Research Article

Water quality assessment of a temperate urban lagoon using physico-chemical and biological indicators

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Abstract
The aim of this work was to assess the water quality of the urban lagoon located in Parque Unzué (Gualeguaychú, Argentina) using physico-chemical and bacteriological parameters, the composition of micro-phytoplankton assemblages and functional groups (FGs) and to evaluate their annual variability. Twenty-two samplings in three stations were collected between 2015 and 2018, physico-chemical and bacteriological parameters were measured and micro-phytoplankton (20–200 µm) was collected, identified to the lowest taxonomic level and classified in functional groups. Physico-chemical and bacteriological parameters indicated that the lagoon presented high organic pollution and no significant differences ($p < 0.05$) were observed between sampling stations, but there were differences between the annual periods of sampling. In general, a detriment to water quality can be seen from 2015 to 2018. This was observed in the simplified water quality index (SWQI) values. Micro-phytoplankton assemblages were compounded by 48 genera distributed into Bacillariophyceae (19), Chlorophyceae (12), Cyanophyceae (7), Euglenophyceae (5), Conjugatophyceae (Zygnematophyceae) (3) and Dinophyceae (1). The Chlorophyceae group was the most sensitive to changes in the system and specifically, the genus *Chlorella* was an early warning indicator. Nineteen FGs were identified, and the majority were characteristic of hypereutrophic, small, turbid and highly enriched lagoons. We conclude that the lagoon located in Parque Unzué showed permanent organic pollution that kept increasing throughout the study time and therefore, that it is possible that the current conditions lead to the collapse of the system.

Keywords Gualeguaychú · Parque Unzué · Functional groups · Organic pollution · Phytoplankton · Guanotrophy

1 Introduction

Urban lagoons are particular ecosystems present in many cities and part of the urban ecology [50]. Some have a natural or anthropogenic origin with several functions, such as increasing the life quality, mitigating the effects of the urban climate [50, 58, 67] and being a biodiversity refuge [17]. However, urban water bodies are subject to increasingly negative environmental impacts [63]. They are usually affected by habitat fragmentation and organic pollution [17, 25, 85] that impact in the composition and distribution of the species assemblages and which assemblages can therefore be considered as urban health indicators [38]. More recently, the guanotrophy (nutrient addition by bird excrements) effects on water quality have been the subject of investigations [92].

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On the other hand, the phytoplankton is an extremely diverse polyphyletic group of photosynthetic protists and cyanobacteria, which generates input to food webs and drives the biogeochemical cycle [73, 77]. The phytoplankton assemblage changes can reflect the presence of pollutants, especially nutrients [41] which cause an increase in the micro-phytoplankton abundance [1, 52] and in the tolerant species [56] and a decrease in the sensitive species [26]. These assemblages are good indicators due to respond quickly to ecological changes, due to their fast growth rates [32, 75, 84, 87] and permit detecting any possible alteration in water quality [13, 23, 54, 75]. Traditional phytoplankton monitoring is based on biomass, chlorophyll-a or accessory pigments and composition and abundance of species [2, 7, 31, 53]. More recently, the approach provided by functional groups began to be used. These classifications cluster species with common traits and similar responses to environmental changes and have been proposed for phytoplankton by several authors, such as Abonyi et al. [2], Beamud et al. [6], Kruk et al. [47], Padisák et al. [64], Reynolds [70], Reynolds et al. [71] and Salmaso and Padisák [78]. A particularly influential functional classification is that proposed by Reynolds et al. [71] since it is based not only on the individual functional traits but also on the ranges of the environmental conditions in which the species are found. Kruk et al. [47] have proposed an alternative classification based on morphological aspects. Following these approaches, trait-based approaches have been increasingly applied as a tool to explain and predict the response of phytoplankton species to environmental conditions, both in marine and continental aquatic systems [6, 48].

It is possible to find numerous scientific studies on urban lagoons in the world [33, 59, 63, 80], showing the importance they have in the cities. Conversely, the Latin American cities have given little importance to these ecosystems in urban ecology, despite the accelerated losses of biodiversity [83]. Argentina has a significant diversity of urban lagoons and the studies carried out there have focused mainly on epidemiological aspects [27]. Therefore, the phytoplankton studies in these ecosystems are scarce [15, 29, 34, 35, 60–62].

The purpose of this work was to assess the water quality of the lagoon located in Parque Unzué using physico-chemical and bacteriological parameters, the composition of micro-phytoplankton assemblages and functional groups and to evaluate the annual variability of all parameters in the study area. Our hypothesis is that the lagoon presents organic pollution generating alterations on phytoplankton assemblages and that it is possible to find early warning indicators.

2 Materials and methods

2.1 Study area description

The urban lagoon in Parque Unzué (33°00′46″S–58°29′24″W, Fig. 1) is located in a multipurpose park of (Gualeguaychú) corresponding to Mesopotamian Pampas [55]. The average rainfall in the city of Gualeguaychú is of approximately 1257.48 mm (1999–2015) [57]. In the highlands, the Gualeguaychú river basin has moderately good, deep, dark-colored soils with a dense argillic clay–silt horizon, medium surface runoff with fairly slow permeability, deep water table and erosion light water. On the banks, the soils are deep, with very slow surface runoff and slow permeability without erosive risk [39, 42].

