The Effects of Water Withdrawal and *A. urmiana* on Phytoplankton Communities in Urmia Lake (Northwest, Iran)

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Abstract

Urmia Lake is one of the largest permanent hypersaline lakes in the world. The lake can be characterized as an oligotrophic lake concerning phytoplankton production. Due to agriculture development and low precipitation in recent years in Urmia Lake's basin, the water level has declined as much as 4 m compared to 15 years ago. Water level decline influence the phytoplankton population through increased water salinity. Furthermore, *Artemia urmiana* Gunther as the major zooplankton in hypersaline lakes may affected on phytoplankton populations. Therefore, the purpose of the present study was evaluation how *A. urmiana* impact on the phytoplankton structure in Urmia lake. Eight stations were selected in south and north parts of the lake. Sampling were performed monthly during May 2018 to June 2020. Phytoplankton structure were analysed by inverted microscopy. Environmental parameters water temperature, pH, salinity, water level, Total Dissolved Solids (TDS), Electric conductivity (EC) were determined in each sampling. Seasonal fluctuations of algal abundance influence *A. urmiana* population in temperate large hypersaline lakes such as Urmia Lake. However, *A. urmiana* grazing pressure has significant effects on microalgal density. This study indicated that salinity is not increased directly by water level decline in Urmia Lake.

Keywords: *A. urmiana*, Cyanophyta, *Dunaliella salina*, phytoplankton population, Urmia Lake, Water Withdrawal.

Introduction

Hypersaline environments is a unique ecosystem due to biogeochemical processes occurring, so that, they may be considered as integral and dynamic part of the biosphere (Mohebbi, 2010; Shadrin, 2009).

Excessive consumption of surface and ground waters, coupled with frequent droughts (Manaffar et al., 2020) has escalated Urmia Lake's water situation to a critical level. Evidence for this includes: a drying lake, wetlands with declined depth; declining groundwater levels; water quality degradation; soil erosion; desertification and frequent dust storms. The Iranian government has promoted increasing irrigation to increase

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agriculture productivity which has encouraged an expansion of cultivated areas across the Urmia Lake basin (Madani et al., 2016). Farmers, however, have not employed new technologies and practices, resulting in inefficient irrigation and production. Decreasing river inflow has severely disrupted the lake ecosystem. The brine shrimp *A. urmiana* densities have been decreased sharply, so that only cysts can be observed at low density in the remained lake water (Asem et al., 2012, 2019). Algal communities of the lake have been disturbed remarkably and their diversity and density have been declined. Plants biodiversity of periphery wetlands has been decreased, leaving only a few taxa of aquatic macrophytes, and algal-dominated systems. The onset of a drought in 2007 over the Urmia Lake basin together with an increase in the rate of groundwater depletion reduced the water storage of the whole basin. This study also confirmed a general decreasing trend in the basin stream flow that pronounced in the downstream stations. On average, the lake has lost 34± 1 cm/yr of its water level from 2002 to 2014, equal to a loss of water areal extent at an average rate of 220± 6 km^2/yr. Totally, the lake has lost about 70-80% of its surface area over the last 14 years (Tourian et al., 2015; Asem et al., 2019). Their results also indicate that the lake volume has decreasing at an alarming rate of 1.03± 0.02 km^3/yr.

Based on the analysis of remote sensing data, Chaudhari et al. (2018) found 98% and 180% increasing in agricultural lands and urban areas, respectively, in the lake basin from 1987 to 2016. Comparison of river inflow to the lake from 1995 to 2010 suggested that human water management activities together with tripled irrigation requirement caused a reduction in stream flow of about 1.74 km^3/year, which accounted for about 86% of the total depletion in the lake volume during the same period (Chaudhari et al., 2018). Hypersaline lakes management and protection as changing ecosystems depend largely on an understanding of the influence of salinity on biological productivity and community structure. In other words, salinity level changes both directly or indirectly affect on the primary production which in turn may influence *A. urmiana*, as the major macrozooplankton of hypersaline waters. On the other hand, *A. urmiana* population is able to influence phytoplankton composition by feeding on them; therefore there is a continuous reciprocal interaction between *A. urmiana* and phytoplankton population in hypersaline environments (Mohebbi, 2010). So, the objective of the present study was to compare two different phases of lake water level in terms of microalgal composition and *A. urmiana* population in order to provide a better understanding the dynamics of these unique ecosystems when water level drops.

Materials and Methods

Sampling and species identification

When water level was lower than 1271 m above sea level, boat sailing was impossible in the lake due to low depth of water, so sampling was performed from side stations in beach (sampling at 2018), while in high water levels periods (2019-2020) samples were taken by boat. Totally, we selected eight sampling site in different parts of the lake (Fig. 1). Sampling were carried out monthly, from May 2018 to June 2020 during 26 months. In each station 3 samples were taken for *A. urmiana* life stages and density assessment, physico-chemical factors analysis and phytoplankton enumeration and identification study. After fixation by logul solution, phytoplankton samples were kept in cold, dark condition for laboratory analysis. Phytoplankton counting and identification were done using 5 ml settling chambers with a Nikon TS100 inverted microscope at 400× magnification according to 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. Phytoplankton taxa were determined according to Prescott (1962), Tiffany and Britton (1971) and Bellinger (1992). *A. urmiana* samples were collected by net (150 µ mesh size) in definite distance, as the sectional area of collecting net was known the volume of water passed through net was calculated easily.

