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Seasonal variations of plankton structure as bioindicators in Zayandehrud Dam Lake, Iran

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Abstract: Zayandehrud Dam Lake located in Isfahan province is the largest lake in central Iran. In this study, the plankton communities including phytoplankton and zooplankton were studied as bioindicator organisms for assessment of water quality in the Zayandehrud Dam Lake. The water and phytoplankton organisms were collected from four stations at different seasons during 2014 by using a Nansen bottle sampler. The zooplankton samples were collected with a plankton net (mesh size = 50 µm). The phytoplankton community was composed of Bacillariophyceae, Cyanophyceae, Euglenophyceae, Dinophyceae and Chrysophyceae. The zooplankton community viz; Cladocera, Rotifera and Copepoda were found to have a density range of 13–155, 21–141 and 11–93 (ind. m^{-3}), respectively. In general, phytoplankton and zooplankton communities, especially the presence of genera such as *Cyclotella*, *Dynobrion*, *Bosmina* and *Daphnia* (as indices of oligotrophic lakes) and also absence of *Microsystis*, *Brachionus* and *Lecane* are seen as important indices of eutrophic lakes. It could be concluded that the Zayandehrud Dam Lake can be classified as a healthy water body.

Key words: water quality; phytoplankton; zooplankton

Introduction

Human activities have affected the water quality in many natural and artificial water bodies, including lakes and reservoirs during recent decades. This has had both a quantitative and qualitative effect on the water needed for social and economic purposes. Proper water management strongly depends on the long term monitoring of the hydrology and water quality freshwaters (Kennedy 1999).

The phytoplankton community plays a key role in aquatic ecosystems and provides basic requirements such as carbon fixation, oxygen production as well as food generation (Fathi et al. 2001; Khan 2003). Phytoplankton are important primary producers in aquatic systems that could be assigned as efficient bio-indicators of water quality (Peerapornpisal et al. 2004). Phytoplankton species are able to survive and adapt to different habitat conditions, although each specific species has a defined niche according to its physiological requirements and the limits imposed by environmental conditions. In temperate waters, phytoplankton succession is strongly linked to meteorological phenomena, water stratification, seasonal cycling, and patterns of population distribution (Wetzel 2001). For instance, some species are highly dominant in eutrophic waters, whereas others are very sensitive to environmental changes. Thus, the diatoms *Melosira* and *Cyclotella* usually exist in clean freshwaters, while *Nitzschia*, *Microcystis* and *Aphanizomenon* are commonly found in polluted waters (Rice et al. 2012). The species of *Chlamydomonas*, *Euglena* and *Scenedesmus* (Prescott 1973), and *Microcystis* (Prescott 1973; Peerapornpisal et al. 2004) are indicators of eutrophic waters. Reynolds and Lund 2006 reported that *Aphanizomenon*, *Microcystis* and *Ceratium* can inhabit waters high in phosphate and *Anabaena* is found in waters with a slight nitrogen content. Some blue-green algae such as *Microcystis, Anabaena, Anabaenopsis, Aphanizomenon* and *Cylindrospermopsis* produce toxic components and algal bloom that may affect water quality and ecosystem health (Hitzfeld et al. 2000; Cook et al. 2004). Furthermore, they may cause a problem with taste, unfavorable odors and high water turbidity(Borgh 2004).

Freshwater zooplankton are important assemblages in aquatic systems that mostly consist of rotifers and cladocerans (Beaugrand et al. 2000). They are a wide taxonomic group of animals that play a key role in biodiversity, cycling of organic materials, are an intermediate link between phytoplankton and ichtyoplankton (fish larvae) and an essential part of the food web in aquatic systems. In addition, zooplankton have been used as bioindicators to assess the water quality in aquatic ecosystems (Figueredo and Giani 2001). Since they have a short life span and fast regeneration they often undergo dramatic and rapid changes in response to temporal and spatial variations of physico-chemical environmental conditions (Figueredo and Giani 2001; Rajagopal et al. 2010).

In recent years, the Zayandehrud Dam Lake has become a sensitive and fragile system mostly due to the occurrence of low local precipitation and a lack of adequate water inflow. This has resulted in a drastic deterioration of water quality. Some research has been carried out on the limnology of the Zayandehrud Dam lake (Hamidi 2012; Shams 2006), but the investigation of its physico-chemical properties coincided with a need to investigate the plankton community. In the present study, seasonal plankton succession was studied in Zayandehrud Dam Lake over a one-year period. The purpose of this study was to identify plankton abundance and to measure physico-chemical parameters used for evaluating water quality.