The study area is a small, eutrophic and non-stratified lagoon with high turbidity corresponding to a polymictic lagoon. It has a depth of 1.7 m, a perimeter of 0.82 km, an area of 2.75 km^2, a maximum length of 0.32 km and a maximum width of 0.14 km. Its euphotic zone (Z_{eu}) values vary between 0.36 and 1.27 m. It has a recreational use, without direct human contact [34, 86] and it is used as a refuge for biodiversity. Water input comes from the rain, from possible overflows of the Gualeguaychú river [35] and from artificial replacements to compensate for water level losses. The guanotrophy is a permanent nutrient and an organic matter input in the system. Moreover, during the summer, there is usually a punctual contribution of wastewater from a campsite [17] and the guanotrophy can be increased by migratory birds. Regarding this latter point, there are native and exotic species of flora and fauna (Supplementary material), particularly, an important diversity of birds (34 species) can be found, including migratory species such as the white heron (*Egretta thula* and *Ardea alba)* and cattle heron *(Bubulicus ibis)*. In addition, 30 phytoplankton genera including invasive genus *Ceratium* and potentially toxic cyanobacteria [35] and 13 macroinvertebrate taxa [17] were found.

2.2 Selection of sampling stations and frequency

A study area exploration was carried out, and then, three sampling stations representative with easy and permanent access were selected. In each sampling stations, 22 water samples were taken between May 2015 and May 2018, performing at least one sampling per climate station. The frequency was influenced by climatic conditions and accessibility of the study area. During intense rainfall periods and a level increase of the Gualeguaychú river, the study area can be flooded once or twice a year.

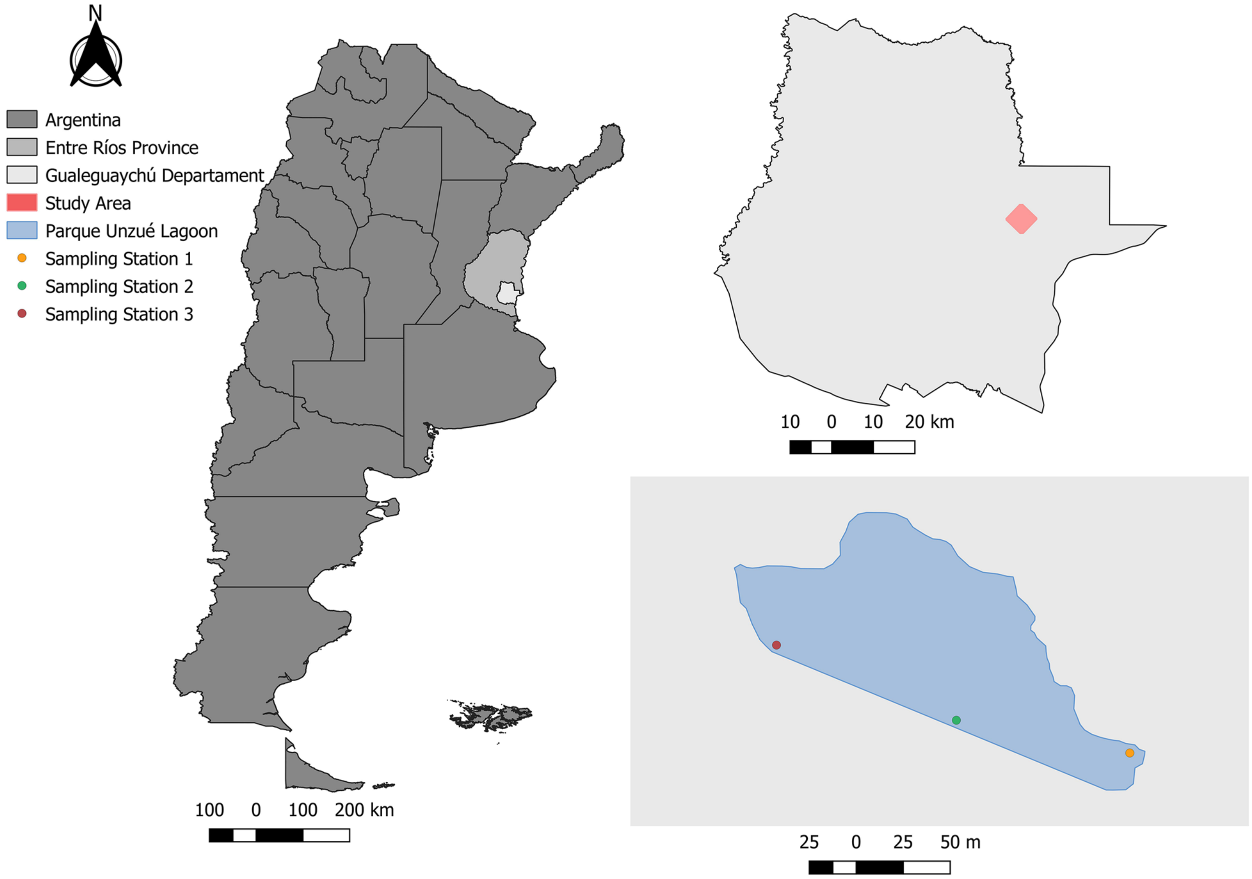

Fig. 1 Description of the study area (QGIS 3.2, 2018)

2.3 In situ measurement and field data collection

Physico-chemical variables were measured in situ, namely pH, water and air temperature, electric conductivity (EC) with Hanna HI991003 portable meter and dissolved oxygen (DO) with YSI model 55 were measured. Meters were calibrated beforehand [4].

