transition zone as a result of decreasing flow velocity and light penetration. The maximum number of total organisms in depth samples was observed at the depth of 2–4 m, reflecting availability of light and temperature.

Key words: CCA, DCA, phytoplankton, physicochemical parameters, spatiotemporal characterization

1. Introduction

The availability of water, one of the most important parameters of the ecosystem and life, has been threatened by rapid growth of environmental problems, and the increase in population and human activities (Loucks, 2000). Phytoplankton is affected firstly by the changes in the aquatic ecosystem due to their being at the base of the aquatic food chain. Algal population dynamics change rapidly in reservoirs due to the fact that the physical and chemical properties of reservoirs are more unstable than those of natural lakes (Wehr and Sheath, 2003). Therefore, the reservoirs' phytoplankton, distribution, species richness, and related environmental factors need to be studied. Biological water quality determination methods have been developed as a result of long years of research. These methods have been intended to identify medium- and long-term effects of environmental changes. Today, biological water quality determination studies are used in addition to chemical water analyses (Iliopoulou-Georgudaki et al., 2003).

Canonical correspondence analysis (CCA) gives evidence for temporal and spatial gradients of phytoplankton biomass (Ter Braak, 1986). Nowadays, the relationship between water quality and phytoplankton or algal communities is determined by CCA in most studies (Ersanli and Gonulol, 2007; Borges et al., 2008; Çelik and Ongun, 2008; Rychtecký and Znachor, 2011; Tezel Ersanli and Hasirci, 2013).

The aim of this study was to determine the physical and chemical properties, and phytoplankton quantity at various strata of the water and to compare the data obtained from those samples, to monitor the changes in spatial and temporal differences of some physicochemical parameters and phytoplankton assemblages in a reservoir used for irrigation and supplying drinking water.

2. Materials and methods

Dodurga Reservoir is located in Sinop Province in northern Turkey (41°27′47″– 41°32′17″N and 34°53′07″–34°54′00″E). It was constructed between 1994 and 2010 on Keçili Creek of Çarsak Stream, which is the side arm of Gökırmak River. The volume of the reservoir is 0.500 hm^3 with a depth of 51 m from the base. The reservoir was established for irrigation and supplying drinking water (DSİ, 2010). The geographical location of Dodurga Reservoir and the sampling stations is given in Figure 1.

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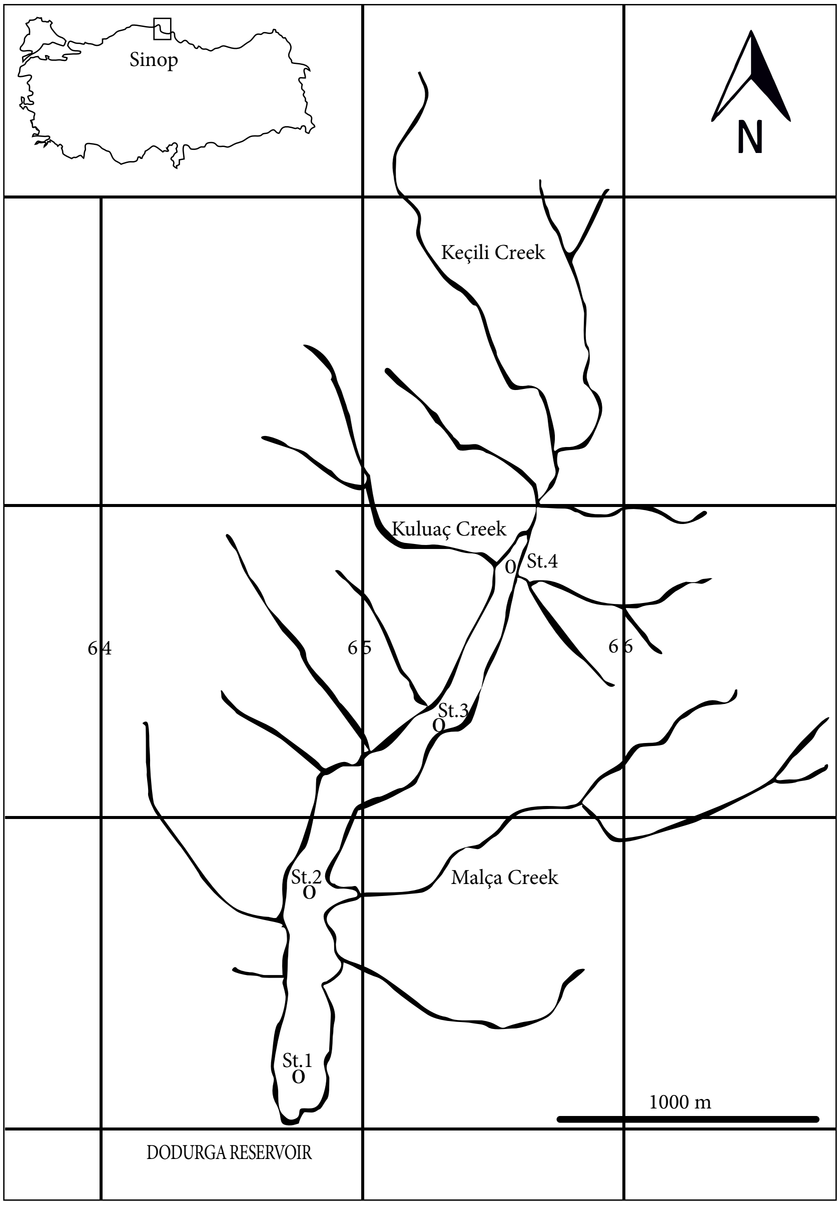

