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Seasonal variations in phytoplankton communities in Zayandeh-Rood Dam Lake (Isfahan, Iran)

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Abstract: Variations in the phytoplankton of Zayandeh-Rood Dam Lake were studied seasonally from September 2005 to August 2006 at 4 different stations. A total of 112 species and 53 genera belonging to 6 divisions were identified. The species belonging to Bacillariophyta, Chlorophyta, Cyanophyta, Euglenophyta, and Dinophyta were found frequently. Chrysophyta species were found in low numbers. *Cyclotella meneghinina* Kütz., a centric diatom, was the dominant species at all stations. The density of the phytoplankton was between 470 and 150,470 cells/cm^3. According to the Shannon-Weaver Index, the highest and the lowest diversities were determined in November and May, respectively. Regarding physico-chemical analysis and phytoplankton composition, it seems that Zayandeh-Rood Dam Lake is oligo-mesotrophic, and some species of phytoplankton can be used as indicators for evaluating water quality.

Key words: Phytoplankton, seasonal variation, Zayandeh-Rood Dam Lake, oligo-mesotrophic lake

Introduction

Although there have been a number of studies carried out in Zayandeh-Rood Dam Lake in Isfahan, Iran (Parvizian, 2003), no taxonomic study giving a general, quantitative description of the seasonal phytoplankton succession in this lake has been done so far. The purpose of the present study was to determine the composition of phytoplankton in Zayandeh-Rood and to contribute to the algal flora of Iran. Algae, especially phytoplankton, are the source of oxygen in aquatic systems and the main autochthonous primary producers used in determining water pollution levels (Atıcı, 2002; Diehl et al., 2002). This lake is important as a drinking water and irrigation source, and for production of electrical energy and agriculture for Isfahan Province. Vascular plants were absent from all stations in this lake. In this study, in addition to phytoplankton species compositions, their relative percentages, and certain physical and chemical properties of the lake were examined.

Materials and methods

Zayandeh-Rood Dam Lake is located 110 km west of the city of Isfahan in central Iran. The total area of the lake's surface is 48 km^2 and its volume is about 12.5×10^8 m^3. This mountain lake is situated 2000 m above sea level and it is a dimictic lake. In this study, the important factors affecting the growth and density of phytoplankton such as pH,

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dissolved oxygen (DO), electrical conductivity (EC), temperature, biological oxygen demand (BOD) and chemical oxygen demand (COD), NO_3, PO_4, and SO_4 were analyzed. Phytoplankton samples were taken from 4 sampling stations from November and December 2005, March 2005, and May 2006 to July and August 2006. The locations of the sampling stations were as follows: station 1 (Yan Cheshmeh), 50°42′32.4″N, 32°43′34″E; station 2 (Sazman Omran), 50°39′53.2″N, 32°44′18.8″E; station 3 (Tangeh Siah), 50°35′57.1″N, 32°43′21.9″E; station 4 (Mashhad Kaveh), 50°34′18.2″N, 32°43′21.9″E (Figure 1). Three-litre samples were taken in plastic bottles; at each station one sample was taken with a Hydro Biosplankton net (55 µm mesh size), and from the surface and 0.5 and 3 m depths using a Nansen sampler (Wetzel & Likens, 1991). These samples were taken to the laboratory and fixed with 4% formaldehyde on the same day. The samples were concentrated by centrifugation at 1500 rpm. Taxonomic identifications were performed according to Cox (1996), Prescott (1970, 1984), Patrick and Reimer (1975), and Whitford and Schumacher (1984). The phytoplankton were photographed with a Zeiss Axioster Plus research microscope. Temperature, DO, pH, EC, and salinity were measured directly with multimeters Consort C_{535}, and BOD and COD were determined by APHA (1986). Nitrate, phosphate, and sulphate values were determined by the calorimetric method, orthophosphate by the molybdate method and by the spectrophotometer DR/2010 model HACH. Statistical analysis included analysis of variance (ANOVA) and Duncan's multiple range test. Regression correlation was determined with SPSS and MSTATC software. Multiple regression analysis was used to develop quantitative relationships between phytoplankton density and physical and chemical variables. The diversity of phytoplankton communities was calculated and compared using the Shannon-Weaver index.

Physical and chemical parameters

The physical and chemical parameters of Zayandeh-Rood Dam Lake are given in Table 1.

Regarding physical and chemical analysis, the highest nitrate concentration, found in March 2006 immediately after the rainy season, may be attributed to landslip. The seasonal variations in the physical and chemical parameters at different stations are shown in Figures 2-9.