Study area

Zayandehrud Dam Lake is the largest artificial constructed lake located in central Iran (Central Asia). The lake is 110 km west of the city of Isfahan and the prevailing climate conditions are cold and wet (Fig. 1). The

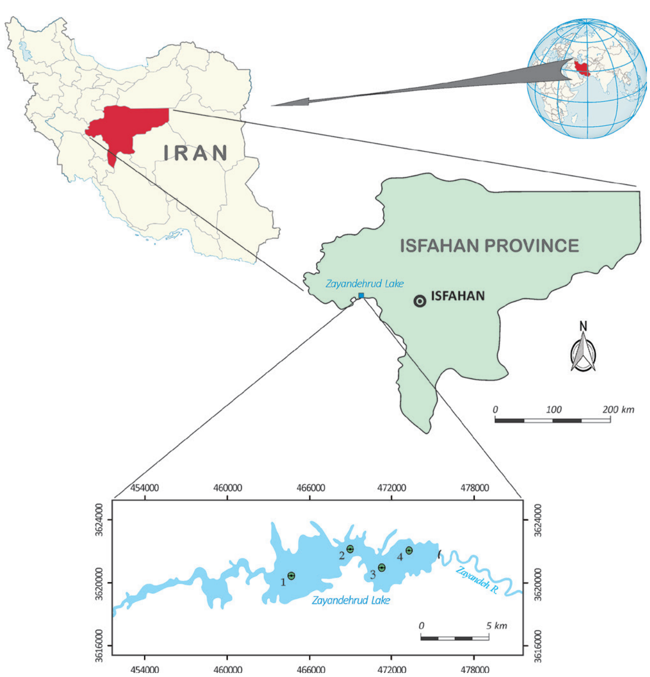

Fig. 1. The sampling stations of Zayandehrud Dam Lake in Esfahan, Iran

lake waters are used for a variety of purposes including supply of water for agriculture and irrigation, drinking water, industry and recreation. It is also a suitable habitat for aquatic species such as fish and migratory birds. The most important indigenous fish are *Capoeta damascina*, *Capoeta aculeate* and *Chondrostoma regium*. The annual precipitation and evapotranspiration is 938 and 699 mm, respectively. Altitude above sea level, lake area and volume are: 2063 m, 48 km^2 and 1250 hm^3, respectively. Samples were collected from four different stations (Fig. 1) and all samples were assigned as four replications. The duration of the current study was one-year, from April 2011 to March 2012 with sampling conducted twice in each season (45-day interval).

Methods

Water collection for physico-chemical properties

The water samples were collected from different depths using a Nansen water bottle sampler. The depths were 0.5 m (surface), 5 m (middle) and bottom (near the bottom) at each station. Physico-chemical properties including temperature, pH, EC and dissolved oxygen were measured in the field with portable equipment, while the other parameters of NO_3, NO_2 and PO_4 were determined in the laboratory using standard analytical techniques (Rice et al. 2012) during different seasons.

Plankton sampling

Phytoplankton samples were taken from different stations during each sampling by collection in a 1 dm^3 water bottle sampler. The samples were fixed with 4% formalin for identification and counting. The samples were poured into the 1 dm^3 cylinder container for settlement and concentrated and then kept for 1-week before laboratory work. Each sample was then siphoned out carefully and adjusted to a 25 cm^{-3} sample for counting and identification. The algal taxa were identified according to keys of Brettum (2005) and Bellinger (2010). The counting (density) of each division of phytoplankton was estimated by using a glass Sedgewick Rafter counting chamber (Bellinger and Sigee 2010).

Zooplankton species were sampled using a zooplankton net (50 µm mesh size) by vertical towing. The collected samples were placed in 1 dm^3 plastic bottles and were preserved in 4% buffer formalin solution. They were kept at 4°C until further analysis. The zooplankton species were sorted and observed under a stereo microscope and were then identified using an inverted microscope with magnification ×100. The density of zooplankton was obtained by the method described by Harris et al. (2000) under a zooplankton plexiglass Bogorov chamber. For identification of species, the keys of Phan et al. (2015) were used.

Table 1. Physico-chemical parameters of surface water in the Zayandehrud Dam Lake during sampling period (mean ±standard deviation)

