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Main predictors of phytoplankton occurrence in lotic ecosystems

Principais preditores na ocorrência do fitoplâncton em sistemas lóticos

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Abstract: Aim: Our goal was to relate the phytoplankton metacommunity to its possible determinants in a micro watershed: (I) determinants related to landscape-scale filtering, (II) determinants referring to local microhabitat filtering, (III) determinants referring to previous colonization, and (IV) determinants representing three different dispersal routes. **Methods:** Eight sampling stations were selected along the Cascavel River watershed, located in the state of Paraná, Brazil. Samples were collected quarterly for three years. All phytoplankton samples were quantitatively analyzed to determine the density of the metacommunity. In addition, it was characterized the landscape in terms of land use and occupation, and environmental characterization in terms of physical and chemical variables of the water. All data underwent relevant statistical analysis, where variance partitioning was carried out using partial RDA models, with prior selection of predictor variables, to estimate the relative role of each predictor in the community. We also compared three possible dispersal routes: "Asymmetric Eigenvector Map" (AEM), "Overland" and "Watercourse". **Results:** It was found that the metacommunity was best explained by "asymmetric eigenvector mapping" (AEM), indicating that because it is a small spatial scale the high connectivity between the sampling stations enables species to disperse overland as well. The different filters act together and depend on rainfall variation. Besides fluctuating temporally, the influence of these mechanisms is subject to which dispersal hypothesis is being considered. **Conclusions:** At the watershed scale, we argue that small-scale processes should be considered, since they homogenize the landscape and consequently leave the environmental gradient similar between sampling stations. In addition, the connectivity of colonization patches is essential to understand the behavior of microalgae that have a high dispersal capacity and are not restricted only to the river course.

Keywords: dispersion; mass effect; scale; landscape.

Resumo: Objetivo: O objetivo do trabalho foi relacionar a metacomunidade fitoplanctônica com seus possíveis determinantes em uma microbacia hidrográfica: (I) determinantes relacionados à filtragem em escala de paisagem, (II) determinantes referentes à filtragem local de micro-habitat, (III) determinantes referentes a colonização anterior e (IV) determinantes representando três diferentes rotas de dispersão. **Métodos:** Foram selecionadas oito estações de amostragem ao longo da microbacia do Rio Cascavel, localizada no estado do Paraná, Brasil. As coletas foram realizadas trimestralmente durante três anos. Todas as amostras de fitoplâncton passaram por análise quantitativa para averiguar a densidade da metacomunidade. Além disso fizemos a caracterização da paisagem tanto o uso e ocupação do solo e caracterização ambiental quanto as variáveis físicas e químicas da água. Todos os dados passaram por análises estatísticas pertinentes, onde a partição da variância foi realizada utilizando modelos RDA parciais, com seleção prévia das variáveis preditoras, para estimar o papel relativo de cada preditor na comunidade. Ainda comparamos três possíveis rotas de dispersão: Mapa de Autovetores Assimétricos" (AEM), "Terrestre" e "Curso d´água". **Resultados:** Constatou-se que a metacomunidade foi mais bem explicada pelo "mapa de autovetores assimétricos" (AEM), indicando que por se tratar de uma pequena escala espacial a alta conectividade entre as estações de amostragem possibilita que as espécies se dispersem também por terra. Os diferentes filtros atuam em conjunto e dependem da variação de chuva. Além de flutuar temporalmente, a influência desses mecanismos está sujeita a qual hipótese de dispersão está sendo considerada. **Conclusões:** Na escala da microbacia hidrográfica, argumentamos que os processos de pequena escala devem ser considerados, uma vez que homogeneízam a paisagem e, consequentemente, deixam o gradiente ambiental semelhante entre as estações de amostragem. Além disso, a conectividade das manchas de colonização é essencial para entender o comportamento das microalgas que têm alta capacidade de dispersão, não se restringindo apenas ao curso do rio.

Palavras-chave: dispersão; efeito de massa; escala; paisagem.

1. Introduction

An important constituent of aquatic ecosystems, phytoplankton are defined as a group of photosynthesizing microorganisms, unicellular or multicellular, that play a key ecosystem function in biogeochemical cycles (Reynolds, 2006). They are still recognized as indispensable components of the trophic web in aquatic ecosystems, playing the role of primary producers (Field et al., 1998; Hitchcock, 2022). Microalgae in this group have short generation times and are highly sensitive to environmental changes (Machado et al., 2016). Because they respond predictably to changes in the environment, phytoplankton are an ideal group to explore the determinants of metacommunity organization (Wojciechowski et al., 2017).

Metacommunities can be understood as local communities that interact with each other through connectivity enabled by species dispersal (Leibold et al., 2004). This concept helps to elucidate distribution patterns of organisms in a specific region by quantifying the relative effects of different filters, like landscape, environment and historical community (Mihaljevic, 2012). Understanding the structuring mechanisms of metacommunities and their biogeographic patterns is fundamental in ecological studies, encompassing several theoretical paradigms, such as those proposed by Leibold et al. (2004), where *patch-dynamic, the species-sorting, the mass effects* and the *neutral* act as different processes under organisms. In the *patch-dynamic* understanding, habitats are considered homogeneous and community structure occurs as a function of dispersal limitation, which follows the dynamics of extinction and colonization. *Species-sorting*, on the other hand, considers habitats to be heterogeneous, and consequently niche differences between species drive dispersal rates. Under the *mass effects* approach, the effect of environmental conditions is restricted as a result of high dispersal rates, allowing species to persist even in adverse habitats. Finally, in the *neutral* perspective, species and environments are functionally similar, and community structure occurs in view of stochastic events of dispersal, colonization, speciation and extinction (Hubbell, 2011).

One of the structuring filters of metacommunities is the landscape, which at different scales is essential to understand ecological phenomena (Heino et al., 2015). Changes in land use, such as expansion of urbanized areas, cattle ranching, deforestation, and improper waste disposal are the main anthropogenic factors that deteriorate water quality (Vörösmarty et al., 2010; Akhtar et al., 2021). These activities affect the entire aquatic ecosystem by altering concentrations of nutrients essential for phytoplankton growth and interfering with the availability of light necessary for photosynthesis, thus reducing biodiversity (Almeida et al., 2022; Zhang et al., 2022). At regional scales, such as micro-watersheds, there is a tendency for landscape homogenization, further intensifying the influence of land use on aquatic communities (Medeiros et al., 2022).

In addition to the landscape, the abiotic and biotic conditions in each colonization patch act as environmental filters for the species that make up the metacommunity (Huszar et al., 2015; Chaparro et al., 2023). In aquatic ecosystems, environmental parameters such as nutrient availability, solar radiation below the water surface, the acidity level (pH) and water temperature, as well as biological interactions, play a key role in regulating phytoplankton dynamics (Reynolds, 2006). Another important filter is the historical composition of this metacommunity, i.e., how previous species explain the structure of the current metacommunity (Wojciechowski et al., 2017). This influence occurs through the dominance and persistence of certain taxa, which use various strategies to survive in environments along a temporal gradient (Lürling, 2021).

The influence of these filters (landscape, environment and historical community) on the biogeographic distribution patterns of microorganisms at various scales are clearly observable in the context of metacommunity theory (Leibold et al., 2004; Heino et al., 2015). Furthermore, phytoplankton constituent species, due to their diminutive size, enjoy numerous efficient dispersal strategies, such as drought-resistant spores and attachment to particles, allowing them to passively disperse in different ways, either through water or land (Incagnone et al., 2015; Lansac-Tôha et al., 2021). At small scale, dispersal is even more efficient due to the absence of barriers (Moresco et al., 2017).

To understand how these filters structure the metacommunity and influence different forms of dispersal, it is still necessary to consider temporal changes, mainly driven by hydrological variations (Dittrich et al., 2016; Lansac-Tôha et al., 2021). Temporal variation considers, for example, seasonality between samplings, excluding landscape or environmental information (Padial et al., 2014). Seasonality dictates, among other factors, precipitation patterns over time, which, when it comes to aquatic environments, becomes the main driver of river flow. Relating precipitation to landscape, spatial and environmental filters is inevitable, since it can intensify or attenuate the effects of the landscape on aquatic ecosystems through surface runoff (Jeppesen et al., 2015; Zhao et al., 2018; Nobre et al., 2020); facilitate or hinder dispersal through the variation in connectivity provided by rainfall (Rodrigues et al., 2018); alter the chemical and physical variables of water, such as temperature, nutrient transport, dissolved oxygen, among others (Pourfallah-Koushali et al., 2021). These factors together influence the availability of habitats and structure the phytoplankton community present at the sites (Calijuri et al., 2002; Choudhury et al., 2015; Thompson et al., 2015).

In this sense the present paper evaluates how spatial and environmental filters, historical metacommunity and dispersal act on the phytoplankton metacommunity structure of a watershed during a three-year period. For this purpose, it was tested the following hypotheses: (I) the relative role of the filters is dependent on the variation of precipitation in different seasonal seasons; (II) because it is a small spatial scale, dispersal will not be limited only by water flux.

2. Materials and Methods

2.1. Study area

Located in western Paraná State, the Cascavel River Watershed (Figure 1) covers a drainage area of approximately 17.50 km^2 (Cembranel et al., 2017). Along this extension, the Cascavel River is found in mostly agricultural, urban areas (where the main headwaters are located) and reserve or forest areas (FUNDETEC, 1995). This region is characterized as subtropical with an average annual temperature of 21 °C. The greatest number of dry periods occurs in the coldest months (May to August), mostly in the fall and winter; the greatest number of rainy periods occurs in the warmest months (September to April), mostly in the spring and summer (Alvares et al., 2013; Salton et al., 2021).

2.2. Field and laboratory methodology

Were selected eight sampling stations (Table 1) with the goal of covering the soil uses in the Cascavel River watershed region, which are divided into sites of agricultural, industrial, extractive activities and urban settlements, following the source-river direction. To understand the temporal dynamics of these sites, the collections were performed quarterly considering the four seasonal seasons, starting in the winter of 2017 and ending in the fall of 2020, resulting for a total of 12 collections and N=96 samples (N=24 for each season). All samples were deposited in the Herbarium of the State University of Western Paraná - UNOPA, linked to the Brazilian Network of Herbaria and the computerized data available on speciesLink (www.splink.cria.org.br). Rainfall data were provided by the Meteorological Institute of Paraná (SIMEPAR, 2023).

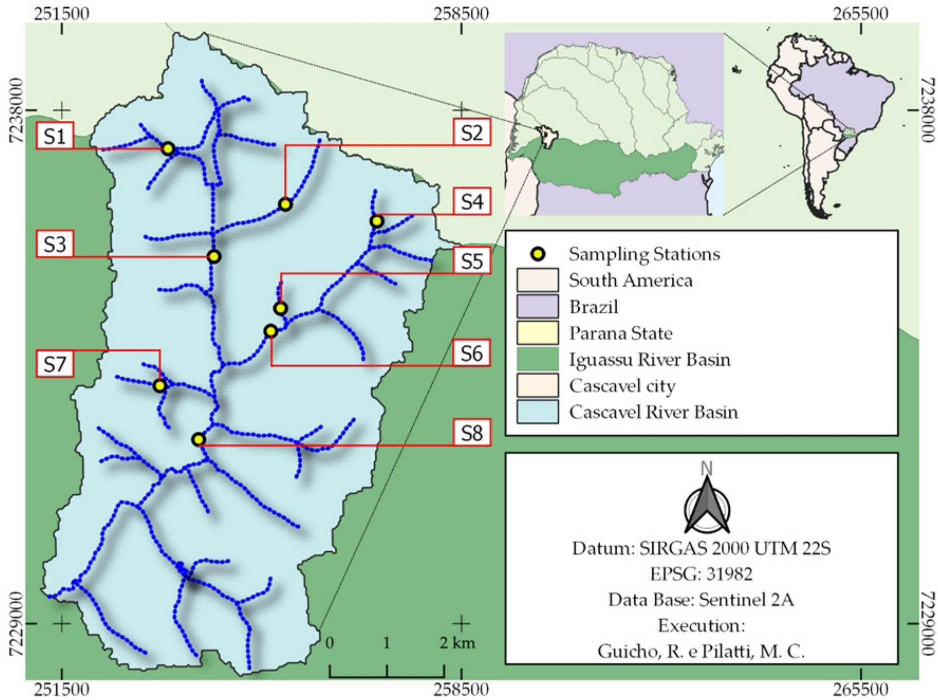

Figure 1. Location of sampling stations (S) in the watershed of the Cascavel River, Municipality of Cascavel - PR, Brazil.

2.3. Filters: metacommunity, landscape, environment and dispersion

2.3.1. Metacommunity

The phytoplankton metacommunity was collected directly from the subsurface of the water column and fixed *in situ* with acetic lugol. We chose not to use the plankton mesh for the quantitative analyses in order to avoid overestimating the biological material. The quantitative analysis was estimated according to the methodology described by Utermohl (1958) and Lund et al. (1958), with the aid of an Olympus inverted microscope, model CKX41. The sedimentation time was equivalent to the height of the chamber used (Margalef, 1983). The individuals were counted in the form in which they occurred in nature: cells, colonies, cenobia, or filaments (Sun, 2003). Phytoplankton density was calculated according to the American Public Health Association (APHA, 2017) and results were expressed as individuals per milliliter (ind. mL^{-1}). The phytoplankton metacommunity of the previous period was considered as a predictor of the phytoplankton metacommunity of the following period, therefore, the first period does not present historical community data, and is used as a predictor for the second period onwards (see also Wojciechowski et al., 2017).

Table 1. Geographic coordinates of the sampling stations (S) along the Cascavel River watershed, belonging to the City of Cascavel - PR, Brazil.

Sampling stations	Latitude	Longitude
S1	24°57’32.93”S	53°26’33.32”W
S2	24°58’06.80”S	53°25’21.70”W
S3	24°58’35.81”S	53°26’06.85”W
S4	24°58’17.29”S	53°24’24.75”W
S5	24°59’05.99”S	53°25’23.83”W
S6	24°59’18.90”S	53°25’32.20”W
S7	24°59’48.82”S	53°26’42.08”W
S8	25° 00’13.36”S	53°26’19.12”W

2.3.2. Landscape

Was used the QGis software to perform the manual classification of land use and land cover measures from images obtained from the Sentinel 2A satellite with spatial resolution of 10m. The classification of the study area was based on the Technical Manual of Land Use - Brazilian Institute of Geography and Statistics (IBGE, 2013), which has information about the classes and land uses, being the five main classes in the region: rural, urban, forest, water and mining.

2.3.3. Environment

Data regarding the sampling of physical and chemical variables such as temperature, electrical conductivity, dissolved oxygen, pH, turbidity, depth and flow were measured *in situ* by multiparameter probe Horiba U-5000. The laboratory for environmental and agricultural analysis (ACQUASOLLUS-Campo Mourão) analyzed oxygen consumption due to chemical oxidation and organic matter, total dissolved phosphorus, orthophosphate, nitrate, total solids, dissolved solids, suspended solids, total coliforms, thermotolerant coliforms and chlorophyll-a concentrations. The analyses were performed following the standardized methods in Standard Methods (APHA, 2017).

2.3.4. Dispersion

The following methodologies were considered to generate the possible dispersion routes:

(1) To test "Overland", we considered that the sampling stations connected bidirectionally, following both upstream-downstream and downstream-upstream directions. To do this, we created a spatially connected network with links across the sampling stations, from an ordination matrix generated using the coordinates of the sampling stations (Euclidean distances resulting from the Principal Coordinate of Neighboring Matrices (Borcard & Legendre, 2002);

(2) To test the asymmetric eigenvector mapping "AEM", the points were related using their latitude and longitude. In addition, the connectivity or non-connectivity of the points was considered (Blanchet et al., 2008);

(3) To test the "Watercourse", we considered that the sampling stations connected only as a function of river water flow. For this, the water bodies were characterized from the National Water Agency (ANA), generating a distance matrix, thus resulting in a spatial network model with directional links over the water course.

2.4. Data analysis

All analyses were performed using R Core Team (2022) using the packages *vegan* (Oksanen et al., 2020), *adespatial* (Dray et al., 2012) and *spdep* (Bivand, 2022). To characterize the sampling stations, it was used the environmental variables (non-collinear). To avoid collinearity, we used the *Forward Selection* (function "*ordistep*", package "*spdep*") which selects which variables maximize the fit of the model, so even if they have some correlation between them, they are selected without affecting the fit of the model (Blanchet et al., 2008; Radbruch et al., 2020). These were previously standardized (function "*log*") by standard deviation and subjected to Principal Component Analysis (PCA) (Legendre & Legendre, 2012). For species density was used a *Bray-Curtis* similarity matrix after *Hellinger* transformation, used to ensure that data on species is processed taking into account their individual characteristics, thus avoiding the excessive attribution of importance to the presence of many zeros or very high abundances.

The phytoplankton metacommunity density matrix was related to the matrices of the following predictors: local environmental variables, spatial variables (connectivity by dispersal routes), landscape and metacommunity characteristics from the previous period (historical community). For this, we used matrices summarized in a principal coordinate analysis applied to *Bray-Curtis* distance matrix (function "*pcoa*", package "*vegan*") (Bray & Curtis, 1957). *PCoA* was used to improve the correlations of the predictor matrices with the community matrices, since the number of predictor variables exceeded the number of sampling units, it was necessary to synthesize them into axes (Legendre & Legendre, 2012). Seeking to estimate the relative role of each predictor in the phytoplankton metacommunity, we used variance partitions performed from partial RDA (function "*varpart*", package "vegan") (*pRDA*) models (Legendre & Legendre, 2012). We followed the same approach as Medeiros et al. (2022), who used models generated separately for each period, considering the relative densities of periphytic diatoms. To complement these results, our work analyzes the total phytoplankton metacommunity. The graphs were produced with the "*plot*" function and modified with design software.

3. Results

3.1. Metacommunity

A total of 106 taxa were found, distributed in ten classes: Chlorophyceae (42), Bacillariophyceae (21), Zygnematophyceae (14), Cyanophyceae (13), Euglenophyceae (8), Dinophyceae (3), Coscinodiscophyceae (2), Mediophyceae (1), Trebouxiophyceae (1), Chrysophyceae (1). In general, throughout the period sampled, the genus with the highest relative abundance at sampling stations S1, S2, S4 and S5 was *Pseudanabaena* Lauterborn, at stations S3 and S8 we can highlight the genus *Merismopedia* Meyen, at S6 the genus with the highest contribution in relative abundance was *Gomphonema* Ehrenberg, and finally at sampling station S7 *Cocconeis* Ehrenberg stood out.

3.2. Landscape

The watershed of the Cascavel River was characterized mostly by urban areas, including sampling stations S2, S3, S4 and S7, parallel to agricultural areas that include stations S5 and S6. Stations S1 and S8 have a larger forested area compared to the others (Figure 2). Despite this, the headwaters are highly impacted by urbanization, a factor also observed at the points impacted by rural extension.

3.3. Environment

The principal component analysis (PCA) for the environmental variables summarized 30% of the total variability (Figure 3). The first axis of the PCA explained the variability mainly in relation to flow (correlation value: 0.20) and mean depth (0.20) positively, related to sampling station S8 during the summer of 2018 (D). Already negatively this axis grouped dissolved solids (-0.47) and total dissolved solids (-0.52) considerably distancing the sampling station S1 during spring 2018 (C). The second axis is positively related to orthophosphate (0.26) and dissolved oxygen (0.18), variables related to sampling station S1 during winter 2019 (A). Negatively this axis explains variability as a function of turbidity (-0.37) and thermotolerant coliforms (-0.35), significantly distancing sampling station four during spring 2017 (C).

Throughout the period sampled the watershed of the Cascavel River showed high accumulated precipitation in the spring of 2017 followed by

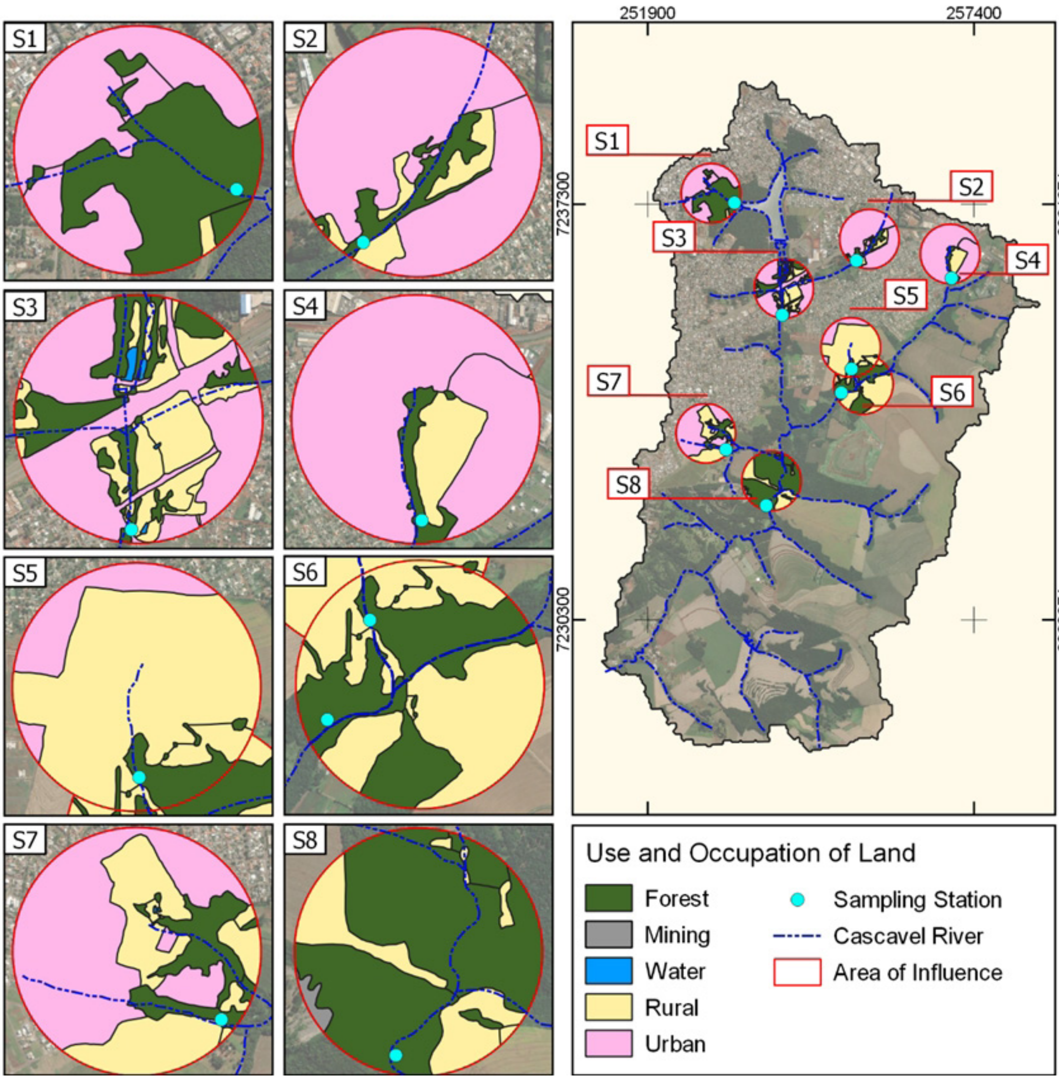

Figure 2. Detailed land use and sampling stations following the upstream-downstream flow with a diameter of 1 km.

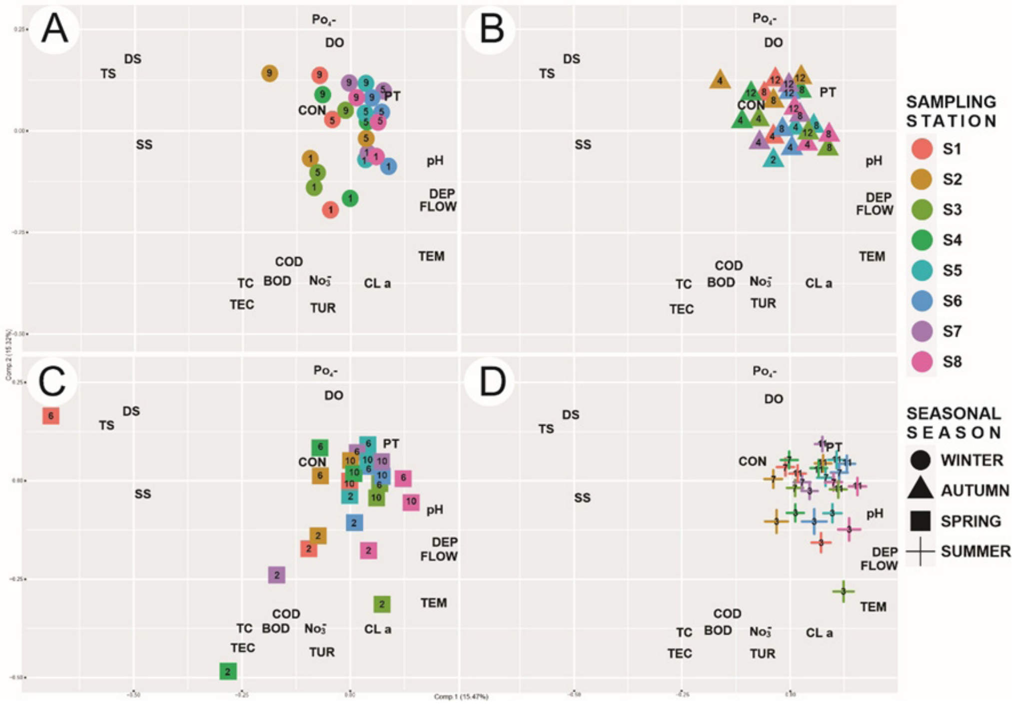

Figure 3. Principal Component Analysis (PCA) for physical, chemical and biological data analyzed in the eight sampling stations (S) of the Cascavel River, PR-Brazil. Legend: (A) Winter; (B) Autumn; (C) Spring; (D) Summer. TEM: temperature, DEP: depth, CON: electrical conductivity, DO: dissolved oxygen, TUR: turbidity, FLOW: flow rate, COD: chemical oxygen demand, BOD: biochemical oxygen demand, NO_3^-: nitrate, PT: total dissolved phosphorus, PO_4^-: orthophosphate, CLa: chlorophyll-a, TS: total solids, DS: dissolved solids, SS: suspended solids, TC: total coliforms and TEC: thermotolerant coliforms.

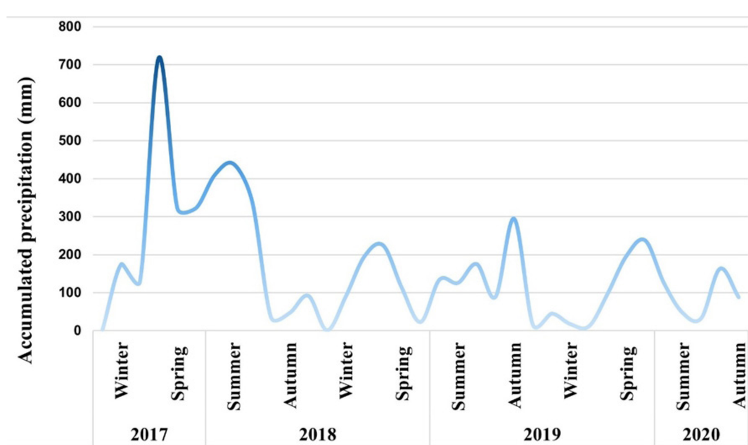

Figure 4. Accumulated precipitation (mm) as a function of seasonality in the city of Cascavel - PR, Brazil. Data provided by SIMEPAR (2023).

the summer of 2018. We can also highlight the winter of 2018 with the highest precipitation of the season this year compared to the others (Figure 4).

3.4. Dispersion

In general, the spatial filter in which the predictors showed the greatest ability to explain the metacommunity was “AEM”, followed by “Overland”, while “Watercourse” showed less explanatory power compared to the others (Figures 5 and 6). The metacommunity referring to summer 2019 (C7) was best explained by the predictors, with 52% of the variance explained by landscape, 1% by environmental filters, 4% by spatial filters, and 17% by historical

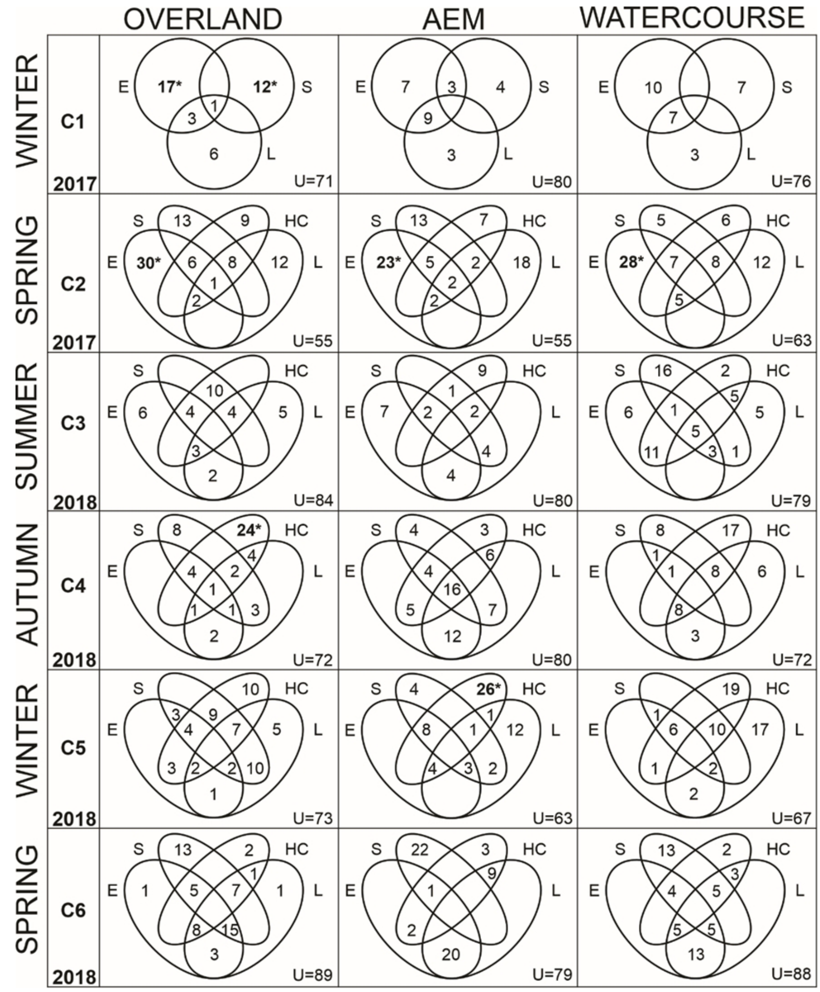

Figure 5. Results of the Partial Redundancy Analysis (pRDA). Relative contributions (% explanation) of environment (E), spatial (S), historical metacommunity (HC) and landscape (L) explaining the variation in relative abundance in phytoplankton metacommunities from the seasons winter, spring, summer, autumn, winter and spring, the respectively C1 to C6. We used possible dispersal routes "Overland", "AEM" and "Watercourse" as spatial predictors (see methods). U = unexplained component. Explanation percentages significantly different from a null model ($p < 0.05$) are represented by "*" and bold.

metacommunity (Figure 6). "Overland" explained best the metacommunity corresponding to winter 2019 (C9), with 14% of the variance explained by this spatial filter, "AEM" stood out with 22% explanation in spring 2018 (C6), while "Watercourse" demonstrated 16% of the variance explained in the metacommunities referring to summer 2018 and fall 2019 (C3 and C8 respectively).

Environmental filters stood out in spring 2017 (C2), where they were significant in all three dispersal routes. The landscape filter stood out in explaining the metacommunity relating to winter 2019 (C9), being significant in all three dispersal routes. Whereas the historical metacommunity became representative starting in the fall of 2018 (C4), it obtained its greatest power of explanation (42%) in the winter of 2019 (C9), in the dispersal routes "AEM" and "Watercourse".

4. Discussion

The dynamics of phytoplankton metacommunities has received increasing attention in Brazilian scientific studies, however, floodplains (Devercelli et al., 2016; Diniz et al., 2023) and lentic environments, such as lakes or reservoirs (e.g., Bortolini et al., 2017, 2019; Wojciechowski et al., 2017; Rodrigues et al., 2018; Loaiza-Restano et al., 2020), are addressed more frequently. The phytoplankton present in lotic environments is still poorly explored (Huang et al., 2023). In this sense, Medeiros et al. (2022) evaluated

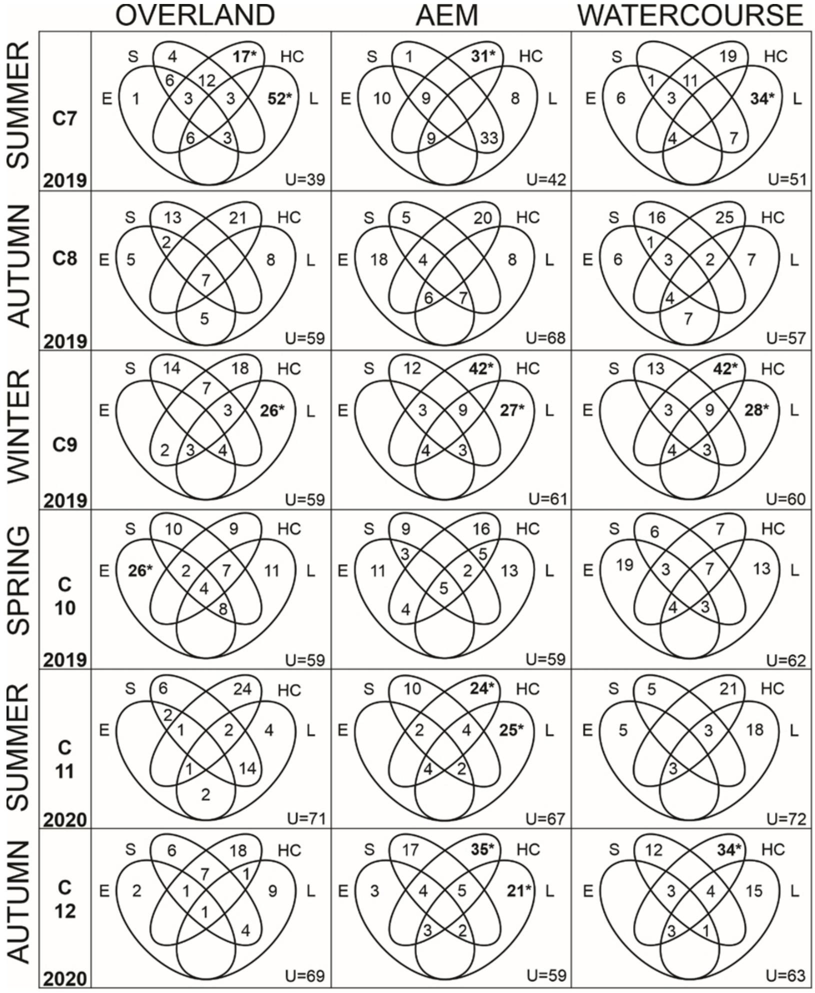

Figure 6. Results of the Partial Redundancy Analysis (pRDA). Relative contributions (% explanation) of environment (E), spatial (S), historical metacommunity (HC) and landscape (L) explaining the variation in relative abundance in phytoplankton metacommunities for the seasons summer, autumn, winter, spring, summer and autumn, respectively C7 to C12. We used possible dispersal routes "Overland", "AEM" and "Watercourse" as spatial predictors (see methods). U = unexplained component. Explanation percentages significantly different from a null model ($p < 0.05$) are represented by "*" and bold.

periphytic diatoms in a watershed responsible for public supply in the western region of Paraná.

Thinking of complementing the analyses previously performed by Medeiros et al. (2022), were used the same analysis approach, however, the present work evaluated the total phytoplankton metacommunity, consisting of the other groups of microalgae (phytoflagellates, green algae, cyanobacteria and diatoms), during a longer sampling period, an important factor to avoid biased conclusions. The results obtained and discussed below corroborate the two hypotheses proposed during the research, where (i) the relative role of the filters was dependent on the variation in precipitation in the different seasonal seasons; (ii) and because it is a small spatial scale, dispersion was not limited to the flow of water alone.

The classes that contributed most to the species richness of the phytoplankton metacommunity were Chlorophyceae (40%) and Bacillariophyceae (13%). These classes are composed of microalgae with high adaptability power, considered cosmopolitan, developing even under adverse conditions (Bicudo & Menezes, 2017; Medeiros et al., 2022; Silva et al., 2023a). Among the genera with the highest relative abundances are *Pseudanabaena* and *Merismopedia*, found in sampling stations with environmental conditions similar, such as neutral pH (6), low concentrations of biochemical oxygen demand (1.27 $mg.L^{-1}$) and high concentrations of total dissolved solids (45.79 $mg.L^{-1}$), to other works that also observed higher abundances of these genera (Gomes et al., 2021; Mohan & Piryadarshinee, 2023).

The environmental conditions favor the development of algae belonging to the class Cyanophyceae are a result of the watershed of the Cascavel River transiting mainly between urban and agricultural areas, with the headwaters being located within the city and the surrounding area of the city used for soybean and corn monoculture (Guicho et al., 2021). This landscape results in a series of anthropic impacts on aquatic ecosystems, such as deposition of effluents without adequate treatment, reduction of riparian vegetation, and alteration of limnological conditions, factors that reflect directly on the phytoplankton metacommunity (Yaqoob et al., 2023). Studies conducted in the same watershed consolidated the effects of urbanization and agriculture on limnological variables (Medeiros et al., 2020). When assessing environmental fragility (calculation performed using slope, soil type, and landscape) Peres et al. (2022) found that the watershed of the Cascavel River presents a high environmental fragility, being one of the most impacted in the western region of the state of Paraná, Brazil.

The aforementioned landscape stood out in the winter of 2019, which corresponds to the seasonal season with the lowest precipitation of the entire period sampled. This proves the expected hypothesis, where (I) the relative role of the filters is dependent on the variation of precipitation in different seasonal seasons. The prominence of the landscape in the dry season has been reported previously, where land use was the largest contributor in explaining the metacommunity in this period (Silva et al., 2023b). This is possibly due to the limited dispersal of these organisms as a result of reduced connectivity in the dry season, thereby accentuating landscape impacts on isolated colonization patches (Heino et al., 2015; Bortolini et al., 2017). The limitation of dispersal in the dry season may also be a reflection of the species found in the metacommunity, for example diatoms, which have the presence of siliceous structures that contribute to sedimentation (Kruk et al., 2010). Although microorganisms from lotic environments enjoy passive dispersal, river flow decreases considerably in dry periods, and in the case of low-order streams this can result in dry stretches, isolating colonization spots, as well as hindering other forms of dispersal, such as overland via wind and water particles (Ormerod et al., 2011).

The naturally distinct physical characteristics in watersheds, added to land use, have significant relationships with physical and chemical water parameters, which in turn are determinants in phytoplankton development and establishment (Xu et al., 2020; Chaparro et al., 2023). These naturally distinct limnological characteristics are consistent with the continuous river theory (Vannote et al., 1980) representing valuable information associated with various approaches to aquatic ecosystem preservation (Doretto et al., 2020).

When evaluating the environmental filter, it was found that it showed lower explanatory power compared to landscape, which has been reported previously in studies with planktonic organisms (Dias et al., 2016; Rodrigues et al., 2018). Possibly this occurs as a result of the small scale considered, where environmental gradients are little evident due to the mass effect, in addition, the size of the spatial extent is proportional to the amplitude of niches (Heino et al., 2015; Viana & Chase, 2019). In the studied micro basin this is reflected in the form of spatial homogenization added to the small scale, resulting in a low variation of local parameters (Rocha et al., 2020; Medeiros et al., 2022).

The environmental filter stood out in the spring of 2017, being significant in all three dispersal routes. This season presented the highest precipitation of the whole sampled period. The high rainfall could explain the relationship of the metacommunity with local environmental factors because of the increased connectivity of the patches in this period, providing a higher dispersal capacity (Moresco et al., 2020). Connectivity by water flow is an essential feature in stream metacommunities, however, after periods of heavy rainfall dispersal rates are known to be high and overland flow represents an important pathway for aquatic microorganisms (Grönroos et al., 2013; Pellowe-Wagstaff & Simonis, 2014; Heino et al., 2015).

We also assessed the potential effect of previous metacommunity occupancy on current community composition, a filter that is rarely included in work on phytoplankton metacommunity structuring (Wojciechowski et al., 2017). This filter became significant starting in the fall of 2018, in a timely manner in the different dispersal routes. This may be related to the high precipitation at the beginning of the sampled period, causing the metacommunity to need time to re-establish itself again after the disturbance (Foets et al., 2020). In addition, this variable was significant in a punctual way and without patterns throughout the sampling period, possibly because phytoplankton are subject to several environmental filters, added to the short water retention time, which hinders their establishment and accentuates stochastic distribution (Naselli-Flores & Padisák, 2016). However, the various groups of microalgae have numerous strategies to survive in this variable environment along a temporal gradient, like as nutrient acquisition, suspension and morphologies that hinder predation (Lürling, 2021).

Regarding the different forms of dispersal, the metacommunity was best explained by "AEM", which, compared to the other forms, does not necessarily consider the direct connectivity of the sampling stations, but rather latitude and longitude. This result meets the second hypothesis, where (II) because it is a small spatial scale the dispersal will not be limited only by water flow, due to the high connectivity between the sampling stations, enabling species to disperse over land as well (Grönroos et al., 2013; Heino et al., 2015; Bortolini et al., 2017).

These results contribute to the understanding of how environmental, landscape and historical filters can drive phytoplankton composition (Padial et al., 2014; Mohd-Din et al., 2022). Rather than reaching a definitive conclusion of the exact factors that explain the metacommunity, this work reinforces that different variables act together and depend on seasonal changes that govern the physical, chemical and biological processes of lotic environments, which in turn act on phytoplankton dynamics (Aboim et al., 2020; Haque et al., 2021). We observed that the landscape is the best filter for the dry period, while for the flood period the best filter is the environment. It was found that besides fluctuating temporally, the influence of these mechanisms depends on which dispersal hypothesis is being considered (Bortolini et al., 2017; Medeiros et al., 2022). We also emphasize the importance of considering the scale and connectivity of the colonization patches, because even in a micro basin, the spatial structure was important in explaining the metacommunity.

Global water resources have been widely recognized as the most essential among natural resources, yet anthropogenic activities, social, economic, and public management factors reduce water quantity and quality among different territories (Tabrez et al., 2022; Tang et al., 2022). Understanding ecological mechanisms using phytoplankton is essential for diversity conservation and management of watersheds that provide ecosystem services central to human well-being (Peter et al., 2021; Peng et al., 2022; Yang et al., 2022). Thus, we encourage long-term biological monitoring, which in addition to aiding in understanding the behavior of these microorganisms, is the basis for biodiversity conservation.

References

Aboim, I.L., Gomes, D.F., & Mafalda Junior, P.O., 2020. Phytoplankton response to water quality seasonality in a Brazilian neotropical river. Environ. Monit. Assess. 192(1), 70. PMid:31883033. http://dx.doi.org/10.1007/s10661-019-7882-5.

Akhtar, N., Syakir Ishak, M.I., Bhawani, S.A., & Umar, K., 2021. Various natural and anthropogenic factors responsible for water quality degradation: a review. Water 13(19), 2660. http://dx.doi.org/10.3390/w13192660.

Almeida, T.P., Macena, D.Â., Simões, J.S.T., Mareco, E.A., Calciolari Rossi, R., & Favareto, A.P.A., 2022. Análise de parâmetros de qualidade da água e teste de genotoxicidade em peixes da bacia hidrográfica do rio Pirapozinho – SP, Brasil. Res. Soc. Dev. 11(3), e46711319309. http://dx.doi.org/10.33448/rsd-v11i3.19309.

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Moraes Gonçalves, J.L., & Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorol. Z. 22(6), 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

American Public Health Association – APHA, 2017. Standart methods for the examination of wastewater. Washington: APHA.

Bicudo, C.E.M., & Menezes, M., 2017. Gêneros de algas de águas continentais do Brasil: chave para identificação e descrições. São Carlos: RiMa.

Bivand, R., 2022. R packages for analyzing spatial data: a comparative case study with areal data. Geogr. Anal. 54(3), 488-518. http://dx.doi.org/10.1111/gean.12319.

Blanchet, F.G., Legendre, P., & Borcard, D., 2008. Modelling directional spatial processes in ecological data. Ecol. Modell. 215(4), 325-336. http://dx.doi.org/10.1016/j.ecolmodel.2008.04.001.

Borcard, D., & Legendre, P., 2002. All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. Ecol. Modell. 153(1-2), 51-68. http://dx.doi.org/10.1016/S0304-3800(01)00501-4.

Bortolini, J.C., Silva, P.R.L., Baumgartner, G., & Bueno, N.C., 2019. Response to environmental, spatial, and temporal mechanisms of the phytoplankton metacommunity: comparing ecological approaches in subtropical reservoirs. Hydrobiologia 830(1), 45-61. http://dx.doi.org/10.1007/s10750-018-3849-8.

Bortolini, J.C., Pineda, A., Rodrigues, L.C., Jati, S., & Velho, L.F.M., 2017. Environmental and spatial processes influencing phytoplankton biomass along a reservoirs-river-floodplain lakes gradient: a metacommunity approach. Freshw. Biol. 62(10), 1756-1767. http://dx.doi.org/10.1111/fwb.12986.

Bray, J.R., & Curtis, J.T., 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monogr. 27(4), 325-349. http://dx.doi.org/10.2307/1942268.

Calijuri, M.C., Dos Santos, A.C.A., & Jati, S., 2002. Temporal changes in the phytoplankton community structure in a tropical and eutrophic reservoir (Barra Bonita, S.P.: Brazil). J. Plankton Res. 24(7), 617-634. http://dx.doi.org/10.1093/plankt/24.7.617.

Cembranel, A.S., Sampaio, S.C., Remor, M.B., Gotardo, J.T., & Rosa, P.M.D., 2017. Geochemical background in an oxisol. Eng. Agric. 37(3), 565-573. http://dx.doi.org/10.1590/1809-4430-eng.agric.v37n3p565-573/2017.

Chaparro, G., O'Farrell, I., & Hein, T., 2023. Hydrological conditions determine shifts of plankton metacommunity structure in riverine floodplains without affecting patterns of species richness along connectivity gradients. Aquat. Sci. 85(2), 41. http://dx.doi.org/10.1007/s00027-023-00937-z.

Choudhury, A.K., Das, M., Philip, P., & Bhadury, P., 2015. An assessment of the implications of seasonal precipitation and anthropogenic influences on a mangrove ecosystem using phytoplankton as proxies. Estuaries Coasts 38(3), 854-872. http://dx.doi.org/10.1007/s12237-014-9854-x.

Devercelli, M., Scarabotti, P., Mayora, G., Schneider, B., & Giri, F., 2016. Unravelling the role of determinism and stochasticity in structuring the phytoplanktonic metacommunity of the Paraná River floodplain. Hydrobiologia 764(1), 139-156. http://dx.doi.org/10.1007/s10750-015-2363-5.

Dias, J.D., Simões, N.R., Meerhoff, M., Lansac-Tôha, F.A., Velho, L.F.M., & Bonecker, C.C., 2016. Hydrological dynamics drives zooplankton metacommunity structure in a Neotropical floodplain. Hydrobiologia 781(1), 109-125. http://dx.doi.org/10.1007/s10750-016-2827-2.

Diniz, L.P., Petsch, D.K., Mantovano, T., Rodrigues, L.C., Agostinho, A.A., & Bonecker, C.C., 2023. A prolonged drought period reduced temporal β diversity of zooplankton, phytoplankton, and fish metacommunities in a Neotropical floodplain. Hydrobiologia http://dx.doi.org/10.1007/s10750-023-05140-7.

Dittrich, J., Dias, J.D., Bonecker, C.C., Lansac-Tôha, F.A., & Padial, A.A., 2016. Importance of temporal variability at different spatial scales for diversity of floodplain aquatic communities. Freshw. Biol. 61(3), 316-327. http://dx.doi.org/10.1111/fwb.12705.

Doretto, A., Piano, E., & Larson, C.E., 2020. The River Continuum Concept: lessons from the past and perspectives for the future. Can. J. Fish. Aquat. Sci. 77(11), 1853-1864. http://dx.doi.org/10.1139/cjfas-2020-0039.

Dray, S., Pélissier, R., Couteron, P., Fortin, M.J., Legendre, P., Peres-Neto, P.R., Bellier, E., Bivand, R., Blanchet, F.G., De Cáceres, M., Dufour, A.-B., Heegaard, E., Jombart, T., Munoz, F., Oksanen, J., Thioulouse, J., & Wagner, H.H., 2012. Community ecology in the age of multivariate multiscale spatial analysis. Ecol. Monogr. 82(3), 257-275. http://dx.doi.org/10.1890/11-1183.1.

Field, C.B., Behrenfeld, M.J., Randerson, J.T., & Falkowski, P., 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. Science 281(5374), 237-240. PMid:9657713. http://dx.doi.org/10.1126/science.281.5374.237.

Foets, J., Wetzel, C.E., Teuling, A.J., & Pfister, L., 2020. Temporal and spatial variability of terrestrial diatoms at the catchment scale: controls on communities. PeerJ 8, e8296. PMid:31915584. http://dx.doi.org/10.7717/peerj.8296.

Fundação para o Desenvolvimento Científico e Tecnológico – FUNDETEC, 1995. Recuperação ambiental da bacia hidrográfica do rio Cascavel. Cascavel.

Gomes, A.L., Cunha, C.J., Lima, M.O., Sousa, E.B., Costa-Tavares, V.B., & Martinelli-Lemos, J.M., 2021. Biodiversity and interannual variation of cyanobacteria density in an estuary of the Brazilian Amazon. An. Acad. Bras. Cienc. 93(4), e20191452. PMid:34705935. http://dx.doi.org/10.1590/0001-3765202120191452.

Grönroos, M., Heino, J., Siqueira, T., Landeiro, V.L., Kotanen, J., & Bini, L.M., 2013. Metacommunity structuring in stream networks: roles of dispersal mode, distance type, and regional environmental context. Ecol. Evol. 3(13), 4473-4487. PMid:24340188. http://dx.doi.org/10.1002/ece3.834.

Guicho, R., Ferreira, J.H.D., Medeiros, G., Siqueira, J.A.C., Souza, S.N.M., & Prior, M., 2021. Method for estimating the wind power micro and minigeneration applied to a city with a subtropical climate in south America. Res. Soc. Dev. 10(12), e105101220009. http://dx.doi.org/10.33448/rsd-v10i12.20009.

Haque, M.A., Jewel, M.A.S., Akhi, M.M., Atique, U., Paul, A.K., Iqbal, S., Islam, M.S., Das, S.K., & Alam, M.M., 2021. Seasonal dynamics of phytoplankton community and functional groups in a tropical river. Environ. Monit. Assess. 193(11), 704. PMid:34623504. http://dx.doi.org/10.1007/s10661-021-09500-5.

Heino, J., Melo, A.S., Siqueira, T., Soininen, J., Valanko, S., & Bini, L.M., 2015. Metacommunity organisation, spatial extent and dispersal in aquatic systems: patterns, processes and prospects. Freshw. Biol. 60(5), 845-869. http://dx.doi.org/10.1111/fwb.12533.

Hitchcock, J.N., 2022. Microplastics can alter phytoplankton community composition. Sci. Total Environ. 819, 153074. PMid:35038524. http://dx.doi.org/10.1016/j.scitotenv.2022.153074.

Huang, Z., Pan, B., Soininen, J., Liu, X., Hou, Y., & Liu, X., 2023. Seasonal variation of phytoplankton community assembly processes in Tibetan Plateau floodplain. Front. Microbiol. 14, 1122838. PMid:36891389. http://dx.doi.org/10.3389/fmicb.2023.1122838.

Hubbell, S.J. 2011. The unified neutral theory of biodiversity and biogeography (MPB-32). Princeton: Princeton University Press. http://dx.doi.org/10.1515/9781400837526.

Huszar, V.L.M., Nabout, J.C., Appel, M.O., Santos, J.B.O., Abe, D.S., & Silva, L.H.S., 2015. Environmental and not spatial processes (directional and non-directional) shape the phytoplankton composition and functional groups in a large subtropical river basin. J. Plankton Res. 37(6), 1190-1200. http://dx.doi.org/10.1093/plankt/fbv084.

Incagnone, G., Marrone, F., Barone, R., Robba, L., & Naselli-Flores, L., 2015. How do freshwater organisms cross the "dry ocean"? A review on passive dispersal and colonization processes with a special focus on temporary ponds. Hydrobiologia 750(1), 103-123. http://dx.doi.org/10.1007/s10750-014-2110-3.

Instituto Brasileiro de Geografia e Estatística – IBGE, 2013. Manual técnico de uso da terra. Rio de Janeiro: IBGE.

Jeppesen, E., Brucet, S., Naselli-Flores, L., Papastergiadou, E., Stefanidis, K., Nõges, T., Nõges, P., Attayde, J.L., Zohary, T., Coppens, J., Bucak, T., Menezes, R.F., Freitas, F.R.S., Kernan, M., Søndergaard, M., & Beklioğlu, M., 2015. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. Hydrobiologia 750(1), 201-227. http://dx.doi.org/10.1007/s10750-014-2169-x.

Kruk, C., Huszar, V.L.M., Peeters, E.T.H.M., Bonilla, S., Costa, L., Lürling, M., Reynolds, C., & Scheffer, M., 2010. A morphological classification capturing functional variation in phytoplankton. Freshw. Biol. 55(3), 614-627. http://dx.doi.org/10.1111/j.1365-2427.2009.02298.x.

Lansac-Tôha, F.M., Bini, L.M., Heino, J., Meira, B.R., Segovia, B.T., Pavanelli, C.S., Bonecker, C.C., de Deus, C.P., Benedito, E., Alves, G.M., Manetta, G.I., Dias, J.D., Vieira, L.C.G., Rodrigues, L.C., do Carmo Roberto, M., Brugler, M.R., Lemke, M.J., Tessler, M., DeSalle, R., Mormul, R.P., Amadio, S., Lolis, S.F., Jati, S., Siqueira, T., Silva, W.M., Higuti, J., Lansac-Tôha, F.A., Martens, K., & Velho, L.F.M., 2021. Scale-dependent patterns of metacommunity structuring in aquatic organisms across floodplain systems. J. Biogeogr. 48(4), 872-885. http://dx.doi.org/10.1111/jbi.14044.

Legendre, P., & Legendre, L., 2012. Numerical ecology. Amsterdam: Elsevier.

Leibold, M.A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J.M., Hoopes, M.F., Holt, R.D., Shurin, J.B., Law, R., Tilman, D., Loreau, M., & Gonzalez, A., 2004. The metacommunity concept: a framework for multi-scale community ecology. Ecol. Lett. 7(7), 601-613. http://dx.doi.org/10.1111/j.1461-0248.2004.00608.x.

Loaiza-Restano, A.M., Marquardt, G.C., Ferragut, C., & Bicudo, C.E.M., 2020. Spatial and temporal variation of the phytoplankton structure in cascading oligotrophic reservoirs of southeast Brazil. Acta Limnol. Bras. 32, e12. http://dx.doi.org/10.1590/s2179-975x7618.

Lund, J.W.G., Kipling, C., & Le Cren, E.D., 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11(2), 143-170. http://dx.doi.org/10.1007/BF00007865.

Lürling, M., 2021. Grazing resistance in phytoplankton. Hydrobiologia 848(1), 237-249. http://dx.doi.org/10.1007/s10750-020-04370-3.

Machado, K.B., Teresa, F.B., Vieira, L.C.G., