Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Original Article
Acta Limnologica Brasiliensia, 2024, vol. 36, e1
https://doi.org/10.1590/S2179-975X6123
ISSN 2179-975X on-line version

Phytoplankton community diversity, dominance, and rarity: a case study of tropical urban lakes

Diversidade, dominância e raridade da comunidade fitoplanctônica: um estudo de caso em lagos urbanos tropicais

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Cite as: Martins, M.P.M. et al. Phytoplankton community diversity, dominance, and rarity: a case study of tropical urban lakes. *Acta Limnologica Brasiliensia*, 2024, vol. 36, e1.

Abstract: Aim: The aim of this study was to evaluate how phytoplankton community diversity, dominance, and rarity are influenced by different local environmental conditions in urban lakes. We expect that richness will be negatively influenced in lakes with higher nutrient concentrations and high turbidity, while abundance will be positively influenced. Thus, lakes with these conditions will have greater dominance of a few species and lower rarity, and the opposite in lakes with lower nutrient concentrations and less turbidity. **Methods:** Phytoplankton and abiotic variables samples were collected in fourteen lakes distributed in the municipality of Goiânia, Goiás, Brazil, during a rainy period. **Results:** It was possible to identify an environmental heterogeneity among the lakes. We identified a separation of the lakes according to phytoplankton richness and density, especially due to the contribution of green algae, desmids, and cyanobacteria. Most lakes showed high diversity and evenness values, with a predominance of rare taxa and few dominant species. The main variables associated with phytoplankton were water temperature, dissolved oxygen, turbidity, and nutrient concentrations. **Conclusions:** Therefore, the study of species diversity, dominance, and rarity based on phytoplankton richness and abundance and their relationship with different local environmental conditions can be an important model for assessing water quality in urban lakes.

Keywords: planktonic algae; urbanization; environmental heterogeneity; shallow lakes.

Resumo: Objetivo: O objetivo deste estudo foi avaliar como a diversidade, dominância e raridade da comunidade fitoplanctônica são influenciadas por diferentes condições ambientais locais em lagos urbanos. Nós esperamos que a riqueza será influenciada negativamente em lagos com maiores concentrações de nutrientes e maior turbidez, enquanto a abundância será influenciada positivamente. Assim, haverá uma maior dominância de poucas espécies e menor raridade em lagos com essas condições, sendo esperado o contrário em lagos com menores concentrações de nutrientes e menor turbidez. **Métodos:** As amostras do fitoplâncton e das variáveis abióticas foram coletadas em quatorze lagos distribuídos no município de Goiânia, Goiás, Brasil, durante um período chuvoso. **Resultados:** Foi possível identificar uma heterogeneidade ambiental entre os lagos. Nós identificamos uma separação dos lagos em função da riqueza e densidade fitoplanctônica, especialmente devido à contribuição de algas verdes, desmídias e cianobactérias. A maioria dos lagos apresentou altos valores de diversidade e equitabilidade, com predominância de táxons raros e poucas espécies dominantes. As principais variáveis que estiveram relacionadas com o fitoplâncton, foram a temperatura da água, oxigênio dissolvido, turbidez e as concentrações de nutrientes. **Conclusões:** Portanto, o estudo da diversidade, dominância e raridade baseada na riqueza e abundância fitoplanctônica e a sua relação com as diferentes condições ambientais locais pode ser um importante modelo na avaliação da qualidade da água em lagos urbanos.

Palavras-chave: algas planctônicas; urbanização; heterogeneidade ambiental; lagos rasos.

1. Introduction

Urbanization is a global process inherent to human social development, but it can contribute to ecosystem degradation and biodiversity loss, depending on its intensity and pressure on the environment. However, most studies assessing the impacts of urbanization on biodiversity are carried out in terrestrial ecosystems compared to aquatic ones (Hill et al., 2017). For example, urban lakes can be considered highly vulnerable environments to urbanization, as they are usually spatially isolated habitats, small, and poorly protected by monitoring programs (Thornhill et al., 2017). Furthermore, it is estimated that more than 75% of the world's population will live in cities by 2050 (Ziter, 2016), which will increase the pressure on all types of urban ecosystems, especially freshwater ecosystems (Gavrilidis et al., 2019), and therefore studies that consider these ecosystems should be expanded.

One of the main effects of urbanization on the aquatic ecosystem is the eutrophication, which has become one of the main problems associated with the degradation of water quality and environmental integrity of urban lakes (Le et al., 2010; Nabout & Nogueira, 2011; Frau et al., 2018; Chen et al., 2020), because nutrient inputs to aquatic ecosystems, especially nitrogen and phosphorus, influence the proliferation of harmful cyanobacteria blooms (Paerl et al., 2020). In addition, recent studies have shown that the negative effects of adding nutrients to water include changes in physical environmental conditions, such as electrical conductivity and turbidity, and changes in community structure, such as species dominance and even the exclusion of rare species over time (Dittrich et al., 2023; Machado et al., 2023). Thus, eutrophication can lead to species loss and the dominance of a few opportunistic organisms that, due to their high biomass, increase turbidity and limit light in the water column (Soares et al., 2013; Paerl & Otten, 2013), directly affecting ecosystem functioning.

The understanding of urban lakes as important elements for environmental quality and social life in cities is very relevant, because these ecosystems, which are important blue elements of landscapes and generally associated with urban parks, guarantee many benefits to society (Li et al., 2017). The ecosystem services provided by urban lakes can range from local climate regulation to symbolic and aesthetic services, ecotourism, and recreation, as well as promoting cognitive effects (Hossu et al., 2019; De Groot et al., 2002; Hasan et al., 2020). Therefore, they are spaces that deserve attention because of the multiple benefits they can provide to society.

Urban ecosystems are excellent models for assessing anthropic impacts on the environment and its biodiversity, informing their management, and evaluating the provision of ecosystem services. The central question addressed here is whether urban lakes can provide a level of biodiversity similar to that recorded in lakes in the wider landscape (Hill et al., 2017), constituting a healthy and suitable environment for both biodiversity conservation and the various human uses.

Thus, taking the above into account, knowledge of the phytoplankton diversity in urban lakes can provide elements to promote management actions or recovery of these ecosystems, since these organisms are modulated by the environmental context (Chang et al., 2022). Cyanobacteria and planktonic algae are highly diverse and respond very effectively to the intensity of stressors and anthropogenic changes (Salmaso & Tolotti, 2021). This is due to the diversity of functional characteristics of the community, related to morphology, physiology, behavior, and life history (Litchman & Klausmeier, 2008; Kruk et al., 2010). Indeed, phytoplankton has been recognized as an important indicator of the impact of landscape use on the environmental integrity of lakes in urban areas (Kakouei et al., 2021).

The main objective of this study was to evaluate how diversity, dominance and rarity of the phytoplankton community are influenced by different local environmental conditions in tropical urban lakes. We expect that lakes with higher nutrient concentrations and higher turbidity will be less diverse and composed of a few high abundance species. Thus, there will be greater dominance of few species and lower rarity (species with low abundance), while the opposite will be expected in lakes with lower nutrient concentrations and lower turbidity.

2. Material and Methods

2.1. Study area

This study was carried out in 14 urban shallow lakes distributed in different geographical regions in the municipality of Goiânia, Goiás, Brazil (Figure 1). All lakes located in public parks in Goiânia were sampled, which are: L1 (Leolídio di Ramos Caiado Park; lake area - 20,744.96 m^2), L2 (Liberdade Park; lake area - 1,403.93 m^2), L3 (Beija Flor Park; lake area - 4,529.78 m^2), L4 (Balneário Park; lake area - 200 m^2), L5 (Cascavel Park; lake area – 8,597.03 m^2), L6 (Vaca Brava Park; lake area – 13,931.39 m^2), L7 (Areião Park; lake area – 13,705.39 m^2), L8 (Jardim Botânico Park; lake area – 49,603.27 m^2), L9 (Flamboyant Park; lake area – 13,289.42 m^2), L10 (Fonte Nova Park; lake area – 2,714.52 m^2), L11 (Lago das Rosas Park; lake area – 12,154.97 m^2), L12 (Bosque dos Buritis Park; lake area – 7,883.26 m^2), L13 (Nova Esperança Park; lake area – 5,254.84 m^2) e L14 (João Carlos Fernandes de Oliveira Park; lake area – 3,239.89 m^2). Sampling in the lakes was carried out in March 2020. According to the Trophic State Index (TSI) proposed by Lamparelli (2004), urban lakes were classified as oligotrophic (L7 and L14), mesotrophic (L1, L2, L3, L5, L8, L9, L10, L11, L12 and L13) and eutrophic (L4 and L6).

2.2. Sampling and analysis of samples

For each lake we measured *in situ* parameters such as water temperature (°C), pH, electrical conductivity (µS cm^{-1}), dissolved oxygen (mg L^{-1}), and turbidity (NTU), using a portable digital potentiometer. In addition, we collected 1500 mL of water for laboratory analysis of total phosphorus concentrations (µg L^{-1}), orthophosphate (µg L^{-1}), nitrate (mg L^{-1}), ammoniacal nitrogen (mg L^{-1}), and chlorophyll-a (µg L^{-1}). On the same day, part of the samples was filtered using Whatman GF/C membranes. The concentration of chlorophyll-a was quantified by maceration of these membrane filters with acetone (90%), and the reading was taken in a spectrophotometer (Golterman et al., 1978). The unfiltered samples were used for the determination of total phosphorus, while the concentrations of orthophosphate, nitrate, and