Parameter	Apr	Jun	Jul	Aug	Oct	Dec	Mar	Yearly mean
Temp. [°C]	13.8 ±0.6	14.4 ±0.5	19.4 ±0.2	18.1 ±0.7	16.0 ±0.3	10.2 ±0.2	7.0 ±0.0	14.5 ±0.8
DO [mg dm^{-3}]	13.6 ±0.5	9.5 ±0.6	7.9 ±0.7	7.5 ±0.5	7.2 ±0.7	7.9 ±0.3	12.3 ±0.3	9.5 ±0.5
EC [µS cm^{-1}]	299.2 ±3.0	271.0 ±8.2	248.9 ±3.7	236.2 ±6.2	248.0 ±3.3	255.9 ±0.8	349.2 ±8.1	271.1 ±7.4
pH	8.15 ±0.01	8.16 ±0.04	8.06 ±0.08	8.29 ±0.02	8.22 ±0.06	8.17 ±0.01	8.26 ±0.04	8.18 ±0.01
PO_4 [mg dm^{-3}]	0.025 ±0.003	0.013 ±0.002	0.018 ±0.004	0.038 ±0.011	0.075 ±0.006	0.099 ±0.037	0.038 ±0.007	0.041 ±0.007
NO_3 [mg dm^{-3}]	1.79 ±0.04	1.51 ±0.05	1.35 ±0.07	1.65 ±0.08	0.82 ±0.02	0.89 ±0.05	1.54 ±0.17	1.40 ±0.07
NO_2 [mg dm^{-3}]	0.028 ±0.002	0.016 ±0.004	0.024 ±0.008	0.022 ±0.002	0.016 ±0.007	0.016 ±0.001	0.052 ±0.001	0.025 ±0.002
N : P ratio	79.7:1	97.7:1	89.8:1	49.8:1	12.9:1	11.4:1	47.6:1	55.6:1

Statistical analysis

Statistical analyses were carried out using SPSS 16.0. The ANOVA was performed to determine significant differences in water quality, phytoplankton and zooplankton data at various seasons. The means were compared using the Duncan multiple range test at a significant level of 95%.

Results

Physico-chemical characteristic

The physico-chemical water parameters of the Zayandehrud Dam Lake are shown in Table 1. The mean water temperature, dissolved oxygen (DO), electrical conductivity (EC) and pH were: 7.00–19.37°C, 7.15–13.88 mg O_2 dm^{-3}, 236.2 –349.2 µS cm^{-1} and 8.06–8.29, respectively. The annual mean of PO_4 and NO_3 was 0.41 and 1.40 mg dm^{-3}, respectively. The highest and the lowest amounts of PO_4 were obtained in December (autumn) and June (spring), respectively. The NO_3 concentrations were highest and lowest in August (summer) and October (autumn), respectively. Average NO_2 content attained its maximum value in winter (March) and the minimum value in autumn.

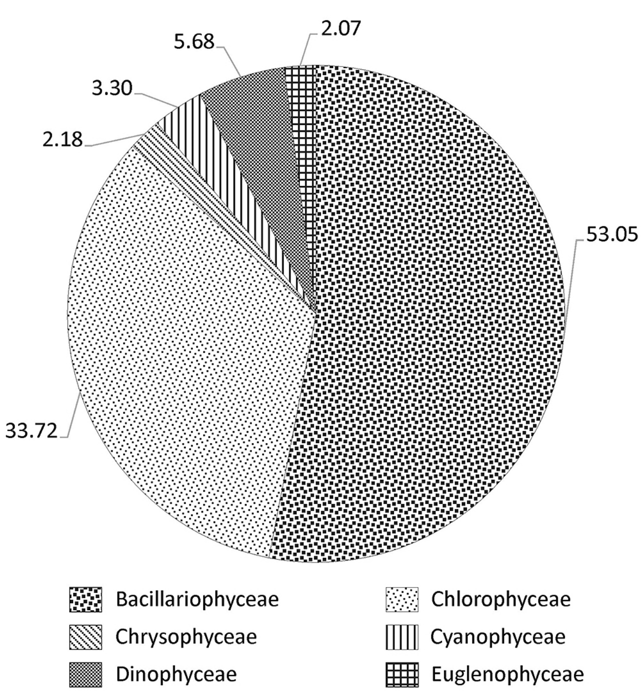

Fig. 2. Relative abundance of different groups of phytoplankton through the sampling period

Phytoplankton composition and abundance

The relative abundance (density) of different phytoplankton groups is presented in Figure 2. The results showed that Bacillariophyta (53.0%) and Chlorophyta (33.7%) were dominant.

The mean density of phytoplankton communities at different depths is shown in Figure 3. The maximum density of phytoplankton was estimated on the surface and at medium depth while the lowest was at the bottom (depth of more than 10 m). The highest and lowest density of phytoplankton was observed in August and March, respectively. Generally, the phytoplankton peak was 904791.7 cells per dm^{-3} in the middle water layer in the August sampling.

