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Phytoplankton of Aras dam reservoir (Iran): an attempt to assess water quality

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Abstract

The Aras reservoir, located in the north-west of Iran, plays an important role in fisheries, drinking and agricultural water supplies and recreational activities in the region. This study was performed to characterize the seasonal fluctuations of phytoplankton communities and their relationship with environmental factors in the Aras reservoir from August 2013 to May 2014. Sampling was carried out seasonally from 5 sampling locations. In each location three samples were taken for phytoplankton identification and enumeration, chemical analysis and chlorophyll *a* determination. In total, 72 species belonging to 5 divisions were determined. Cyanobacteria contained the highest density (74%) during the study period with *Pseudanabaena limnetica* as the most abundant species. This group retained its dominance the whole year round which indicated the poor quality and high nutrient load of the Aras reservoir, mainly due to human activities. On average, Trophic State Index (TSI) showed that water in the reservoir was eu-hypereutrophic. The results indicated that phytoplankton density negatively correlated with Secchi disc depth (R^2 = -0.479), total alkalinity (R^2 = -0.564), total hardness (R^2 = -0.727) and HCO_3 concentration (R^2 = -0.589). On the other hand, there was a positive correlation between the phytoplankton density and TP (R^2 = 0.734). A comparison between the present and a previous study indicated that the cyanobacterial bloom pattern in the Aras reservoir has shifted from warm season toward an all year round cycle which in addition to basin pollution due to anthropogenic activities, can be related to global warming and climate change.

Keywords: Phytoplankton, Water quality, Reservoir, Cyanobacteria, Trophy

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Introduction

Phytoplankton being the major primary producer in various reservoirs is an important food source for higher organisms. The knowledge of phytoplankton distribution in reservoirs with reference to their spatial and temporal pattern is important in understanding the status of ecosystem structure and functioning (Ahmed and Wanganeo, 2015). In reservoirs, not only do light and temperature regulate the seasonal phytoplankton pattern, but other variables are also of great relevancy (Espindola *et al*., 1996). The seasonal succession of phytoplankton is a well investigated phenomenon in freshwater ecology, and various studies have described the pattern and underlying mechanisms of seasonal dynamics (e.g. Sommer *et al*, 1986; Marshal and peters, 1989; Katsiapi *et al*., 2011; Mohsenpour Azari *et al*., 2011). Increased growth of certain groups of phytoplankton especially blue green algae that decreases phytoplankton diversity is a key factor in the determination of water quality in reservoirs. Thus, understanding the process of phytoplankton variation can be particularly useful in water quality evaluation, improvement and management decisions.

The Aras reservoir plays an important role in the region such as in fisheries, agricultural, industrial, and domestic uses as well as in drinking water supplies (Mohebbi *et al*., 2012a). In spite of these crucial roles, few studies have been performed on the phytoplankton communities and water quality in this reservoir. The present study intended to characterize the seasonal variations of phytoplankton communities in the reservoir. It also aimed to find relationships between phytoplankton community and environmental factors (physico-chemical properties) in order to assess its trophic state and water quality and to compare present and past data on the Aras reservoir.

Materials and methods

The Aras River is one of the largest rivers of the Caspian Sea basin which flows along the Iran-Azerbaijan border (Mohebbi *et al*., 2012a). The Aras dam reservoir is located at 39° 5' N and 45° 24' E. This reservoir is a great water resource which was constructed on this river for electrical power production in 1970 (Aliyev *et al*., 2013). The reservoir provides water for irrigation to about 400,000 ha of arable lands in Iran and Azerbaijan (Filipuzzi and Faramarzi, 2007).

Water samples were collected seasonally by using a Ruttner sampler at 5 sampling locations from August 2013 to May 2014 (Fig. 1). In a stratified water column such as the Aras reservoir, equal volumes were taken from the surface, 3 m and 5 m depths. Samplings were mostly done in the morning. Aliquots from each depth were combined, and approximately 1 L of the composite sample was preserved with 4% formaldehyde solution for later phytoplankton analysis. However, some live samples were taken for more accurate phytoplankton identification.

Phytoplankton samples were preserved in cold, dark conditions for laboratory analysis.

Additional discrete samples from the same depths were collected and combined accordingly for chemical analysis. Discrete samples from the deep chlorophyll layer were taken for later analysis of chlorophyll *a*.