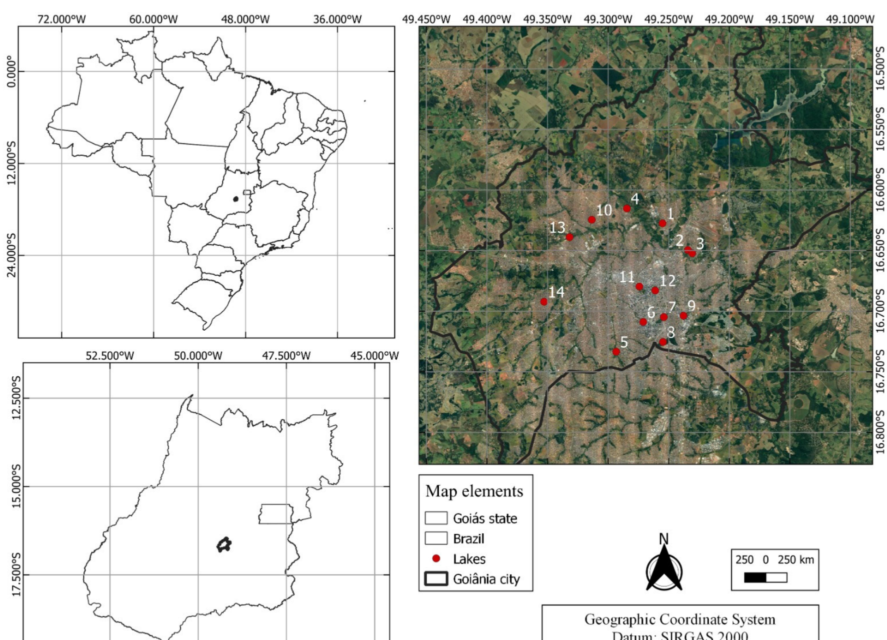

Figure 1. Location of the urban lakes and their distribution in the municipality of Goiânia, Goiás, Brazil. (1 - L1; 2 - L2; 3 - L3; 4 - L4; 5 - L5; 6 - L6; 7 - L7; 8 - L8; 9 - L9; 10 - L10; 11 - L11; 12 - L12; 13 - L13; 14 - L14).

ammoniacal nitrogen, were measured from the filtered samples. Total phosphorus and orthophosphate concentrations were determined using the ascorbic acid method and spectrophotometer readings (Golterman et al., 1978). The concentrations of nitrate and ammoniacal nitrogen were determined by the cadmium reduction and the salicite methods, respectively, followed by reading in a spectrophotometer (APHA, 2017).

For each lake, we collected quantitative samples of phytoplankton directly with bottles at the subsurface of the limnetic region and fixed with Lugol's acetic solution. Qualitative samples were also taken with a plankton net (20 µm) and fixed with Transeau's solution, only for the taxonomic identification of the phytoplankton (Bicudo & Menezes, 2017). The samples are stored at the Laboratory of Taxonomy, Ecology and Cultivation of Algae (LATEC) of the Federal University of Goiás.

In the laboratory, we estimated phytoplankton density from the quantitative samples, according to APHA (2017), using an inverted microscope (Olympus CKX41 model at 400×magnification). Counting was carried out randomly by fields, according to the method of Utermöhl (1958), and the sedimentation time was at least three hours for each centimeter of chamber height (Margalef, 1983). The results of phytoplankton density were expressed in individuals (cells, cenobium, colonies, or filaments) per milliliter (individuals mL^{-1}), according to the forms in which the algae occur in nature. Phytoplankton richness was considered as the number of total taxa present in each quantitative sample. Taxa were identified through the specialized literature, based on the morphological and morphometric characteristics of the taxa, whenever possible at the lowest taxonomic resolution, and the taxonomic framework followed that proposed in Bicudo & Menezes (2017) and Guiry & Guiry (2022).

2.3. Data analysis

The diversity index of the phytoplankton community, expressed in bits.in[1], was estimated using the Shannon-Weaver Diversity Index (H') (Shannon & Weaver, 1963). Equitability (E), as a measure of how homogeneously density is distributed among species, was also estimated according to Pielou (1966). Whittaker diagrams or dominance curves, a method that uses information on the number of species and the relative abundance of each species in the communities, were used to assess the number of dominant or rare species within the communities of each lake, as this method plots species on the X-axis from most abundant to least abundant, while on the Y-axis the relative abundances of species are plotted on a logarithmic scale (log10) (Silva et al., 2022). The Whittaker curve is considered one of the most important methods for estimating species abundance distributions (Ulrich et al., 2010).

To assess the environmental heterogeneity among urban lakes, we applied a Principal Component Analysis (PCA) using the environmental variables sampled in each lake (water temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total phosphorus, orthophosphate, nitrate, ammoniacal nitrogen, and chlorophyll-a). To evaluate the distribution of phytoplankton among the different urban lakes, we applied a NMDS (Non-Metric Multidimensional Scaling Analysis) using composition (presence and absence) and species density data. NMDS was based on the first two axes (NMDS 1 and MNDS 2) and was performed using Jaccard dissimilarity coefficients for presence-absence data and Bray-Curtis dissimilarity for density data (Clarke, 1993). Finally, to assess the relationship of phytoplankton with environmental conditions of urban lakes, we applied Bioenv, since this method searches for the best subset of environmental variables with Spearman's maximum correlation, where we use a community dissimilarity matrix using density (Bray-Curtis) and presence and absence (Jaccard) data transformed to log (x + 1) (Clarke & Ainsworth, 1993).

All analyses were performed using the free statistical software R (R Development Core Team, 2021) with the vegan (Oksanen et al., 2017) and BiodiversityR (Kindt & Coe, 2005) packages.

3. Results

3.1. Environmental heterogeneity in urban lakes

An environmental heterogeneity was observed among the sampled lakes. Lake L4 had the lowest values of dissolved oxygen and pH and the highest concentrations of nutrients (total phosphorus, nitrate, and ammoniacal nitrogen). Lake L6 had the highest dissolved oxygen and pH, and the highest concentration of chlorophyll-a. Lakes L1 and L5 had the highest values of turbidity and low concentrations of chlorophyll-a. The variation of all environmental variables measured in the lakes can be seen in Figure 2.

The first two axes of Principal Components Analysis explained 57% of the environmental

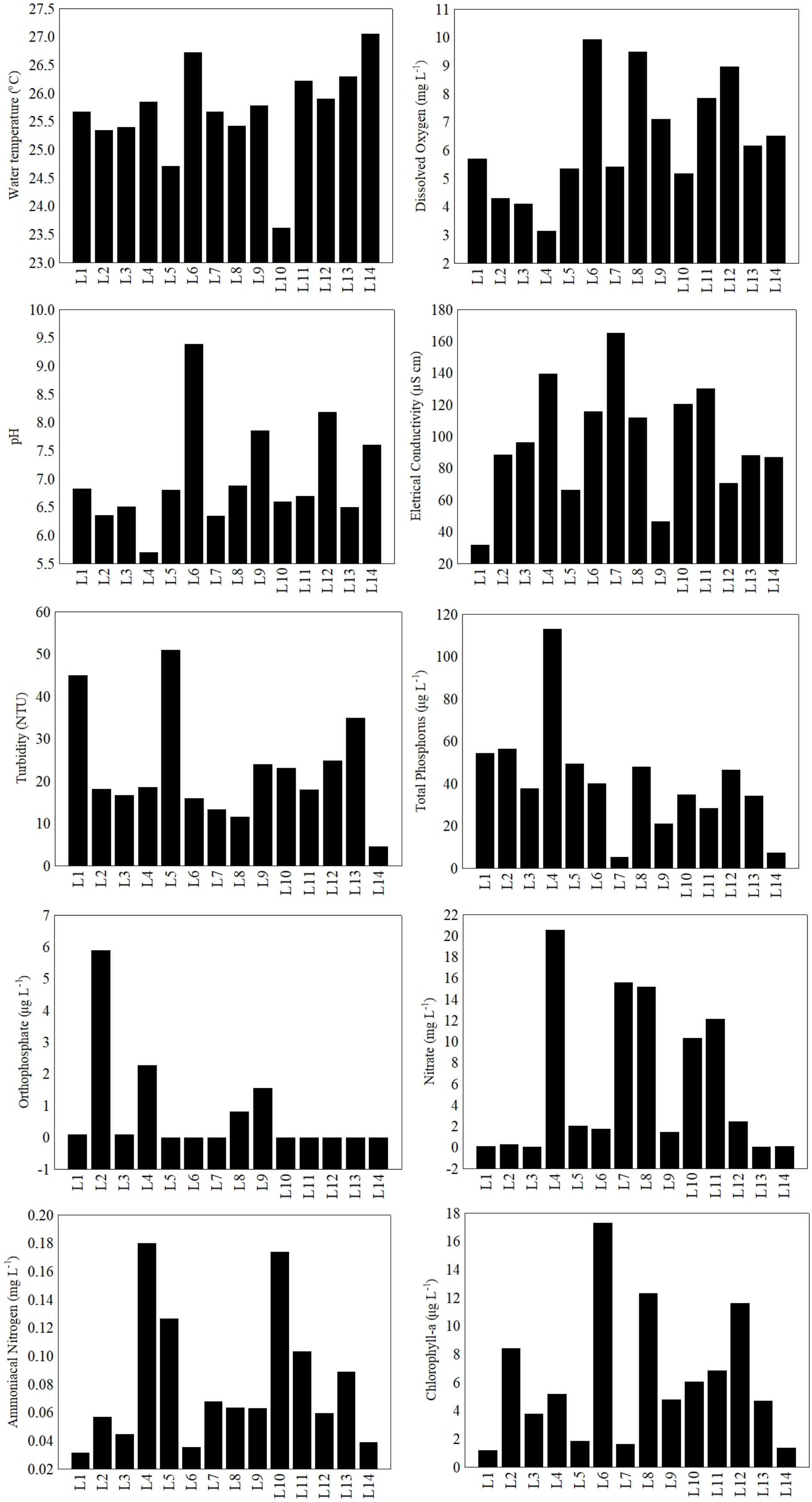

Figure 2. Variation of the local environmental conditions measured in the urban lakes of Goiânia, Goiás, Brazil.

heterogeneity in the lakes, with axis 1 explaining 34% and axis 2 explaining 23%. The first axis was positively correlated with dissolved oxygen (0.42), pH (0.47), water temperature (0.31), and chlorophyll-a (0.23), and negatively correlated with ammoniacal nitrogen (-0.42), nitrate (-0.31), and total phosphorus (-0.28). Axis 2 was correlated with electrical conductivity (0.54), and turbidity (-0.50). It was possible to visualize a clear separation of lakes by environmental heterogeneity (Figure 3).

3.2. Phytoplanktonic community in urban lakes

3.2.1. Richness, abundance, diversity and evenness of the phytoplankton community

A total of 189 taxa of cyanobacteria and algae were recorded in the 14 urban lakes, which are distributed in the following taxonomic classes: Cyanophyceae (26 taxa), Chlorophyceae (80 taxa), Trebouxiophyceae (15 taxa), Klebsormidiophyceae (2 taxa), Coscinodiscophyceae (1 taxon), Mediophyceae (3 taxa), Bacillariophyceae (18 taxa), Cryptophyceae (5 taxa), Chrysophyceae (2 taxa), Zygnematophyceae (17 taxa), Dinophyceae (1 taxon), Euglenophyceae (13 taxa), and Xantophyceae (6 taxa).

Lakes L6 and L4 had the highest and lowest total taxa richness, respectively. The highest total density was found in lake L12, while the lowest density was found in lake L13. Lake L4 also had the lowest Shannon diversity index and evenness index, while lake L11 had high diversity and evenness index (Figure 4).

Regarding the taxonomic groups, it was possible to observe a greater contribution to the richness of taxa, mainly green algae (e.g. Chlorophyceae), and cyanobacteria (Cyanophyceae), especially in lakes L2, L6, and L11. For density, green algae, mainly Chorophyceae (e.g. *Desmodesmus armatus* var. *armatus, Colestarum* sp., *Monoraphidium contortum* (Thuret) Komárková-Legnerová, *Monoraphidium irregulare* (G.M.Smith) Komárková-Legnerová) were important contributors in lakes L4 and L6, and L12, as well as cyanobacteria (e.g. *Aphanocapsa delicatissima* W.West & G.S.West, *Aphanocapsa elachista* W.West & G.S.West, *Cyanogranis ferruginea* (F.Wawrik) Hindák ex Hindák, *Eucapsis densa* M.T.P.Azevedo, Sant'Anna, Senna, Komárek & Komárková, *Microcystis panniformis* Komárek, Komárková-Legnerová, Sant'Anna, M.T.P.Azevedo, & P.A.C.Senna, *Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek, *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg, *Rhabdoderma lineare* Schmidle & Lauterborn, *Synechocystis aquatilis* Sauvageau), which contributed to the phytoplankton density mainly in lakes L8, L9, and L12, and diatoms (*Achnanthidium minutissimum* (Kützing) Czarnecki) with important contribution in lake L6. In lake L14, Chrysophyceae (e.g. *Dinobryon bavaricum* Imhof) and Zygnemathophyceae (e.g. *Cosmarium contractum* Kirchner var. *minutum*) were also important in density (Figure 5). According to the NMDS, a separation of the lakes according to phytoplankton composition and density could be identified (Figures 6a and 6b).

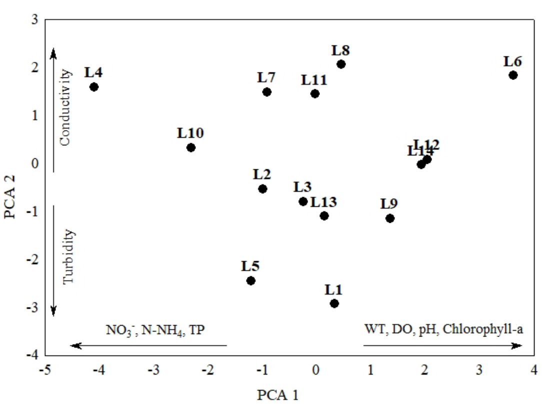

Figure 3. Result of the Principal Component Analysis carried out with the environmental variables measured in the urban lakes of Goiânia, Goiás, Brazil (WT = water temperature; DO = dissolved oxygen; TP = total phosphorus; N-NH_4 = ammoniacal nitrogen; NO_3^- = nitrate).

3.2.2. Dominance and rarity of the phytoplankton community

According to Whittaker's dominance curve, it could be observed that in most of the lakes, the communities were mainly composed of rare algae (many taxa with low abundances) and few dominant algae (few taxa with high abundances) (Figure 7). The cyanobacteria and algae with the highest abundances in the different lakes were taxa belonging to Cyanophyceae, Chlorophyceae, Bacillariophyceae, Coscinodiscophyceae, Cryptophyceae, Chrysophyceae, and Zygnemathophyceae.

3.2.3. Phytoplankton relationship with local environmental conditions of urban lakes

The Bioenv analysis, although it showed weak correlations between the set of environmental variables and the composition (Table 1) and the density (Table 2) of phytoplankton, showed that species composition was correlated with water

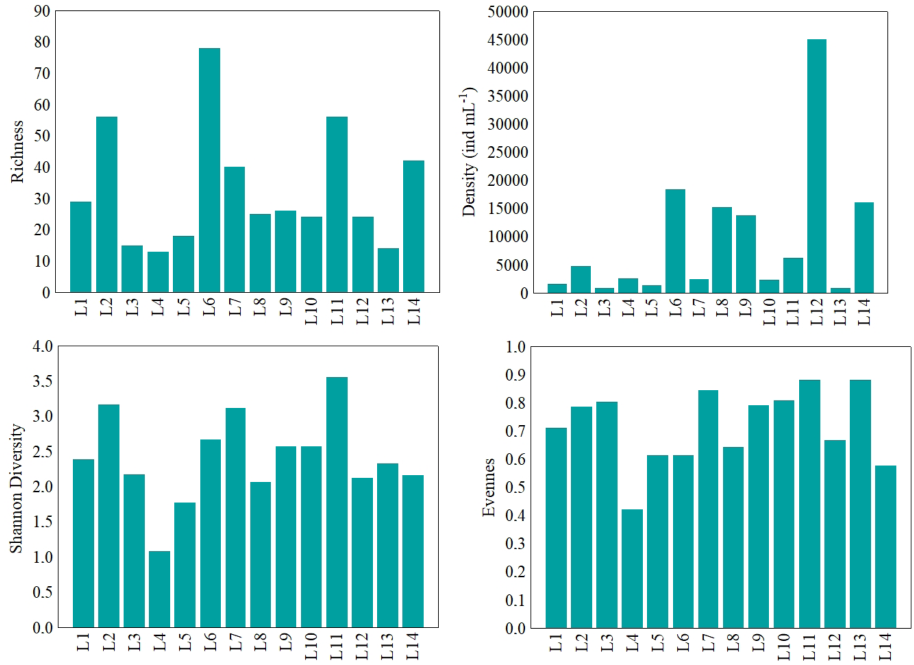

Figure 4. Phytoplankton richness, density, Shannon diversity and evenness in urban lakes of Goiânia, Goiás, Brazil.

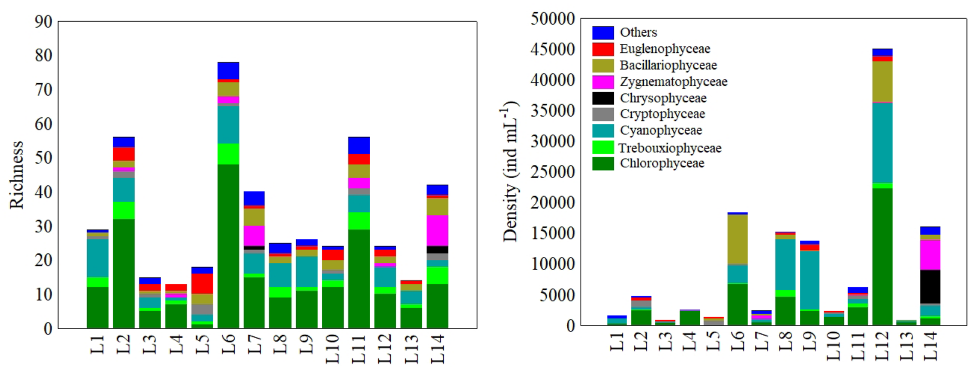

Figure 5. Richness and density of the taxonomic groups of the phytoplankton in the urban lakes of Goiânia, Goiás, Brazil.

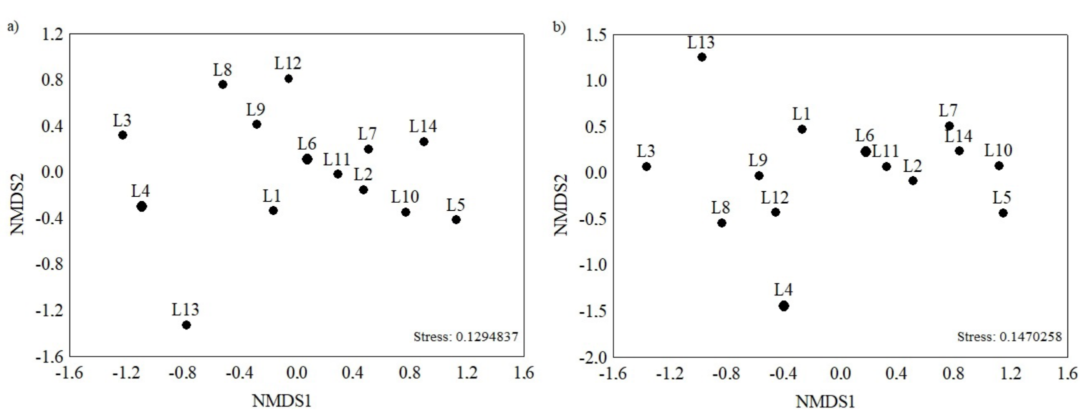

Figure 6. Result of NMDS performed for presence-absence data (a) and density data (b) of phytoplankton in urban lakes of Goiânia, Goiás, Brazil.

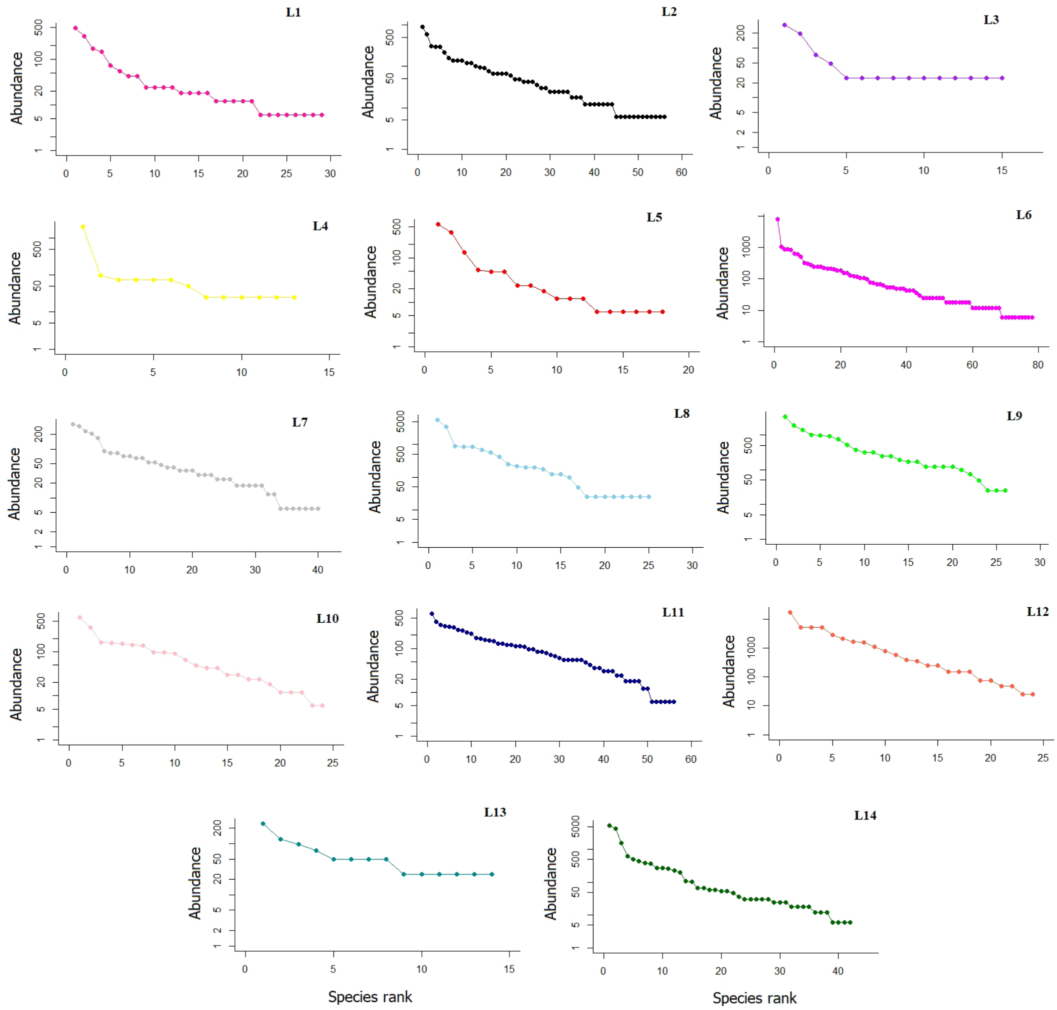

Figure 7. Whittaker diagrams comparing the occurrence of rare and dominant species among the urban lakes of Goiânia, Goiás, Brazil.

Table 1. Bioenv result for presence-absence data of phytoplankton and environmental variables of urban lakes in Goiânia-GO.

Size	Model									Correlation
1	N-amo									0.1638
2	Turb	TP								0.2083
3	DO	Turb	TP							0.2386
4	DO	Turb	TP	N-amo						0.2433
5	**WT**	**DO**	**Turb**	**TP**	**N-amo**					**0.2537**
6	WT	DO	Turb	TP	Nitrate	N-amo				0.2204
7	WT	DO	Turb	TP	P-orto	Nitrate	N-amo			0.1793
8	WT	DO	pH	Turb	TP	P-orto	Nitrate	N-amo		0.1309
9	WT	DO	pH	Cond	Turb	TP	P-orto	Nitrato	N-amo	0.0535

WT = water temperature; Turb = turbidity; DO = dissolved oxygen; Cond = electrical conductivity; TP = total phosphorus; P-orto = orthophosphate; N-amo = ammoniacal nitrogen. Maximum correlation value in bold.

Table 2. Bioenv result for density date of phytoplankton and environmental variables of the urban lakes of Goiânia-GO.

Size	Model									Correlation
1	N-amo									0.1668
2	Turb	TP								0.2860
3	**Turb**	**TP**	**N-amo**							**0.3037**
4	WT	Turb	TP	N-amo						0.2758
5	WT	Turb	TP	Nitrate	N-amo					0.2338
6	WT	DO	Turb	TP	Nitrate	N-amo				0.1990
7	WT	DO	Cond	Turb	TP	Nitrate	N-amo			0.1643
8	WT	DO	Cond	Turb	TP	P-orto	Nitrate	N-amo		0.0794
9	WT	DO	pH	Cond	Turb	TP	P-orto	Nitrate	N-amo	0.0019

WT = water temperature; Turb = turbidity; DO = dissolved oxygen; Cond = electrical conductivity; TP = total phosphorus; P-orto = orthophosphate; N-amo = ammoniacal nitrogen. Maximum correlation value in bold.

temperature, dissolved oxygen, turbidity, total phosphorus, and ammoniacal nitrogen, while the main density relationships were with turbidity, ammoniacal nitrogen, and total phosphorus.

4. Discussion

The results showed how environmental heterogeneity influenced phytoplankton diversity, dominance, and rarity in the studied urban lakes. Although we found weak relationships between local environmental conditions and the phytoplankton community through Bioenv, it was possible to observe that water temperature, dissolved oxygen, turbidity, and nutrient concentrations were the main conditions related to the phytoplankton communities in this set of urban lakes. The environmental heterogeneity of the lakes was also evident in the PCA, where it was possible to observe the separation of the lakes according to local environmental conditions. Likewise, the NMDS made it possible to observe the separation of the lakes according to the phytoplanktonic composition and density of the sites, in addition to the fact that it was possible to detect that most lakes have their communities composed mainly of rare cyanobacteria and algae and a few dominant species. Finally, the groups that contributed most to the diversity in the lakes were green algae and cyanobacteria.

The sampled lakes have a high diversity of phytoplanktonic species, especially rare species (many taxa with low abundance), with most lakes having an even distribution of species abundance (evenness > 0.6). Thus, according to our hypothesis, we found that the majority of lakes (mesotrophic and oligotrophic) with low to moderate concentrations of nutrients and turbidity had high species diversity, with many rare species and few abundant species. In nature, the contribution of rare species to the formation of communities is a recurring pattern (Magurran & Henderson, 2003; Leitão et al., 2016). These species are considered to be those with low populations, limited geographic distribution, or a small range of environmental tolerance (Mouillot et al., 2013). However, species with small population sizes may be more vulnerable to extinction (Magurran, 2005). In relation to lakes considered eutrophic, such as lake L4, we found lower richness, diversity and equitability, with the dominance of few species of green algae and cyanobacteria, while in lake L6, also eutrophic, we found a high abundance of *A. minutissimum*, but also the presence of many rare species. Thus, we can consider that our hypothesis was partially confirmed.

The lakes L4, L6, L12, and L14 showed the highest dominance of taxa (taxa with high abundances). These lakes had some local environmental conditions that were different from the other lakes. For example, lake L4 had low dissolved oxygen, low pH, and high electrical conductivity and nutrient concentrations, while lakes L6 and L12 had high pH and higher chlorophyll-a concentrations, and lake L14 had low values of turbidity and nutrients. Phytoplankton species are highly variable in their responses to environmental conditions, particularly the acquisition of resources such as light and nutrients, which directly influence reproduction, resource acquisition, and predation avoidance (Litchman & Klausmeier, 2008). Therefore, the different local environmental conditions of these lakes influenced the greater dominance of taxa in the phytoplankton communities at these sites.

Among the different taxonomic groups, green algae predominated in many of the sampled lakes, demonstrating their important contribution to phytoplankton diversity. Green algae constitute a cosmopolitan group, with high abundance in tropical waters and preferential occurrence in mesotrophic to eutrophic lakes, mainly related to temperature conditions, light, and nutrient availability (Komárek & Fott, 1983; Padisák et al., 2009; Kruk & Segura, 2012), and may be important components of the flora of urban aquatic ecosystems (D'Alessandro & Nogueira, 2017). In our study, we can highlight the record of *M. contortum*, which was present in eleven of the fourteen lakes sampled, with a higher abundance in lake L8, as well as the taxon *M. irregulare*, which was dominant in abundance in lake L12. Thus, based on the local environmental conditions of the studied lakes, such as moderate turbidity, slightly alkaline pH, and availability of nutrients such as phosphorus, nitrate, and ammoniacal nitrogen, it was possible to detect the high contribution of the group.

Cyanobacteria, on the other hand, constituted the second largest group in terms of species richness, and abundance, and this group has been significantly affected by higher temperatures and nutrient availability (Paerl, 2017). Thus, many cyanobacteria are associated with water eutrophication and can become dominant in lakes, leading to the development of blooms with cyanotoxin production (van Apeldoorn et al., 2007; Paerl et al., 2020), resulting in impaired biodiversity and lake water quality. In our study, the local environmental conditions favored the development of this group in several lakes, especially in lakes L8, L9, and L12 (lakes with moderate nutrient concentrations) where the highest abundances of cyanobacteria were recorded. We must emphasize that although cyanobacteria are associated with eutrophication scenarios, the presence of the group can occur in mesotrophic and oligotrophic environments and even associated with blooms (Reinl et al., 2021).

Diatoms contributed to the phytoplankton richness and abundance and were recorded in all lakes. Diatoms are a great bioindicator group because the group's relationship to the chemical environment is well established, they are well studied taxonomically, and because they have silica frustules, they are well preserved for later verification of identification (Brabcová et al., 2017). Lakes L1, L5, L6, and L11 were the lakes with the highest abundance of diatoms, and lakes L1 and L5 also had the highest turbidity values. Among the preferred environmental conditions of the group is its affinity for aquatic environments with greater turbidity and higher concentrations of nutrients (Reynolds et al., 2002; Padisák et al., 2009). The most abundant taxa of diatoms found in these lakes were *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cyclotella* sp., and *Achnanthidium minutissimum* (Kützing), which are common taxa in continental aquatic environments (Moura et al., 2021). *A. minutissimum*, for example, abundant in lake L6, is considered to be one of the most abundant species in the world (Potapova & Hamilton, 2007).

The desmids recorded in the sampled lakes were important for species richness, although the group had a low contribution to abundance, except for the taxon *Cosmarium contractum* Kirchner var. *minutum* (Schmidle), which was important in density in lake L14 (lake with low nutrient concentrations and low turbidity). Desmids comprise a cosmopolitan group occurring in oligotrophic to eutrophic environments (Coesel, 1982) and have been used as bioindicators due to their high sensitivity to environmental changes (González Garraza et al., 2019). In addition to *C. contractum* var. *minutum*, the high contribution of the chrysophycean *D. bavaricum* Imhof was also recorded in the same lake. Chrysophyceans are mixotrophic flagellated algae, and in general, low light availability or low dissolved nutrient availability regulates the development of the group (Hamsher et al., 2020). In our study, although light availability may not have been a limiting resource due to the low turbidity of the lake, we recorded the lowest concentrations of dissolved nutrients (e.g., nitrate, ammoniacal nitrogen, and orthophosphate), which certainly contributed to their development.

Therefore, evaluating the relationship between phytoplankton and the local environmental conditions of urban lakes can be an important tool to assess the water quality of these ecosystems, since the anthropic actions caused by the development of cities, can affect the functioning of these lentic environments, interfering in its integrity and the provision of ecosystem services. Thus, the study of species diversity, dominance, and rarity, based on phytoplankton richness and abundance and their relationship with different local environmental conditions, reflects the conditions of each lake and this can be the first step in studying these ecosystems. Discover the local biodiversity is extremely important to propose measures for the preservation and conservation of these urban ecosystems, which seem to be important holders of biodiversity. Finally, urban lakes, even with different environmental conditions, can be important providers of phytoplankton diversity in a landscape context, and therefore we suggest intensifying studies to assess the integrity of these ecosystems over time and the maintenance of their biodiversity.

Acknowledgements

This paper is developed in the context of the Institutos Nacionais de Ciência e Tecnologia (INCT) in Ecology, Evolution and Biodiversity Conservation, supported by MCTIC/CNPq (proc. 465610/2014-5) and Fundação de Amparo à Pesquisa do Estado de Goiás (FAPEG).

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Received: 29 June 2023
Accepted: 13 November 2023

Associate Editor: Fabiana Schneck.