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Phytoplankton Community of a Boron Mine Waste Storage Reservoir

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A B S T R A C T

This study aimed to assess the composition, seasonality, and abundance of the phytoplankton community of a Boron (B) mine effluent storage reservoir, Çamköy Reservoir, Balıkesir, Turkey. For this purpose, phytoplankton and certain physicochemical parameters were sampled seasonally between April 2015 and January 2016. B concentrations ranged from 554 mg L^{-1} to 689 mg L^{-1}. A total of 39 taxa were identified during the study. The percent composition for each phytoplankton group was as follows: Bacillariophyta 67%, Chlorophyta 10%, Cyanobacteria 8%, Euglenophyta 8%, Mioza 5%, and Charophyta 2%. In summer 2015 no phytoplankton was detected in the samples and the excessive B concentrations (above 600 mg L^{-1}) in the reservoir seem to be the reason for the lack of phytoplankton in the summer samples. The most common taxa were *Navicula digitoradiata* (Bacillariophyta), *Surirella ovata* (Bacillariophyta), and *Nitzschia amphibia* (Bacillariophyta). The reservoir had a low number of phytoplankton taxa and abundance compared with the natural lakes probably due to the excessive B levels. The phytoplankton community of the reservoir was composed of taxa that preferred alkaline waters.

Keywords: Boron, Çamköy Reservoir, phytoplankton, waste

A R T I C L E I N F O

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Bir Bor Madeni Atık Depolama Barajının Fitoplankton Kommunitesi

Öz: Bu çalışmanın amacı, bir Bor (B) madeni atık toplama barajı, (Çamköy Barajı, Balıkesir) fitoplanktonun kompozisyonu, mevsimselliği ve bolluğunu tespit etmektir. Bu amaçla, Nisan 2015 ile Ocak 2016 tarihleri arasında fitoplankton ve bazı fizikokimyasal parametreler için örnekleme yapılmıştır. B derişimi 554 mg L^{-1} ile 689 mg L^{-1} arasında değişmiştir. Çalışma süresince toplamda 39 takson tespit edilmiştir. Fitoplankton kompozisyonu, %67 Bacillariophyta, %10 Chlorophyta, %8 Cyanobacteria, %8 Euglenophyta , %5 Mioza ve %2 Charophyta 'dan oluşmuştur. 2015 yaz döneminde hiç fitoplankton türü tespit edilmemiş olup bunun sebebinin yüksek B seviyelerinin (600 mg L^{-1} üzeri) olabileceği tahmin edilmiştir. Tespit edilen en yaygın taksonlar, *Navicula digitoradiata* (Bacillariophyta), *Surirella ovata* (Bacillariophyta) ve *Nitzschia amphibia* (Bacillariophyta) olmuştur. Yüksek Bor içeriğinden dolayı, doğal göllere nazaran gölette daha düşük fitoplankton takson sayısı ve yoğunluğu tespit edilmiştir. Göletin fitoplankton kommunitesi alkali suları tercih eden taksonlardan oluşmuştur.

Anahtar kelimeler: Bor, Çamköy Barajı, fitoplankton, atık

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Introduction

The industrialization has dramatically increased the demand for the mining of minerals worldwide (Stürmer 2013). However, mining has severely affected the sustainability of ecosystems, including surface waters (Lesley et al. 2008). Turkey is one of the leading countries for Boron (B) mining in the world (Türe and Bell 2004). The majority of B reserves in Turkey are in the western part of the country, including Balıkesir (Türker et al. 2016).

The metalloid B is naturally present in freshwater bodies at less than 0.1 mg L^{-1} concentrations, but mining activities have elevated B levels significantly in some water bodies (Nable et al. 1997). The widespread use of B with its high solubility in the water has raised concerns about its excessive levels in some surface waters (Rees et al. 2011).

Although B has been recognized as an essential element for higher plants, studies on B requirements in algae have produced controversial results (Dembitsky et al. 2002; Villavicencio et al. 2007). It has been shown that some aquatic plants can accumulate high levels of B (Damiri 2007). Fernandez et al. (1984) found that after seven days of exposure to B, the bioconcentration factor increased significantly in the green alga *Chlorella pyrenoidosa* H. Chick. Marín and Oron (2007) found that pH significantly affected the bioaccumulation of B in the duckweed (*Lemna gibba L.*).