The presence and absence of phytoplankton is presented in Table 2. The results showed that the phytoplankton composition comprised 58 genera from 6 major phytoplankton groups. The highest number of species was in the Chlorophyta (21 genera), Bacillariophyta (20 genera), Cyanophyta (8 genera), Eugleno-

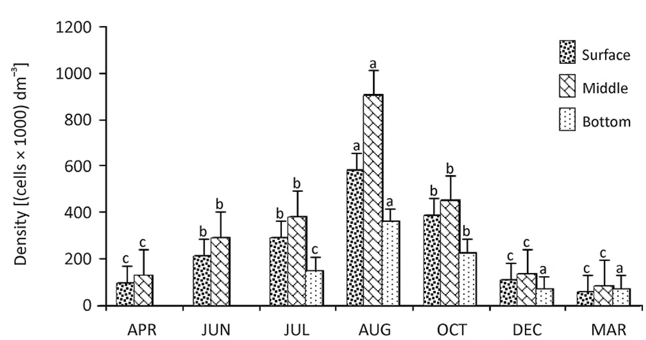

Fig 3. Phytoplankton density on the surface (0.5–5 m), middle (5–10 m) and bottom (more than 10 m) layers during the study period. The same lowercase letters indicate no significant differences in phytoplankton density (p > 0.05). Data presented as mean values (bars) and standard deviations (whiskers)

Table 2. List of presence (+) and absence (–) of observed phytoplankton during the study period

Phytoplankton	Apr	Jun	Jul	Aug	Oct	Dec	Mar
Bacillariophyceae							
Amphipleura	+	–	–	+	–	–	–
Amphora	+	+	+	+	–	–	–
Asterionella	+	+	+	+	–	–	–
Coconies	+	–	–	+	–	–	–
Cyclotella	+	+	+	+	+	+	+
Cymbella	+	–	+	+	+	+	
Diatoma	+	+	+	+	+	+	+
Diploneis	+	–	–	+	+	+	+
Eunotia	+	–	–	–	–	–	–
Fragilaria	+	+	+	–	+	+	+
Gomphonema	+	+	+	+	+	+	+
Gyrosigma	+	–	–	+	+	+	+
Meridion	+	+	–	–	–	–	–
Melosira	+	+	–	–	–	–	–
Navicula	+	–	+	+	+	+	+
Nitzschia	+	–	+	+	–	–	+
Pinnularia	+	–	–	+	–	–	–
Stephanodiscus	+	–	–	+	–	–	–
Surirella	+	+	–	+	+	+	+
Synedra	+	+	+	+	+	–	+
Chlorophyceae							
Actinastrum	–	–	+	+	–	–	–
Ankistrodesmus	+	+	+	+	+	+	+
Carteria	+	+	–	–	+	+	–
Chaetophora	–	–	–	+	–	–	–
Chlamydomonas	+	+	+	–	+	+	–
Chlorella	+	+	+	+	+	+	+
Chlorococcum	–	–	+	+	–	–	–
Closterium	–	–	+	–	–	–	–
Coelastrum	–	–	–	+	–	–	–
Cosmarium	–	–	+	+	+	+	–
Cylindrocystis	–	–	–	+	–	–	–
Elakatothrix	+	+	+	+	+	+	+
Eudorina	–	–	–	+	–	–	–
Microspora	–	–	+	+	–	–	–
Oocystis	+	–	–	+	–	–	–
Pandorina	–	–	+	+	+	–	–
Pediastrum	–	–	–	+	+	–	–
Selenastrum	–	–	+	+	+	+	–
Senedesmus	–	–	+	+	+	+	–
Tetraspora	–	–	+	+	+	+	–
Tetraedron	–	–	+	+	+	+	–
Chrysophyceae							
Dinobryon	+	+	+	+	+	+	+
Mallomonas	+	–	+	+	+	+	–
Cyanophyceae							
Anabena	–	+	–	–	–	–	–
Aphanocapsa	–	–	–	+	–	–	–
Chrococcus	–	–	+	+	+	–	–
Merismopedia	–	–	+	+	–	–	–
Nostok	–	–	+	+	–	–	–
Oscillatoria	–	+	+	+	+	–	–
Spirulina	–	–	–	+	–	–	–
Synechococcus	–	–	+	+	+	–	–
Dinophyceae							
Ceratium	+	+	+	+	+	+	–
Glenodinium	+	+	+	+	+	+	–
Peridinium	+	+	+	+	+	+	+
Euglenophyceae							
Euglena	+	+	+	+	+	+	–
Lepocinclis	–	+	+	+	+	+	–
Phacus	+	+	–	–	–	–	–
Trachclomonas	+	+	+	+	–	–	–
Number of genera	34	25	37	47	30	26	16

phyta (4 genera), Dynophyta (3 genera) and Chrysophyta (2 genera). The dominant genera were *Cyclotella*, followed by *Chlorella*, *Elkatothrix* and *Ankistrodesmus* throughout the study period.