Physico-chemical parameter analysis

Salinity was measured by a refractometer model ATAGO (Japan). In dry period, when salinity was higher than the apparatus measurement range, the water was diluted with distilled water first, then the salinity was measured. In these condition, the real salinity was calculated by multiplying in correct dilution coefficient. Temperature was measured in situ by alcoholic thermometer. EC, TDS and pH were measured by WTW LF 320 EC meter and a Testo 320 PH meter, respectively. Transparency of water was mea-

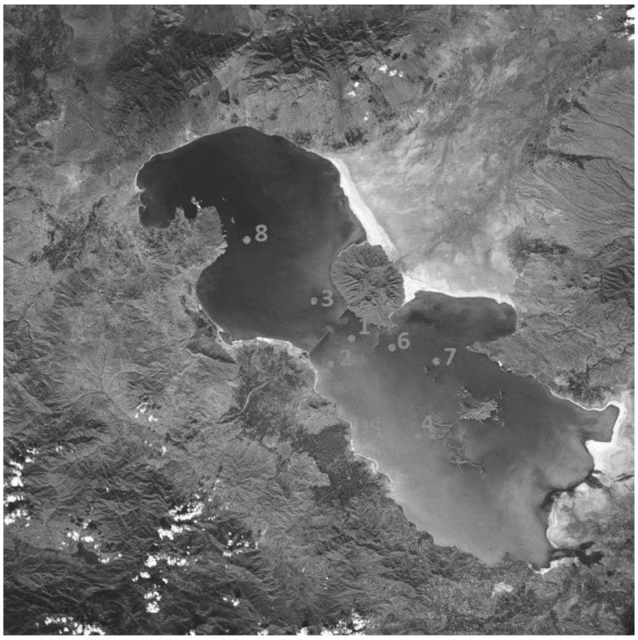

Fig. 1. Location of sampling sites on Urmia Lake in this study

sured by Secchi disc (30 cm diameter). Water level fluctuations of Urmia Lake was extracted from West Azarbaijan Water Management Company's web site (http://www.agrw.ir).

Statistical analysis

Correlation among some variables were calculated in Excell 2013 program. Correspondent analysis (CA) and Detrended Correspondent analysis (DCA) was performed to observe relations between water level reduction and some physico-chemical variables. Furthermore, as *A. urmiana* feeds on phytoplankton so it influences phytoplankton structure. Therefore, the analysis tried to indicate any links among *A. urmiana* population and phytoplankton structure. The data were standardized (mean = 0, variance = 1) before running the analysis. The distance matrix obtained was then used to construct the UPGMA tree. Two-way clustering of samples was carried out using the unweighted pair group method with arithmetic mean (UPGMA), according to the environmental parameters. The Euclidean distance was determined among the studied samples from standardized data. Statistical analysis were performed by PAleontological STatistics (PAST) version 3.04 (Hammer et al., 2001) program.

Results

Totally, eight algal species were identified in Urmia Lake in this study. 6 species belong to Bacillariophyta, the most abundant algal group in the lake. *D. salina* as the only representative of chlorophyta, however, this green algae composed about 99.6 percent of total algal density in Urmia Lake and 1 species belongs to cyanobacteria, (Table 1 and Fig. 2).

Water level in Urmia lake indicated a seasonal fluctuation during a year (Fig. 3). However, due to water withdrawal, Urmia lake's average level values were lower than its ecological level (1274 m) in this study. Water level in Urmia lake was particularly lower than 1271 m during 2018, while in 2019 it was higher than 1271 m which coincided with *Artemia* biomass appearance in the lake. The lowest and highest values of TDS in Urmia lake was observed in June 2019 and July 2019 respectively (Fig. 4). TDS is a pa-

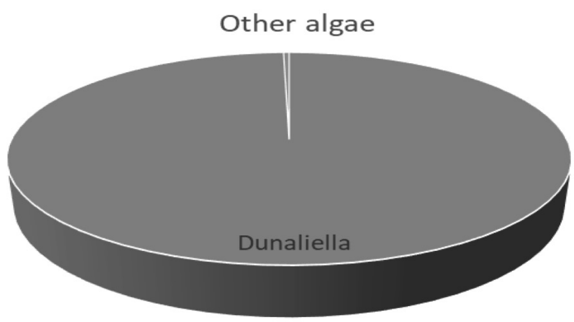

Fig. 2. Algal composition of Urmia Lake during April 2018 to March 2020.

Table 1. Algal species density in Urmia Lake during April 2018 to March 2020.

Density (%)	Mean Density (Ind/L)	Algal species	Spr 18	Sum 18	Aut 18	Win 18	Spr 19	Sum 19	Aut 19	Win 19	Spr2 0
99.6	1923025	*D. salina* (Dunal) Teodoresco	+	+	+	+	+	+	+	+	+
	2172	*Oscillatoria* sp.	+	+	-	-	+	-	-	-	-
	2573	*Navicula* sp.	+	+	+	+	+	-	-	+	+
	271	*Cocconies pediculus* Her.	-	+	-	+	-	-	-	-	-
0.4	1801	*Nitzschia* sp.	-	-	+	+	+	-	-	-	+
	219	*Synedra ulna* (Nitzsch) Ehrenberg	-	+	+	-	-	-	-	-	-
	62	*Symbella prostrata* (Berkeley) Cleve	-	-	+	-	-	-	-	-	-
	287	*Cyclotella* sp.	-	-	+	-	-	-	-	-	+

rameter that shows the total amounts of salts dissolved in water.