Phytoplankton

A total of 112 species belonging to 6 divisions were identified. A floristic list of identified phytoplankton is given in Table 2 and pictures of some species are shown in Figure 10. The scientific names of algae species were checked with the AlgaeBase website. Bacillariophyta comprised 47% (53 species) of total species and were dominant. The remaining divisions were Chlorophyta with 23% (26 species), Cyanophyta with 10% (12 species), Euglenophyta with 9% (9 species), Dinophyta with 8% (8 species), and Chrysophyta with 3% (4 species) (Figure 11). Bacillariophyta had the highest species number in different seasons. *Cyclotella meneghinina* was the dominant diatom in all samples regardless of season. It was followed by the pennate diatom species *Nitzschia palea*, *Navicula salinarum*, *N. radiosa*,

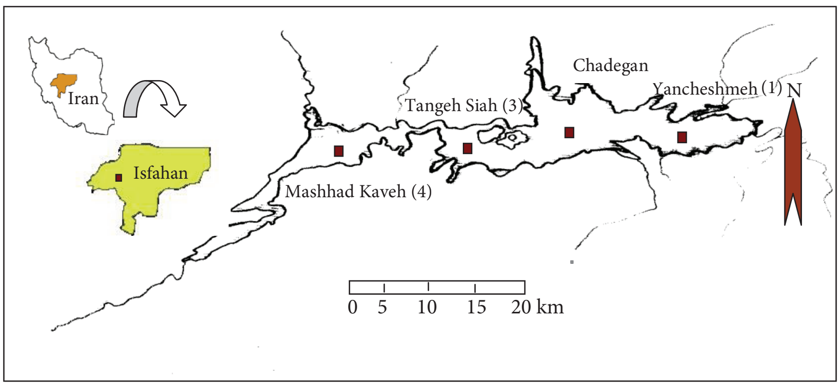

Figure 1. Map of studied area in Zayandeh-Rood Dam Lake.

Table 1. The physical and chemical parameters of Zayandeh-Rood Dam Lake.

Parameters	Autumn	Winter	Spring	Summer
Temperature (°C)	18.9-25	8.5-24.5	24.2-35.9	24.5-30.2
Secchi depth (m)	2.99	1.90	3.81	3.67
pH	7.46-8.68	7.16-8.94	8.1-8.31	8.61-8.77
DO (mg L^{-1})	7.7-9.4	6.85-12.85	3.95-8.35	6.8-9.25
EC (µS cm^{-1})	128-206	200-263	210-258	195-250
Salinity (mg L^{-1})	68-110	107-140	112-137	103-122
Turbidity (NTU)	1.01-5.57	1.12-29.6	1.23-2.58	1.58-6.56
BOD (mg L^{-1})	2.65-3.87	1.02-2.41	1.43-4.08	1.99-4.95
COD (mg L^{-1})	18-32	126-152	105-149	69-99
NO_3 (mg L^{-1})	2.2-3	12.9-36.2	12.7-29	4.1-30
PO_4 (mg L^{-1})	0.2-0.6	0.1-5.1	0.1-13	0.1-6.2
SO_4 (mg L^{-1})	8-16	9-23	1-14	2-19

Cymbella affinis, and *Ulnaria ulna*. The density of phytoplankton showed a downward tendency in November 2005 after an increase in numbers was detected from spring to July (Figure 12). *Cymbella affinis* occurred much more abundantly at station Mashhad Kaveh, reaching its greatest density (950 cells/cm^3) in November 2005. The highest number of phytoplankton, 150,470 cells/cm^3, was recorded at station 2 in August 2006. Some species, such as *Gyrosigma acuminatum* (Naviculaceae) and *Gomphonema truncatum*, showed maximum abundance only at station 4 in December 2005. Chlorophyta formed the second dominant phytoplankton division, with reasonably high species diversity (26 species). Chlorophyta featured in the spring when it was warm (Figure 12). This division constituted 23% of the total. *Chlamydomonas angulosa*, *Oocystis borgei*, *Selenastrum minutum*, and *Scenedesmus bijuga* were observed during May 2006. *Chroococcus dispersus*, *Merismopedia punctata*, *M. elegans*, and *Spirulina major* were the most important species of Cyanophyta. Euglenophyta constituted 9% of the total phytoplankton. In general, the group showed a downward tendency towards mid-spring and then gradually increased in numbers in parallel with the number of diatoms until the end of summer. The species *C. hirundinella*, *Glenodinium quadridens*, and *Peridinium cinctum* were observed mostly in the summer and at stations 2 and 3 in Zayandeh- Rood Dam Lake (Figure 12). The lowest density was found in December 2005. Such fluctuations in phytoplankton density and diversity can be attributed to the seasonal temperature changes and the water level of the lake. Chrysophyta was less important than other divisions. This group made up 3% of the total phytoplankton.

In the study period, diversity ranged between 0.55 and 1.63. The highest diversity was 1.63, at station 4 in August 2005. The lowest value (0.55) was observed at station 2 in November 2006 (Figure 13).

The density variations in phytoplankton at different seasons and depths are shown in Figures 14 and 15. The high density and low diversity of phytoplankton indicated that the tropic status was highest at station 2.

According to the regression results, the density of phytoplankton with COD and turbidity values has positive and negative correlations, respectively (Figures 16 and 17).