Zooplankton community composition

The distribution and density of zooplankton during different sampling is presented in Table 3. Three major classes, including copepod, cladocerans and

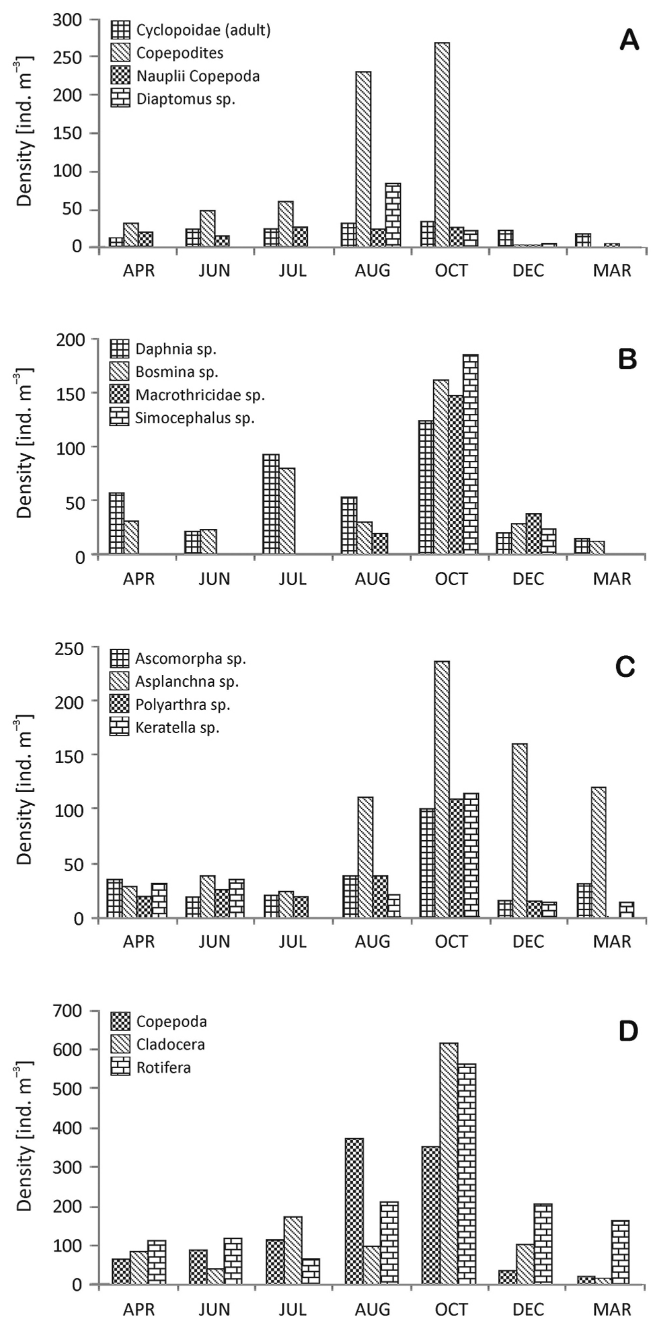

Fig 4. Density of copepod (A), cladoceran (B), rotifer (C) and total density (D) in the Zayandherud Dam Lake

Table 3. Distribution and density (ind. m^{-3}) of various genera of zooplankton in Zayandherud Dam Lake

Classes	Genera	Apr	Jun	Jul	Aug	Oct	Dec	Mar
Copepoda	Cyclopoidae (adult)	13.1 ±1.3	23.9 ±3.2	23.9 ±3.2	31.3 ±9.2	34.9 ±22.7	23.6 ±8.9	16.9 ±2.7
	Copepodites	31.4 ±5.9	48.5 ±12.7	62.2 ±10.2	233 ±70.2	271.3 ±37.8	4.0 ±1.9	–
	Nauplii Copepoda	20.7 ±2.0	16.3 ±0.0	27.1 ±9.4	23.9 ±5.9	26.4 ±7.7	4.0 ±1.9	5.4 ±1.7
	Diaptomus sp.	–	–	–	84.3 ±32.5	23.6 ±1.8	5.4 ±1.7	–
	Total	65.2 ±9.2	88.8 ±15.9	113.2 ±22.7	372.6 ±117.8	356.2 ±70.0	37.0 ±14.3	22.2 ±4.4
Cladocera	*Daphnia* sp.	56.8 ±15.3	20.7 ±2.9	91.9 ±40.9	53.7 ±14.9	125.6 ±23.0	18.5 ±2.2	13.8 ±2.0
	Bosmina sp.	29.2 ±10.0	22.8 ±4.8	80.1 ±54.4	29.3 ±18.8	162.3 ±28.5	27.7 ±6.6	12.3 ±1.7
	Macrothricidae sp.	–	–	–	18.9 ±13.2	148.1 ±21.4	36.2 ±2.5	–
	Simocephalus sp.	–	–	–	–	185.0 ±45.5	22.1 ±4.7	–
	Total	86.0 ±25.4	43.1 ±7.7	172.0 ±95.3	101.9 ±47.0	621.0 ±118.5	104.5 ±16.0	14.3 ±3.7
Rotifera	*Ascomorpha* sp.	34.5 ±7.0	18.5 ±2.5	20.7 ±2.9	37.8 ±15.3	101.4 ±39.2	16.3 ±0.0	32.1 ±4.1
	Asplanchna sp.	27.1 ±9.2	37.8 ±15.3	25.0 ±6.1	112.1 ±95.8	237.3 ±113.4	160.6 ±48.2	32.1 ±4.1
	Polyarthra sp.	20.7 ±3.5	26.1 ±5.6	18.5 ±2.5	39.0 ±4.6	109.9 ±27.3	15.2 ±3.4	–
	Keratella sp.	32.3 ±8.6	35.5 ±12.9	–	21.7 ±3.7	115.6 ±22.5	13.8 ±4.4	13.8 ±3.0
	Total	114.6 ±28.3	117.8 ±36.3	64.2 ±11.5	210.5 ±119.4	564.2 ±202.4	205.9 ±56.2	165.6 ±4.7
	Total	266.0 ±62.8	249.6 ±59.8	349.3 ±129.6	685.0 ±284.2	1541 ±390.8	347.4 ±86.5	202.1 ±12.8

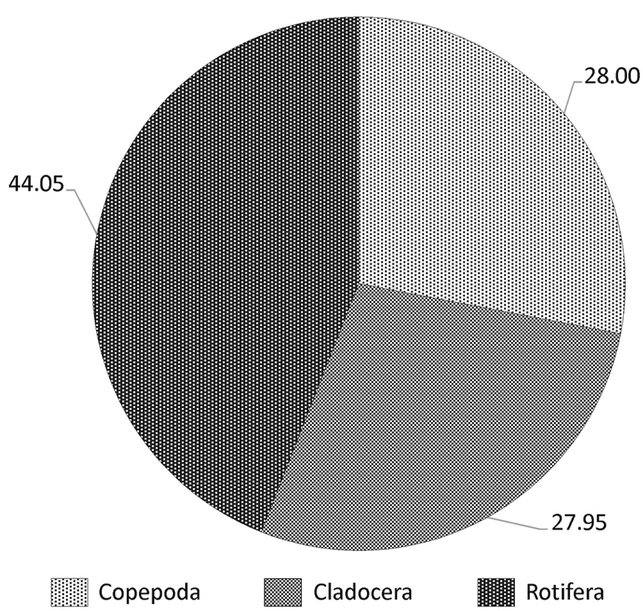

Fig 5. Relative density percentage of main zooplankton groups during the sampling period

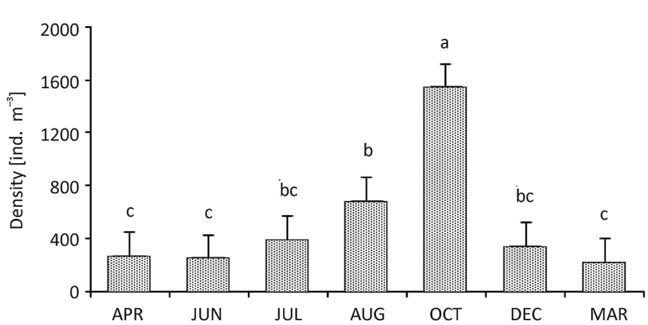

Fig 6. Mean zooplankton abundance during a different sampling time. The same lowercase letters indicate no significant difference in zooplankton abundance ($p > 0.05$). Data presented as mean values (bars) and standard deviations (whiskers)

rotifers were found, and the dominant genera were identified. The copepod assemblage was enumerated based on different stages of nauplii, copepodites and adults. The highest density of copepod population was observed in August and the lowest in March (Kumari et al. 2008). For cladocera, the maximum density was estimated in October (Kumari et al. 2008) dominated by *Simocephalus* sp. and *Bosmina* sp. The rotifer gerera, including *Ascomorpha* sp., *Asplanchna* sp., *Polyarthra* sp. and *Keratella* sp., were almost evenly distributed throughout the study period. The highest total rotifer density was obtained in October (Sunkad and Chavan 2013). Overal, the total density of copepod, cladocera and rotifer ranged from 22.2–372.6, 14.3–620.9 and 64.2–564.2 ind. m^{-3}, respectively (Fig. 4). In addition, the relative density of different zooplankton groups is presnted in Figure 5 for further comparision. Rotifera constituted the largest group, comprising 44.05% of the zooplankton; followed by Copepod (28%) and Cladocera (27.95%). There are significant differences among the various stages ($p < 0.05$). The mean zooplankton population demonstrated an increasing trend from spring, then reached its maximum in autumn and finally dropped to its minimum value in winter (Figs. 4–6). Table 2 shows the mean density of different genera of zooplankton during the sampling period.