EC values fluctuation during June to August 2019 increased and in July 2019 reached highest level (Fig. 5). EC in Urmia lake was linked with water TDS and salinity. As shown in Figure 6, seasonal salinity fluctuation pattern was greatly agreed with lake's water level changes. Urmia lake during 2018 was more salty than 2019 and 2020 (Fig. 6). There was a negative correlation between water salinity and *D. salina* density in Urmia lake (Fig. 7). In salty lakes, lower number of phytoplankton may be observed. Correlation between water level and salinity was negative and weak (Fig. 8), because when water

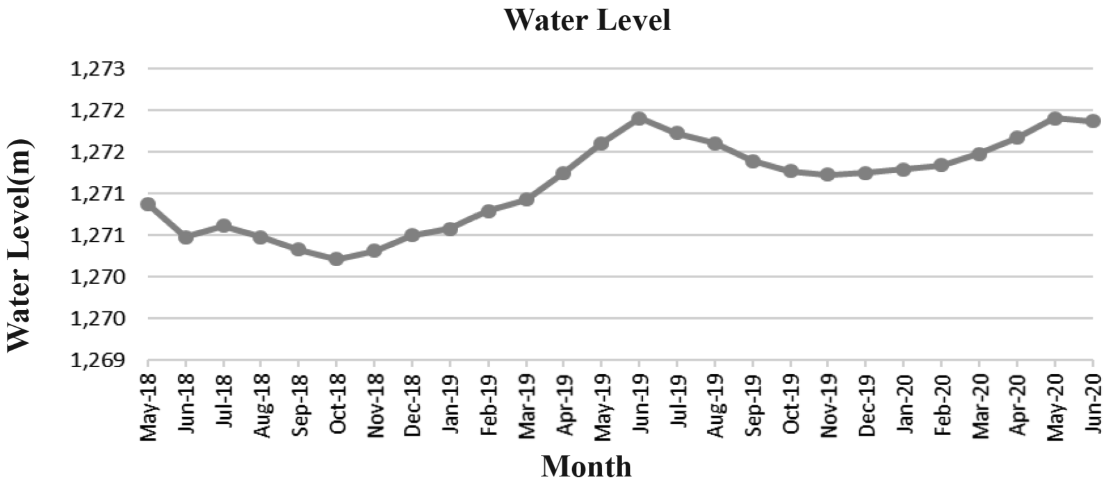

Fig. 3. Urmia Lake water level fluctuations during May 2018 to June 2020.

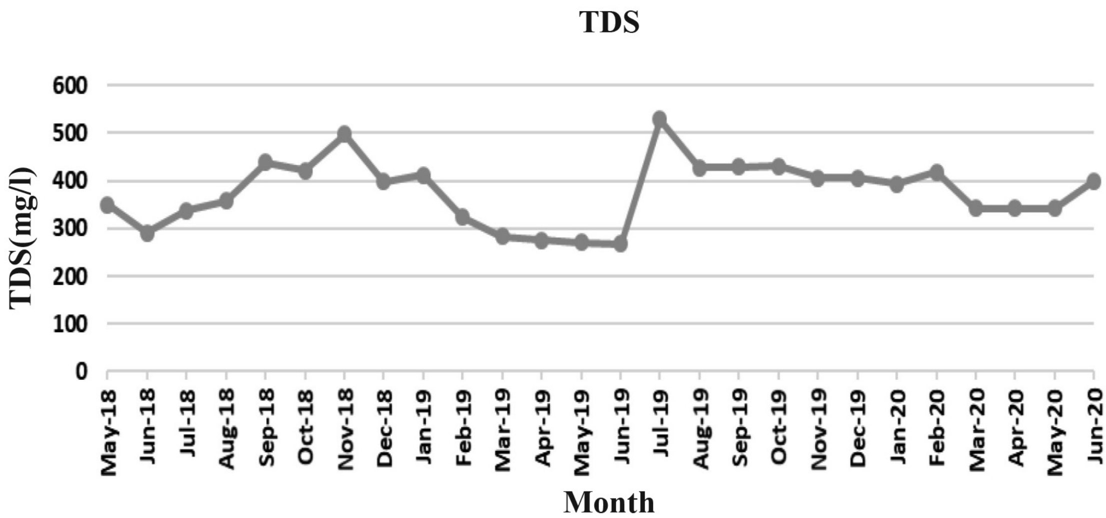

Fig. 4. Urmia Lake TDS fluctuations during May 2018 to June 2020.

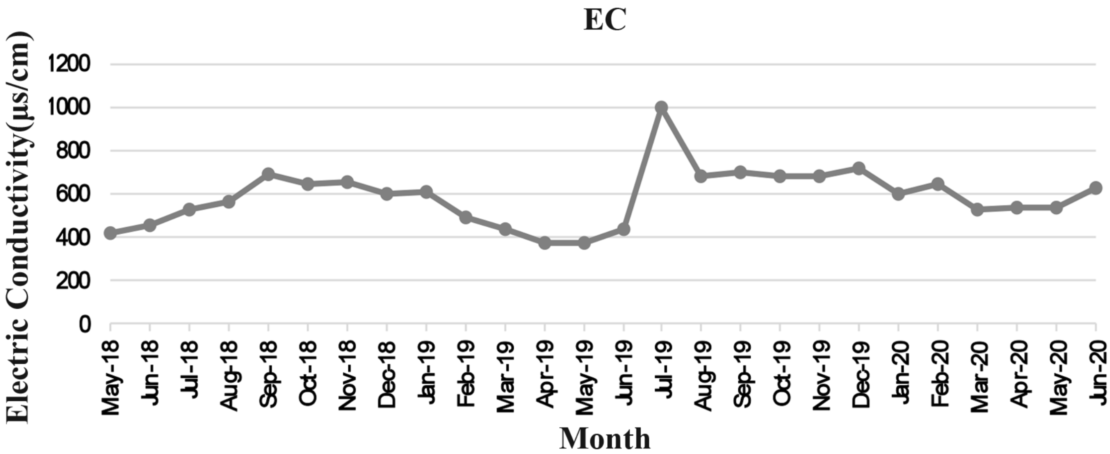

Fig. 5. Urmia Lake EC fluctuations during May 2018 to June 2020.

