Effluent Diversion to Revive Urmia Lake (Iran) and its Negative Effect on Phytoplankton Composition

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Abstract

Saline lakes are valuable environments which are undergone shrinking due to the global warming and anthropogenic factors. As one of the major hypersaline lakes in the world and the natural habitat of the brine shrimp *Artemia urmiana*, the desiccation of Urmia Lake (Iran) can be a catastrophe. One of the implemented strategies by officials against the shrinking of this lake is diverting the effluents into the lake. Despite some advantages, this approach can negatively impact the microflora of the lake. *Dunaliella* was the dominant genus with a density of 98.63 through a 12-month study in Zanbil, Agh Gonbad, Kazem Dashi, and Myan Gozarstations. The analysis revealed the higher percentage of *Oscillatoria* sp. during February 2023, in the stations of Zanbil, Agh Gonbad, and Myan Gozar. Due to the proximity of these stations to the point where the water effluent from Urmia City's wastewater treatment plant enters Urmia Lake, the increased levels of nitrogen and phosphorus in the effluent can be attributed to this phenomenon. The toxic nature of this blue-green alga towards Artemia means that utilizing effluent to restore Urmia Lake has the potential to disrupt the lake's food chain.

Keywords: Desiccation, Effluent, Phytoplankton, *Artemia, Dunaliella*

Introduction

Saline lakes as natural occurrences are worthy due to their economic value and geologic records of ancient times ((Litchfield, 2011; Eugster and Hardie, 1978). Due to their importance, the study of lakes as ecological environments has gained special consideration (Rahimi and Breuste, 2021), with a focus on their shrinking and desiccation as a large number of the planet's salty lakes are decreasing in size very quickly resulting in a reduction in the habitats of aquatic birds and economic advantages and therefore endangering the human health (Wurtsbaugh et al., 2017). The main reason for the drying up of lakes is greatly due to anthropogenic activities and influenced by the rise in human water consumption, particularly for farming purposes (Williams, 1996).

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Like many lakes in the world Urmia Lake in Iran, the biggest hyper-saline lake in the Middle East, is undergone desiccation and disappearance (Alipour et al., 2014), and over the last 20 years, it has experienced a reduction in water level of around 90%, and there have not been sufficient efforts made towards its restoration (Pouladi et al., 2021). As a largest natural habitat of a unique brine shrimp species *Artemia urmiana*, conserving the lake from desiccation and reviving its biota is of particular importance.

To cope with shrinking Urmia Lake as an environmental crisis, several strategies are proposed that some of them are implemented, including improving water management practices in the surrounding areas (Abadi, 2019; Pouladi et al., 2021), and diverting water from nearby rivers (Eimanifar and Mohebbi, 2007). Recently, officials have declared that treated water effluents from Urmia Lake's peripheral cities particularly the most populated ones, Tabriz and Urmia, are going to be discharged into the lake; this treatment is used to help revive the ecosystem. Therefore, one of the applied approaches in water management and reviving Urmia Lake is transferring effluent/ treated wastewater to the lake.

Today, the use of reclaimed wastewater to reinforce or revive aquatic ecosystems is going to be a popular practice due to population increases all over the world. This practice is particularly applicable in arid and semi-arid regions where the availability of water is more crucial. One of the main advantages of this strategy is the fact that this is a consistent source of water, even during periods of low rainfall. Additionally, the effluent is rich in nutritional elements such as nitrogen and phosphorous (Hamdhani et al., 2020). High concentrations of these elements encourage the microalgae particularly cyanobacteria dominance in aquatic ecosystems, which in turn provide food for aquatic organisms. Moreover, using recycled sewage is a cost-effective way to supplement a lake's water supply, especially compared to expensive alternatives. Similar practices have been successfully applied to lakes and other water bodies. For example, Rajokri Lake in India was revived by the utilization of treated wastewater (Srivastava and Tc, 2021).