Discussion

Physico-chemical water parameters

The water temperature and dissolved oxygen have a decisive role in lakes during different seasons in temperate regions. The maximum and minimum water temperature were measured in July and March, respectively. These changes are attributed to climate, seasonal temperature variation, rainfall, evaporation and wind direction. Because the lake is located in a cold mountain area the mean annual surface water temperature was almost 14.5°C and the middle and bottom area of lake were colder. These conditions ensured an aerobic hypolimnion layer throughout the whole the study period. In fact, suitable content of dissolved oxygen can be an indication of non-polluted water (Salmaso et al. 2003). The lower oxygen obtained in July may be due to the increase of water temperature, respiration and consumption of different organisms and the decomposition of organic matter (Hamidi 2012; Oguzkurt and Ozhan 2008; Sarang and Sharma 2009). It is worth noting that the slightly lower mean death and the presence of inlet/outlet flows prevent water layer formation. Water conductivity (EC) was measured as salinity contents. The EC values were within a narrow range and indicated that the lake had constant EC as reported for freshwaters (Sarang and Sharma 2009). These minor changes could be related to precipitation, evaporation, air temperature and hydrological conditions (Makhlough 2008). The Zayandehrud Dam Lake has alkaline water with a pH of nearly 8. The lake alkaline pH was mostly attributed to photosynthesis, respiration and the decomposition of organic matter (Moss 1998). In addition, Oguzkurt and Ozhan (2008) reported that the enhancement of pH in summer (July and August) may be influenced by photosynthetic activity.

On the basis of its NO_3 and PO_4 contents the lake can be classified as meso-trophic during spring (April and Jun) to summer (July and August) and as oligo-trophic in the remaining seasons. These fluctuations mostly arise from anthropogenic activates such as agriculture and biogeochemical cycles. From the point of view of pollution, this lake is classified as a non-polluted water body based on its mean phosphate concentration of 0.1 mg dm^{-3} (WHO 2004).

Phytoplankton as a Bio-indicator

The structure and function of phytoplankton communities are important in the health of aquatic ecosystems (Lopes et al. 2005). Spatial and temporal variation in the physical, chemical and biological characteristics of a lake play a regulatory role in phytoplankton dynamics. One of them concerns nutrients and their concentration that are essential in the determination of phytoplankton composition and abundance in aquatic systems (Abate et al. 2017). NO_3 and PO_4 are among the most important of these nutrients and their ratio (N:P) may be used as an efficient tool for determining of the trophic state of water bodies (Yun and An 2016).

In this study the ratios of N: P were between 11.4:1 and 12.9:1 (October–December) and between 47.6:1 and 97.7:1 (other months) indicating that the Zayandehrud Dam Lake is mesotrophic and oligotrophic. Correspondingly, the genera of phytoplankton including; *Cyclotella* sp., *Asterionella* sp. and *Dinobryon* sp. confirm the oligo-mesotrophic status in different seasons. Furthermore, the genera *Ceratium* sp., *Glenodinium* sp. and *Euglena* sp. characteristic of eutrophic conditions were recorded in low abundance during the study period. Moreover, *Microsystis* sp., which is an indicator of eutrophic status, was not observed.

In all seasons, the phytoplankton community was dominated by Bacillariophyta. Diatoms are highly sensitive to environmental changes, hence they are considered as bio-indicators. As such, they can be utilized to determine the environmental conditions with a high degree of certainty (Richardson et al. 2007; Teubner 2003). Diatoms are indicators of clean water (Sakset and Chankaew 2013). In this research, *Cyclotella* exhibited the highest distribution, being present in all stations and sampling times. Therefore, the dominance of *Cyclotella* can serve as a good water quality indicator in all seasons. The species composition and density of Chlorophyta are important in aquatic ecosystems. For instance, *Chlamydomonas* and *Scenedesmus* are indicators of eutrophic waters (Peerapornpisal et al. 1999; Prescott 1973). In summer, the density of Chlorophyta increased with increasing of water temperature and the density of most genera increased. In the current study, the low density of genera such as *Scenedesmus* (46205 cells per dm^{-3}) and *Chlamydomonas* (4083.33 cells per dm^{-3}) could be considered as evidence of low production in this lake.