A standard Secchi disk (SD) of 30-cm-diameter was used to measure the water transparency and total depth. Moreover, in each sampling station, 1-L of lagoon water was collected using clean amber glass bottles in order to determine physico-chemical parameters which are described below. For bacteriological parameters, 250 mL of water was collected using a plastic sterile bottle. Furthermore, qualitative micro-phytoplankton (20–200 μm) samples were collected using a Zeppelin net [82] of pore = 30 μm and fixed with 50% Transeau solution [24] according to Gianello et al. [35]. Samples were conserved at refrigeration temperature (4 °C) [72] until their analysis.

Additionally, rain data (Dirección de Hidráulica de Entre Ríos) and the hydrometric level (HL) of the Gualeguaychú river (Prefectura Naval Argentina) were obtained from databases of those institutions.

2.4 Physico-chemical and bacteriological tests

2.4.1 Phosphorus

Total phosphorus (TP) was measured in unfiltered samples which were digested by heat in an acid medium [4]. Soluble reactive phosphorus (SRP) was measured in filtered samples with a filter of 0.45 μm [4]. Both TP and SRP were measured as a duplicate using stannous chloride method with a spectrophotometer (UV–VIS ZUZI 4211/50) at 690 nm [4]. Previously, a calibration curve was performed in the range 0–1000 expressed as μmolP-PO_4^{3-}/L.

2.4.2 Chemical oxygen demand

Chemical oxygen demand (COD) was measured in order to obtain a total organic matter indicator of the study area. COD was measured in unfiltered samples which were digested by heat in an acid medium by reflux closed [4]. Samples were measured for a duplicate by spectrophotometric method (UV–VIS ZUZI 4211/50) at 600 nm [4]. Previously, a calibration curve was performed in the range 20–900 expressed as μgO_2/L.

2.4.3 Chlorophyll-a

Chlorophyll-a (chl-a) was measured in accordance with Crettaz-Minaglia et al. [18] using a spectrophotometer (UV–VIS ZUZI 4211/50) after extraction with 100% methanol, at 665 and 750 nm before and after acidification with 1 N HCl, following the technique of Marker et al. [51]. The concentration of chl-a was expressed in µg/L and was an indicator of phytoplankton biomass of the lagoon.

2.5 Total mesophilic aerobic and coliforms bacteria

Total mesophilic aerobic bacteria (TMAB) were determined by the method of the fluid plate [4]. Serial dilutions of each sample were made and plated for duplicate with plate count agar (Britania) [72] so as to get between 30 and 300 colonies [4]. Plates were incubated for 48 h at 35 °C ± 1 °C in a dark stove [4], and the colonies' number was multiplied by the dilution factor and reported as colony forming units (CFU)/100 mL [22].

Furthermore, total coliforms (TC) were measured by a method of multiple tubes [4]. Lactose-fermenting colonies from MacConkey (Britania) broth were presumed to be total coliform bacteria and were subject to further testing [22]. Serial dilutions of each water sampling were made and put in tubes for a duplicate [72]. They were incubated for 48 h at 35 °C ± 1 °C in a dark stove [4]. Tubes were recorded as positive when they presented gas inside the Durham bells and a color change from purple to yellow [72]. The concentration of TC was expressed in MPN.100 mL^{-1}.

2.6 Micro-phytoplankton

Samples were observed with an optical microscope Olympus® at 40–100 X, and the micro-phytoplankton was classified up to the gender taxonomic level following specific keys of each group according to Gianello et al. [35], Komárek et al. [45] for Chlorophyceae, Komárek and Anagnostidis [43, 44] for Cyanophyceae, Krammer and Lange–Bertalot [46] and Zalocar de Domitrovic and Maidana [93] for Bacillariophyceae and Tell and Conforti [88] for Euglenophyceae.

2.7 Data analysis

Field data were analyzed with Paleontological Statistic (PAST) [37] and Systat Software Inc® version 12.0. Descriptive statistics were used to characterize the variability of physico-chemical and bacteriological parameters. Previously, Shapiro–Wilks normality test was performed, and then, the nonparametric Kruskal–Wallis test with significance level $\alpha < 0.05$ was also carried out over all the data set and, finally, Mann–Whitney pairwise comparison test was performed to compare sampling stations and the annual sampling periods.

Moreover, water quality was determined using a simplified water quality index (SWQI) (Eq. 1 modified to [16]).

$$\mathrm{SWQI} = t * \left(\sum Vi * Pi\right) \tag{1}$$

where Vi is a transformation function and Pi is the assigned importance of the parameters. The parameters used were: t = temperature, EC = electric conductivity, DO = dissolved oxygen, COD = chemical oxygen demand and SD = Secchi disk. Index allowed to classify the water quality in: very poor (SWQI = 0–10), poor (SWQI = 11–30), regular (SWQI = 31–70), good (SWQI = 71–94) and very good (SWQI = 95–100).