A significant difference was observed using ANOVA between phytoplankton density and turbidity at different stations ($P < 0.05$). At different depths only amount of nitrate showed a significant difference. A significant difference was observed in all of the physical and chemical variables with the exception of salinity at different stations. Regarding the results of ANOVA and Duncan's test, a significant difference was found between sampling stations in terms of phytoplankton density and turbidity.

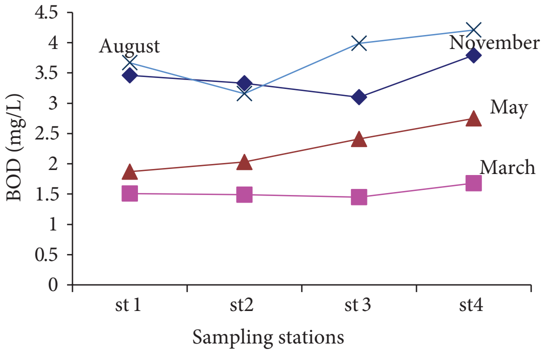

Figure 2. The seasonal variations in BOD.

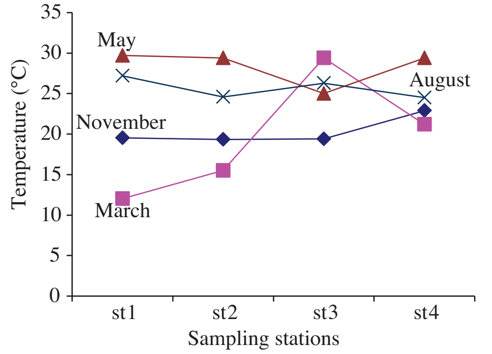

Figure 6. The seasonal variations in temperature.

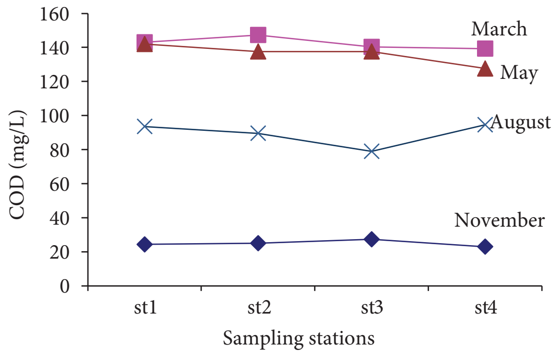

Figure 3. The seasonal variations in COD.

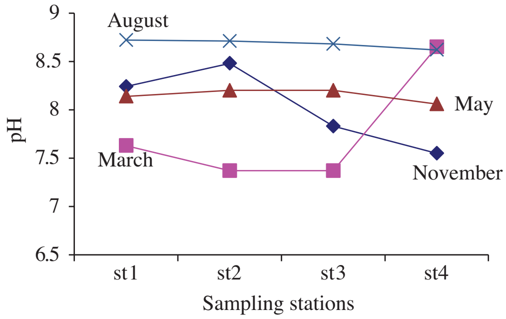

Figure 7. The seasonal variations in pH.

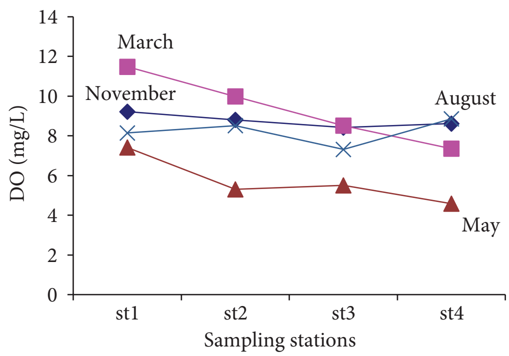

Figure 4. The seasonal variations in DO.

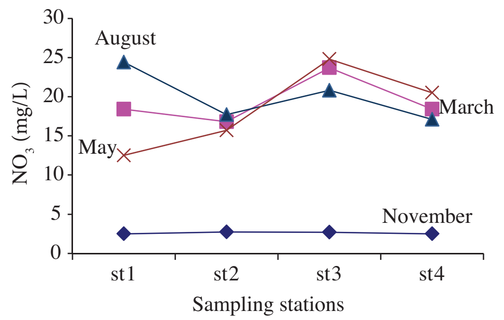

Figure 8. The seasonal variations in NO_3.

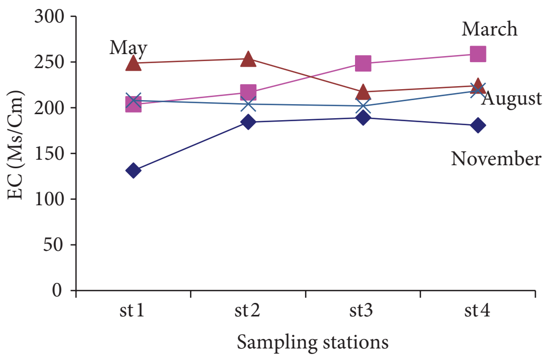

Figure 5. The seasonal variations in EC.

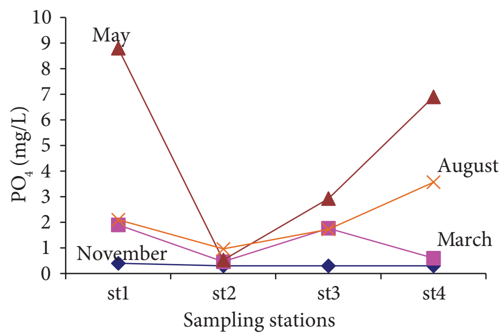

Figure 9. The seasonal variations in PO_4.

Table 2. List of identified phytoplankton species in Zayandeh-Rood Dam Lake (2005-2006)*.

Phytoplankton	**Autumn**	**Winter**	**Spring**	**Summer**
Bacillariophyta:				
Achnanthidium lanceolatum Grun.		A		
Amphora ovalis Kütz.		A		
Asterionella formosa Hassal.	B	D	D	A
Cocconies pediculus Ehr.	C	A		B
Cocconies placentula (Ehr.) Cleve.	A		A	
Cyclotella meneghiniana Kütz.	D	D	D	D
Cymatopleura solea (Breb.) W.Sm.		A		
Cymbella affinis Kütz.	A	B		A
Cymbella cesatii (Rab.) Grun.	A	B		
Cymbella cistula (Ehr.) Kirch.		B		
Denticula tenuis Kütz.		A		
Diatoma hyemalis (Roth.) Heib.		B		
Diatoma vulgaris Bory.	A			
Diploneis ovalis (Hilse) Cleve.		A		
Encyonema minutum (Hilse) D.G.Mann	A			
Epithemia sorex Kütz.		A		
Eunotia bilunaris (Ehr.) Mills		A		
Fragilaria crotonensis Kitton	B	C	B	
Gomphonema olivaceum (Lyngb.) Kütz.	A			
Gomphonema truncatum Ehr.	B	A		
Gyrosigma acuminatum (Kütz.) Rabh.	A	A		A
Gyrosigma spenceri (W.Sm.) Cleve				A
Meridion circulare (Greve.) Agard.		A		
Navicula angusta Grun.				A
Navicula cryptocephala Kütz.	A	A		A
Navicula cryptotenella Lange-Bert.		A		A
Navicula digitoradiata (Greg.) Ralfs		A		
Navicula lanceolata (Agardh.) Kütz.	B		A	B
Navicula radiosa Kütz.				A
Navicula salinarum Grun.	B	B	C	C
Navicula tenella Meise.				A
Navicula tenelloides Meist.	A	A		
Navicula veneta Kütz.	A			
Navicula sp.	A	A	A	
Nitzschia bacilliformis Hust.	A			
Nitzschia diversa Hust.	A			
Nitzschia draveillensis Coste & Ricard	A	A		
Nitschia fossilis Grun.	A	A		
Nitzschia frustulum (Kütz.) Grun.	A			

Nitzschia graciliformis Lange-Bert. & Simonsen	A			
Nitzschia gracilis Hantzsch	A		A	
Nitzschia intermedia Hantzsch ex Cleve & Grun.				A
Nitzschia ovalis Arnott		A		
Nitzschia palea (Kütz.) W.Sm.		A	A	
Nitzschia pusilla Grun.		A		
Nitzschia radicula Hust.	A			
Pinnularia major Ehr.	A	A		
Pinnularia sudetica (Hilse) Perag.	A	A		A
Stephanodiscus hantzschii Grun.		A		
Surirella linearis W.Sm.	A			
Surirella roba Lecl.		A		
Ulnaria acus (Kütz.) M.Aboal.	A	A		
Ulnaria nana F.Meister		A		
Ulnaria ulna (Nitzsch) Compère	A	A	C	C
Chlorophyta:				
Ankistrodesmus braumii (Naeg.) Collins	A			
Ankistrodesmus convolutus Corda	B	A		
Carteria klebsii (P.A.Dang.) Dill.				A
Chlamydomonas angulosa Dill.		A		A
Chlorella vulgaris Beye.		A		A
Chlorella ellipsoidea Gern.				B
Cosmarium sp.			A	
Elakatothrix gelatinosa Wille.	D	D	D	D
Elakatothrix viridis (Snow) Printz		A		
Kirchneriella contorta (Schmidle.) Bohlin	A			
Mougeotia sp.				A
Nephrocytium aghardhianum Naeg.	D	B		A
Nephrocytium limneticum G.M.Sm.	B	A		
Nephrocytium lunatum W.West		A		
Oocystis borgei Snow	A			A
Oocystis crassa Wittr.	A	B		
Oocystis solitaria Wittr.		A		
Pediastrum braunii Wartm.			A	
Pediastrum integrum var. *priva* Printz			D	B
Pediastrum integrum var. *scutum* Raci.			B	B
Planktosphaeria gelatinosa G.M.Sm.	A			
Scenedesmus bijuga (Turp.) Lagerh.	A	A		
Selenastrum minutum (Naeg.) Collins				A
Sphaerocystis schroeteri Chodat	A	A		
Spirogyra sp.	A			A
Tetraedron muticum f. punctulatum (Reinsch)	A			
Chrysophyta:				
Dinobryon divergens Imhof	B	B	A	C