For Chrysophyta, genera such as *Dinobryon* and *Mallomonas* were identified. Their highest abundance was observed in August (5645 cells per dm^{-3}). Chrysophyta was not seen in winter due to the severe reduction in water temperature in March. *Dinobryon* sp. were mostly observed in spring and summer. In oligotrophic lakes this may be attributed to the higher water temperature in these seasons (Onyema 2008). *Chroococcus* and *Synechococcus* were the most important genera of Cyanophyta detected. Valan (1982) introduced the *Oscillatoria* genus for assessing the water quality index, and this genus has been found to be highly effective in indicating polluted water. This genus was observed to have a low density in the Zayandehrud Dam Lake, and as such its water can be seen as good in quality.

Ceratium, *Glenodinium* and *Peridinium* were the most important detected genera of Dynophyta. Dynophyta, observed in low abundance (6.22%), are indices for eutrophic lakes. This is an indication that Zayandehrud Dam Lake has not reached a eutrophic state. Euglenophyta had the lowest abundance percentage (2.07%) which also suggests a low level of pollution and production in this lake. They had the highest intensity in August (8291 cells per cm^{-3}). *Euglena* and *Lepocinclis* were the most important observed genera.

In general, the summer period revealed Cyanophyta, Dinophyta and Euglenophyta dominance when the water temperature and nutrient concentration were highest. It is well known that changes in the physico-chemical characteristics of any lake can lead to concomitant qualitative and quantitative changes in phytoplankton communities (Fathi et al. 2001). Temporal variations in phytoplankton communities have two peaks. The first one occurred in the summer and the second peak, which is smaller, was observed in early autumn. Since the massive growth of algae often occur in warm water (Onyema 2008), it can be concluded that the higher water temperature in summer is responsible for the higher density of phytoplankton (Vajravelu et al. 2018). Density reduction of planktonic populations in autumn and winter could be caused by reduction in water temperature, low light intensity, length of day and grazing by zooplankton (Onyema 2008). Actually, different planktonic species can tolerate different ranges of temperature as well as light and nutrient limitations.

Zooplankton as a Bio-indicator

Zooplankton communities generally change in response to the quality of water. Zooplankton densities greatly depend on the composition and abundance of phytoplankton (Vanni 1987; Lampert 1987). In this study, the lower zooplankton densities in June and July can be attributed to the nutrient concentrations, low density of phytoplankton and higher fish grazing rate. On the other hand, lake became more homogenous in the autumn (October and December) due to severe winds, and dissolved substances were released to the water column that made better utilization of solar radiation during the photosynthesis process. Enhanced primary production may lead to an increase of zooplankton density in autumn. Another reason for lower density of zooplankton in autumn and winter could result from the sharp reduction in water temperature. Published literature also suggests that changing of water quality has significant effects on the structure of zooplankton assemblages that can affect the functioning of the aquatic ecosystem (Sousa et al. 2008).

Since the taxonomic groups of zooplankton are characterized by various behaviors, they can be valuable organisms for use as bio indicators in aquatic systems. For instance, rotifers respond more quickly to environmental changes and were used to change the quality of water among other zooplankton. Rotifers are opportunistic organisms (r-strategist species adapted to fast population growth during favorable seasons) whose densities change with temperature in a short time (Matsumura et al. 1990). According to Dirican et al. (2009), the presence of rotifers such as *Brachionus*, *Keratella* and *Lecane* are indicative of eutrophic conditions. But in this study, *Brachionus* and *Lecane* were not present and *Keratella* was reported only in low abundance, which could indicate that the Lake water has not reached eutrophic level. Cladocerans prefer to live in clear waters (Singh 2000). The most important genera of Cladocera were *Bosmina* and *Daphnia*, which were present at all stages of sampling. According to Kumari et al. (2008), *Bosmina* and *Daphnia* are indicators of clean water. According to Singh (2000), *Chydorus* and *Ceriodaphnia* are an indicators of eutrophication, although neither of them were recorded in the present study. Copepoda are another sub-dominant group of zooplankton which occur in almost all types of fresh water bodies and form an important component of fish food (Sukad and Chavan 2013). Copepoda were mainly represented by immature forms of nauplii and copepodite. According to Kumari et al. (2008), Cyclopoidae and their nauplii are indicators of clean water.

Conclusions

According to the physico-chemical and biological findings of this research, the lake water was classified as healthy water and is suitable for human consumption. The success of a lake management and restoration program depends on the detection of spatial and temporal changes that may indicate changes in environmental conditions. Sustained integrated monitoring of the water body is strongly recommended for the purpose of modeling future safe policy management in the Zayandehrud Dam Lake.

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