On the other hand, the micro-phytoplankton richness was calculated and classified in the functional group (FG) according to Padisák et al. [64] and Reynolds et al. [71]. Statistical analysis of multiple correlations between micro-phytoplankton functional groups and water parameters was made using a principal component analysis (PCA) and a correlation matrix with iterative imputation [49] as input. Previously, the data were normalized. Moreover, richness comparison in each sampling station was made using Bray–Curtis cluster analysis (1957) [28].

3 Results

3.1 Description of parameters

In relation to hydrological variables, the cumulative rain of the week before the sampling varied between 0 mm (28/11/2015, 15/11/2017) and 95 mm (23/12/2017) and the cumulative rain of the month before the sampling varied between 0 mm (28/11/2015) and 359 mm (20/01/2017). The minimum HL of the Gualeguaychú river was 1.02 m (30/05/2015) and the maximum 3.02 m (17/10/2015) (Table 1).

On the other hand, the physico-chemical and bacteriological parameter description (median, M = maximum, m = minimum and SD = standard deviation) is shown in Table 1, and the data were separated in periods of study (years). In the same table, it can be observed which was the median of these parameters, used as a measure of central tendency because the parameters measured did not present normal distribution according to the Shapiro Wilks normality test. The water parameters indicated that temperature varied, according to temperate climatic stations, between 12.4 and 30.0 °C, pH varied between around slightly acid values (5.75) and slightly alkaline values (9.05), with low EC (127 µS cm^{-1} and 783 µS cm^{-1}) (Table 1). DO

Table 1 Statistics description (median, *M* = maximum, *m* = minimum and SD = standard deviation) of the physico-chemical and bacteriological parameters

	Temperature °C	pH	EC µS cm^{-1-1}	DO mg L^{-1}	TD m	SD m	Chl-a µg L^{-1}	SRP µmol L^{-1}	PT µmol L^{-1}	COD mg L^{-1}	TMAB UFC.100 mL^{-1}	TC NMP.100 mL^{-1}	CRW mm	CRM mm	HL m
Year 1															
Median	20.9^{a}	7.33*	460^{a}	4.76^{a}	0.50^{a}	0.30^{a}	132^{a}	8.26^{a}	18.4^{a}	110.6^{a}	5.65E+05^{a}	2.30E+03^{a}	3.60	67.0	1.98
m	12.4	6.71	290	1.53	0.30	0.20	65.9	3.06	3.69	65.79	1.30E+04	3.00E+02	0.00	0.00	1.02
M	29.2	8.54	783	10.80	0.70	0.45	474	79.7	82.9	364.0	1.85E+07	4.60E+04	67.6	148	3.02
DS	5.27	0.46	136	2.84	0.13	0.06	140	29.1	30.3	76.50	4.01E+06	1.46E+04	22.7	51.1	0.59
Year 2															
Median	21.3^{a}	7.21^{a}	272^{a}	3.70^{a}	0.49^{a}	0.25^{a}	126^{a}	27.8^{a}	30.7^{a}	110.6^{a}	1.46E+06^{a}	4.30E+03^{a}	14.6	104	1.64
m	12.7	6.87	127	0.95	0.24	0.15	63.2	0.988	9.75	50.86	6.30E+05	3.00E+02	3.00	70.6	1.31
M	30.4	9.05	783	14.4	1.68	0.40	664	46.4	47.3	170.3	5.63E+14	4.60E+04	73.4	359	2.40
SD	5.73	0.67	245	3.73	0.44	0.06	149	13.8	12.8	34.89	1.37E+14	9.82E+03	26.4	103	0.41
Year 3															
Median	21.0^{a}	6.84^{b}	510^{a}	2.61^{b}	0.51^{a}	0.28^{a}	23.2^{b}	11.1^{b}	25.6^{a}	236.8^{a}	3.80E+05^{a}	4.60E+03^{a}	25.6	137	1.82
m	13.0	5.75	270	1.86	0.33	0.15	4.20	2.11	7.10	77.70	7.00E+04	3.00E+02	0.00	16.5	1.24
M	28.0	7.53	596	5.79	0.90	0.53	211	24.7	74.6	1759	4.00E+06	1.10E+06	95.0	172	2.58
SD	5.69	0.44	110	1.37	0.16	0.10	60.6	6.43	23.7	533.5	1.06E+06	2.73E+05	42.6	67.9	0.46

Field data were separated by the period of study. *TD* total depth, *SD* Secchi disk, *CRW* cumulative rainfall of a previous week, *CRM* cumulative rainfall of a previous month, *HL* hydrometric level

Different letters are significant differences ($p < 0.05$)

values had high variability between anoxic (0.95 mg L^{-1}) and oversaturated (14.33 mg L^{-1}) both values being too anomalous (Table 1) with a median to 4.76 mg L^{-1}.