Phytoplankton populations and their interactions with environmental factors are difficult to generalize. It is more even challenging to examine the interactions between phytoplankton dynamics and water quality parameters in effluent recipient aquatic ecosystems because of their highly dynamic nature (Thomas et al. 2018).

Man-made reservoirs are the main recipients of effluents from mines. Planktonic organisms are directly affected by the effluent inputs. However, our knowledge about phytoplankton in the effluent recipient water bodies is limited. Most of the studies performed so far concentrated on the taxonomy and ecology of phytoplankton in natural waters (Pomati et al. 2017). The resistant phytoplankton species may have adapted to water bodies receiving mine waste.

The link between macronutrient enrichment and increased productivity in lakes is well-established (Schindler 2012). However, the effects of excessive metal concentrations have not been studied comprehensively (Hassler et al. 2012). This study aimed to determine the effects of B mine effluent on the phytoplankton community composition, seasonality, and abundance in Çamköy Reservoir, Balikesir, Turkey as a B mine effluent storage reservoir.

Materials and Methods

Research Area

Çamköy Reservoir is located at 39° 27' 43" N and 28° 10' 09" E, 30 km southeast of Balıkesir, Turkey (Figure 1). The construction of the reservoir started in 1987 and was completed in 1991 by the State Water Works for effluent deposition from B mine sites. The reservoir has a maximum depth of 33 m and a surface area of 1 km^2. During the mining, a large number of ore is excavated, producing a vast amount of B-rich effluent. The effluent is pumped by pipes from mine sites to the reservoir and it is settled in the bottom (State Water Works 2018).

Field Work and Sampling

Sampling was carried out seasonally between April 2015 and January 2016. Due to legal restrictions on boat access to the reservoir, samples were taken only at one station. The station was set at the opposite side of the waste entrance point at the edge of the reservoir. Samples were taken below the surface (about 0.5 m) using a Kemmerer water sampler. In the field, phytoplankton samples were placed in 250 ml bottles and fixed with Lugol's solution until processed in the laboratory.

Figure 1. The map showing the location of Çamköy Reservoir and the sampling station in it.

In the laboratory, phytoplankton samples were poured into 50 ml graduated cylinders and were allowed to settle for 24 h. After that, 45 ml of water was aspirated from each graduated cylinder and the remaining 5 ml was poured into a small glass vial for microscopic analysis (APHA 1995). The samples were examined by an Olympus compound microscope. Phytoplankton species were identified according to Bourrelly (1966), Huber-Pestalozzi (1983), Round et al. (1990), Krammer and Lange-Bertalot (1991), Hartley (1996), John et al. (2002), and Komarek and Anagnostidis (2005). Taxonomic names were updated and based on www.algabase.org (Guiry and Guiry 2020).

In situ parameters including, water temperature, pH, oxidation-reduction potential (ORP), specific conductance (SC), and dissolved oxygen concentration (DO), were measured using a YSI multiprobe. Total suspended solids (TSS) were determined by filtering 1-liter water through Whatman 934-AH filters that were pre-rinsed, dried (105 °C), ashed (550 °C), and tared (APHA 1995). The concentrations of nitrate-nitrogen (NO_3-N), soluble reactive, and phosphorus (SRP) were determined spectrophotometrically in the laboratory according to standard methods (APHA 1995).

Water samples for B analysis were placed in 1-liter dark plastic bottles and transported to the laboratory in a cooler. Borosilicate glassware was used during the analysis to prevent the contamination of samples. Water samples were adjusted to pH 2 with HNO_3 being added to each. B levels were determined by a high-resolution continuum source atomic absorption spectrometer by triplicate measurements in the regional laboratory of the State Water Works in Balıkesir.

The nonparametric Spearman rank correlation test was used to measure the degree of association between physicochemical variables, the total number of phytoplankton taxa, and abundance using SPSS (ver. 11.0) software.

Results

Water temperature ranged from 24.8 ºC in August 2015, to 8.7 ºC in January 2016 (Figure 2a). pH ranged from 9.24 in August 2015, to 8.59 in January 2016 (Figure 2b). SC ranged from 2237 µS cm^{-1} in August 2015, to 736 µS cm^{-1} in January 2016 (Figure 2c).