Dinobryon cylindricum Imhof		A		
Dinobryon sertularia Ehr.			A	A
Dinobryon sociale Ehr.				B
Cyanophyta:				
Anabaena sp.		A	A	A
Chroococcus dispersus var. *minor* G.M.Sm.	A		A	B
Chroococcus dispersus (Keissl.) Lemm.		B		B
Chroococcus limneticus var. *subsalsus* Lemm.	A	A	A	B
Chroococcus minor (Kütz.) Naeg.	A	A		A
Chroococcus minutus (Kuetz.) Naeg.		A		
Merismopedia elegans A.Braun				C
Merismopedia glauca Ehr.				A
Merismopedia punctata Meyen.				C
Nostoc sp.	A	A		
Oscillatoria sp.	A			
Spirulina major Kütz.		A	A	
Dinophyta:				
Ceratium hirundinella (O.F.Muell.) Duj.	C	A	A	C
Glenodinium inconspicum Lemm.		A	A	
Glenodinium quadridens (Stein) Schiller	C	A	B	C
Glenodinium sp.	A			
Peridinium cinctum (Muell.)	C	B	A	C
Peridinium cinctum var. *tuberosum* (Meun.) Lind.	A	A		A
Euglenophyta:				
Euglena caudata Hübner		A		
Euglena polymorpha P.A.Dang.	A		A	A
Lepocinclis acuta Prescott		A		B
Lepocinclis ovum (Ehr.) Lemn.		A	A	
Trachelomonas scabra var. *longicollis* Playfair	A		A	B
Trachelomonas robusta Swir.			B	
Trachelomonas playfairi Defl.			A	

*A: Rare 10%-20%, B: Occasional 21%-40%, C: Frequent 41%-80%, D: Dominant 81%-100%

Temperature showed a significant difference at Mashhad Kaveh. In general, at all of the stations pH, salinity, BOD, COD, and SO_4 were not significantly ($P > 0.05$) different. Moreover, a significant difference was observed in phytoplankton density, NO_3, and BOD in autumn compared with the other seasons. Amount of PO_4 in May and SO_4 in March showed a significant difference. Finally, among the different depths only nitrate showed a significant difference at 0.5 m depth. In addition, at different stations, Sazman Omran in comparison with the other sites showed a significant difference, but phytoplankton density did not change at any of the depths significantly. As a result, in order to determine the characteristics of the lake, it is necessary to carry out physical and chemical analyses of the lake water and phytoplankton composition.

Discussion

According to pH and salinity, phytoplankton species were alkalibiontic and mesohaline, respectively. This lake had alkaline water with low salinity, especially