Figure 1. The geographical location of Dodurga Reservoir and sampling stations.

Four stations were selected to investigate the water's physical and chemical properties and phytoplankton dynamics in the reservoir. The sampling was conducted monthly between August 2010 and July 2011. Surface water samples were collected from the four stations, while the depth water samples were collected only from the first sampling station with 2-m intervals until reaching 10 m.

Water transparency (WT) was measured by Secchi disc. Water temperature (T), pH, conductivity (C), redox potential (ORP), and dissolved oxygen (DO) were measured with the portable digital Hach Lange brand HQ40D model multi-function measuring equipment. Nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), phosphorus (Phos), and total hardness (TH) were measured according to the APHA, AWWA, WEF (2005); total organic matter (OM) was measured by a previously described method (Şengül and Türkman, 1991); and silica (Si) was measured with a spectrophotometrical test kit.

Water samples were taken by Hydro-Bios Nansen bottle (2 L). Plankton samples were collected horizontally with a Hydro-Bios plankton net (55 µm). Plankton counts and identification were performed according to the Utermohl method (Sournia, 1978) using a Micros Austria MCXI600 inverted microscope and Leica DM500 light microscope. The counting results were evaluated according to APHA, AWWA, WEF (2005).

Diatom samples were mixed in equal volumes (1:1) of concentrated nitric acid (HNO_3) and potassium dichromate ($K_2Cr_2O_7$) was added until the solution color turned from green to yellow to remove organic materials and to make wall structures visible. The samples were boiled until the sample volume reached one third (APHA, AWWA, WEF, 2005).

The identification of algae was conducted according to Anagnostidis and Komárek (1988), Komárek and Anagnostidis (1986, 1989, 1999), Hartley (1996), Krammer and Lange-Bertalot (1991a, 1991b, 1999a, 1999b), John et al. (2003), Krammer (2003), Wehr and Sheath (2003), and Tsarenko et al. (2006). Systematic arrangement of groups was performed in accordance with the AlgaeBase database (Guiry and Guiry, 2012).

The statistical analyses, CCA and detrended correspondence analysis (DCA), were performed using Canoco 4.0 (Ter Braak, 1986).

3. Results

A total of 35 taxa were identified: 6 Charophyta, 13 Chlorophyta, 1 Cyanophyta, 4 Dinoflagellata, 3 Euglenozoa, and 8 Ochrophyta. The list of taxa identified in the reservoir is presented in Table 1. The maximum, minimum, and mean values and standard deviation of physicochemical parameters are given in Table 2 for the surface water samples and in Table 3 for the depth water samples.

In the DCA analysis conducted on species abundance at the surface, the first two axes ($\lambda_1 = 0.679$, $\lambda_2 = 0.312$) explained 35.4% of the total variation in the species data set. The lengths of gradient were 3.165 SD in the first axis and 2.877 SD in the second axis. Maximum gradient length did not exceed 4 SD. The CCA was carried out using 11 environmental variables and 29 phytoplankton species (Figure 2). The CCA results in surface samples are presented in Table 4.

In the DCA analysis conducted on the species abundance in depth samples, the first two axes ($\lambda_1 = 0.724$, $\lambda_2 = 0.269$) explained 41.6% of the total variation in the species data set. The lengths of gradient were 2.411 SD in the first axis and 3.557 SD in the second axis. Maximum gradient length did not exceed 4SD. The CCA was conducted using 5 environmental variables and 26 phytoplankton species for depth samples (Figure 3), and the results for depth samples are presented in Table 5.

4. Discussion

During the study period, the total number of organisms decreased in autumn and winter and increased in spring and summer, parallel to temperature changes. Secchi disc depth was elevated in January 2011 due to the lower density of phytoplankton and less suspended solids, and it was least in February 2011 because of wind mixing the suspended solids. According to limit values of productivity levels in the OECD (1982), the reservoir showed a eutrophic character in terms of Secchi disc values. Electrical conductivity varies widely in drinking water and electrical conductivity can be 10,000 µS/cm in some industrial waste (Şengül and Türkman, 1991). The values obtained from our reservoir (353.9 ± 14.9) show that the water has not been contaminated industrially. The reservoir water had slightly alkaline properties according to pH values, which were measured in both surface and depth water. The reason for the low pH in the surface water during winter is the decrease in the total abundance and the related reduction in the use of CO_2. It was observed that the pH values decreased slightly from the surface towards the bottom. This situation may be related to the breathing activity of living organisms at the bottom of the reservoir or an increase in released CO_2 concentration by oxidation of organic substances. The ORP value changed between 95.2 and 273.4 mV in the surface water and between 72.7 and 252.0 mV in the depths throughout this study and fall between the reference values (Answers, 2011). Silica uptake availability is important for the growth of the diatoms in water and the decrease in silica is related to the growth of silica-organisms. In the present study, it was observed that the amount of silica was parallel to the increase in *Cyclotella krammerii* from February 2011 to July 2011. The amount of organic matter varied between 7.6 mg/L and 17.4 mg/L at the surface stations throughout the study period. The highest amount of organic matter was in November 2010 at station 4 as a possible result of the death and decay of plant and animal species or a reduction in the amount of precipitation. According to phosphorus values, the reservoir has an oligotrophic character (OECD, 1982). The average total hardness value was 19.7 °FS in the surface samples in the present study and our reservoir water is in the slightly hard water group (Egemen and Sunlu, 1999).

According to the CCA ordination graph in the surface samples as shown in Figure 2, species are divided into certain groups along a gradient of environmental variables. Nitrate, dissolved oxygen, pH, temperature, and phosphorus measured here were found to be related to *Cyclotella krammerii*, *Navicula insularis*, *Ulnaria acus*, *Gomphonema olivaceum*, *Kirchneriella lunaris*, *Scenedesmus bijuga*, *Microspora crassior*, *Closterium acutum*, *Euglena proxima*, *Phacus parvulus*, and *Trachelomonas pulcherrima* var. *minor*. On the other hand, total hardness, silica, water transparency, conductivity, organic matter, and oxidation reduction potential were found to be related to *Tetraedron minimum*, *Cosmarium bioculatum*, *Peridiniopsis cunningtonii*, and *Gonatozygon kinahanii*. Species distributed throughout nitrate, dissolved oxygen, pH, temperature, and phosphate were in

Table 1. List of phytoplankton species identified in Dodurga Reservoir and species CCA scores.

TAXA	SURFACE	DEPTH
CYANOPHYTA (CYANOBACTERIA)		
Anabaena aequalis Borge	—	1
OCHROPHYTA		
Cyclotella krammerii Håkansson	1	2
Navicula insularis Ehrenberg	2	—
Navicula schmidtii Lagerst	—	3
Ulnaria acus (Kützing) M. Aboal	3	4
Gomphonema olivaceum (Hornemann) Brébisson	4	5
Dinobryon sociale Ehrenberg	5	7
Opephora gemmata (Grunow) Hustedt	—	6
Chlorobotrys regularis (West) Bohlin	6	—
CHLOROPHYTA		
Tetraedron minimum (A. Braun) Hansgirg	7	8
Kirchneriella lunaris (Kirchner) K. Möbius	8	9
Pseudopediastrum boryanum (Turpin) E. Hegewald	9	—
Acutodesmus obliquus (Turpin) Hagewald & Hanagata	—	10
Ankistrodesmus falcatus (Corda) Ralfs	10	11
Scenedesmus communis E.H. Hagewald	—	12
Scenedesmus bijuga (Turpin) Lagerheim	11	—
Gonium formosum Pascher	12	—
Microspora crassior (Hansgirg) Hazen	13	13
Comasiella arcuata var. *platydiscus* (G.M. Smith) E. Hegewald & M. Wolf	14	—
Ulothrix aequalis Kützing	15	14
Dictyosphaerium pulchellum H.C. Wood	16	—
Thorakochloris nygaardii B. Fott	17	—
CHAROPHYTA		
Gonatozygon kinahanii (W. Archer) Rabenhorst	18	15
Staurastrum pendulum var. *pinguiforme* Croasdale	19	16
Closterium acutum Brébisson	20	17
Mougeotia calcarea (Cleve) Wittrock	—	18
Cosmarium bioculatum Brébisson ex Ralfs	21	19
Cosmarium tinctum Ralfs	22	20
DINOFLAGELLATA		
Ceratium hirundinella (O.F. Müller) Dujardin	23	21
Peridiniopsis cunningtonii Lemmermann	24	22
Peridinium cinctum (O.F. Müller) Ehrenberg	25	23
Ceratium hirundinella var. *silesiacum* (Schroeder) Huber-Pestalozzi	26	—
EUGLENOZOA		
Euglena proxima P.A. Dangeard	27	24
Phacus parvulus G.A. Klebs	28	25
Trachelomonas pulcherrima var. *minor* Playfair	29	26

Table 2. The descriptive statistics of the physicochemical parameters in surface water of Dodurga Reservoir.

	Minimum	Maximum	Mean	Std. Deviation
T (°C)	9.2	26.6	17.1	5.9
DO (mg/L)	7.1	11.7	9.4	1.2
C (µS/cm)	313.0	386.0	353.9	14.9
ORP (mV)	95.2	273.4	177.0	56.3
pH	8.0	8.7	8.4	0.2
WT (cm)	30.0	330.0	133.3	73.3
Si (mg/L)	2.2	10.5	4.4	1.5
Nitrate (mg/L)	0.0	0.5	0.2	0.1
TH (°FS)	16.0	26.8	19.7	2.1
P (mg/L)	0.2	0.9	0.5	0.2
OM (mg/L)	7.6	17.4	11.1	3.0

Table 3. The descriptive statistics of the physicochemical parameters in depth samples of Dodurga Reservoir.

	Minimum	Maximum	Mean	Std. Deviation
T (°C)	9.6	26.6	15.7	4.8
DO (mg/L)	3.7	11.4	8.9	1.6
C (µS/cm)	340.0	392.0	366.5	13.3
ORP (mV)	72.7	252.0	176.4	53.7
pH	7.7	8.7	8.3	0.2

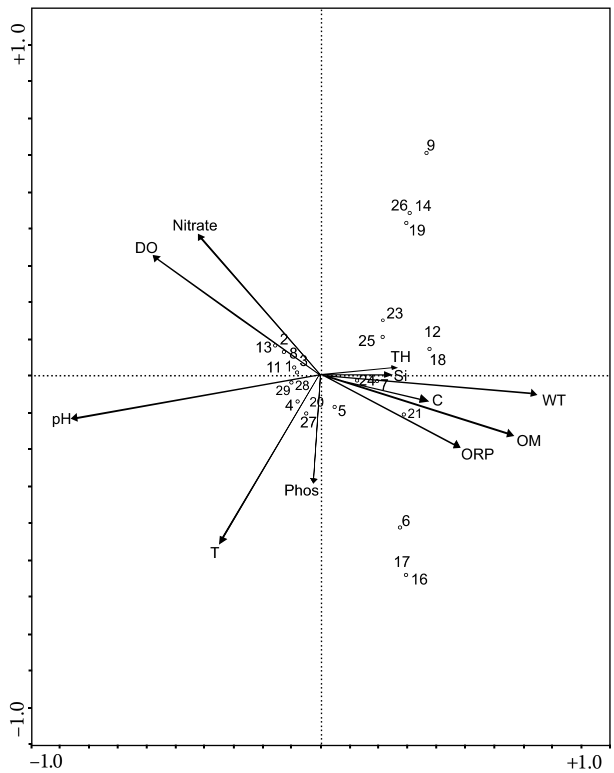

Figure 2. Canonical correspondence analyses (CCA) for surface samples (species scores for taxon names see Table 1).

late winter, spring, and early and mid-summer. Moreover, species distributed throughout total hardness, silica, water transparency, conductivity, organic matter, and oxidation reduction potential were in early winter and autumn.