DO concentrations ranged from 7.4 mg L^{-1} in August 2015, to 10.84 mg L^{-1} in January 2016 (Figure 2d). ORP ranged from 21.4 MV in August 2015, to 4.7 MV in January 2016 (Figure 2e). TSS ranged from 2.1 mg L^{-1} in November 2015, to 28.9 mg L^{-1} in August 2015 (Figure 2f).

B concentrations ranged from 554 mg L^{-1} in April 2015, to 689 mg L^{-1} in August 2015 (Figure 2g). NO_3-N concentrations ranged from 0.43 mg L^{-1} in November 2015, to 0.8 mg L^{-1} in January 2016 (Figure 2h). SRP concentrations ranged from 0.078 mg L^{-1} in November 2015, to 0.09 mg L^{-1} in August 2015 (Figure 2i).

In Çamköy Reservoir, a total of 39 taxa were identified (Table 1). Bacillariophta made 67% (26 taxa), Chlorophyta made 10% (4 taxa), Cyanobacteria made 8% (3 taxa), Euglenophyta made 8% (3 taxa), Mioza made 5% (2 taxa) and Charophyta made 2% (1 taxon) of the total number of taxa (Figure 3a). The highest number of phytoplankton taxa (23) was obtained in January 2016 and the lowest (0) in August 2015 (Figure 3b). The highest phytoplankton abundance (55531 cell ML^{-1}) was obtained in April 2015 and the lowest (0 cell ML^{-1}) in August 2015 (Figure 3c).

Discussion

The total number of phytoplankton taxa (39) was lower in Çamköy Reservoir compared with the other reservoirs in the same vicinity. Sevindik et al. (2011) reported 192 phytoplankton taxa from Çaygören Reservoir and 174 taxa from Ikizcetepler Reservoir. The reason for this was probably the excessive B levels in Çamköy Reservoir (Davis et al. 2002; Gunes et al. 2006; Marín and Oron 2007; Şaşmaz and Öbek 2009). High levels of B in the reservoir must have prevented the development of sensitive phytoplankton species, resulting in low species numbers due to their low tolerance limits to B toxicity (Reid 2007).

Navicula digitoradiata (avg. 20152 cell L^{-1}), *Surirella ovata* Kützing (avg. 11151 cell L^{-1}), and *Nitzschia amphibia* Kützing (avg. 10151 cell L^{-1}) were the most abundant diatoms collected during the study. Diatoms of Çamköy Reservoir were stress-resistant species. *N. digitoradiata* is one of the rarest diatoms that are found in unique waters with moderate salinity (Zeimann et al. 2001). High ionic content (measured as SC) of this waste storage reservoir may have favored the growth of *N. digitoradiata.*

Fore and Grafe (2002) listed *S. ovata* as pollution tolerant species in the diatom assemblages of 23 Idaho rivers subjected to human disturbance. They stated that diatoms were robust indicators of metal contamination of natural waters. *N. amphibia* is commonly collected at sites with heavy metal pollution. Szabo et al. (2005) studied Tisza River in Hungary after the bursting of a mine-storing reservoir to the river and collected high numbers of *N. amphibia* showing that this species is tolerant to metal toxicity.

Chlorophyta was represented by four taxa and they were collected only in spring and fall seasons. *Pandorina morum* (O.F. Müller) Bory in J.V.Lamouroux, Bory, and Deslongschamps (avg. 2151 cell L^{-1}) was the most common green algae during the study. Anuja and Chandra (2012) conducted a study on a polluted tank and reported that *P. morum* was a pollution indicator species.

The low species number and abundance of green algae could have been due to high levels of B in the reservoir. Garcia-González et al. (1990) provided sound evidence that B was required by marine and freshwater diatoms, whereas green algae did not require it for growth, and they were intolerant to the high B levels.

Cyanobacteria were represented by three taxa (*Oscillatoria tenuis* C.Agardh ex Gomont (avg. 452 cell L^{-1}), *Chroococcus minutus* (Kützing) Nägeli (avg. 332 cell L^{-1}) and *Leptolyngbya* sp. Anagnostidis and Komárek (avg. 225 cell L^{-1}) at low densities. The low species number and abundance of Cyanobacteria in Çamköy Reservoir is probably due to excessive levels of B in the reservoir (Reid 2007). Low levels of B are required for the nitrogen fixation by Cyanobacteria, but excessive levels are toxic for members of this group (Gerloff 1968).

Euglenophyta was represented by three taxa, *Trachelomonas granulosa* Playfair (avg. 3120 cell L^{-1}), *Trachelomonas intermedia* P.A.Dangeard (avg. 1011 cell L^{-1}) and *Trachelomonas volvocina* (Ehrenberg) Ehrenberg (avg. 853 cell L^{-1}). Except for summer, euglenoids were present at each sampling period. Euglenoids are abundant in moderately polluted water bodies all over the world (Li et al. 2014; Naselli-Flores 2000). *Trachelomonas* species are known to quickly respond to environmental changes in polluted lakes (Wołowski 2002).

Miozoa was represented by two taxa, *Tripos furca* (Ehrenberg) F.Gómez (avg. 712 cell L^{-1}) and *Glenodinium* sp. Ehrenberg (avg. 312 cell L^{-1}). *T. furca* is a cosmopolitan species mostly collected from salt and brackish waters worldwide (Morton et al. 2011).

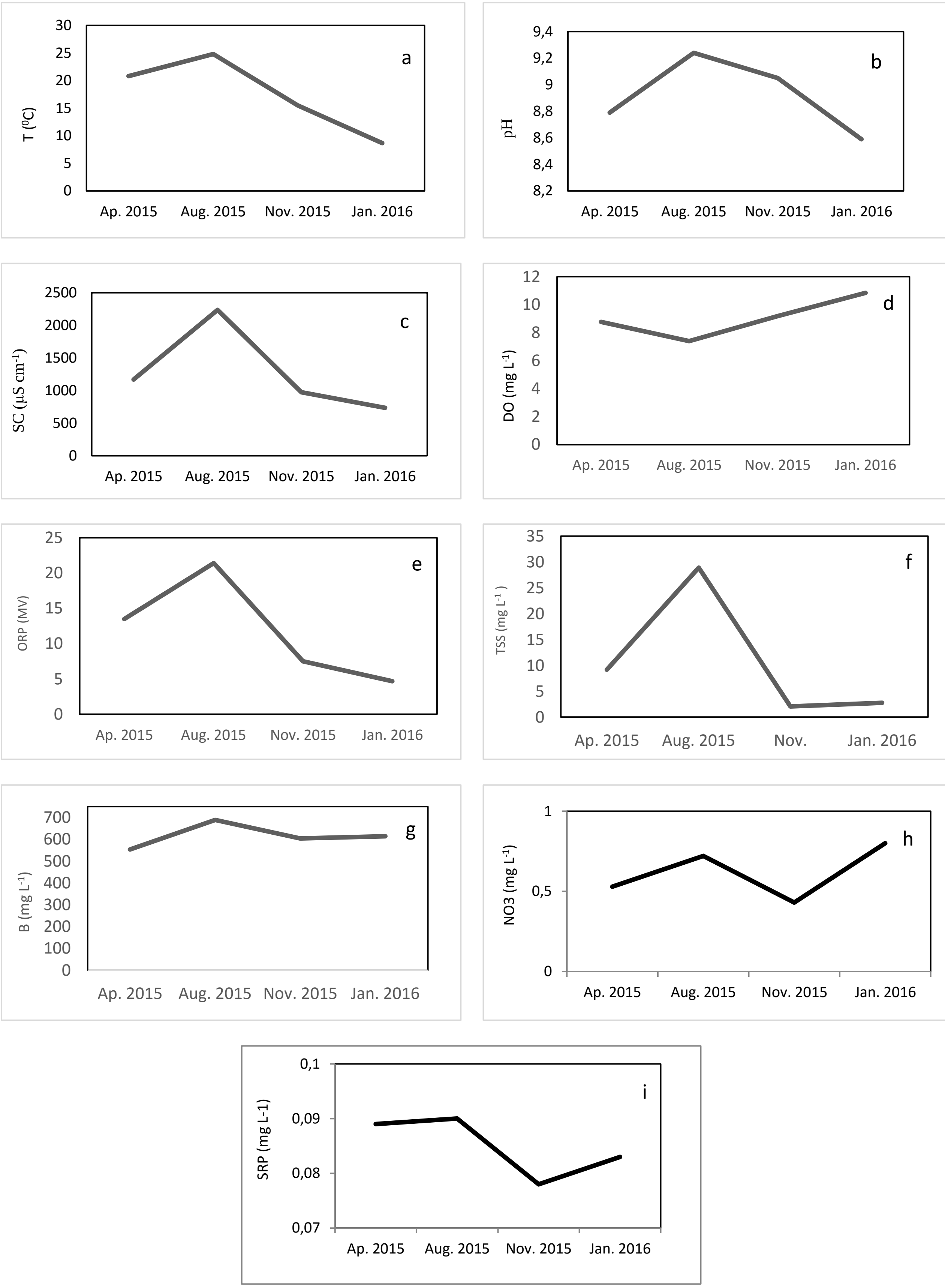

Figure 2. Seasonal variations in a) the water temperature (T; ºC), b) pH, c) specific conductance (SC; µS cm^{-1}), d) dissolved oxygen (DO; mg L^{-1}), e) oxidation-reduction potential (ORP; MV), f) total suspended solids (TSS; mg L^{-1}), g) Boron (B; mg L^{-1}), h) nitrate-nitrogen (NO_3-N; mg L^{-1}), i) soluble reactive phosphorus (SRP; mg L^{-1}) of Çamköy Reservoir

Table 1. The list of phytoplankton taxa collected from Çamköy Reservoir

Taxa	Spring	Summer	Fall	Winter
Bacillariophyta				
Amphora eximia J.R.Carter 1974	-	-	-	+
Amphora ovalis Kützing 1844	+	-	-	-
Achnanthidium affine (Grunow) Czarnecki 1994	+	-	-	-
Anomoeoneis sphaerophora Pfitzer 1871	-	-	+	-
Aulacoseira italica (Ehrenberg) Simonsen 1979	-	-	-	+
Cymbella caespitosa (Kützing) Brun 1880	-	-	+	-