It is crucial to exercise caution when utilizing effluents to prevent any potential adverse effects on the environment. For instance, the treated wastewater might contain small amounts of hazardous chemicals or other contaminants that have the potential to harm aquatic ecosystems. (Hamdhani et al., 2020). Additionally, the nutrients in the effluent could contribute to the growth of harmful algae blooms, which can cause problems like oxygen depletion (Wurtsbaugh et al., 2019). Plenty of research evaluated the quality of effluent-fed water bodies (Du et al., 2014; Boyle and Fraleigh, 2003). It has been shown that discharging effluents into lakes results in fluctuation in the diversity of the phytoplankton community with an enhancement in the abundance of blue-green algae (Chow-Fraser et al., 1998). Vidya et al. (2020) evaluating the phytoplanktonic population of the Vembanad wetland, India attributed the higher abundance of Cyanophyceae particularly Oscillatoria and Phormidium to anaerobic conditions and higher levels of nutrients such as nitrogen and phosphorus. Moreover, they indicated a higher abundance of *Ceratium* sp. from the Dinophyceae family which prefers nutrient-rich environments (Vidya et al., 2020). It has been shown that the turbidity of high-nutrient water results in the predominance of low light-tolerant taxa (Chow-Fraser et al., 1998). When it comes to diversity, there are different results from the investigations on phytoplankton communities in nutrient-rich water bodies; some claim that effluent causes a decremental effect on diversity (Chow-Fraser et al., 1998), while others show enhancement of this parameter as a result of high nutrient content in the environment followed by algal bloom (Okbah and Hussein, 2006).

Some solutions are provided by investigators to reduce the drawbacks of nutrient accumulation in surface layers of water followed by algal bloom and eutrophication. Owens et al. (2013) in their investigation used deep outfall to diminish the loading of effluent to surface layers of water and prevent its effects on dissolved oxygen.

However, it is important to note that the microorganisms present in the effluent have the potential to change the biota of effluent-fed lakes. The impact of treated sewage effluent on the microbiota of the biggest hyper-saline lake in the Middle East, Urmia Lake, remains largely unexplored.

This study aims to evaluate the microorganisms of Urmia Lake, shedding light on the effects that effluents might have on the lake's biology and food chain. These effects could, in turn, have broader implications for the whole ecosystem.

Material and methods

Study site and sampling

Fig. 1. The situation of determined sampling sites in Urmia Lake, and the outfall of effluents from Urmia into the lake

Urmia Lake is located in the northwest of Iran in a semi-arid region of the world with less than 300 mm annual precipitation (Feizizadeh et al., 2013). Considering sever shrinking, morphometric characteristics, and outcropping of a large section of the Urmia Lake bed four sampling sites were determined in northern and southern parts of the lake including Zanbil, Agh Gonbad, Myan Gozar, and Kazem Dashi (Fig. 1). Samplings were performed monthly for 12 months from March 2022 to February 2023. The geographical situations of sampling sites were determined and recorded (Table 1). The ecological conditions of Urmia Lake were so harsh, that in some stations particularly in the dry season water was patchy and the lake appeared as isolated water patches. However, we tried to consider and regard the scientific principles and sampling standards. Samplings were performed monthly for 12 months from March 2022 to February 2023.

Phytoplankton identification and data analysis

Phytoplankton samples were preserved in cold and dark conditions following the fixation by Lugol solution. After settling phytoplankton to the bottom of 5ml-settling chambers, they were counted and identified by using a Nikon TS100 inverted microscope at 400× magnification based on the Utermöhl method (1958). At least 50 fields or 100 individuals of the most abundant species were counted in each sample (Venrick, 1978). Phytoplankton taxa were determined according to Prescott (1962), Tiffany and Britton (1971), and Bellinger (1992). In each site, the species composition and density of the phytoplankton community were analyzed.

Results

The water level of Urmia Lake, water surface area, and volume were extracted from the East Azarbaijan water resources management company website (http://www.azarwater.ir) (Fig. 2). The water level, surface area, and volume during January and February2023) were lost. Therefore, these data were not included in the analysis.

The algal flora found in Urmia Lake is unique, much like other hypersaline lakes. The majority of its biota is made up of *Dunaliella*, which has a high tolerance to salinity. This research identified seven genera of algae in Lake Urmia, with species falling into three groups: green algae (Chlorophyta), blue-green algae (Cyanophyta), and diatoms (Bacillariophyta). In terms of population distribution, *Dunaliella* spp. made up 98.63% of the algal flora abundance, while the remaining algal species accounted for only 1.37% of the abundance. (Table 3).