The phosphorus nutrients values were high during all the period of study (Table 1) and the main proportion was available (SRP) for the micro-phytoplankton and bacteria. Therefore, it is possible that phytoplankton had not been restricted by this nutrient. In Table 1, it can be observed that the minimum concentrations of SRP and TP were 0.988 μmol L^{-1} and 3.69 μmol L^{-1} and the maximum concentrations were 79.7 μg L^{-1} and 82.9 μg L^{-1}, respectively. COD values were too high and varied between 50.86 and 1759 mg L^{-1} with a median of 110.6 mg L^{-1}. This indicates that the DO concentrations were not enough to degrade the organic matter of the aquatic system. Chl-a varied widely between 4.20 and 664 μg L^{-1} with a median of 132 μg L^{-1}. Regarding bacteriological parameters, the lagoon in Parque Unzué had a very high bacteriological charge. TMAB varied between 1.30E+04 CFU.100 and 1.85E+07 CFU.100 mL^{-1} with a median of 5.65E+05 CFU.100 mL^{-1}, and CT varied between 3.00E+02 MPN.100 and 4.60 E+04MPN.100 mL^{-1} with a median of 2.30E+03 MPN.100 mL^{-1}.

Figure 2 shows that phosphorus, COD, TC and hydrometric level correlated positively between them, but correlated negatively with the cumulative rain, pH and DO. On the other hand, chl-a, richness, temperature and TMAB correlated positively between them, but correlated negatively with SD and EC. In the parameter comparison, no significant differences ($p < 0.05$) were found between sampling stations. During annual sampling periods, no significant differences were found either in none of the following environmental parameters: temperature, EC, TP, COD, TMAB and CT. However, very significant differences ($p < 0.001$) were found between the annual sampling periods on chl-a ($p = 0.001$), pH ($p = 1.7E{-}5$) and SRP ($p = 4.8E{-}4$) and significant differences ($p < 0.05$) on DO ($p = 0.04$). Chl-a, pH, DO and SRP values were lower in the last year (Table 1).

On the other hand, the SWQI varied between 17.9 (poor water quality) and 44.0 (regular water quality) with an average of 27.6 (poor water quality) (Table 2). Fifty percent of the frequency SWQI data was 26.7 (poor water quality), and no significant differences ($p > 0.05$) were found between sampling stations and the annual period of sampling.

Micro-phytoplankton richness value was 48, and it was distributed into Bacillariophyceae (19), Chlorophyceae (12), Cyanophyceae (7), Euglenophyceae (5), Conjugatophyceae (Zygnematophyceae) (3) and Dinophyceae (1) (Table 3). Fifty percent of the reported genera was found in the first year, reaching 90% in the second year. Bacillariophyceae was very frequent in the second year with the presence of genera such as *Nitzschia, Sellaphora, Cymbella, Hantzschia, Geissleria, Diatoma, Cyclotella, Caloneis* and *Diploneis* which were not present the following year. Euglenophyceae, Cyanophyceae and Conjugatophyceae were present in all sampling stations and all the study period and Dinophyceae was only present in station 1 during the first year. Regarding Chlorophyceae, it was observed that *Chlorella* was present during the first year, decreasing its frequency in the second year until it was not present in the third year. This genus was correlated positively with DO, richness, chl-a and pH, and negatively with COD (data not shown). It was similar to the genera *Scenedesmus, Staurastrum* and *Eudorina*, although these last genera had low frequency. Although some genera present during the first year were not present in the third year, genera such as *Tetrastrum, Tetraedron, Ankyra* and *Crucigenia*, appeared to be replaced in the same FGs. In the first year of the study, the micro-phytoplankton richness varied between 6 genera (28/11/2015) and 19 genera (30/05/2015) and in the second year, an increase in the richness could be observed varying from 14 to 25 genera in the samplings of 14/05/2016 and 6/4/2017, respectively. In the third year of the study, a decrease in richness was found varying between 2 genera (19/05/2018) and 11 genera (23/12/2017). The richness values were 42, 40 and 33 in stations 1, 2 and 3, respectively, and the richness values were similar in sampling stations throughout the years. The richness ranged between 21 and 23 in the first year, 29 and 34 in the second year and 10 and 16 in the third year. In Fig. 3, a cluster analysis between the sampling stations using phytoplankton richness and the stations similarity can be observed. The distance between sampling station 1 and 2 was 0.965 and 0.960 between these two and sampling station 3. Nineteen FGs were identified, and the majority of these were characteristic of shallow, turbid, eutrophic to hypereutrophic and nutrient-rich water courses. The dominant FGs were J and W1, as they were found in all the samplings and followed by the MP and W2 groups which were found in 16 and 13 samplings, respectively. Twelve genera observed in the lagoon located in Parque Unzué did not classify as any type of FG. Despite the variation in the genera number between the three sampling stations, the majority had its equivalent FG. *Mougeotia* (T), *Staurodesmus* (N), *Ceratium* (LM), *Microcystis* (M) and *Dolichospermum* (H1) were present without an equivalent FG. However, these genera had low frequent appearing in 1 or 2 samples (Table 3). Figure 2a shows a PCA, and Fig. 2b shows the multiple correlations on analyzed parameters. The PCA allowed us to explain 95% of the sampling in the study area. The first year was correlated positively with cumulative rains, pH and DO, and it was characterized by high richness of micro-phytoplankton and by the presence of the following FGs: P,

