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Biotic and Abiotic Factors Affecting the Population Dynamics of *Ceratium hirundinella*, *Peridinium cinctum*, and *Peridiniopsis elpatiewskyi*

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Abstract: The present research was conducted to assess the impact of abiotic and biotic factors on the growth of freshwater dinoflagellates such as *Ceratium hirundinella, Peridinium cinctum,* and *Peridiniopsis elpatiewskyi*, which reduce the quality of drinking water in the Zayandeh Rud Reservoir. To this end, 152 algal and zoological samples were collected from the reservoir located in the Central part of Iran in January, April, July, and October 2011. Abiotic factors such as pH, temperature, conductivity, transparency, dissolved oxygen, and nutrient concentration of the water were measured in all study stations. The results showed that the population dynamics of dinoflagellates in the Zayandeh Rud Reservoir was different depending on season, station, and depth. The findings proved that *C. hirundinella* was one of the dominant autumn planktons in the highest biovolume in the Zayandeh Rud Reservoir. While *P. elpatiewskyi* was present in the reservoir throughout a year with biovolume peak in summer. Accompanying bloom of *P. elpatiewskyi* and *C. hirundinella, P. cinctum* also grew in well-heated summer and autumn waters. It was further found that *Ceratium* density was positively correlated with sulfate ion concentrations, while the growth of *P. cinctum* and *P. elpatiewskyi* were associated, first and foremost, with NO₂⁻ and Mn.

Keywords: aquatic ecosystem; dinoflagellates; spatial distribution; seasonal dynamics; CCA analysis; water quality; Zayandeh Rud Reservoir; Iran

1. Introduction

Freshwater dinoflagellates of genera *Ceratium*, F. Schrank 1793; *Peridinium*, Ehrenberg 1830; and *Peridiniopsis*, Lemmermann 1904, are quite often components of biocenosis in many bodies all over the world and may even cause harmful blooms that negatively affect the water quality [1–4]. Some abilities of dinoflagellates are (i) tolerance to high irradiance [5]; (ii) migration in a water column to optimize photosynthesis and growth [5]; and (iii) toxin excretion [3] allow them to compete, grow, and dominate in the phytoplankton community. Furthermore, their diversity and biomass, just like the algae diversity and abundance of the other divisions, are formed under the influence of hydrological conditions and important environmental factors such as temperature, light intensity, and nutrient concentration [6–8]. Thus, the population dynamics of other algae and invertebrates, as the main feeders of phytoplankton [9], is also an impacted biological factor. In other words, a dinoflagellate growth and bloom can be influenced by both abiotic and biotic factors.

Reviewing the literature, *Ceratium hirundinella*, (O.F. Müller) Bergh 1881, is the most widespread freshwater dinoflagellate, which is present in almost all water bodies of the world. It is also responsible for the smell and taste of drinking water [10,11]. Distribution of *C. hirundinella* has been

properly examined under the influence of various physical and chemical factors in different latitudinal zones [12–17]. The presence of *C. hirundinella* in a water body is positively related to water ionic content, such as HCO_3^- , SO_4^{2-} , Ca^{2+} and Mg^{2+} [6,18]. In turn, higher ionic content is observed in water bodies that are stratified than in those that do not [14]. However, this alga was also found both in stratified and mixed periods [16]. The growth peak of *C. hirundinella* is immediately above the thermocline [15].

Among genera of *Peridinium* and *Peridiniopsis*, *Peridinium aciculiferum*, *Peridinium gatunense*, *Peridinium bipes*, and *Peridiniopsis minima* are known as the causative agents of harmful bloom in freshwaters [1,2,4]. Ecology of *Peridinium cinctum*, (O.F. Müll.) Ehrenb. 1838, and influence of some physical [8] and chemical parameters such as nitrite and phosphorous on its growth and reproduction have already been studied [5,19–21]. Regel et al. [5] found out that the species has to migrate to an optimal depth for better photosynthesis (30% surface irradiance); out of which, negative growth was observed. *Peridiniopsis elpatiewskyi*, (Ostenf.) Bourr. 1968, is known as a subtropical form, presented from May to September with a maximum in August in the Northern Hemisphere and preferred depth near the surface [22]. Nevertheless, there is no enough knowledge of ecological growth condition of *P. elpatiewskyi*. Its only distribution and morphology in some water bodies throughout the different parts of the world (i.e., Cuba [23]; Israel [22]; Ukraine [24]; Greece [25]; Germany [26]; Chili [27]) has been reported.