The CCA ordination graph among the samples of deep water as shown in Figure 3 showed some correlations between *Gomphonema olivaceum* and *Mougeotia calcarea* with conductivity; *Kirchneriella lunaris* with dissolved oxygen; *Navicula schmidtii* and *Microspora crassior* with pH and dissolved oxygen; *Acutodesmus obliquus* and *Staurastrum pendulum* var. *pinguiforme* with oxidation reduction potential; *Euglena proxima*, *Phacus parvulus*, and *Trachelomonas pulcherrima* var. *minor* with temperature; and *Cyclotella krammerii*, *Ulnaria acus*, *Opephora gemmata*, and *Ankistrodesmus falcatus* with temperature and pH. Species distributed throughout the temperature were in June 2011 and July 2011 as a possible positive affinity to higher temperature values in water. Species distributed throughout the pH, dissolved oxygen, and conductivity were March 2011 and April 2011 samples as a result of the rainy season. December 2010, February 2011, and March 2011 samples were distributed throughout conductivity and oxidation reduction potential. September 2010, October 2010, December 2010, January 2011, and April 2011 samples were distributed throughout oxidation reduction potential.

Table 4. The results of CCA for surface samples.

Axes	1	2	Total inertia
Eigenvalues	0.660	0.235	2.797
Species-environment correlations	0.986	0.899	
Cumulative percentage variance			
of species data	23.6	32.0	
of species-environment relation	39.6	53.7	

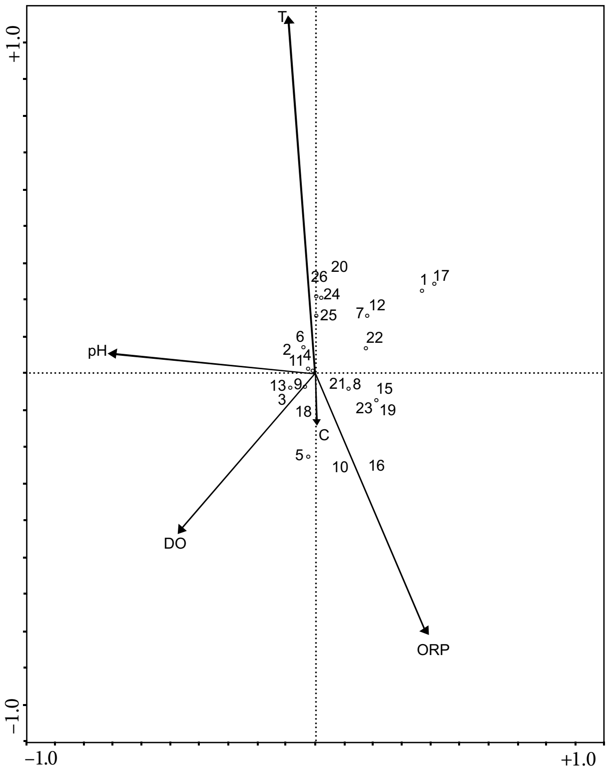

Figure 3. Canonical correspondence analyses (CCA) for depth samples (species scores for taxon names see Table 1).

Most species in Dodurga Reservoir belong to the division Chlorophyta. The abundance increased in spring and early summer and the maximum number of organisms was identified in May 2011. *Tetraedron minimum* was the dominant species in November 2010, December 2010, and January 2011. *Kirchneriella lunaris* was the subdominant species in phytoplankton. *Scenedesmus* spp. were rarely present at the surface and depth in Dodurga Reservoir but they were found to be intensely present in Mogan Lake (Obalı, 1984) and Altınapa Reservoir (Yıldız, 1985). *Scenedesmus bijuga* was related to the dissolved oxygen and was present in the surface water in the present study. According to Reynolds et al. (2002), *S. communis* and *T. minimum* are common in mesotrophic and eutrophic lakes and show low-light sensitivity. Filamentous species from Chlorophyta have never been very important in terms of abundance and variety of species in reservoirs (Bellinger and Sigee, 2010). They stated that these species were dominant especially in environments that have metal contamination, cultural eutrophication, and acidification.

Cyclotella krammeri from Ochrophyta was dominant at all surface and depth stations from February 2011 to July 2011. Similarly, species of *Cyclotella* have been recorded in many studies in natural lakes and reservoirs in Turkey (Aykulu et al., 1983; Gönülol and Aykulu, 1984; Taş and Gönülol, 2007). Bellinger and Sigee (2010) reported that *Cyclotella* spp. showed an increase especially in oligotrophic lakes in spring. *Cyclotella krammerii* was dominant and *Kirchneriella lunaris* was subdominant in April 2011 and May 2011 in both surface and depth samples.

Closterium acutum from Charophyta was found in August 2010, September 2010, October 2010, February 2011, June 2011, and July 2011; *Staurastrum pendulum* var. *pinguiforme* was found in September 2010, January 2011, and June 2011. *Cosmarium bioculatum* was distributed in mesotrophic lakes (Reynolds et al., 2002) and it increased in August 2010, October 2010, and January 2011; also *C. tinctum* was seen only in July 2011 and in less abundance.

Ceratium hirundinella from dinoflagellates represents the epilimnion in eutrophic lakes (Reynolds et al., 2002) and it was recorded that it is sometimes present at the surface and rarely present at depths, and it was observed in large numbers in September 2010. *Peridinium cinctum* was often present at the surface and depth and it significantly increased at all stations in October 2010 and November 2010. This species has been recorded in many reservoir studies in Turkey (Gönülol and Aykulu, 1984; Yazıcı and Gönülol, 1994; Gönülol and Obalı, 1998; Taş and Gönülol, 2007). *Peridiniopsis cunningtonii* changed often and sometimes at all stations and it increased in August 2010, September 2010, October 2010, and December 2010. Bellinger and Sigee (2010) reported that dinoflagellates were high in number in late summer and autumn phytoplankton at the surface waters in oligotrophic waters.

Table 5. The results of CCA for depths stations.

Axes	1	2	Total inertia
Eigenvalues	0.504	0.133	2.386
Species-environment correlations	0.846	0.741	
Cumulative percentage variance of species data	21.1	26.7	
Cumulative percentage variance of species–environment relation	62.2	78.7	

Euglena proxima and *P. parvulus* from Euglenozoa were found rarely at the surface and depth stations and they were observed in June 2011 and July 2011; also *G. formosa* was observed only in February 2011. *Trachelomonas pulcherrima* var. *minor*, representative of shallow mesotrophic lakes, increased in July 2011 in Dodurga Reservoir. *Euglena* spp. were abundant in areas of present organic pollution (Bellinger and Sigee, 2010). They were found often in Bayındır Reservoir (Atıcı et al., 2005) and present sometimes in Altınapa Reservoir (Yıldız, 1985) and Mogan Lake (Obalı, 1984).

The total number of organisms was highest at station 3 followed by station 2 in May 2011. This may be associated with the presence of the transition zone of these stations. Borges et al. (2008) stated that generally phytoplankton present a longitudinal distribution pattern with greater concentrations in the transition zone of reservoirs and the short retention time of reservoirs constituted the principal limiting factor to phytoplankton development. Rychtecký and Znachor (2011) reported that the transition zone is characterized by high phytoplankton biomass and production, decreasing flow velocity, and increased water residence time and light penetration. The maximum number of total organisms in the depth samples was observed in May 2011 at 2 m and then 4 m as a result the availability of light and nutrients, and temperature.

In conclusion, Dodurga Reservoir has an oligotrophic character according to its morphometric structure, phosphorus, and high level of the water column. However, it is oligotrophic in spring and summer while it is mesotrophic in winter because of phytoplankton growth. Accordingly, the trophic structure of the reservoir varies from oligotrophic to mesotrophic. Phytoplankton abundance increases in the transition zone of the reservoir. Ochrophyta, Chlorophyta, Dinoflagellata, and Charophyta were dominant, in that order. Moreover, physicochemical parameters showed little variation between surface and depth samples.

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