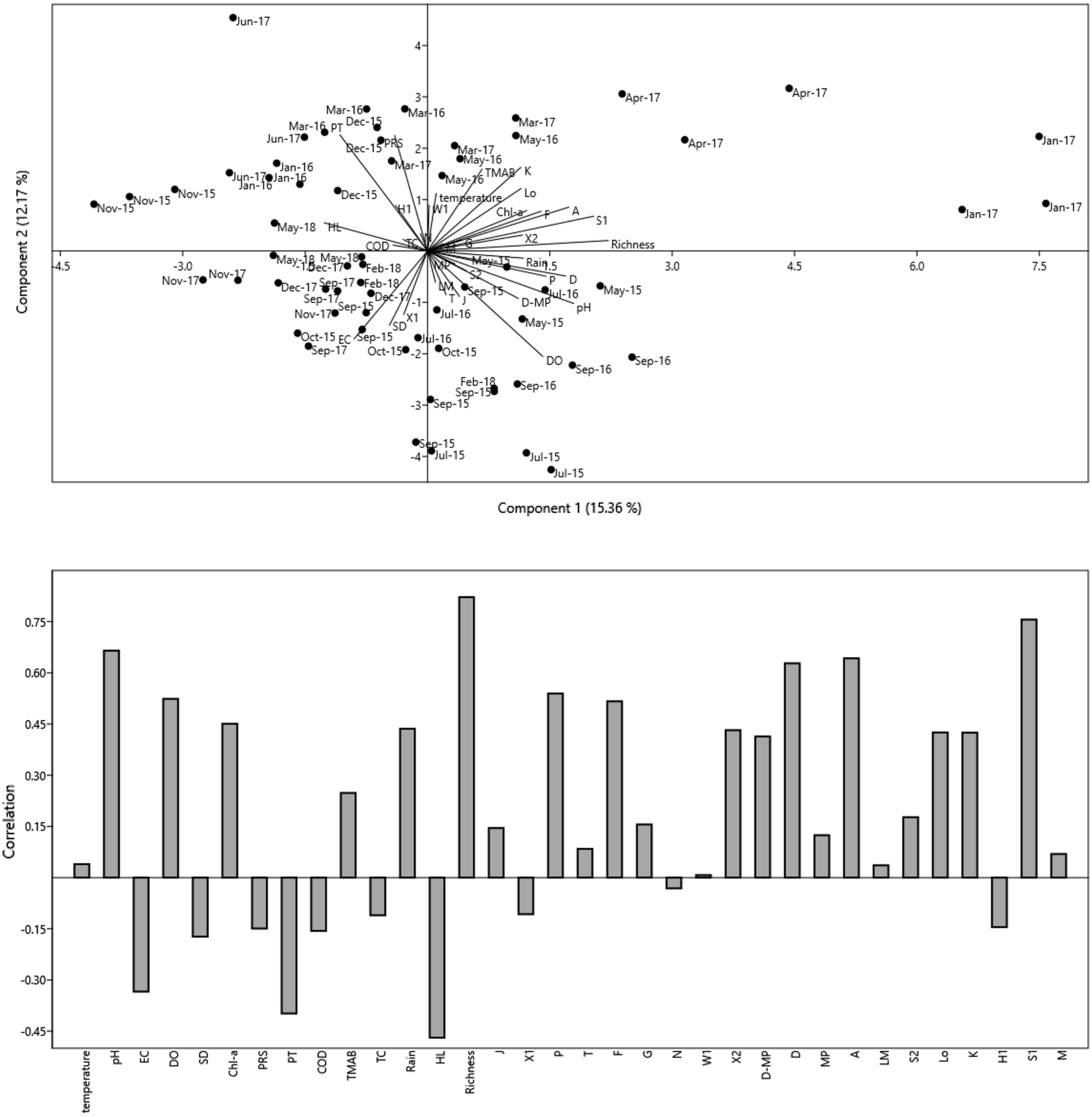

Fig. 2 **a** PCA between FGs and water parameters in the study area. **b** Correlation valuesof the parameters and FGs

D, MP, LM, S2, T, J and MP. The spring correlated with EC and SD with low richness of micro-phytoplankton and the presence to X1. At the end of this period, it was correlated positively with TP, SRP, hydrometric level, COD and TC. The second-year continued with the same correlations and then the autumn-2016 and autumn-2017 periods were correlated positively with temperature, TMAB and chl-a and were characterized by high richness of micro-phytoplankton with the following FGs: K, Lo, F, A, S1, X2, W1, G, M and N. Subsequently, the samples were correlated with cumulative rain, pH and DO. Finally, the third year was positively correlated with TP, SRP, hydrometric level, COD and TC and negatively with pH, DO and cumulative rain with the presence of H1. Then, the end of the period correlated positively with EC and SD with the presence of X1 and negatively correlated with the temperature, chl-a and TMAB with low richness of micro-phytoplankton and the presence of X1. These FGs were characteristic of

Table 2 Values of simplified water quality index (SWQI) applied to data of the lagoon of the Parque Unzué in each date of sampling

Date (mm/dd/yyyy)	*t*	COD	SD	DO	EC	ISQA
05/30/15	1.0	0	0	11.8	14.0	25.8
07/04/15	1.0	0	0	23.2	13.9	37.1
09/05/15	1.0	0	0	25.0	13.5	38.3
09/26/15	1.0	0	0	12.5	13.4	25.9
10/17/15	1.0	0	0	14.0	14.6	28.6
11/28/15	1.0	0	0	16.8	11.9	27.4
12/19/15	0.9	0	0	9.0	12.7	20.2
01/25/16	0.9	0	3	6.1	15.3	21.7
03/05/16	0.9	0	0	9.9	21.6	29.4
05/14/16	1.0	0	0	5.5	21.2	26.7
07/09/16	1.0	0	0	12.7	16.1	28.8
09/10/16	1.0	0	0	25.0	19.0	44.0
01/20/17	0.9	0	0	20.9	21.6	37.6
03/16/17	1.0	0	0	3.6	22.2	25.3
04/06/17	1.0	0	0	9.4	19.7	29.0
06/29/17	1.0	0	0	5.3	17.8	23.1
09/08/17	1.0	0	3	14.3	14.0	31.3
11/15/17	0.9	0	0	6.6	13.3	17.9
12/23/17	1.0	0	0	8.4	13.4	21.0
02/23/18	1.0	0	0	7.5	12.7	19.4
05/19/18	1.0	0	0	6.0	15.3	21.2

Very poor (SWQI = 0–10), poor (SWQI = 11–30), regular (SWQI = 31–70), good (SWQI = 71–94) and very good (SWQI = 95–100). *t* temperature, *EC* electric conductivity, *DO* dissolved oxygen, *COD* chemical oxygen demand, *SD* Secchi disk

hypereutrophic (X1) and stratified environment and low nitrogen concentration (H1).

4 Discussion

Water quality of the lagoon in Parque Unzué was poor-regular throughout the study period, indicating permanent organic pollution characterized by high organic matter, phosphorus compound and low DO concentration. This fact was also reflected on micro-phytoplankton assemblages, in particular in the richness of micro-phytoplankton and the functional groups that was characteristic of shallow environments, rich in nutrients and organic matter [71]. Organic pollution tends to influence phytoplankton more than other factors in the aquatic environment [66] and the organic matter favors to phytoplankton mixotrophic, increasing the development of the Euglenophyceae group [14, 21, 30, 91]. Although the temperature is the main regulatory factor in temperate systems [15, 56, 60], no seasonality in the variation of the physico-chemical parameters was observed in the study area. On the other hand, no cyclic annual variability in the lagoon was observed, but an increase in system deterioration over time, specifically reflected in the micro-phytoplankton assemblages, was noticed. Regarding this, Chlorophyceae was the most sensitive group and specifically, the variation in the presence of *Chlorella* can be interpreted as an early warning indicator of the system. This genus is commonly found in the natural environment and also used as a water quality bioindicator [19]. Although it has tolerance to organic contamination [66], it is susceptible to relatively low pHs [68] as recorded during the third year of study. Moreover, in the same year, it was observed that chl-a and DO concentration also decreased. Chl-a is an important pigment necessary for photosynthesis, since it allows converting light energy to chemical energy and is also an indicator of primary production [3, 40]. During the photosynthesis, the inorganic carbon decreases, increasing the pH and DO values in the water [20]. In such situation, a decreasing richness of micro-phytoplankton and micro-phytoplankton frequency was observed in the last year of this study. In addition, the DO decreased even though the content of organic matter and bacteria (TMAB and CT) did not vary between the sampling periods. This could imply that the decrease in DO concentration (as a net balance) occurred due to the low production of oxygen by the primary producers. It is possible that this situation toward which the system advanced, particularly during

Table 3 List of micro-phytoplankton richness and FGs classification

FGs	Genera	*n* Sampling	General characteristic of FGs
J	*Pediastrum*	18	Shallow, mixed and highly enriched systems
	Scenedesmus	19	
	Coelastrum	4	
	Tetrastrum	7	
	Crucigenia	4	
X1	*Chlorella*	9	Surface environments, eutrophic to hypertrophic
	Schroederia	2	
	Ankyra	2	
P	*Staurastrum*	5	Characteristics of eutrophic waters
	Fragilaria	12	
	Aulacoseira	8	
T	*Mougeotia*	**1**	Persistently mixed layers, where light is limiting
F	*Dictyosphaerium*	2	Clear, deeply mixed meso-eutrophic, lakes
	Sphaerocystis	1	
G	*Eudorina*	5	Nutrient-rich conditions in stagnating water columns; small eutrophic lakes and very stable phases in larger river-fed basins and storage reservoirs
	Tetraedron	4	
W1	*Phacus*	18	Ponds, even temporary, rich in organic matter from livestock or wastewater
	Euglena	21	
	Lepocinclis	1	
N	*Staurodesmus*	**1**	Can be represented in shallow lakes
W2	*Trachelomonas*	14	Meso-eutrophic ponds, even temporary, shallow lakes
	Strombomonas	5	
MP	*Navícula*	16	Frequently stirred up, inorganically turbid shallow lakes
	Gomphonema	8	
	Cymbella	3	
	Surirella	4	
D	*Nitzschia*	3	Shallow turbid waters including rivers
	Diatoma	1	
A	*Cyclotella*	5	Clear, deep, base-poor lakes, with species sensitive to pH rise
LM	*Ceratium*	**2**	Eutrophic to hypertrophic, small- to medium-sized lakes
S2	*Spirulina*	6	Warm, shallow and often highly alkaline waters
Lo	*Merismopedia*	9	Deep and shallow, oligo- to eutrophic, medium to large lakes
K	*Aphanocapsa*	11	Shallow, nutrient-rich water columns
H1	*Dolichospermum*	**1**	Eutrophic, both stratified and shallow lakes with low nitrogen content
S1	*Pseudanabaena*	2	Turbid mixed environments
M	*Microcystis*	**2**	Water bodies eutrophic to hypertrophic, small to medium
Without classification	*Amphipleura*	3	
	Sellaphora	4	
	Pinnularia	13	
	Reimeria	1	
	Gomphoneis	1	
	Hantzschia	2	
	Geissleria	2	
	Caloneis	1	
	Gyrosigma	1	
	Diploneis	1	
	Chroococcus	3	