During the period from October to December 2022, the water level of Lake was exceptionally low, resulting in the

Table 1. The geographical coordinates of sampling sites in Urmia Lake

Station	Zanbil	Agh Gonbad	Myan Gozar	Kazem Dashi
Latitude	37° 47′ 6.38" N	37° 47′ 40.44" N	37° 47′ 26.00" N	38° 03′ 07.52" N
Longitude	45° 21′ 37.13" E	45° 23′ 11.40" E	45° 21′ 40.47" E	45° 12′ 08.67" E

absence of algae at the sampling sites. (Table 2). Moreover, there were no sightings of *Dunaliella* spp. at any of the monitoring stations during the months of October and November 2022, as well as January 2023. Excluding the months with zero algal density, the minimum and maximum densities of algae were recorded in August 2022 and June 2022, reaching 2200 and 2117257 No/L, respectively, at Kazem Dashi and Zanbil stations (Fig. 3). Moreover, the lowest and highest *Dunaliella* spp. densities were observed in February 2023 and June 2022, with 4460 and 2110917 No/L, respectively, at Kazem Dashi and Zanbil stations.

Moreover, the minimum and maximum average annual density of algae were observed in Kazem Dashi and Agh Gonbad stations with 4070 and 229650 No/L, respectively. Myan Gozar and Zanbil were in the middle ranks in terms of algae abundance with 96364 and 229098 No/L, respectively (Fig. 4).

Conversely, no algae were detected at Zanbil station between August and December 2022, at Agh Gonbad station in July, August, October, November, and December, at Myan Gozar from August to December 2022, and at Kazem Dashi in July, and from September to December 2022. The algae density was

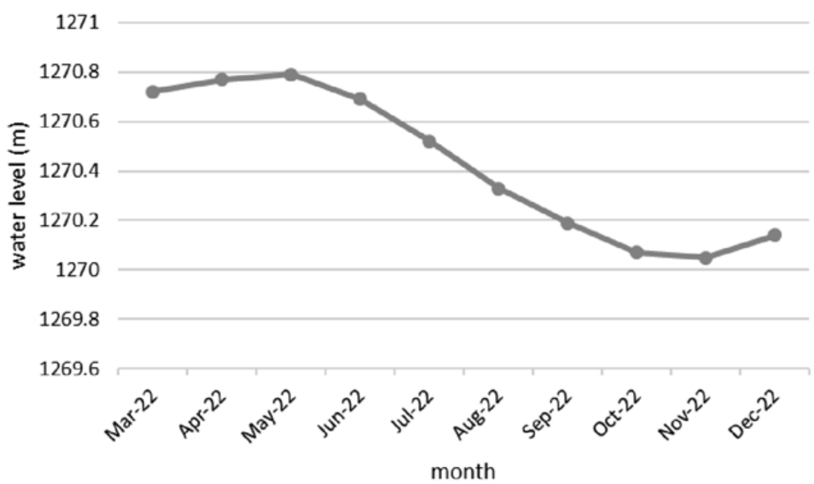

Fig. 2. Water level of Urmia Lake from March to December 2022 adopted from http://www.azarwater.ir

Table 2. Systematic classification of algal species of Lake Urmia from March 2022 to February 2023

Phylum	Class	Order	Family	Genus	Species
Chlorophyta	Chlorophyceae	Chlamydomonadales	Dunaliellaceae	*Dunaliella*	*Dunaliella* spp.
Cyanobacteria	Cyanophyceae	Oscillatoriales	Oscillatoriaceae	*Oscillatoria*	*Oscillatoria* sp.
		Chroococcales	Microcystaceae	*Microcystis*	*Microcystis botrys*
Gyrista	Bacillaryophyceae	Bacillariales	Bacillariaceae	*Nitzschia*	*Nitzschia* sp.
		Naviculales	Naviculaceae	*Navicula*	*Navicula* sp.
		Thalassiophysales	Catenulaceae	*Amphora*	*Amphora pediculus*
		Rhabdonematales	Tabellariaceae	*Diatoma*	*Diatoma vulgare*