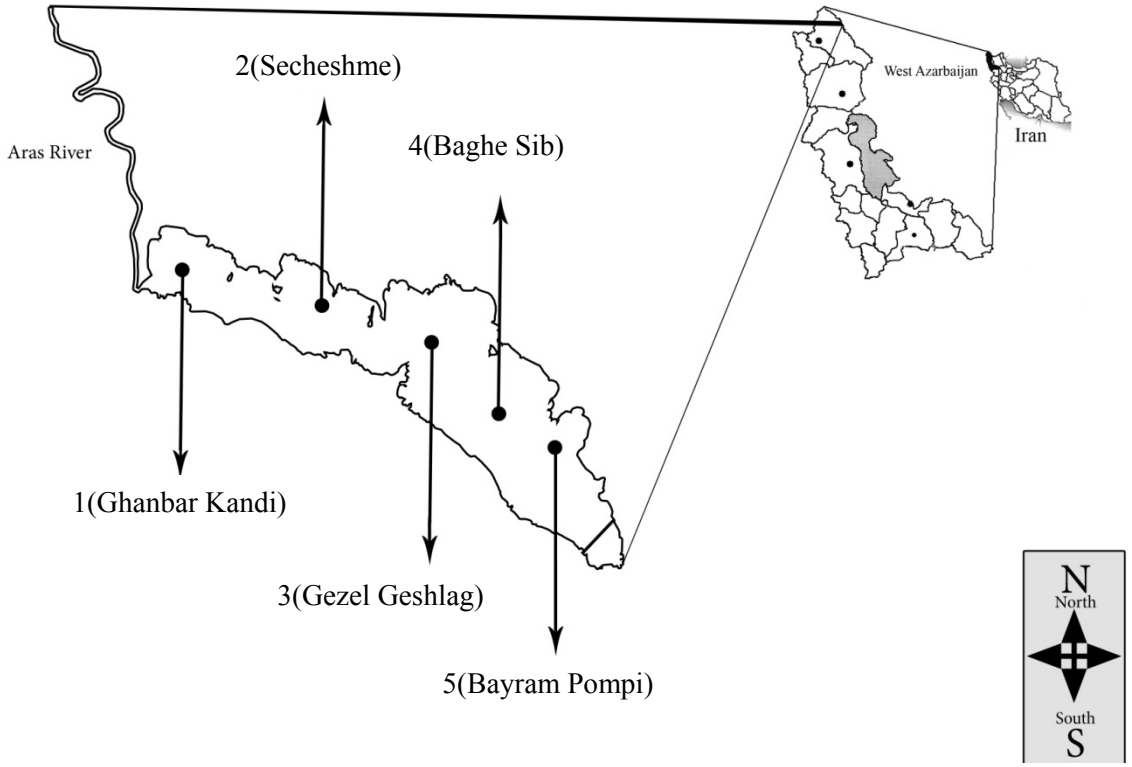

Figure 1: The map showing sampling locations in the Aras Reservoir.

Phytoplankton counting and identification were done using 5-mL settling chambers with a Nikon TS100 inverted microscope at 400× magnification by Utermöhl's method (1958). At least 50 fields or 100 individuals of the most abundant species were counted in each sample (Venrick, 1978). The phytoplankton community in each site was analyzed in terms of taxonomic composition, species, and density. The phytoplankton taxa were identified according to the following references: Desikachary (1959), Prescott (1962), Tiffany and Britton (1971), Bellinger (1992), Van den Hoek *et al*. (1995), Komárek and Anagnostidis (1989, 1999, 2005).

Water temperature, dissolved oxygen (DO), and pH were measured in situ at every sampling location in the superficial water layers (50 cm depth) with a WTW 320 Oxymeter and a Testo 320 pH meter, respectively. Dissolved nutrients (TP, TN), total hardness and total alkalinity were analyzed as described in Greenberg *et al*. (1992). Digestion with potassium

persulfate was used to determine total phosphorus (TP) concentrations. Total phosphorus and total nitrogen were determined using a spectrophotometer model T80+ UV/VIS (PG Instruments Ltd, UK.).Transparency of water was measured with a 30-cm diameter Secchi disc. Samples for chlorophyll *a* determination were filtered through a 0.45 µm Glass fiber filter (GF/C) buffered with magnesium carbonate. On filtration, the filters were transferred to a test tube and immersed in 90% acetone. Tubes were shaken vigorously and then transferred to a refrigerator and extracted overnight in the dark (Parsons and Strickland, 1965). After a period of 24 h, the samples were read spectrophotometrically at 750, 665 and 654 nm. The spectrophotometer was zeroed at 750 nm using 90% acetone. Chlorophyll *a* concentrations were calculated as follows:

Chl a ($\mu g\ L^{-1}$)=33.0 (665_b–654_a)* V_1/V_2*L

Where, V_1=volume of extract; V_2= volume of sample (L); L= light path or cuvette width (cm) and 665_b , 654_a = absorbance of extract before and after acidification, respectively.

The trophic state of the reservoir was obtained by using the index proposed by Lamparelli (2004). This index has a few limits (Table 1) which indicates various trophy states. TSI is composed of a set of equations:

TSI (SD) = 10 (6 – ((lnSD)/ ln2)) (5)

TSI (Chl) = 10 (6 – (0.92 − 0.34 (ln Chl / ln2)) (6)

TSI (TP) = 10 (6 – (1.77 − 0.42 (ln TP) − ln2)) (7)

where: SD = Secchi disk (m); Chl = Chlorophyll-*a* ($\mu g.L^{-1}$); and TP = Total Phosphorous ($\mu g.L^{-1}$)

Table 1: Limits of trophy states in freshwater defined by Lamparelli (2004).

Limits	Trophy
≤ 47	Ultra-Oligotrophic
47< TSI ≤ 52	Oligotrophic
52 < TSI ≤ 59	Mesotrophic
59 < TSI ≤ 63	Eutrophic
63 < TSI ≤ 67	Supereutrophic
>67	Hypereutrophic

Species diversity (*H′*) was determined using the Shannon-Weaver Index (Ludwig & Reynolds 1988):

$H' = (\Sigma\ pi\ ln\ pi)$

Where

$pi = n/N$

n = No. of individual species, *N* = total density of all organisms.

Statistical analysis including ANOVA (Duncan test) and Standard Deviation (mean±SD) was performed by SPSS 18 software. We had twenty samples (N=20) for each variable. The correlation between phytoplankton density and physico-chemical parameters, regression plots, equations and R^2 (R is the first letter of Regression and shows the level of correlation between two parameters) were obtained by excel 2013 software.

Results

A total of 72 species belonging to five divisions were identified. A list of identified phytoplankton is given in Table

2. Chlorophyta had the highest number of species (31 species), followed by Bacillariophyta (25 species), Cyanobacteria (10 species), Euglenophyta (3 species), and Pyrrophyta (3 species) (Fig. 2). Chlorophyta had the highest species number in different seasons. Bacillariophyta contained the highest number of species in winter. However, Cyanobacteria regardless of its lower species numbers was the most abundant group in all seasons (Figs. 2 and 3). Some species such as *Cyclotella* sp., *Microcystis botrys* Teiling and *Oscillatoria* sp. were present in samples in all four seasons (Table 2).

Table 2: Phytoplankton species composition and occurrence in the Aras Reservoir in 2013-2014.

Season / Algae	Summer	Autumn	Winter	Spring
Cyanobacteria				
Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault	+	+	-	-
Dolichospermum spiroides (Klebhan) Wacklin, L.Hoffmann & Komárek	+	+	-	-
Chroococcus minor (Kützing) Nägeli	+	+	-	+
Chroococcus prescotii Drouet & Daily	+	+	-	-
Chroococoos turgidus (Kützing) Nägeli	-	-	-	+
Merismopedia elegans A.Braun.	+	-	+	-
Merismopedia tennuissima Lemmermann	+	+	-	-
Microcystis botrys Teiling	+	+	+	+
Oscillatoria sp.	+	+	+	+
Pseudanabaena limnetica (Lemmermann) Komárek	+	+	+	-
Chlorophyta				
Actinastrum Hantzschii Lagerheim	+	+	-	+
Actinastrum Hantzschii var. *elangatum* G.M.Smith	+	+	-	-
Ankistrodesmus falcatus (Corda) Ralfs.	+	+	-	+
Characium limneticum Lemmermann	+	-	-	-
Characium sp.	-	+	-	-
Chlamydomonas sp.	-	-	+	-
Chlorella vulgaris Beyerinck [Beijerinck]	+	-	-	-
Chlorococcum humicula (Nägeli) Rabenhorst	-	-	-	+
Closterium parvulum Nägeli	+	-	-	-
Coelastrum sp.	+	-	-	-
Cosmarium sp.	-	+	-	-
Dictyocepharium pulchelum H.C.Wood	-	-	-	+
Gleocystis major Gerneck ex Lemmermann	-	-	-	+
Golenkinia pausispina W. et G.S. West.	-	-	-	+
Monoraphidium fontinale Hindák	+	-	-	-
Oocystis crassa Wittrock	-	-	-	+
Oocystis elliptica West	-	-	-	+
Oocystis solitaria Wittrock	-	-	-	+
Pandorina sp.	-	-	-	+
Pediastrum duplex Meyen	-	-	-	+
Quadrigula closterioides (Bohlin) Printz	+	-	-	-
Acutodesmus acutiformis (Schröder) Tsarenko & D.M.John	+	-	-	-
Scenedesmus arcuatus Var. *platydiscus* G.M.Smith	+	-	-	-
Scenedesmus bijuga (Turpin) Lagerheim	+	+	-	-
Acutodesmus incrassatulus (Bohlin) Tsarenko	+	-	-	-
Scenedesmus quadricauda var. *quadrispina* (Chodat) G.M.Smith	+	+	-	+
	+	-	-	+

Season / Algae	Summer	Autumn	Winter	Spring
Scenedesmus quadricauda var. *longispina* (Chodat) G.M.Smith	+	+	-	-
Scenedesmus bijuga var. alternans (Reinsch) Hansgirg				
Acutodesmus acuminatus (Lagerheim) Tsarenko Selenastrum	+	+	+	-
westii G.M.Smith.	+	-	-	-
Schroderia judayi G. M. Sm.	+	+	-	+
Tetraëdran minimum (A.Braun) Hansgirg.				
Bascillariophyta				
Asterionella gracillima (Hantzsch) Heiberg	-	-	+	-
Cyclotella sp.	+	+	+	+
Eunotia pectinalis (Kützing) Rabenhorst	-	-	+	-
Ceratoneis closterium Ehrenberg	+	+	-	-
Meridion circulare (Greville) C.Agardh	-	-	+	-
Navicula canalis R.M.Patrick	-	-	+	-
Navicula mutica Kützing	-	-	+	-
Navicula cryptocephaloides Hustedt	-	-	+	-
Navicula protracta (Grunow) Cleve	-	-	+	-
Navicula salinarum Grunow	-	-	+	-
Navicula aitchelbee Bahls	-	-	+	-
Navicula confertacea (Cleve).	-	-	+	-
Navicula caroliniae Bahls	-	-	+	-
Navicula lanceolata (Agardh.) Kutz.	-	-	+	-
Navicula winona Bahls	-	-	+	-
Navicula sp.	+	-	+	+
Gomphonema angustatum (Kützing) Rabenhorst	-	-	+	-
Gomphonema parvulum (Kützing) Kützing	+	-	-	-
Nitzschia palea (Kützing) W.Smith	-	-	+	-
Nitzschia clausii Hantzsch	-	-	+	-
Nitzschia hungarica Cleve & Grunow	-	-	+	-
Nitzschia sp.	+	+	-	+
Nitzschia closterium (Ehrenberg) W.Smith	+	+	+	+
Synedra acus Kütz.	-	-	+	-
Synedra ulna (Nitz.) Her.	-	-	+	+
Euglenophyta				
Euglena proxima Dang.	-	-	+	+
Trachelomonas hispida (Perty) F.Stein	+	+	+	+
Trachelomonas sp.	-	+	-	-
Pyrrhophyta				
Ceratium hirundinella (O.F.Muell.) Duj.	+	-	-	-
Glenodinium quadridens (Stein) Schiller	+	-	-	-
Peridinium sp.	+	+	+	-

+ = presence, - = absence

The density of phytoplankton showed a downward trend with the highest in summer (27708 ± 7019 cells. mL^{-1}) to the lowest in spring (1840 ± 1257 cells. mL^{-1}). *P. limnetica* occurred much more abundantly at station 3 (Gezel Geshlag), reaching its greatest density (27014 cells. mL^{-1}) in summer 2013. As shown in Fig. 4 Cyanobacteria had the highest density (74%) of phytoplankton in the Aras reservoir during the period of this study. This trend was observed in all seasons. Euglenophyta (14%) formed the second dominant phytoplankton division, with a low species diversity (3 species). Euglenophyta indicated their highest

density in autumn comprising 27% of the total algal density. *Trachelomonas hispida* was the dominant species in this group. Chlorophyta showed its highest species number in the spring when it was warm. However, this division constituted only 5% of the total phytoplankton density (Fig. 5). *Scenedesmus* spp. allocated the highest number of species among Chlorophyta. Bacillariophyta occurred during cold seasons (winter and autumn) with *Naviculla* spp. showing the highest species number. *Ceratium hirundinella, Glenodinium quadridens* and *Peridinium* sp. were species from Pyrrhophyta which were observed in mid-summer, except for *Peridinium* sp. that was seen in autumn as well as in winter. In this study, the majority of the species belonged to functional groups that are typical of eutrophic water systems (Padisák *et al*., 2009). Many of them have a cosmopolitan distribution (e.g. *Microcystis botrys*, *Synedra acus*, *Synedra ulna, Aphanizomenon flos-aqua*, *C. hirundinella*, *Tetraëdron minimum*).

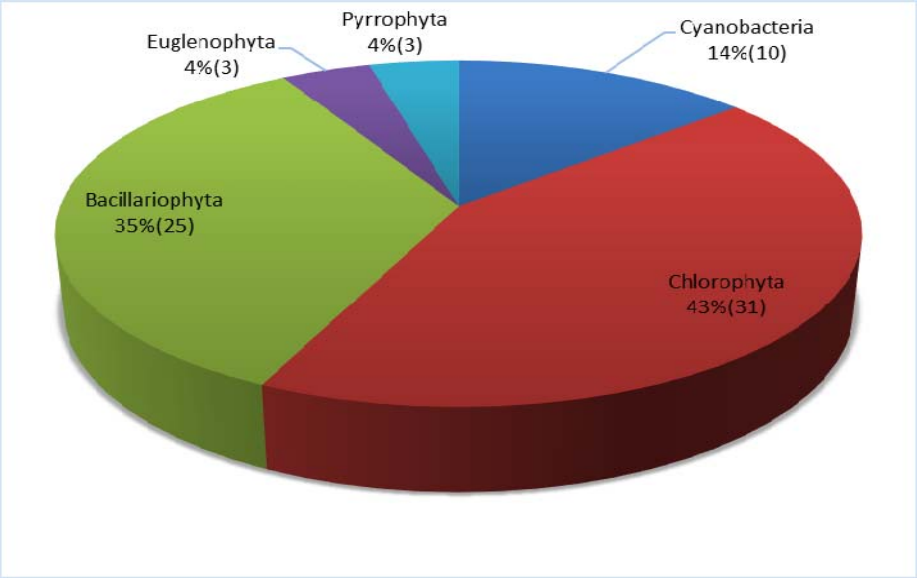

Figure 2: Percentage and species number of identified phytoplankton divisions in the Aras reservoir in 2013-2014.

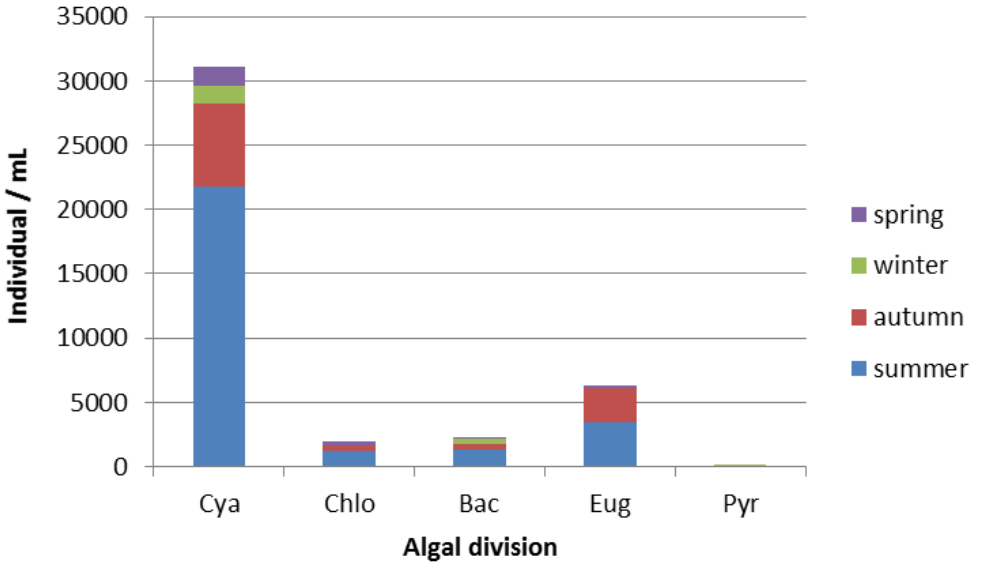

Figure 3: Density of phytoplankton divisions in different seasons in the Aras reservoir in 2013-2014 (Cya=Cyanobacteria; Chl=Chlorophyta; Bac=Bacillariophyta; Eug=Euglenophyta; Pyr = Pyrrophyta).

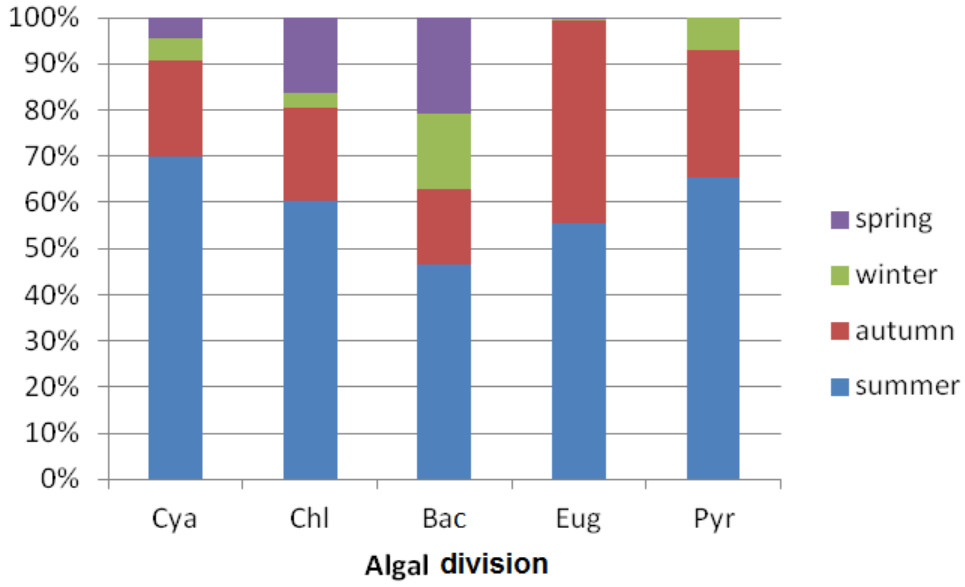

Figure 4: Percentage of phytoplankton divisions' density in different seasons in the Aras reservoir in 2013- 2014 (Cya=Cyanobacteria; Chl=Chlorophyta; Bac= Bacillariophyta; Eug=Euglenophyta; Pyr = Pyrrophyta).

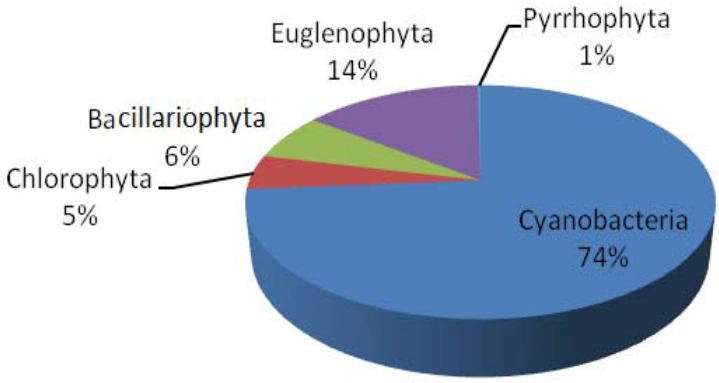

Figure 5: Percentage of density of phytoplankton divisions in the Aras reservoir in 2013- 2014.

The physical and chemical parameters of Aras Lake are given in Table 3. Regarding the results, the highest total phosphorous concentration, found in summer 2013 immediately after the rainy season, may be attributed to the nutrient loading from agricultural run-off and untreated waste water. The pH values were high (8.1- 8.3) during the period of this study which induce high phytoplankton production (Bera *et al*., 2014). Bera *et al*. (2014) also showed that the alkalinity was negatively correlated with algal density which confirms our findings (R^2=-0.56). The higher mean±SD of TP concentrations suggest that phosphorous was a limiting factor for phytoplankton growth (Table 3) in that, TP was positively correlated (R^2=0.734) with phytoplankton density (Fig. 8). Senapati *et al*. (2011) found a positive correlation between nitrate and phytoplankton density which was not in agreement with our study. The negative correlation between the total phytoplankton density and transparency (R^2 =- 0.48, p<0.05) (Fig. 8) in the Aras reservoir indicated that the higher abundance of phytoplankton led to decreased transparency (Hossain *et al*., 2013; Cordero and Baldia, 2015).

Table 3: Physical and chemical parameters in water (mean ± SD) in the Aras reservoir (2013-2014).

Spring	Winter	Autumn	Summer	Parameter
2.7±0.55	0.47±0.63	0.34±0.56	1.13±0.91	TP ($mg.L^{-1}$)
3.2±2.1	1.56±0.56	3.79±3.6	0.84±0.13	TN ($mg.L^{-1}$)
6.65±2.5	3.36±1.2	6.9±4.1	0.75±0.15	TN:TP ($mg.L^{-1}$)
22.3±1.2	8.2±0.45	20.1±0.42	26.8±0.57	Water Temperature (° C)
3.9±0.5	5.2±2.5	10.2±2.1	8.6±0.86	DO ($mg.L^{-1}$)
8.4±0.1	8.1±0.89	8.3±0.61	8.3±0.65	pH
267.6±13.4	318.4±14.7	239.0±13.1	218.4±4.6	T Alkalinity ($mg.L^{-1}$)
36.0±12.9	26.4±8.3	21.6±9.2	36.8±7.7	CO_3^- ($mg.L^{-1}$)
231.6±6.5	292.0±6.8	217.6±18.9	181.6±7.3	HCO_3^- ($mg.l^{-1}$)
411.2±6.6	471.6±7.0	390.4±12.2	317.2±4.8	Total Hardness ($mg.L^{-1}$)
69.1±3.4	89.3±1.5	57.7±4.6	48.7±2.3	Ca^{2+} ($mg.L^{-1}$)
57.9±2.4	60.4±1.5	59.8±1.5	47.4±2.1	Mg^{2+} ($mg.L^{-1}$)
1.29±0.94	0.86±0.13	0.84±0.43	0.11±0.1	Transparency (m)

An attempt to evaluate the trophic state of the Aras Reservoir was made by using the index proposed by Lamparelli (2004) which provided a more accurate classification for reservoirs. Table 4 shows the application of this index to each season and to the overall conditions of the Aras Reservoir. This index classifies the reservoir as oligo-, meso-, and eutrophic according to Chl *a* concentrations. Besides, based on total phosphorous concentrations, the Aras reservoir water was hypereutrophic during the whole study period. Secchi Disc (SD) depths however, show that the Aras reservoir water ranges from eutrophic to hypereutrophic with regard to different seasons (Table 4 and Fig. 6). To evaluate the trophic characterization of an aquatic system, many trophic indexes have been developed for temperate regions (Carlson, 1977; Lamparelli, 2004). The modified Carlson (1977) trophic state index (TSI) (Lamparelli, 2004) for lakes and reservoirs classifies the Aras reservoir as a system with a tendency to be eutrophic [TSI (Chl a) = 61.4±3.7], hypereutrophic [TSI (TP) = 75.6±2.03] and hypereutrophic [TSI (SD) = 70.2±16.6], whether it is calculated with chlorophyll *a*, total phosphorus concentrations or SD (Secchi Disk depths), respectively.

Table 4: Trophic State Index (TSI) (mean ± SD) of the Aras dam reservoir calculated using the modified Lamparelli (2004) index.

Season	TSI(Chla)	TSI(TP)	TSI(SD)	Reservoir trophic state
Summer	85.6±10.3	78.8±0.34	94.8±10.3	Hypereutrophic
Autumn	54.9±7.6	73.7±0.7	64.1±7.6	Mesotrophic-Hypertrophic-Supereutrophic
Winter	53.1±2.3	75.1±0.55	62.3±2.2	Mesotrophic-Hypereutrophic- Eutrophi
Spring	50.28±16.6	74.7±0.47	59.5±10.7	Oligotrophic-Hypereutrophic-Eutrophic
Total	61.4±3.7	75.6±2.03	70.2±16.6	Eutrophic-Hypereutrophic-Hypereutrophic

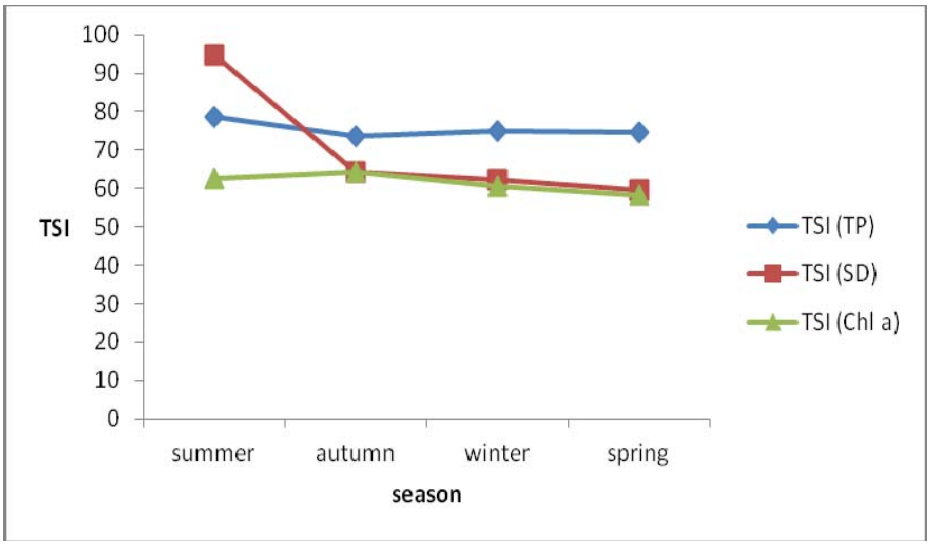

Figure 6: Trophic State Index (TSI) in the Aras reservoir in 2013-2014. TP = Total phosphate, SD=Secchi Disk depth, Chl *a*=Chlorophyll *a* concentration.

The highest and the lowest values of diversity index were observed at station 3 in autumn (1.87) and station 4 in winter (0.44) respectively (Figure 7). The mean values of the Shannon-Weaver diversity index in the Aras reservoir in summer, autumn, winter and spring were 1.3, 1.54, 1.05 and 1.14, respectively.

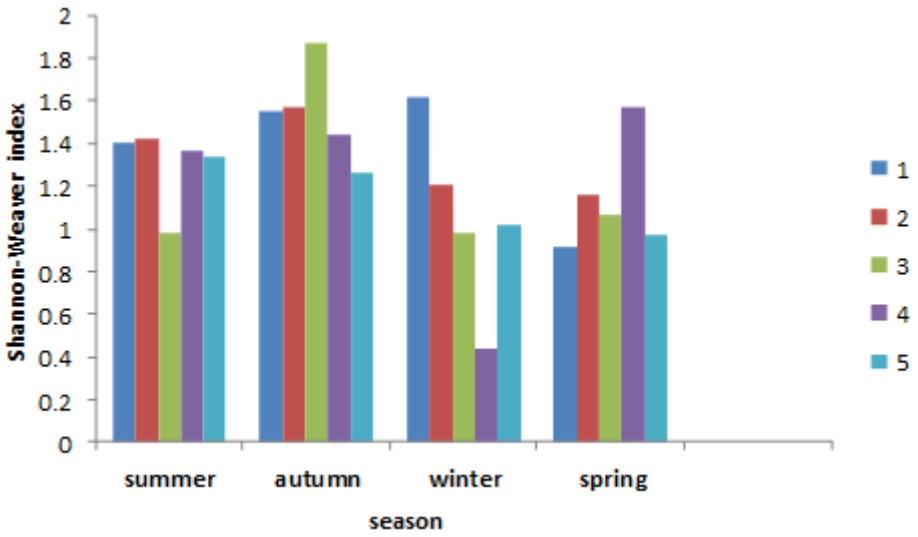

Figure 7: Seasonal changes of Shannon-Weaver diversity index (H´) at sampling stations (1, 2, 3, 4 and 5) in the Aras reservoir.

We determined correlations and calculated regression coefficient (R^2) between the phytoplankton density and some physicochemical parameters of the reservoir. The results indicated that

phytoplankton density negatively correlated with Secchi disc depth (R^2=-0.479), total alkalinity (R^2=-0.564), total hardness (R^2=-0.727) and HCO_3 concentration (R^2=-0.589) (Fig. 8).

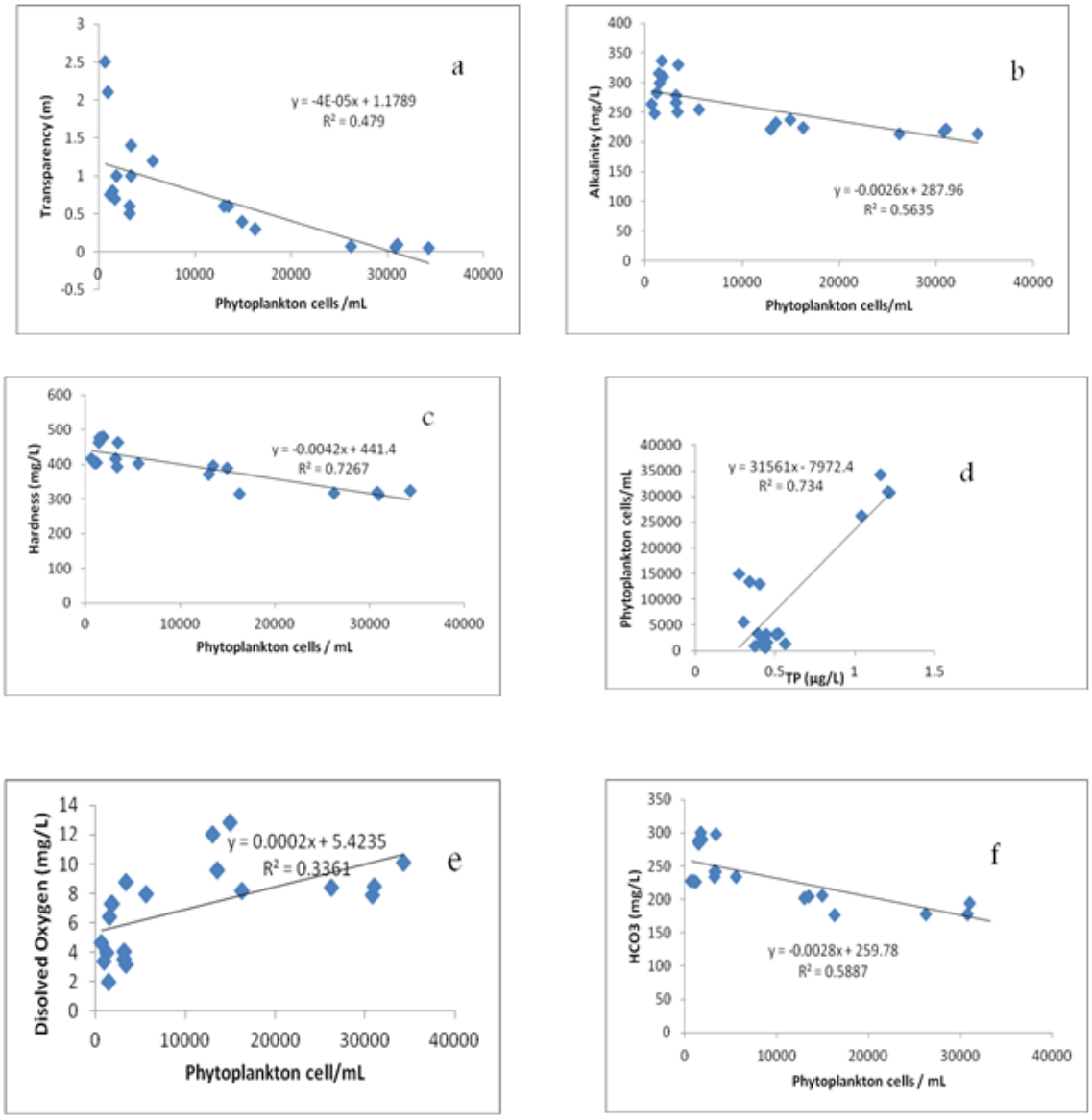

Figure 8: Regression plot between phytoplankton density and some physico-chemical factors in the Aras reservoir.

On the other hand, there was a positive correlation between the phytoplankton density and the concentration of TP (R^2=0.734), (Fig. 8), a moderately positive correlation between the phytoplankton density and DO (dissolved oxygen) (R^2=0.336), (Fig. 8).

Discussion

Phytoplankton dynamics during the period of study in the Aras Reservoir was characterized by 'nuisance' species (Cyanobacteria). The maximum density of Cyanobacteria was observed during the warm period (summer) which then

gradually decreased from autumn to winter and spring but did not disappear completely. In the Aras reservoir, the presence of cyanobacteria at a high density all year round with seasonal fluctuations indicated that the water quality was poor even in the rainy seasons (i.e. winter and spring). It seems that the higher water temperature (Table 3), low precipitations and drought in the region were the main reasons for this condition. The high contribution of Cyanobacteria in the phytoplankton density (Fig. 5) was indicative of poor water quality (Chorus and Bartram, 1999; Jöhnk *et al*., 2008; House *et al*., 2010). Finally, this survey has provided the first occurrence of the *P. limnetica* in the Aras reservoir in the Caspian Sea basin. *P. limnetica* has been identified in many reservoirs (e.g. Nixdorf *et al*., 2003; Kozak, 2005; Grabowska and Mazur-Marzec, 2011) that can produce water blooms in lakes and reservoirs (Kozak *et al*., 2014). In a previous study conducted by Mohebbi *et al*. (2012b) the occurrence of Cyanobacteria was reported in the Aras reservoir, but in that study *Microcystis* was the dominant species (we enumerated the *Microcystis* colonies using an inverted microscope) which formed visible macro colonies only in summer and early autumn. *Microcystis* colonies completely disappeared from the reservoir in winter and spring. However, in the present study the dominant Cyanobacterial species (i.e. *P. limnetica*) indicated a high dominance during the warm period (summer and autumn). This change in Cyanobacterial bloom patterns may be related to global warming and drought inf the region during the last few years. It has been hypothesized that the impact of global warming may lead to an alteration in the development of phytoplankton (Paerl and Huisman, 2009; Gallina *et al*., 2011), and therefore to a possible change in the community structure with the proliferation of Cyanobacteria. As more frequent higher temperatures are expected in a warmer climate, an enhanced biomass increase among the Cyanobacteria and diversity loss in the phytoplankton community can be anticipated. Human activities affect the phytoplankton community either by accelerating global warming or by increasing nutrient loadings entering the aquatic systems.

Several comparative studies all over the world have demonstrated that eutrophication affects the phytoplankton structure and types (Sommer *et al*., 1986, Nixdorf and Deneke, 1997, Reynolds, 1998; Long *et al*., 2013), leading sometimes to local loss of diversity with the explosion of a few species with high abundance (Talling and Lemoalle, 1998). In the Aras reservoir, phytoplankton communities showed considerably more changes in quantity than quality during the period of this study. The decrease in Secchi depth in the water from summer 2013 to early autumn 2013 was partly associated with the increase in densities of Cyanobacteria. This indicated a competitive advantage to Cyanobacteria, once the high densities of *P. limnetica* were obvious in this period. Self-shading caused by Cyanobacteria, which presented the highest densities, influenced the development of Chlorophyta negatively. According to Happey-Wood (1998), self-shading exerted by Cyanobacteria

excluded Chlorophyta due to the advantage of the first group concerning chromatic adaptation. In the present study, this condition was observed in summer and autumn 2013, when the density of Cyanobacteria was the highest, but in spring 2014, Chlorophyta density was relatively increased.

In general, phosphorus was most often the limiting nutrient for phytoplankton growth in freshwater systems (Hecky and Kilham, 1988). The dominance of Cyanobacteria in lakes, in addition to characteristics such as elevated TP and temperature, is usually associated with low TN/TP ratios in turbid waters (Dokulil and Teubner, 2000). Low N:P ratios found in the present study are characteristic of aquatic systems with a high dominance of heterocystous cyanobacteria, which was confirmed by Huszar *et al*., (2000) by studying five reservoirs in Brazil. In this study TN was not the limiting nutrient, but TP was so. Therefore, we used TP to calculate the TSI in the Aras reservoir. When TSI is determined with two or more variables (chlorophyll *a*, total phosphorus and Secchi disk), differences in TSI values might occur (Rakocevic-Nedovic and Holler, 2005), as it happened in Aras reservoir too. On average, the overall trophic state of the Aras reservoir is the euo-hypereutroph according to Lamparelli (2004) index (Table 4). It is obvious that the presence of Cyanobacteria, especially *Ps. limnetica* induced a decrease in the phytoplankton biodiversity linked to an increase in temperature and pH values and a decrease in transparency.

In general, the Shannon-Weaver diversity index was low (0.44-1.87) in the Aras reservoir (Fig. 7). The diversity index can change with key ecological processes such as competition, predation and succession (Sabanci, 2014). The low diversity index values observed in this study generally corresponded to high dominance (%74) of cyanobacteria. The highly significant correlation of TP with phytoplankton density (R^2 =0.734, Fig. 8d) also confirmed the dominance of Cyanobacteria and the eutrophication in the Aras reservoir.

Although in the present study *Microcystis* was present in whole period of study, but did not form large visible colonies as those was reported by Mohebbi *et al*., (2012a) in the Aras reservoir. Since colony size strongly influences buoyancy and vertical migration (Kromkamp and Walsby, 1990), the vertical distribution of colonies can be affected by colony size and large *Microcystis* colonies typically float to the water surface, while small colonies (less than 36 mm) and single-cell *Microcystis* showed a nearly uniform vertical distribution over depth (Wu and Kong, 2009).

Phytoplankton can be used as a good indicator of water quality changes, given its sensitivity and dynamic responses to changes in the surrounding environment (Padisák *et al*., 2006). The results of this study indicated that the Aras reservoir was eutrophic, and phytoplankton communities exhibited a seasonal pattern dominated by Cyanobacteria. Our results also indicated that the dominance of Cyanobacteria was linked to high TP concentrations and water

temperature which seemed to be consistent with other works (Paerl and Huisman 2008; Liu *et al*., 2011).

Briefly, the eutrophication of the Aras reservoir has progressed so that mean Secchi disc transparency declined from 1.42 m in 2008-2009 (Mohebbi *et al*., 2012b) to nearly 0.77 m by 2013- 2014. On the other hand, phytoplankton bloom patterns have shifted from colony-forming cyanobacterium *Microcystis* (Mohebbi *et al*., 2012a) to individual filamentous cyanobacterium, *P. limnetica* in the present study. Therefore, inter-annual data concerning phytoplankton assemblages in the studied water body would also be essential to determine phytoplankton structure variation and create a phytoplankton database for this important freshwater ecosystem of the country. Finally, Cyanobacterial cell abundances in the Aras reservoir should be monitored to prevent diseases in human and animal, because the lake is used by human as a source for drinking water, fisheries and tourism activities.

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