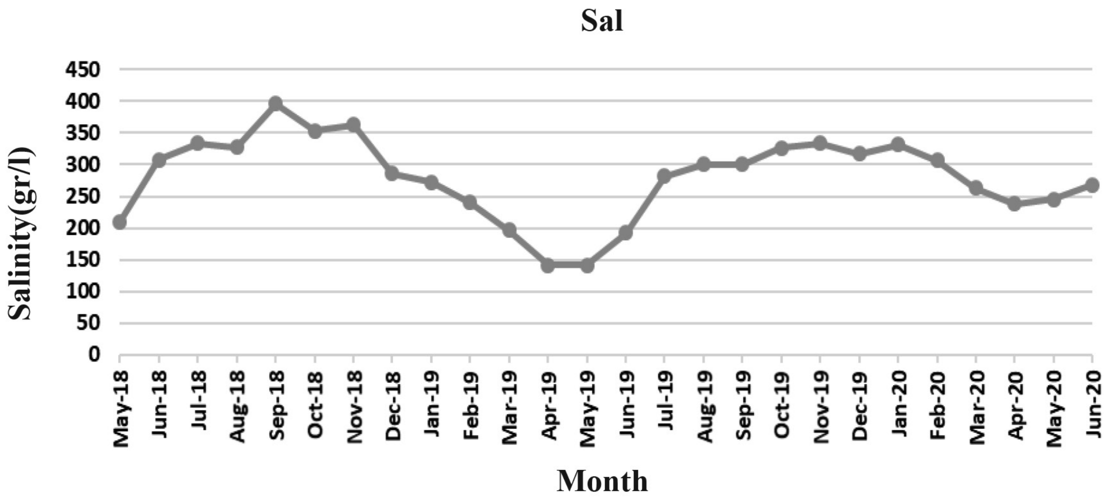

Fig. 6. Urmia Lake salinity fluctuations during May 2018 to June 2020.

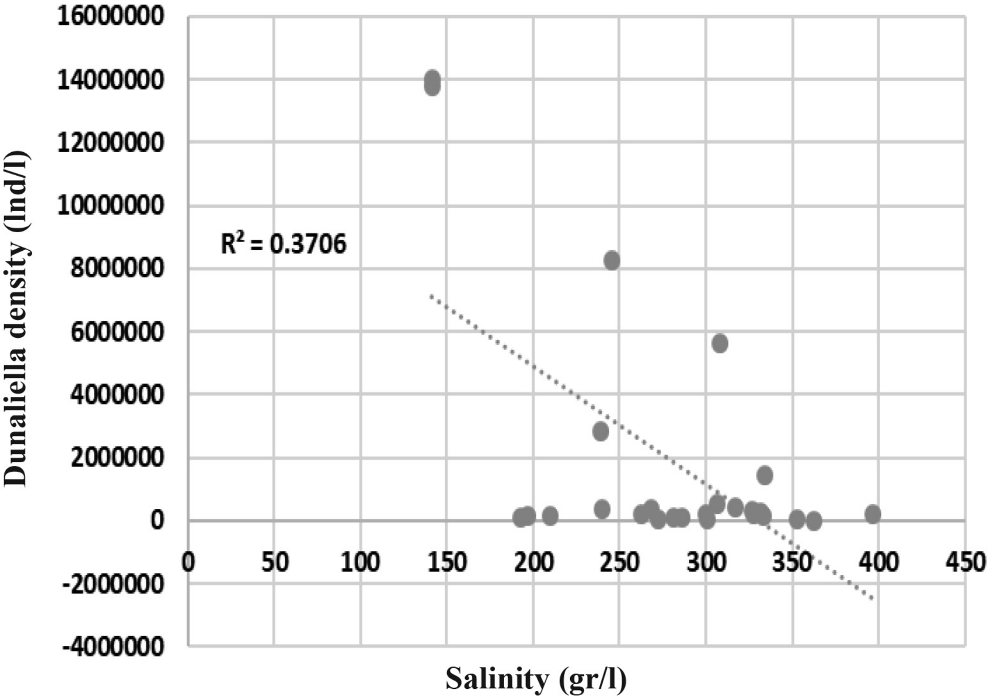

Fig. 7. Correlation between salinity and *D. salina* density in Urmia Lake during May 2018 to June 2020.

level increases it cannot dissolve whole salts toughly precipitated at the bottom of the lake. Figure 9 shows correlation between water salinity and total phytoplankton number in the lake during sampling time. The highest phytoplankton density was observed in the lowest value of salinity (140 gr/l). Like the salinity, EC parameter also negatively correlated with total number of phytoplankton in the lake (Fig. 10). However, this correlation ($R^2 = 0.2856$) was weaker than salinity and TDS correlation with total phytoplankton number (Fig. 11).

Detrended Correspondent Analysis (DCA) of algal species and physico-chemical factors in Urmia Lake during May 2018 to September 2019 is indicated in Fig. 12. *D. salina* dominates the other phytoplankton species which occur occasionally.

Physico-chemical parameters had crucial role in phytoplankton population structure and density in Urmia lake, which may be indicated by Correspondent Analysis (CA) (Fig. 13).

Figure 14 indicates UPGMA clustering of sampling months and physico-chemical variables in this study. The higher values of distances (vertical axis) states high differences in cladogrames. There can be seen four main groups according to various months, with the highest distance values (0.25). These groups which divided to several small groups indicate the months had more different values of physico-chemical parameters (Fig. 14).

Discussion

Hafezieh (2015) evaluated *A. urmiana* stocks in Urmia Lake. He concluded due to

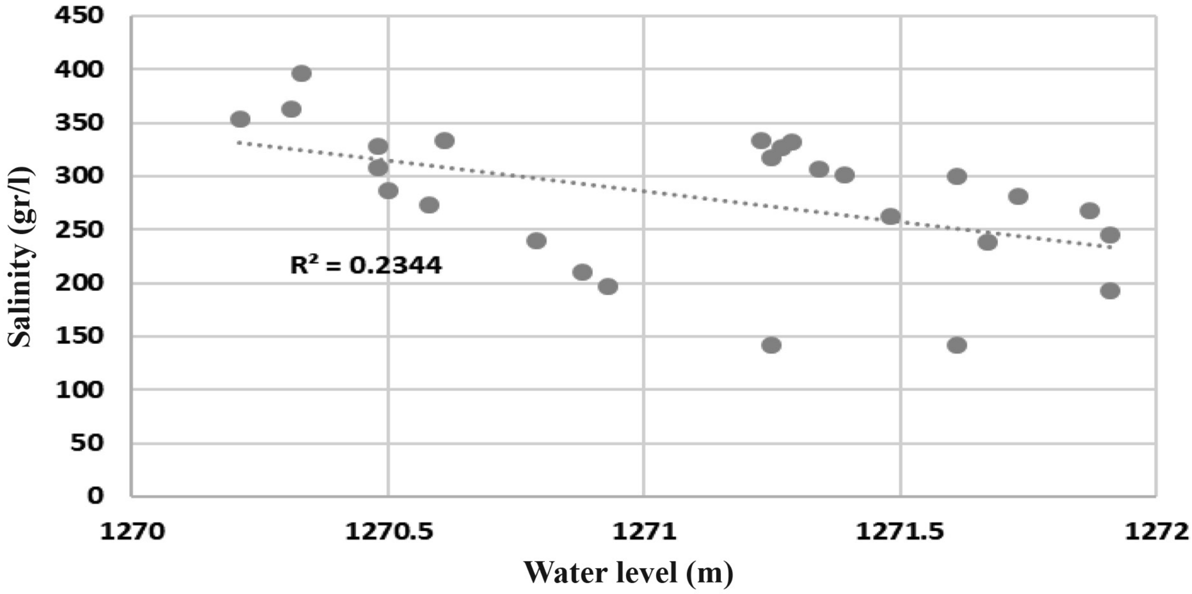

Fig. 8. Correlation between water level and salinity in Urmia Lake during May 2018 to June 2020.

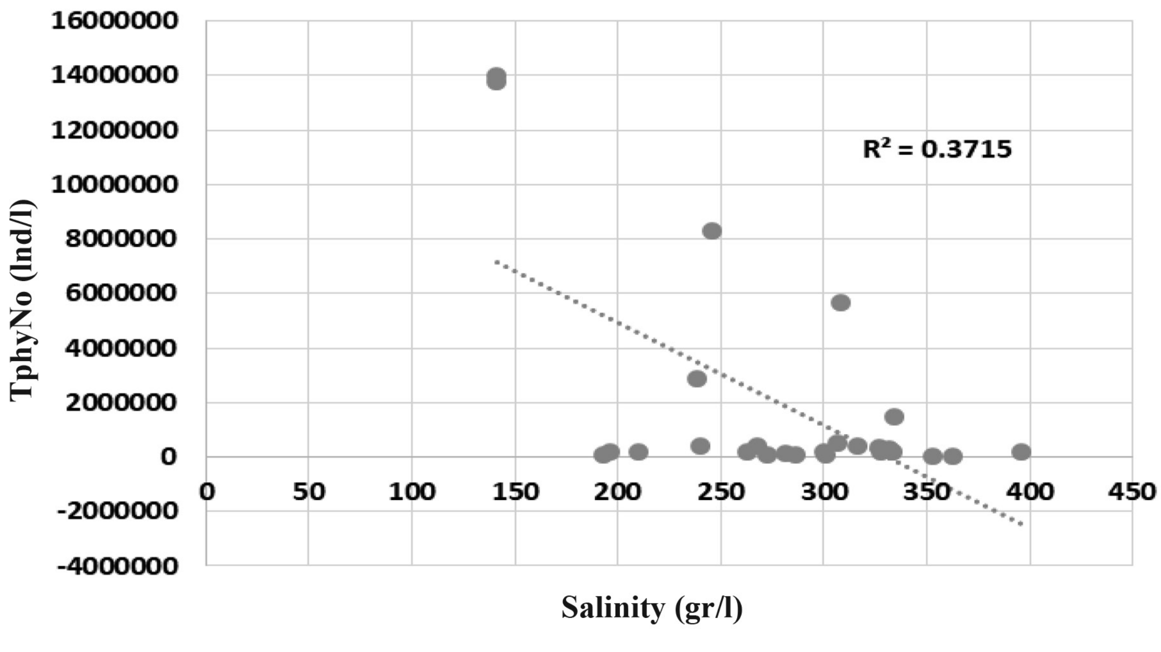

Fig. 9. Correlation between Total Phytoplankton Number and salinity in Urmia Lake.