Fragilaria capucina Desmazières 1830	+	-	-	-
Gomphonema truncatum Ehrenberg 1832	-	-	-	+
Melosira varians C.Agardh 1827	-	-	-	+
Navicula digitoradiata (Gregory) Ralfs 1861	-	-	+	+
Navicula libonensis Schoeman 1970	+	-	-	-
Navicula subtilissima Cleve 1891	-	-	-	+
Nitzschia sp. Hassall 1845	+	-	-	-
Nitzschia pacifica Cupp 1943	+	-	+	+
Nitzschia amphibia Grunow 1862	-	-	+	-
Nitzschia sigmoidea (Nitzsch) W.Smith 1853	-	-	+	+
Pinnularia gibba Ehrenberg 1843	-	-	+	-
Navicula cincta (Ehrenb.) Ralfs 1861	-	-	+	-
Pinnularia hemiptera (Kützing) Rabenhorst 1853	+	-	-	-
Pinnularia microstauron Cleve 1891	-	-	-	+
Pinnularia subrostrata (A.Cleve) Cleve-Euler 1955	-	-	+	+
Stauroneis phoenicenteron (Nitzsch) Ehrenberg 1843	-	-	-	+
Surirella angusta Kützing 1844	-	-	+	+
Surirella minuta Brébisson ex Kützing 1849	-	-	+	-
Surirella ovata Kützing 1844	+	-	-	-
Surirella robusta Ehrenberg 1841	+	-	-	-
Chlorophyta				
Pandorina morum (O.F.Müller) Bory 1824	+	-	-	-
Pediastrum duplex Meyen 1829	-	-	-	+
Pediastrum duplex var. rugulosum Raciborski 1890	-	-	-	+
Pseudopediastrum boryanum (Turpin) E.Hegewald 2005	-	-	+	-
Euglenophyta				
Trachelomonas granulosa Playfair 1915	+	-	-	-
Trachelomonas intermedia P.A.Dangeard 1902	-	-	+	-
Trachelomonas volvocina (Ehrenberg) Ehrenberg 1834	-	-	-	+
Cyanobacteria			-	
Chroococcus minutus (Kützing) Nägeli 1849	-	-	-	+
Leptolyngbya sp. Anagnostidis & Komárek 1988	-	-	+	-
Oscillatoria tenuis C.Agardh ex Gomont 1892	+	-	-	-
Charophyta			-	
Mougeotia C. Agardh 1824	-	-	-	+
Mioza				
Glenodinium sp.Ehrenberg 1836	-	-	-	+
Tripos furca (Ehrenberg) F.Gómez 2013	-	-	+	+