Thus, the present research aims to assess the impact of abiotic and biotic factors on the population dynamics of freshwater dinoflagellates such as *C. hirundinella*, *P. cinctum*, and *P. elpatiewskyi* in the Zayandeh Rud Reservoir, of which its water is used for irrigation and drinking supply (Central Iran).

2. Materials and Methods

2.1. Study Sites

Materials for the present study were collected from the oligotrophic mountain reservoir of Zayandeh Rud, situated in the Central part of Iran on the Zayandeh Rud River in the Esfahan-Sirjan Basin. The reservoir is the most important source of pure water for four provinces in Iran. It is located at 50°15–50°45′ N; 32°30′–33°00′ E with a mean elevation of about 1950 m above mean sea level. It is elongated in an east-west orientation (40 km long and from 0.05 to 4.5 km wide). The drainage basin area covers about 41,503 km². The maximum water-surface is 54 km² and stores some 1470 million m³ at the highest level [28]. The maximum depth is 88 m. However, these parameters are constantly fluctuating [29]. During the investigation, the maximum depth was 51 m. Its retention time is 369 days. The main water source for the reservoir is the Zayandeh Rud River, with its temporary and permanent inflows, that is mainly fed up by melted snow water springing from the Zardkuh Bakhtiyari Mountains at the height of 4221 m above sea level [30]. The majority of water inflows (up to 80%) into the reservoir in May. With discharge waters, the reservoir is polluted with agrochemicals from agricultural fields and orchards. In the reservoir, stratification usually starts in an area located close to the dam in June and ends in late August. Sometimes, short-term stratification is observed in April [28]. The mid-summer thermocline near the dam had a depth between 20 and 22 m during the investigation and the transparency of water can reach 6.5 m in winter, while in the summer, it accounts for 3.0 m. The lower boundary of the photosynthesis layer of phytoplankton reaches to 16–17 m in winter, and it rises to 7–8 m in summer.

To conduct the study, four transects with three stations (left and right banks, and a middle station) were established for the water sampling. The first transect was considered at the water entrance where the river and one of the inflows flow into the reservoir. The second transect was located in the water body mouth. The third one was in the middle of the reservoir. The fourth transect was finally considered near the dam structure. The details of the sampling points and study transects are shown in Figure 1 and Table 1.



Figure 1. Schematic map of Zayandeh Rud Reservoir showing the sampling stations. The transects corresponding sampling stations on the left bank are denoted by 2⁻, 3⁻, 4⁻, while on the right bank by 2⁺, 3⁺, 4⁺, and the middle stations by 1, 2, 3, 4.

Table 1. Geographic coordinates and depths of the middle station of each transect on the Zayandeh Rud Reservoir.

Turnet	Coographic Coordinates	Depth (m)			
Iransects	Geographic Coordinates	January	April	July	October
1	50°31′45.74″ E–32°42′56.38″ N	1.2	1.4	1.5	1.0
2	50°36′31.58″ E–32°43′09.32″ N	10.5	7	8.3	5.5
3	50°39′56.68″ E–32°44′08.97″ N	32	27	28.4	23.5
4	50°44′02.37″ E–32°44′01.72″ N	51	48	49.3	43

2.2. Sampling

In order to study the affecting factors on population dynamics of *C. hirundinella, P. cinctum*, and *P. elpatiewskyi*, some abiotic factors such as pH, surface temperature, as well as depth temperature profile, electrical conductivity (EC), transparency, total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), mineral and organic nitrogen, phosphates, sulfates, Fe, and Mn were considered. Besides, some biotic factors including the qualitative and quantitative algal composition of all algal divisions, and cell numbers of microinvertebrates were measured at all investigated stations. The water transparency was estimated by a Secchi disk. The vertical profiles of temperature were carried out with conductivity-temperature-depth (CTD) sensors (Ocean Seven 316). Qualitative samples were taken with a planktonic net, with a mesh size of 55 µm, by sieving 100 L of water and a part of them were preserved with a 4% formaldehyde. Quantitative algological and zoological samples were also taken with a Ruttner bathometer [31,32].