Table 3. Algae species in Lake Urmia from March 2022 to February 2023

Abundance (%)	Species Name	Mar 2022	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022	Sep 2022	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023
98.63	*Dunaliella* spp.	+	+	+	+	+	-	+	-	-	+	-	+
1.37	*Oscillatoria* sp.	-	+	+	-	-	-	-	-	-	-	-	+
	Microcystis botrys Teiling	-	-	-	-	+	-	-	-	-	-	-	-
	Nitzschia sp.	-	+	-	-	-	-	-	-	-	-	-	+
	Navicula sp.	-	+	+	-	-	+	-	-	-	-	-	-
	Amphora pediculus (Futzing) Grunow	-	+	-	+	-	-	-	-	-	-	-	-
	Diatoma vulgare Bory de Saint-Vincent.	-	+	-	-	-	-	-	-	-	-	-	-

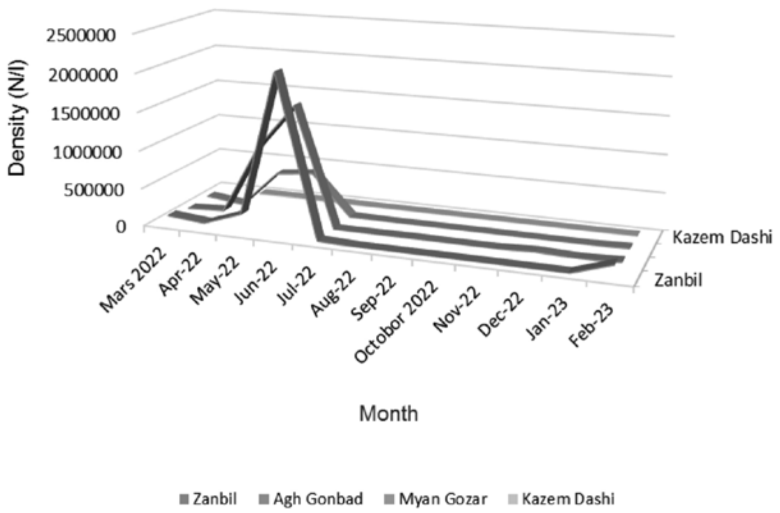

Fig. 3. The monthly average density of total phytoplankton in the sampling stations of Urmia Lake from March 2022 to February 2023

recorded as zero during these periods. The lowest and highest annual average density of *Dunaliella* spp. was observed in Kazem Dashi and Agh Gonbad stations with 3870 and 228511 No/L, respectively. Myan Gozar and Zanbil stations were in the middle ranks with 95008 and 224129 No/L *Dunaliella* spp. (Fig. 4).

In general, in this study, *Dunaliella* spp. and other genera of algae composed 98.63% and 1.37% of algal density in Urmia Lake, respectively (Table 3). The abundance of *Dunaliella* spp. and other genera was calculated separately for all sampling stations and the following results were obtained:

The highest density of *Dunaliella* spp. and the lowest density of other algae during March 2022-February 2023 (average) were related to the Agh Gonbad station with 99.51% and 0.49%, respectively. Myan Gozar station with 98.59% *Dunaliella* spp. and 1.41% density of other genera; and Zanbil station with 97.83% *Dunaliella* spp. and 2.17% other algae are in the middle ranks in this respect (Table 4). Finally, Kazem Dashi