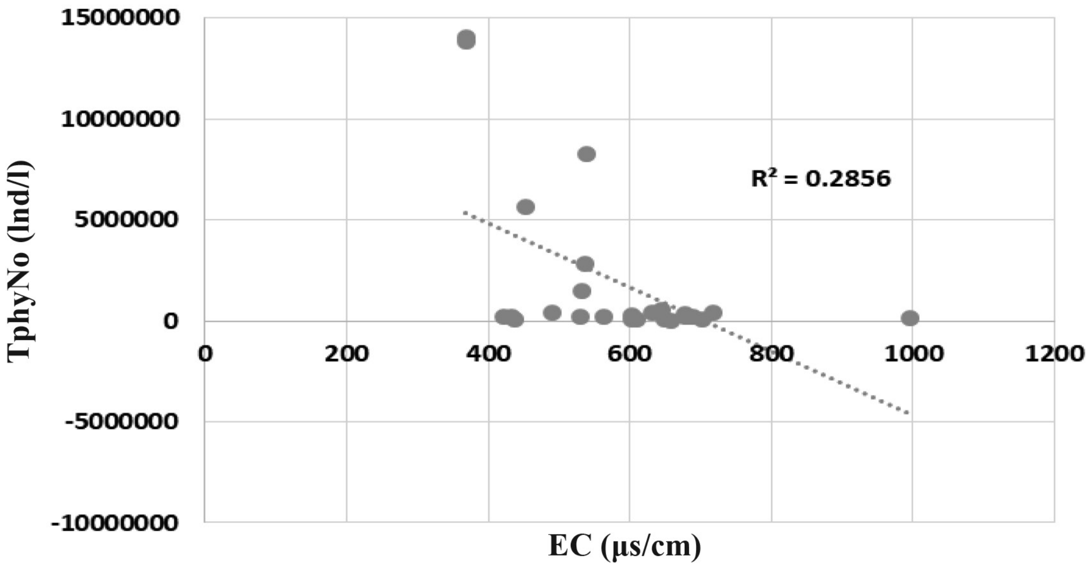

Fig. 10. Correlation between Total Phytoplankton Number and Electric Conductivity in Urmia Lake.

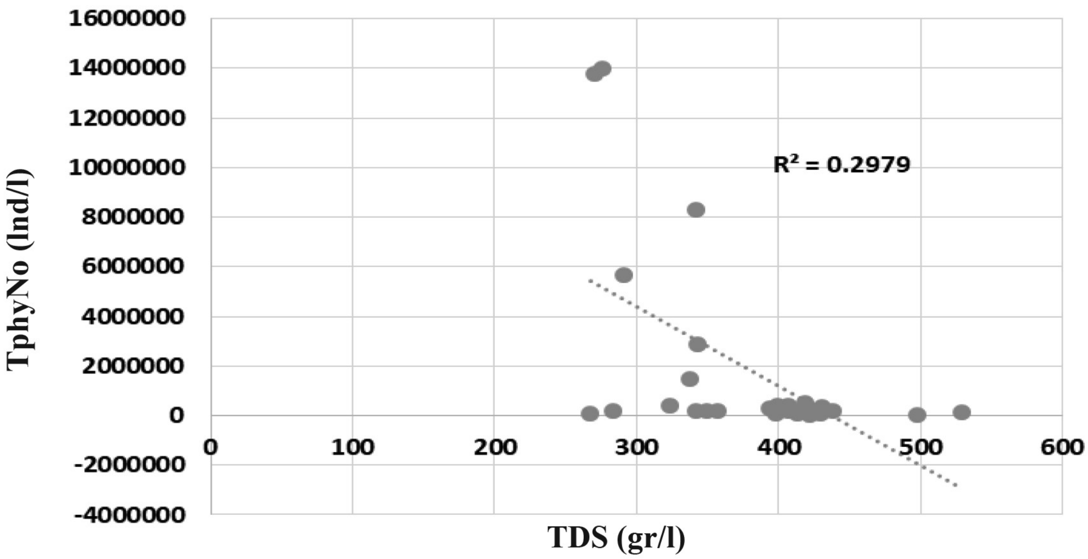

Fig. 11. Correlation between Total Phytoplankton Number and TDS in Urmia Lake.

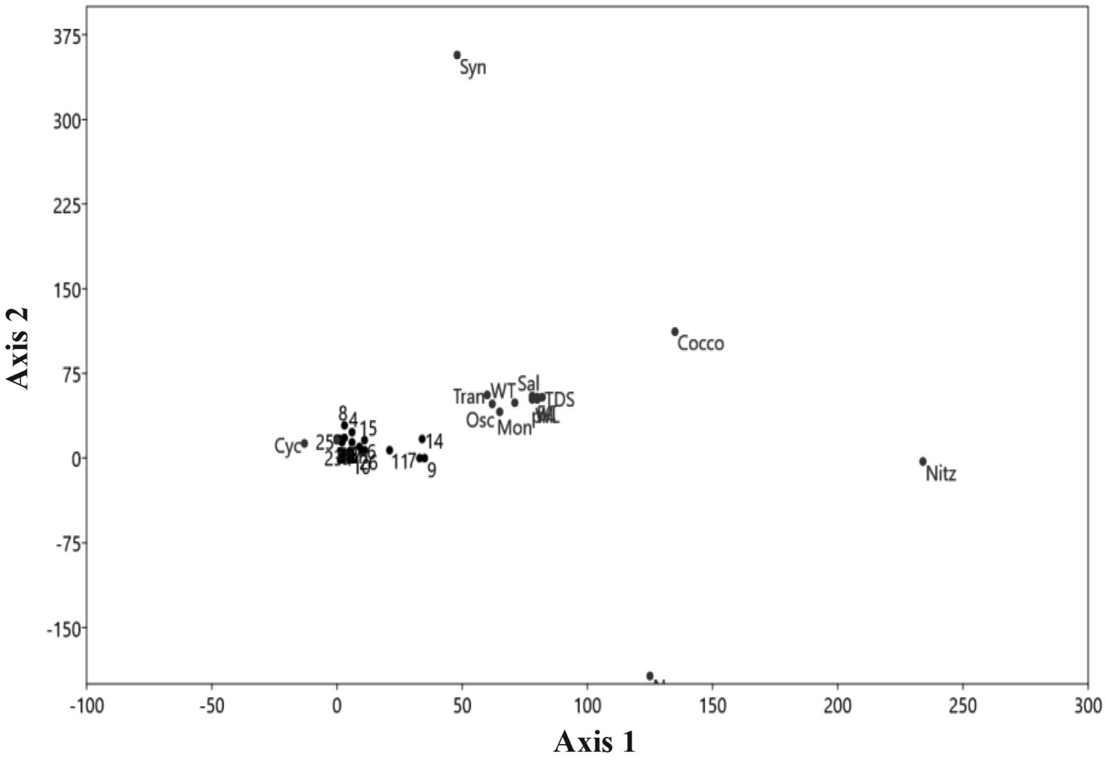

Fig. 12. Detrended Correspondent Analysis (DCA) of algal species and physico-chemical factors in Urmia Lake.

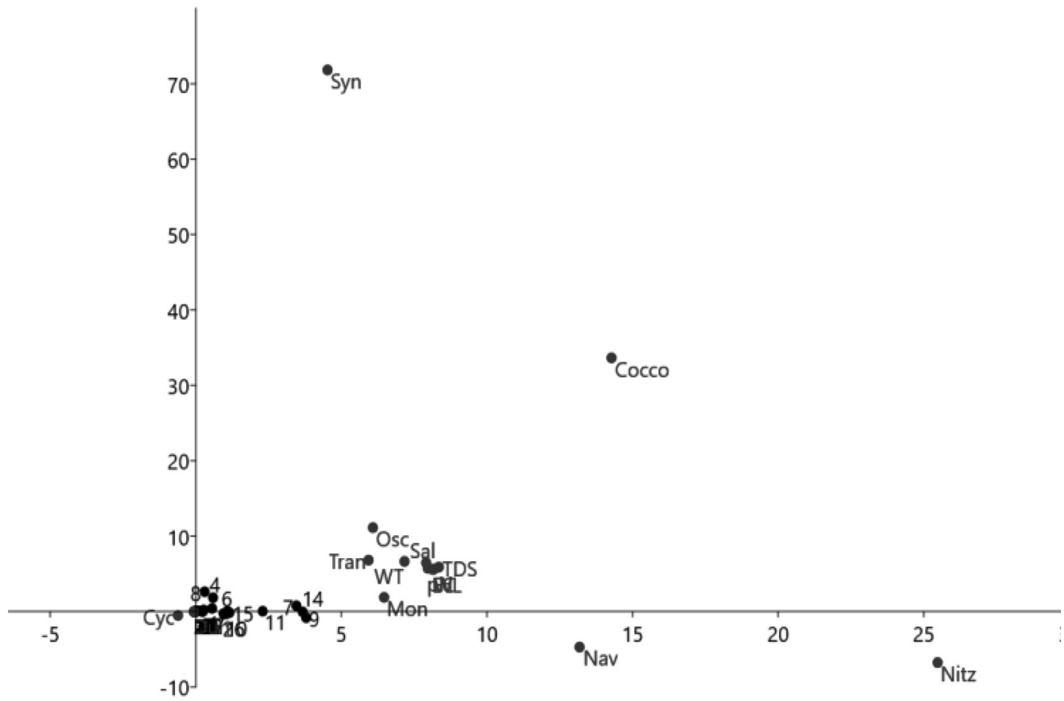

Fig. 13. Correspondent Analysis (CA) of algal species and physico- chemical factors in Urmia Lake.

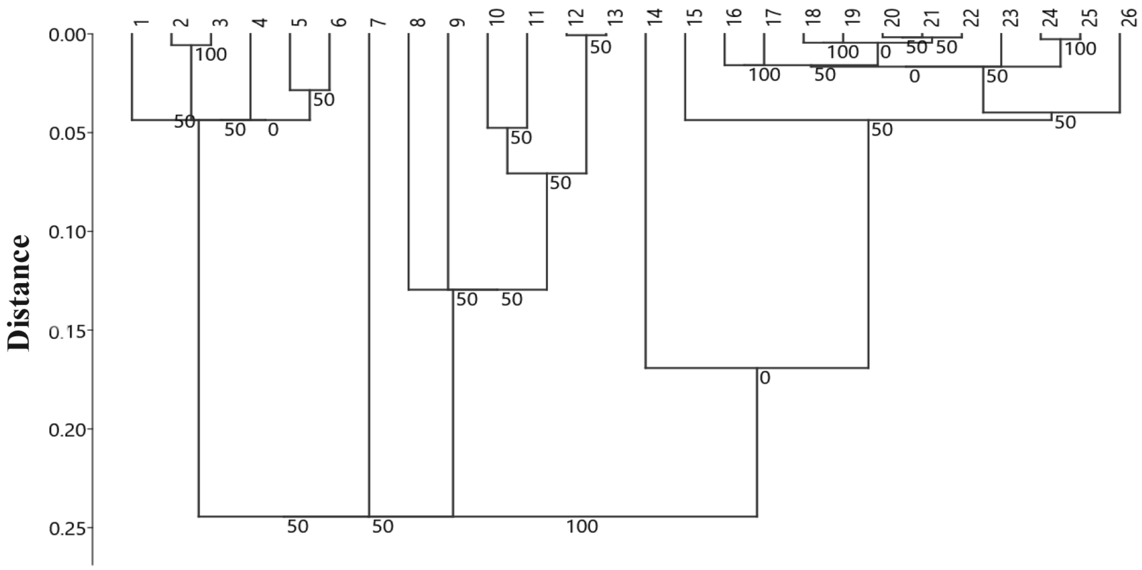

Fig. 14. UPGMA clustering of sampling dates and environmental parameters (each month is defined by a number indicating the sampling time (1 = May 2018, 2 = June 2018, 3 = July 2018 and 4 = Aug 2018, 5 = Sep 2018, 6 = Oct 2018, 7 = Nov 2018, 8 = Dec 2018, 9 = Jan 2019, 10 = Feb 2019, 11 = Mar 2019, 12 = Apr 2019, 13 = May 2019, 14 = June 2019, 15 = Jul 2019, 16 = Aug 2019, 17 = Sep 2019, 18 = Oct 2019, 19 = Nov 2019, 20 = Dec 2019, 21 = Jan 2020, 22 = Feb 2020, 23 = Mar 2020, 24 = Apr 2020, 25 = May 2020, 26 = June 2020); The numbers at the below indicate bootstraps.

water decline in the lake transparency equals depth in whole lake and *A. urmiana* cysts accumulate in surface layer. He also observed that in southern there are more cysts and biomass than north. Velasco et al. (2006) studied the effects of salinity changes on the biotic communities in a Mediterranean hypersaline stream. They suggested that the number of taxa, Margalef's index and Shannon's diversity index decreased when salinity increase. Their results supported the initial hypothesis that dilution causes an increase in richness and biotic diversity, but a reduction in abundance. In other word, the higher the salinity level of the water, the less species diversity and the simpler structure of the ecosystem (Borowitzka, 1981).

Increased drought in arid and semi-arid regions of the world, which most of the inland hypersaline lakes are located in, had dramatic effects on these sensitive ecosystems. In fact, inland hypersaline lakes within closed hydrologic basins are subjected to natural and induced fluctuations in size and salt concentration over both short and long term intervals (Herbst and Blinn, 1998). In temperate hypersaline lakes, salinity as the major dominant parameter determines phytoplankton species composition and diversity. In most of these lakes, *Dunaliella* spp. mostly dominate other microalgae, due to their higher salinity tolerance. For example, in the Great Salt Lake it has been found that when salinity was near 200 g/l, the phytoplankton community was nearly a monoculture of *D. viridis* Teodoresco, 1905 and nitrogen fixing cyanobacteria were absent or infrequent in the pelagic region of the lake, but when salinity decreased to about 50 g/l not only the density of phytoplankton increased, but also nitrogen fixing *Nodularia* sp. was detected in the lake (Wurtsbaugh and Berry, 1990).

As shown in Fig. 8, when water level increases salinity of the lake decreases but this occurs with a very weak correlation between these two parameters (R^2= 02344). This situation happens in the lake, because all salts do not dissolve in the water and salt crystals can be seen in the bottom all year round. Wurtsbaugh and Gliwicz (2001) suggested that the pelagic community of phytoplankton in the Great Salt Lake during periods that *A. urmiana* were present as juveniles or adults (from Mars to June) was dominated by the unicellular green alga *D. viridis* with more than 99% of the numbers of phytoplankton and between 84 and 99% of the biovolume. The densities of this alga were between 2800 and 4130 cells ml.1^{-1}. Other algae such as diatoms *Amphiprora* sp. and *Amphora* sp. contributed modestly to the biovolume on some dates. For example, Mohebbi et al. (2006) reported 3 cyanobacteria (*Anabaena, Oscillatoria* and *Synechoccus*), 2 green algae (*D. salina* and *Ankistrodesmus*) and 11 diatoms (*Navicula, Nitzschia, Cyclotella, Symbella, Synedra, Pinnullaria, Diatoma, Amphiprora, Surirella, Cymatopleura* and *Gyrosigma*). Riahi et al. (1994) observed 6 cyanobacteria (*Anabaena, Anacystis, Chrococcus, Lyngbya, Oscillatoria* and *Synechoccus*) 4 green algae (*Ankistrodesmus, D. salina, Monostroma* and *pandorina*) and 2 diatoms (*Amphora* and *Navicula*). Brine shrimp in the genus *Artemia* are the dominant macrozooplankton present in many hypersaline environments (Wurtsbaugh and Gliwicz, 2001). This crustacean often dominates

food web dynamics in hypersaline environments and its grazing activities control water clarity (Lenz, 1987; Wurtsbaugh, 1992). Brine shrimp are non-selective filter feeders feeding on detritus scraped up from the bottom of the water column or on unicellular algae and other plankton higher up in the water column.

It seems that algal composition as the main food source of *A. urmiana* in both natural habitat and culture media has significant effect on *A. urmiana* growth and reproduction rates. For example Mohebbi et al. (2016) noted that growth of *A. urmiana* was influenced by both the species of phytoplankton in the diet and the culture media used to grow the phytoplankton. Due to their thick silica cell walls, diatoms though valuable, are tougher for the *A. urmiana* to digest. Savage and Knott (1998) studied the effects of limnological factors on parthenogenetic *Artemia* populations from Lake Hayward, western Australia. They suggested that the major mechanism controlling nauplius survival and recruitment of *Artemia urmiana* in Lake Hayward was food quality and quantity.

High salinity of Urmia Lake during recent years up to saturation levels (about 350 ppt) has diminished *A. urmiana* population to less than 1 individual per m^3 compared to 1 individual per liter during the high water levels (Mohammadi et al., 2009). Water level reduction has decreased the *A. urmiana* density in the lake. In 1898 when salinities were likely near 150 g/l, Günther (1899) found 1200-1600 individuals per m^3. Kelts and Shahrabi (1986) reported 3000 *A. urmiana* per m^3 in their lake expedition in 1977. With dropping the water level (Fig. 1), the density of *A. urmiana* decreased rapidly, so that there has been reported no *A. urmiana* in the lake since 2010 (Asem et al., 2012).

Additionally, as the lake shrinks, the *A. urmiana* cysts density drops. Asem et al. (2012) estimated the Urmia Lake cysts density in the upper 50 cm of the water column as 400 cysts/l in 1995, while the density of cysts in the surface 20 cm water layer, based on a stock assessment were 27, 25, 11, 8 and 3 cysts/l in 2003, 2004, 2005, 2006 and 2007, respectively (Ahmadi, 2005, 2007). The decline trend coincided with the start of drought in Urmia Lake. As we showed in Figure 1, After 2007, no *A. urmiana* resource assessment was carried out, however, unofficial reports indicated that there was less than 1 cyst/l of *A. urmiana* in Urmia Lake during 2008- 2017.

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