Overall, 152 algal and zoological samples were collected from the surface, 5, and 10 m depths, from January to October 2011, in the middle of each season between 9:00 and 14:00. Moreover, samples were taken up to 30 m every 5 m in the middle station of the fourth transect in July to study the species behavior below and above the thermocline that has a place in this water area. Peculiarities of sampling, processing, and storage of the algological material are described in Wasser et al. [33].

2.3. Sample Analysis

The dinoflagellate cells study was conducted at the Institute of Evolutionary Ecology of the National Academy of Sciences of Ukraine (Kiev) using an Olympus BX51 light microscope with UPlanFLN 40 ×/0.67 and Plan 40 ×/0.65 Ph 2 lenses. Dinoflagellates were examined in transmitted light and a mode of fluorescence with preliminary staining of cells using Calcofluor White M2R [34]. The cell sizes were determined using the AmScope program. Photomicrographs were made with a Canon EOS

1000D camera in Adobe Photoshop CS5 Extended. Identification of other algae species was carried out with a Nikon Eclipse E200 microscope at the laboratory of the Department of Marine Biology of Tarbiat Modares University (Iran). The diatoms were processed for the purpose to delete the organic contents of the cell by warm methods before microscopic analysis [35,36]. Identification of microinvertebrates was carried out according to former reports [32,37,38]. Algal cells were counted with a Neubauer chamber conducting previously the sedimentation procedure according to Wasser et al. [33]. Cell biovolumes of each species were calculated according to the most suitable geometric models [39,40]. Total biovolumes of each phytoplankton species were calculated by multiplying the counted number of cells per milliliter by an average cell biovolume of that species. The cells of invertebrates were reckoned with a Sedgwick Rafter counter [32].

2.4. Data and Statistical Analyses

The canonical correspondence analysis (CCA) was used to determine relationships between the cell number of investigated dinoflagellates and the investigated abiotic and biotic factors. The statistical analysis was performed with the software SPSS 21.

3. Results

The study found that, among dinoflagellates, three species of *C. hirundinella*, *P. cinctum*, and *P. elpatiewskyi* were the structure-forming species in reservoir biocenosis (Figure 2). These species were found in the water column under the particular abiotic parameters, as presented in Table 2.



Figure 2. Dominant species of dinoflagellates inhabiting the Zayandeh Rud Reservoir: 1—*Ceratium hirundinella*, 2–4—*Peridinium cinctum*, 5–7—*Peridiniopsis elpatiewskyi*; 1, 2, 5—ventral view, 3, 6—dorsal view, 4—antapical view (antapex), 7—apical view (apex). C1–C6—cingulum plates; Sa, Sd, Sp–sulcal plates; 1'–4', 1"–7", 1"'–5"'', 1""–2""—thecal plates.

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Table 2. The value ranges of ablotic water factors restricted to the samples where C. <i>mrunathelia</i> , P.
cinctum, and P. elpatiewskyi (CH, PC, and PE) were present over the study period in the Zayandeh
Rud Reservoir. Abbreviations: TDS, total dissolved solids; EC, electrical conductivity; DO, dissolved
oxygen; COD, chemical oxygen demand; BOD, biochemical oxygen demand.