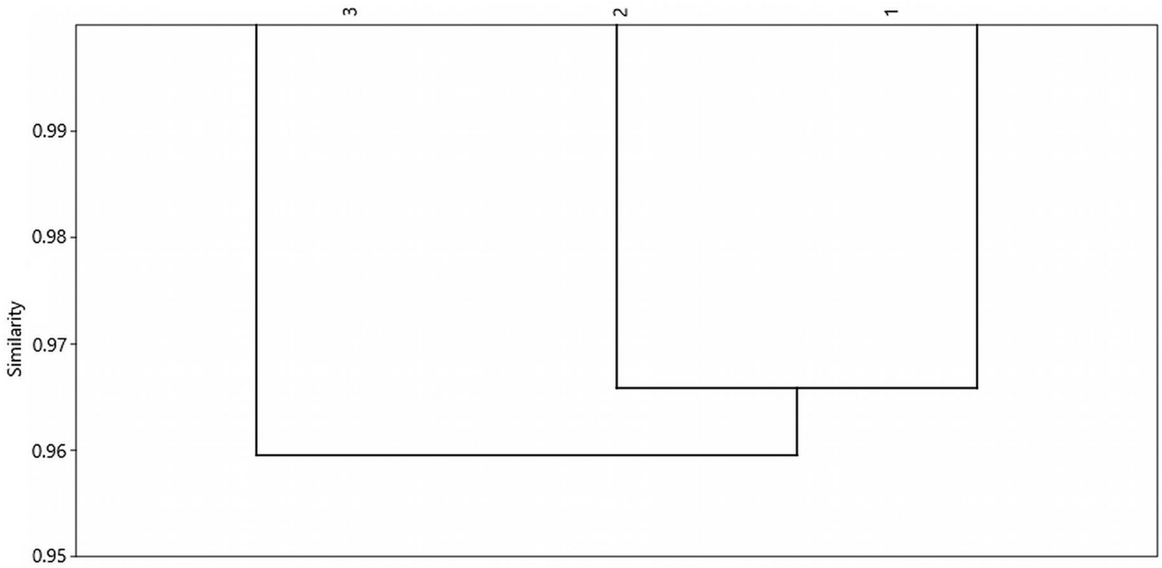

Fig. 3 Cluster analysis between sampling stations according to richness values of each sampling date

the third year, took place due to the important bird load that the lagoon presented. The bird guano showed slightly acidic pH [79] and important concentrations of ions (electrical conductivity, [11]). On the other hand, it can be observed that the TP did not vary between the study period, but SRP decreased in the last period. This indicates minor mineralization of the phosphorus that may have influenced primary productivity or an input change of the phosphorus nutrients. However, SRP always was > 100 µg L^{-1}; therefore, it would not limit the growth of phytoplankton [90].

Our results coincided with similar works in the Pampas region influenced by urbanization [65] and the lagoon in Parque Unzué's FGs were similar to those found in Pampean streams associating the FGs P and W1 with moderate COD values and turbidity and W2 with high values of these variables [5]. Moreover and similar to this work, another study associated the phytoflagellates (mixotrophic) with high concentrations of organic matter and lixiviate pollutants [81]. Investigations have reported bird effects in water quality [89, 92], although they did not observe a correlation between the abundance of birds and the parameters of water quality. They suggest that the effect can be observed in the long term if waterfowl populations gradually increase [89, 92]. Several investigations have associated the nutrients, organic matter and coliforms inputs by bird guano in lagoons [8, 9, 12, 36, 74, 76]. In addition, the elimination of bottom fauna by guanotrophy (ammonia-poisoning) [10, 69] might occur. In this study, we associated a bird effect with the decrease in the pH values, which can affect micro-phytoplankton richness and chl-a production. However, this is an aspect that we must deepen and is therefore on of the objectives of the next research.

Our hypothesis was contrasted, and in this study, we could check that the lagoon in Parque Unzué presented permanent organic pollution and this was reflected in micro-phytoplankton assemblages. Moreover, we established that *Chlorella* presence can be an early warning indicator of the system.

5 Conclusion

We conclude that the lagoon in Parque Unzué presented permanent organic pollution which increased over the study period. It is possible that the system is moving toward collapse if the current contamination levels continue and that the system is at the limit of its capacity to absorb pollution. Given that there are no previous studies in the study area, it is uncertain at what point in the evolution of the system the lagoon is and if it is possible to reverse the current level of organic contamination that is compromising even the survival of species that are tolerant. We found that *Chlorella* was a bioindicator of change in the system, although it is necessary to continue monitoring the study area systematically in order to know if it is possible to use this type of micro-phytoplankton as an early warning indicator in highly contaminated systems and to study the bird effects in the lagoon located in Parque Unzué.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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