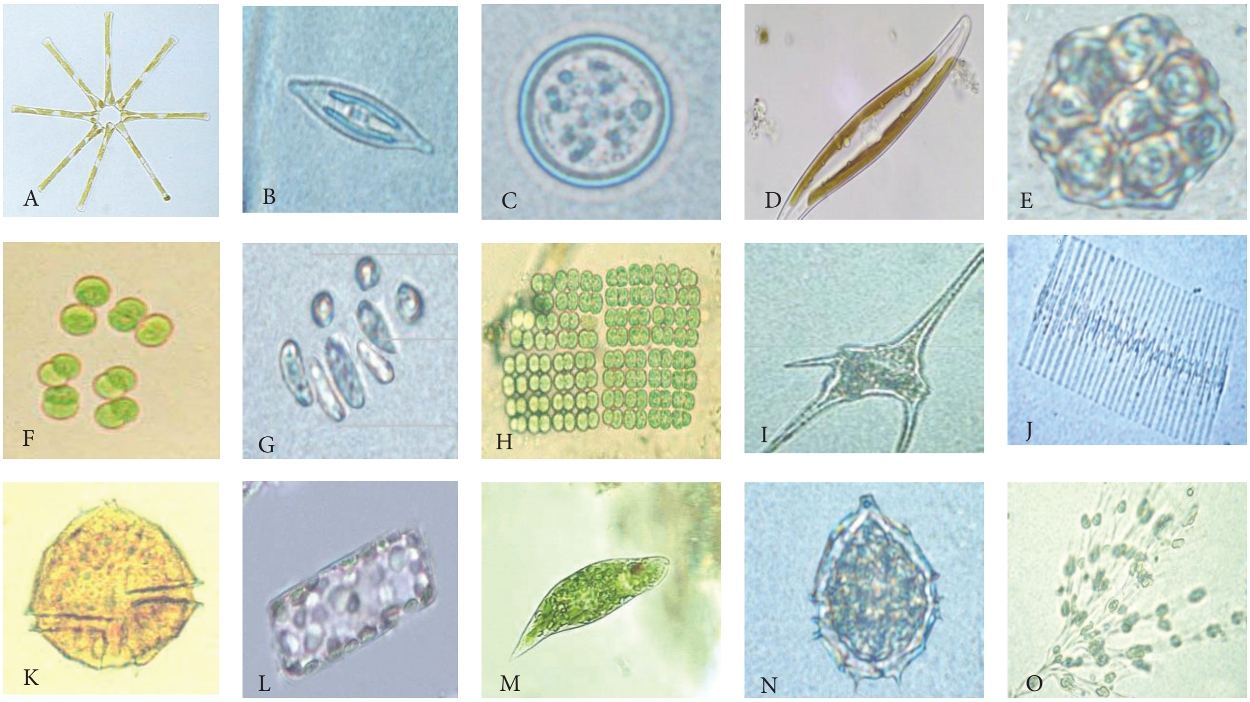

Figure 10. Picture of some of the phytoplankton species found in Zayandeh-Rood Dam Lake (400×). A- *Asterionella formosa*, B- *Navicula salinarum*, C- *Cyclotella meneghiniana*, D- *Gyrosigma acuminatum*, E- *Pediastrum integrum*, F- *Chroococcus dispersus*, G- *Nephrocytium aghardhianum*, H- *Merismopedia elegans*, I- *Ceratium hirundinella*, J- *Fragilaria crotonensis*, K- *Peridinium cinctum*, L- *Diatoma vulgare*, M- *Euglena proxima*, N- *Glenodinium quadridens*, O- *Dinobryon divergens.*

in summer, similar to the results reported by Solak et al. (2012). There was an inverse relationship between EC and Shannon diversity. Physical and chemical data indicated that the lake is oligo-mesotrophic.

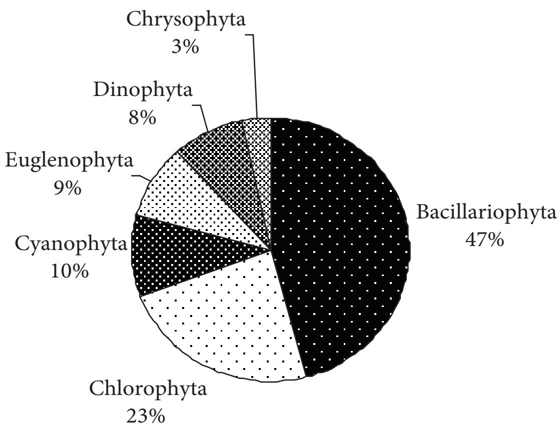

Figure 11. Species abundance of phytoplankton divisions in Zayandeh-Rood Dam Lake.

Bacillariophyta were found in quite high numbers (47% of total organisms, at all stations) and they were dominate species among the algae (Atıcı & Obalı, 2010; Şahin et al., 2010; Baykal et al., 2011; Bariona et al., 2011). *Amphora ovalis*, which grows faster in alkaline water, was rare and low in numbers (Atıcı & Obalı, 2006). In addition, *Nitzschia palea* was the most observed species at Tangeh Siah and Mashhad Kaveh stations, with moderate EC and high nitrate amounts (Skcherbak & Rodkin, 1994). *Navicula salimarum*, *N. radiosa*, *Cymatopleura solea*, and *Ulnaria ulna* were the most common pennate diatoms in the phytoplankton. *Asterionella formosa* and *Fragilaria crotonensis* (araphid species) were detected partially during the research period and were the most frequent organism in winter at stations 1 and 2 (including 128,250 cells/cm^3 and 15,230 cells/cm^3, respectively). These species are characteristic species of mesotrophic lakes (Round, 1981; Gönülol, 2005). Moreover, *Asterionella formosa*