	Species					
Abiotic and Biotic Variables	СН		РС		РЕ	
variables	Min–Max	$Mean \pm S.D$	Min–Max	Mean \pm S. D	Min–Max	$Mean \pm S.D$
Transparency (m)	0.3-6.2	3.3 ± 1.76	2.8-4.2	3.6 ± 0.57	0.68-6.2	3.25 ± 1.83
TDS (ppm)	150-260	191.1 ± 37.21	152-262	195.8 ± 41.4	152-262	192.2 ± 35.9
pH	7.4-8.7	8.04 ± 0.44	6.7-8.4	7.9 ± 0.46	6.7-8.7	8.02 ± 0.45
Temperature (T, °C)	6.4-25.6	14.8 ± 5.6	11-25.6	17.5 ± 4.9	11-25.6	15.06 ± 5.69
EC (μ S cm ⁻¹)	230-413	329.5 ± 66.09	230-413	295 ± 43.26	230-413	324.6 ± 64.2
$DO (mg L^{-1})$	5.2-8.3	7.8 ± 1.35	5.2-8.3	7.1 ± 0.91	5.2-8.3	7.7 ± 1.24
NO_3^{-} (mg L ⁻¹)	3.8-12.6	9.8 ± 4.97	3.8-12.6	8.02 ± 3.12	3.8-12.6	9.64 ± 4.2
NO_2^{-} (mg L ⁻¹)	0.055-0.15	0.07 ± 0.03	0.052-0.11	0.06 ± 0.03	0.052-0.11	0.06 ± 0.03
$PO_4^{-} (mg L^{-1})$	0.02 - 0.17	0.06 ± 0.03	0.02-0.17	0.06 ± 0.03	0.02-0.17	0.06 ± 0.03
SO_4^{-} (mg L ⁻¹)	14.6-236.6	46.2 ± 49.3	14.6-236.6	55.6 ± 56.4	14.6-236.6	44.3 ± 50.05
Fe (mg L^{-1})	0.002-0.2	0.06 ± 0.06	0.002-0.10	0.025 ± 0.038	0.002-0.15	0.06 ± 0.06
$Mn (mg L^{-1})$	0.003-0.006	0.003 ± 0.002	0.001-0.006	0.002 ± 0.001	0.001-0.006	0.003 ± 0.002
$COD (mg L^{-1})$	2–57	12.24 ± 12.72	2–57	14.3 ± 13.6	2–57	11.7 ± 12.79
BOD (mg L^{-1})	1–29	14.25 ± 14.59	1–29	7.53 ± 6.5	1–29	6.24 ± 5.79

In the Zayandeh Rud Reservoir, the investigated dinoflagellates were present in different biovolumes at the water surface depending on the season and station (Figure 3). The average biovolumes for three species cells of *C. hirundinella*, *P. cinctum*, and *P. elpatiewskyi* were calculated 75,078.57 μ m³, 59,511.49 μ m³, and 14,299.84 μ m³, respectively. Furthermore, their abundances were changing in a water column (Figure 4). Temperature depth profiles showed that thermal stratification was observed in the middle station of transect 4 (near the dam) and eventually stabilized during July to produce a precipitous thermocline of 6.7 °C between 20 and 22 m.



Figure 3. The biovolumes of the investigated species at the surface in different stations (2⁻, 3⁻, 4⁻, 2⁺, 3⁺, 4⁺, 1, 2, 3, 4) and months (January, April, July, and October) in the Zayandeh Rud Reservoir in 2011. *CH*, *C. hirundinella*; *PC*, *P. cinctum*; *PE*, *P. elpatiewskyi*.



Ceratium hirundinella





Peridiniopsis elpatiewskyi



Figure 4. Vertical distribution of *C. hirundinella*, *P. cinctum*, and *P. elpatiewskyi* (black line) and depth temperature profile (the red one) in the Zayandeh Rud Reservoir at the middle stations of the third and fourth transects in January, April, July, and October 2011.

The maximum number of cells was recorded for *P. elpatiewskyi* at a 5 m depth near the dam in July while the minimum value was in January. However, it had not the maximum values in biovolume. Monitoring the vertical distribution showed that *P. elpatiewskyi* preferred to concentrate more at a depth between 5 and 15 m above the thermocline. Below that, the cell density was significantly declined. *P. elpatiewskyi* was replaced by *C. hirundinella*, which was one of the dominants in autumn plankton in the Zayandeh Rud Reservoir. Overall, *C. hirundinella* preferred the low flow reservoir areas (transects 3

and 4, which are located closer to the dam), where it was recorded in highest biovolume. In a water column, *C. hirundinella* was spread uniformly enough. Its population density decreased below the thermocline. In January and April, *Ceratium* cells appeared more as cysts. Accompanying bloom of *P. elpatiewskyi* and *C. hirundinella*, *P. cinctum* also grew in well-heated summer and autumn waters. In October, especially favorable conditions for this species occurred near the second transect at the bottom. In January, species were not detected in the samples. *P. cinctum* also gave preference to the depth depending on transects. In stations with insignificant depths, it went down to the bottom (station 2) while, at the deep-water stations, it focused on stratification close to the surface (middle stations of transects 3 and 4) and above the thermocline.

The investigated dinoflagellates were a part of the algal and invertebrate communities. A total of 117 species of algae and 255 invertebrates species were recorded in the course of this study in the Zayandeh Rud Reservoir. A maximum value of the phytoplankton biovolume was in October while a minimum one was observed in January (Figure 5).



Figure 5. The seasonal variations in biovolumes of *C. hirundinella* (CH), *P. cinctum* (PC), *P. elpatiewskyi* (PE) and phytoplankton groups (Cyanophyta, Bacillariophyta, Euglenophyta, Chrysophyta, Xanthophyta, Chl+Str: Chlorophyta and Streptophyta) on average throughout the Zayandeh Rud Reservoir in January, April, July, and October 2011.

Among algae, diatoms were dominant on the species diversity, but not on biovolume. The recorded maximum number of diatomic cells of 1230 cells mL⁻¹ was in January. Three dominant species of Asterionella formosa Hassall, Cyclotella ocellata Pantocsek, and Fragilaria crotonensis Kitton contributed to the reservoir algal flora. The lowest biovolume of diatomic cells was noted in July. Dinobryon divergens O.E.Imhof together with Dinobryon sertularia Ehr. from Chrysophyta division bloomed up to 3.33 mm³ L⁻¹ in the middle of the third transect in April. The population density of green algae and streptophytes varied from 2 to 270 cells mL⁻¹. Chlorophyta and Streptophyta groups were dominated by Pediastrum boryanum (Turpin) Meneghini, Oocystis borgei J.Snow, and Zygnema insigne (Hass.) Kütz. The highest biovolume of green algae was observed in 10 m depth near the dam in autumn when Tetraedron minimum with its variety of T. minimum var. scrobiculatum and less Scenedesmus ellipticus vegetated. The species diversity of zooplankton in a sample ranged from one to 34 species and Protozoa was presented as the most diverse and numerous (to 120 thousand specimens m^{-3}). Balanonema sp. (dominated in winter), Vorticella convallaria (in spring and autumn), Tetrahymena pyriformis (in autumn) of class Ciliata and Amoeba sp. (in spring) constituted the complex of the dominant species of protozoa in the reservoir. Among Metazoa, species of the phylum Arthropoda, such as Leydigia acanthocercoids (dominated in spring), Chydorus sphaericus (in spring), Cyclops sp. (at the third and fourth transects in summer and autumn), Herpetocypris sp. (in winter), Nauplius larva (in summer) and the phylum Rotifera

as *Notholca squamula* (in spring), *Keratella cochlearis* (at the third and fourth transects in spring and throughout the water area in autumn), *Polyarthra euryptera* with *Polyarthra* sp. (at the first and second transects in summer), as well as *Nematod* sp. of the phylum Nematoda (throughout the researched period), were the most numerous.

To find the correlation between the cell number of the three studied species and abiotic and biotic factors, canonical correspondence analysis (CCA) was conducted (Figure 6). Based on the CCA, the eigenvalues of axis 1 ($\lambda = 0.84$) and 2 ($\lambda = 0.39$) explained 57.5% and 26.8% of the relationship. The *C. hirundinella* density was positively correlated with SO₄⁻, BOD, COD, green, and streptophyte algae and negatively correlated with NO₃⁻, and PO₄⁻, while *P. elpatiewskyi* had a positive correlation with temperature and a negative one with EC, NO₂⁻, and Mn. *P. cinctum* was associated moderately with Fe and NO₂⁻.



Figure 6. Canonical correspondence analysis (CCA) biplot showing the relationships between the cell number of *C. hirundinella* (CH), *P. cinctum* (PC), *P. elpatiewskyi* (PE), and abiotic and biotic variables of algal divisions (Cyan: Cyanophyta, Bac: Bacillariophyta, Eug: Euglenophyta, Chrys: Chrysophyta, Xan, Xanthophyta, Chl+Str, Chlorophyta plus Streptophyta) and invertebrates.