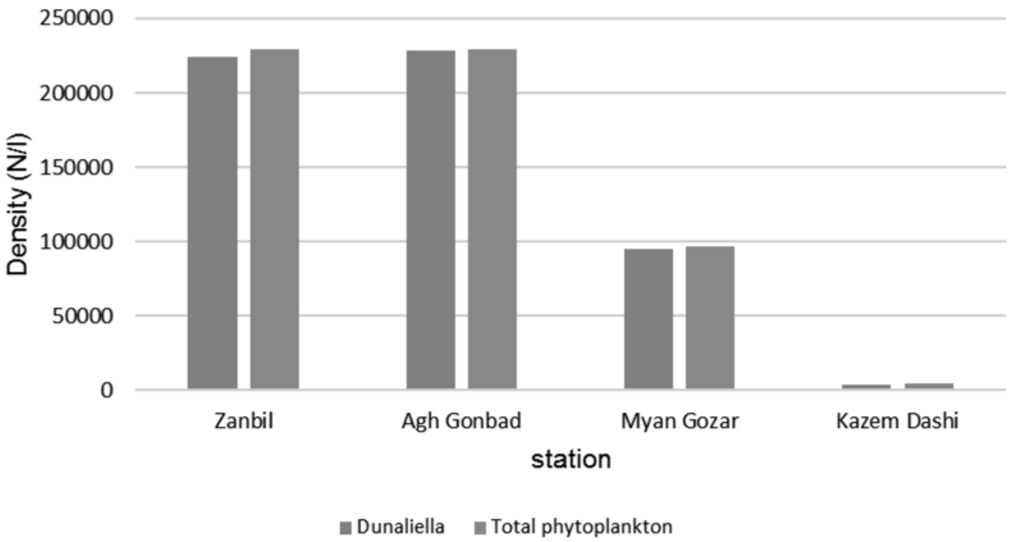

Fig. 4. The monthly average density of total phytoplankton and *Dunaliella* spp. in the sampling stations of Lake Urmia from March 2022 to February 2023

Table 4. The density of *Dunaliella* spp. and other algae in the sampling stations of Urmia Lake (March 2022 to February 2023)

Station/Site	*Dunaliella* spp. (%)	Other algae (%)
Zanbil	97.83	2.17
Agh Gonbad	99.51	0.49
Myan Gozar	98.59	1.41
Kazem Dashi	95.08	4.92

station is at the lowest rank concerning the density of *Dunaliella* spp. (95.08%) and the density of other algae (4.92%) (Table 4).
During February 2023, the density of the *Oscillatoria* genus was at the highest level at Zanbil, Agh Gonbad, and Myan Gozar with values of 34785, 6544, and 5930 No/L, respectively. Conversely, the density of this genus remained constant throughout the investigation (Fig. 5).

Discussion

Urmia Lake (northwest Iran), is one of the world's most important saline lakes and the largest natural habitat for the unique brine shrimp species, *A. urmiana*, which is currently experiencing shrinkage and desiccation. This catastrophe is mainly due to anthropogenic activities and one of the strategies proposed and implemented to revive the lake involves diverting wastewater into the lake. However, nutrient-rich effluent could potentially impact the lake's biota. We conducted a 12-month study on the phytoplankton population of Urmia Lake to evaluate the effect of effluent on the lake's

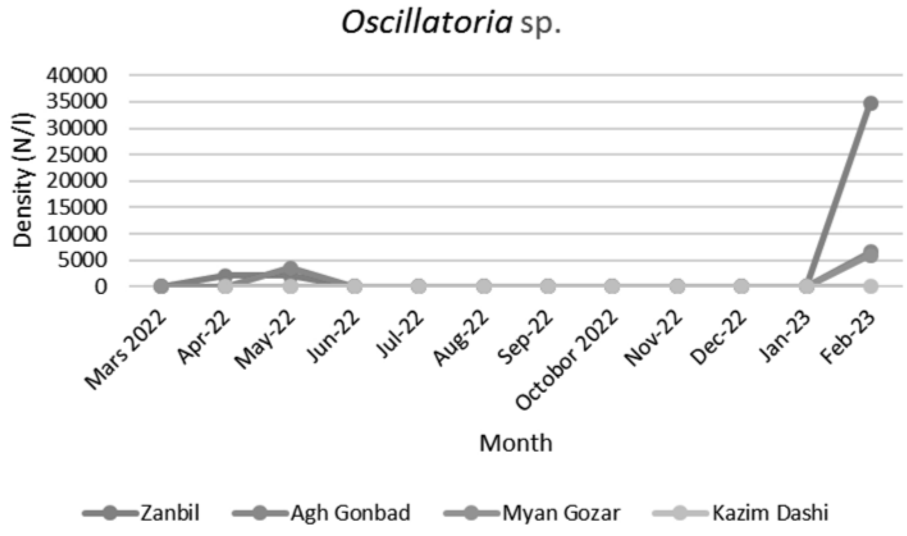

Fig. 5. Density of *Oscillatoria* sp. at Zanbil, Agh Gonbad, Myan Gozar, and Kazem Dashi during the study period

ecosystem.

Based on the results, at Zanbil and Myan Gozar, no algae were observed from August to December, while at Agh Gonbad, algae were not observed in July, August, October, April, and December. Similarly, at Kazem Dashi, no algae were observed from July to December, except for September. This shows that the biological conditions of Urmia Lake, particularly during the hot and dry months of the year, have been highly unfavorable for the growth of algae.

In this study, an analysis of the algal population of Urmia Lake reveals that *Dunaliella* spp. make up a significant majority, accounting for 98.63% of the total algae abundance. On the other hand, the remaining genera of algae contribute to 1.37% of the algal abundance. This observation highlights the remarkable adaptability of *Dunaliella* spp. to the harsh and saline conditions of Urmia Lake. It is worth noting that *Dunaliella* spp. exhibit a wide range of tolerance, particularly in terms of salinity, making them well-suited to thrive in this environment (Mohebbi, 2010). Larson and Belovsky (2013) have demonstrated that salinity plays a dominant role in shaping species diversity in high-saline environments. Additionally, other abiotic factors, such as temperature and nutrients also can affect the composition of phytoplanktonic populations alongside salinity (Barrett and Belovesky, 2020).

A significant aspect of the ongoing investigation regarding the phytoplankton population is the emergence of *Oscillatoria* sp. during February 2023, at three different stations: Zanbil, Agh Gonbad, and Myan Gozar. More interestingly, Considering the geographical locations of these stations, with Kazem Dashi being situated at the northernmost point of the lake without any nearby river inflows, it can be deduced that the simultaneous appearance of Oscillatoria sp. at the three aforementioned stations is likely due to the diversion of water effluent from the wastewater treatment plant of Urmia city into the Urmia Lake near Myan Gozar.This effluent contains a significant amount of phosphorus and nitrogen, which are conducted to the growth of blue-green algae. The density of *Oscillatoria* sp. at the Zanbil station, which is closest to the Urmia sewage treatment plant approximately six times higher than that at the Agh Gonbad and Myan Gozar. This indicates that the presence of this alga is affected by the diversion of urban sewage effluent.

A. urmiana, being a non-selective filter-feeder, can filter all particles smaller than 50 µm (mouth diameter) (Sánchez et al., 2016; Arulvasu et al., 2014). Hence, *Dunaliella* spp., which falls within the size range of 5 to 10 µm, is considered the optimal choice for *A. urmiana's* nutrition in the lake. (Thakkar et al., 2016; Muhaemin, 2004) This preference is based on factors such as size, nutritional composition, and digestibility (Mohebbi et al., 2016). However, in the event of a disruption in the plankton composition of the lake following the discharging of effluents into the lake, filamentous Cyanophytes including *Oscillatoria* may become dominant. It is important to note that *A. urmiana* finds this genus unsuitable in terms of food composition, given its length of up to 70 µm.

The predominance of unwanted and harmful algae should be considered in the recovery plans for Urmia Lake since part of the lake's water is supposed to be supplied from the sewage treatment plants of the cities around the lake such as Tabriz and Urmia. Therefore, the use of urban sewage effluent may cause the ecological balance of Lake Urmia to be disturbed, which should be taken into consideration by officials, experts, and planners of Urmia Lake's restoration program.

It can be concluded that the utilization of sewage effluent in Urmia Lake results in the augmentation of Cyanophytes such as *Oscillatoria*, which is a filamentous, toxic, and unfilterable organism by *Artemia.* Consequently, the utilization of the wastewater effluent cannot be deemed as a dependable approach to reviving Urmia Lake, and in the long term, it can have many negative effects on the ecosystem of the lake. The restoration of Urmia Lake can be achieved by implementing sustainable water management in the agricultural fields of the basin. By doing so, the long-term enhancement of drip irrigation systems and cultivation of drought-resistant crops such as some medicinal plants could be promising.

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