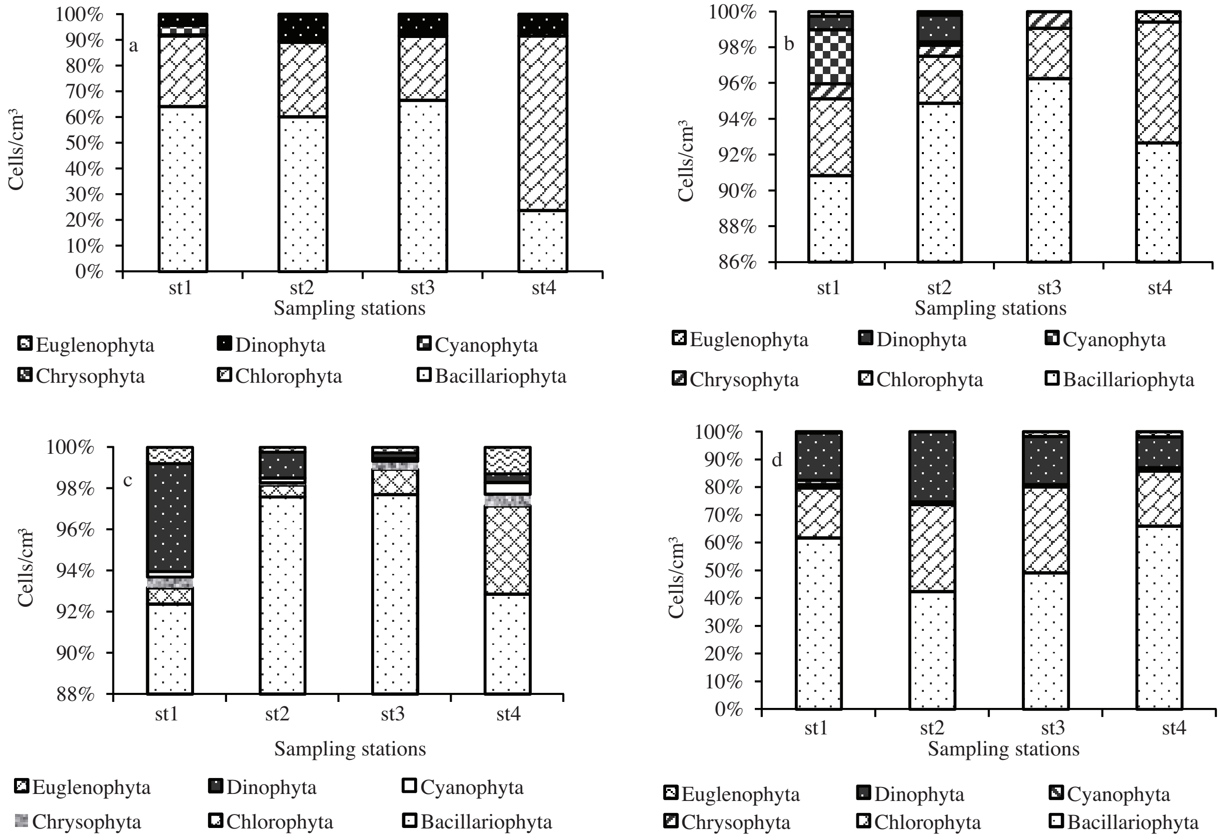

Figure 12. Abundance of phytoplankton divisions. a- in autumn, b- in winter, c- in spring, d- in summer.

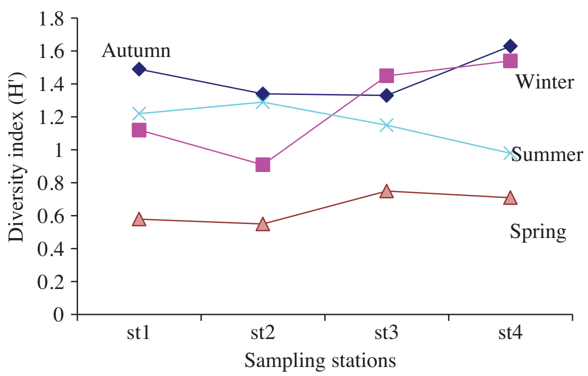

Figure 13. Species diversity in Zayandeh-Rood Dam Lake.

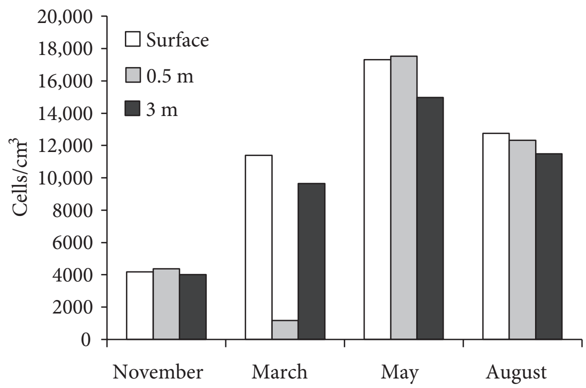

Figure 14. Phytoplankton density in different seasons.

is usually an indicator species of eutrophic structure (Yilmaz & Aykulu, 2010). Chlorophyta formed the second dominant phytoplankton division, with reasonably high species diversity (26 species), and they featured in the spring when it was warm, which is consistent with the results reported by Yilmaz and Aykulu (2010) and Yerli et al. (2012). Chlorococcales, including *Pediastrum integrum*, *Nephrocytium* sp., *Elakatothrix*, and *Oocystis*, are eutrophic (Karjalanin et al., 1996). *Pediastrum integrum* var. *priva*, which is characteristic of mesotrophic lakes, was observed at station 4 in March 2006 (Cocquet

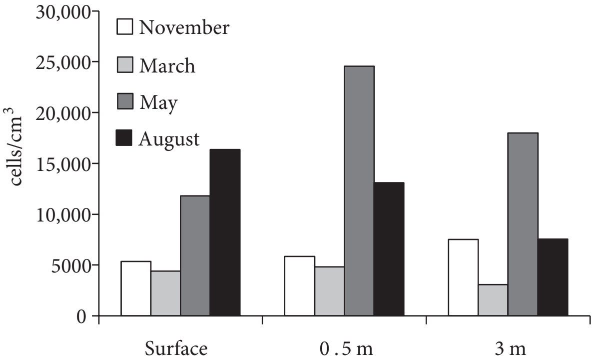

Figure 15. Phytoplankton density at surface and depths of 0.5 and 3 m.

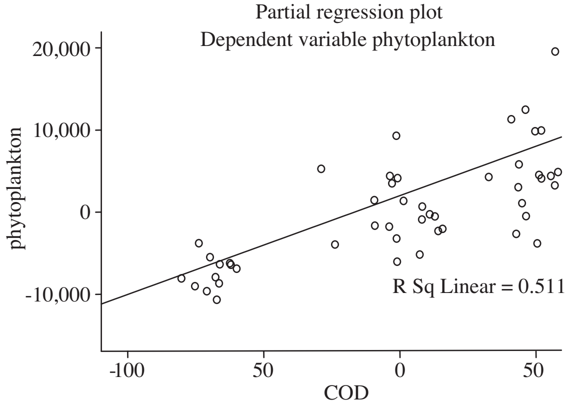

Figure 17. Regression phytoplankton density and COD.

& Vyverman, 2005); this species consumes a high amount of phosphate. *Nephrocytium agardhianum* and *N. limneticum* at station 1 (August-December 2005) and *Elakatothrix gelatinosa* at station 3 (often in May 2006) were observed in Zayandeh-Rood Dam Lake. The density of *Sphaerocystis schroeri* is much lower than that of other species in samples (Karjalanin et al., 1996). The Chlorococcales species were eutrophic indicators (Lei et al., 2005; Reynolds, 2006). *Scendesmus bijuga* was only found at stations 1 and 2 in December 2005. With the temperature rise in summer, densities of *Pediastrum* sp., *Chroococcus* sp., and *Merismopedia* increased as reported by Ibelings et al. (1998) and Kuzmin et al. (1990). Some species such as *Pediasterum integrum* and *Ceratium hirundinella* consume high levels of nitrate in spring and *Asterionella formosa* and *Fragilaria crotonensis* consume more phosphate than nitrate. These species

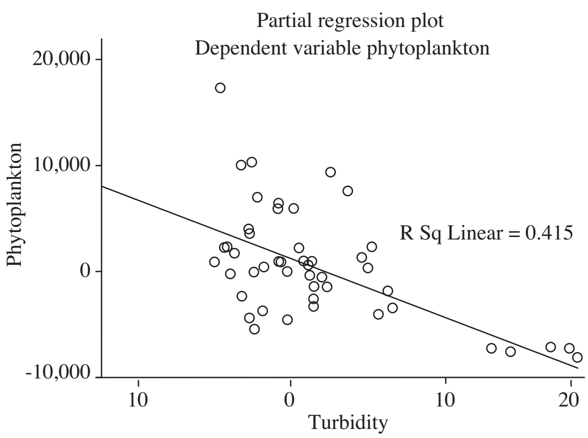

Figure 16. Regression phytoplankton density and turbidity.

have been postulated as indicator species of oligo-mesotrophic lakes (Kilinc, 1998; Lei et al., 2005).

The number of Cyanophyta species was small and remained stable throughout the study. At most they reached just 10% of the total phytoplankton in Zayandeh-Rood Dam Lake. Regarding the inlet from Zayandeh-Rood Dam Lake and mixing water in this lake, the abundance of Cyanophyta is normal. *Euglena proxima*, *E. polymorpha*, and *Lepocinclis* sp., which grow rapidly in rich organic media, were important. These species were found from spring to summer (at stations 3 and 4 in July 2006). These species were resistant to pollution, similar to Dinophyta (Barone & Naselli-Flores, 1994). Three *Trachelomonas* species belonging to the division Euglenophyta were found in Zayandeh-Rood Dam Lake. In general, they were found in nutrient-rich waters (Atıcı, 2002). *C. hirundinella* was detected throughout the study period, increasing in early spring and late summer (Salmaso et al., 2003; Baykal et al., 2011). This species usually prefers eutrophic lakes, but it was reported that it can also occur in mesotrophic lakes (Naz & Türkman, 2005). Polymorphism states were observed in *C. hirundinella* because of the temperature rise in the warm season (Ginkel et al., 2001). As the amount of nitrate and phosphate increased, the density of Dinophyta increased; the same result was reported by Dodds et al. (2002). The amount of nitrate or phosphate limits the growth of Dinophyta. From Chrysophyta, *Dinobryon divergens*, *D. sertularia*, and *D. cylindricum* were observed in this study. *D. divergens* was composed of 1904 cells/cm^3 and higher than that observed in winter at stations 1 and 2. This species had the highest tolerance to low temperatures. In addition, *D. sertularia* is known from the literature to be potentially mixotrophic. This species can also be found in mesotrophic lakes (Naz & Türkman, 2005). It can be stated that the slight rise in density is due to changes in trophic conditions in this lake during the study period.

In conclusion, although this study was done over a short time (1 year), the results show that Zayandeh-Rood Dam Lake can (regarding the presence of 112 species from different divisions and physical and chemical factors) change from oligotrophic to mesotrophic. Therefore, in order to obtain accurate results about the phytoplankton communities in this lake, more studies in terms of ecology and systematics are necessary.

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