4. Discussion

In the phytoplankton community of the Zayandeh Rud Reservoir, *C. hirundinella, P. cinctum*, and *P. elpatiewskyi* were the structure-forming species and their growth peaks were found between summer and late autumn. *C. hirundinella*, which is a well-researched species because of its conspicuous cells and cosmopolitism, in the Zayandeh Rud Reservoir, was present in water throughout a year. However, in winter and spring it appeared more as cysts and in autumn alga reaches the highest biovolume. Its vertical distribution in the water column is not uniformly above the thermocline and photic zone, which is not in conflict with a report of Hedger et al. [15]. Comparing the obtained findings with many other studies, the conclusion can be made that seasonal periodicity of the species *C. hirundinella* is variable and reaches the high abundance in different months depending on the world regions (Table 3).

Species	Water Body	Max Cell Number, Cells mL ⁻¹	Depth	Period of Time	Authors
СН	Zayandeh Rud Reservoir, Iran	400	Surface	In October	Current study
	Albert Falls Dam (South Africa)	5000	-	In October	Hart and Wragg [17]
	The Ishitegawa Reservoir (Japan)	1300	Surface	In July	Kawabata, Kagawa [12]
	Rio Tercero Reservoir	1244	Photic zone	later summer	MacDonagh et al. [16]
Esthaite Water (England)	Esthaite Water (England)	1000	In the 0–5 m layer	In September	Heaney and Talling [10]
	Bermejales Reservoir (Spain)	247	-	In December	Perez-Martinez, Sanchez-Castillo [14]
	Lake Kinneret (Israel)	35	Photic zone	in May	Pollinger, Hickel [22]
РС	Zayandeh Rud Reservoir, Iran	50	At the bottom (5.5 m)	In October	Current study
	Torrens Lake (South Australia)	460	Below the surface mixed layer	In January (summer month)	Regel et al. [5]
	Man-made lake near Tokyo	420	-	-	Pollinger, Hickel [22]
PE	Zayandeh Rud Reservoir, Iran	1500	At a 5 m depth	In July	Current study
	Lake Kinneret (Israel)	100	Near the surface	In summer	Pollinger, Hickel [22]

Table 3. The population density of *C. hirundinella* (*CH*), *P. cinctum* (*PC*), and *P. elpatiewskyi* (*PE*) in some water bodies of the world.

Perhaps, firstly, in different parts of the world in the same month, the water temperature because of the solar radiance can significantly distinguish [41]. Secondly, species can inhabit water where the temperature ranges between 4 and 26 °C [14,16,17]. The present correlation analysis indicated that the species do not rely on temperature and can grow in diverse temperature condition and in stratified and mixed periods that explains its temperature spread. Indeed, in previous works, it was found that the growth of *C. hirundinella* depends more on ionic content of water such as Ca²⁺, Mg²⁺, PO₄⁻, HCO^{3-} , and lest of SO_4^{2-} [6,13,14,18]. The statistical analysis of the current study determined that the main element correlated with the population of C. hirundinella is sulfate SO_4^- . The maximum number of the species cells was noted at notably high values of SO_4^- (from 100 to 236 mg L⁻¹). Photosynthetic organisms especially vascular plants and algae acquire S at their highest oxidation number as sulfate [42]. The ATP sulfurylase sequence of five species from dinoflagellates is known but there is no information about the Ceratium species. Perhaps, S is also one of the main components of C. hirundinella cells and is used for the sulfation of its molecules such as lipids, polysaccharides, proteins, the amino acids cysteine, antioxidants, and others, as in the other algae [43]. In the Zayandeh Rud Reservoir, the main source of sulfate pollution is the runoff water, which comes into the reservoir from agricultural fields distributed in the basin, orchards where sulfate is used in fertilizers, and fish farms as domestic sewage.

Water discharge contributes to water pollution and increases not only sulfate concentration but also nitrite (NO^{2–}) and nitrate (NO^{3–}) that were correlated with the growth of *P. cinctum* and *P. elpatiewskyi*. When no external nitrogen source is available in the environment, even at optimal temperatures, cells of *P. cinctum* and *P. elpatiewskyi* stop their fission [20]. According to conducted statistical analysis, between NO^{3–} and NO^{2–}, *P. cinctum* and *P. elpatiewskyi* preferred to absorb nitrite-nitrogen as a nutrient unlike the green algae undergoing nitrate assimilation to nitrite and then reduction to ammonium [44].

Perhaps, the dinoflagellate has the enzyme complex nitrite reductase, making it competitive in an algological community [31]. The temperature was the second-strongest factor correlated with cells of *P. cinctum* and *P. elpatiewskyi*. Their growth temperature ranged from 11 to 25 °C during the whole investigated period. The species were present in the plankton of the reservoir throughout a year, with their biovolume peaks in summer. In general, in the Zayandeh Rud Reservoir, *P. cinctum* was characterized by a small number of cells compared to some of the world's water bodies (Table 3). It could not compete with *P. elpatiewskyi*, which grew up with it under the same ecological conditions and in the same period of the year. Under stratification, *P. cinctum* migrated to the surface, which is a bit in contrary to that reported by Regel et al. in the South Australia Lake [5]. Furthermore, it was found out that Mn, and to a much lesser extent Fe, were the required trace elements for growth of *P. cinctum* and *P. elpatiewskyi*. pH was weakly variable correlating with the abundance of the dinoflagellate, nevertheless, pH is a factor that contributes to the control of dinoflagellate blooms [45].

Concerning the biotic factor, the variability of C. hirundinella was positively moderately associated with the divisions Chlorophyta and Streptophyta. This fact may point that C. hirundinella and green-streptophyte algae are coexist well and a joint population growth attests to favorable abiotic environmental factors (temperature, EC, pH, and others) for them. P. cinctum was negatively associated with Bacillariophyta. When the diatomic biovolume declined, its biovolume was increased showing that phytoplankton species dominance shifted between these divisions [46]. Moreover, Duarte et al. [47] also concluded that phytoplankton communities with lower diversity were dominated by dinoflagellates and exhibit higher cell numbers and production than communities with higher diversity. This was possible because dinoflagellates had multiple life-form strategies consistent with their diverse habitat specializations, but rely on impoverished bloom species pools, whereas diatoms had a relatively uniform bloom strategy based on species-rich pools and exhibit limited habitat specialization [48]. The population of *P. elpatiewskyi* was positively correlated with Xanthophyta. Concerning Metazoa and Protozoa, all three investigated dinoflagellates had a weak correlation. The cells of *P. elpatiewskyi*, probably due to their size, was the most consumable. Although, overall, invertebrates prefer to feed with smaller cells of green algae, which grow at this time [9,21]. On the other hand, many dinoflagellates produce chemicals which cause them to be unable to be swallowed by invertebrates, enhancing their survival and competitive ability [49]. Moreover, these algae have long generation times and their losses due to grazing were low by comparison with those of other planktonic algae [16]. The cases of consumption of *P. cinctum* by fish that had not been investigated in this work also were known [50].

The quality of the water stored in the Zayandeh Rud Reservoir is typically very good [51], but surface and water column growth of *C. hirundinella* and *P. elpatiewskyi*, that appear during warm, calm periods when the water level is low, may impair the quality of water used for drinking. Therefore, according to the present study, it was firstly important to monitor the parameters such as SO_4^- , which was correlated with *C. hirundinella* growth, and NO_2^- associated with *P. cinctum* and *P. elpatiewskyi* growth, in order to take measures to control the use of fertilizers in orchards, agricultural fields, and domestic sewage, which are the main causes of water pollution by these ions.

5. Conclusions

The current investigation allowed the changes in population dynamics of the three dominant dinoflagellates, such as *C. hirundinella*, *P. cinctum* and *P. elpatiewskyi*, to be identified, under the influence of the biotic and abiotic variables, in the Zayandeh Rud Reservoir (Central Iran). The statistically significant moderate correlations were ultimately established between abiotic parameters and dinoflagellates under consideration. *C. hirundinella* was positively correlated, first and foremost, with SO₄⁻, while *P. cinctum* and *P. elpatiewskyi* had a negative correlation with NO₂⁻ and Mn. Furthermore, the findings proved that biotic factors influenced the growth of the three dinoflagellates less. The results of the present study would help the Zayandehroud Reservoir managers to adopt the most ecologically appropriate measures to maintain the quality of drinking water. However, endeavors

to gain better insight, with high-resolution and longer duration of data collection, are needed in order to draw a comprehensive conclusion.

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