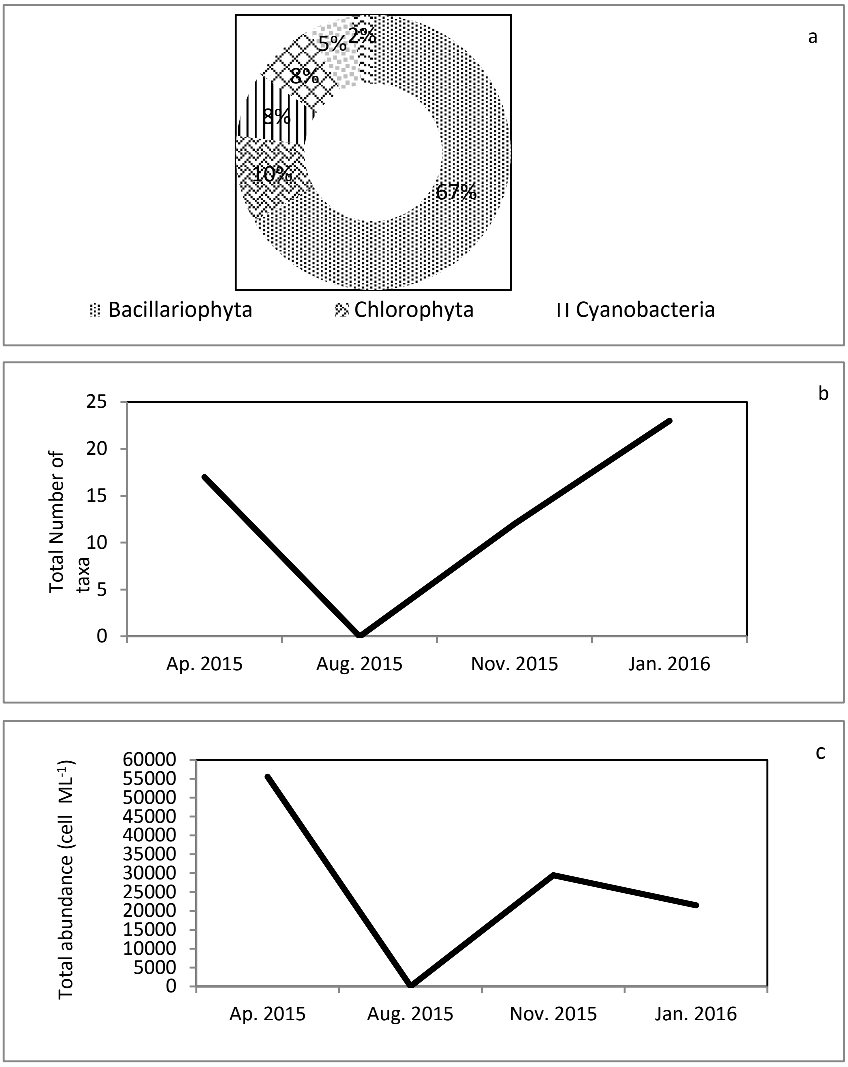

Figure 3. a) The percent composition of the phytoplankton groups, b) the total number of phytoplankton taxa, c) the total abundance of the phytoplankton (cell ML^{-1}) of Çamköy Reservoir

Miozoa members, although not absent, are seldom collected in freshwater samples. *Glenodinium* sp. has been previously reported by Sevindik et al. (2011) in Çaygören Reservoir which is close to Çamköy Reservoir.

In August 2015, no phytoplankters were observed in the samples. The excessive B concentrations (above 600 mg L^{-1}) in the reservoir seem to be the reason for the lack of phytoplankton in the summer samples. Reid et al. (2004) found that *Chara* cells were not affected by the B levels up to 400 mg L^{-1}, but when the concentrations were raised to 600 mg L^{-1}, the cells died in the experimental chamber. It is possible that no phytoplankton species could tolerate B levels greater than 600 mg L^{-1} in Çamköy Reservoir.

In summary, the nutrient concentrations in Çamköy Reservoir are not at the limiting level for phytoplankton, but the number of taxa and the abundance are low compared with natural lakes. This situation leads to the recognition that the low number of phytoplankton taxa and abundance was a result of the excessive B levels in the reservoir.

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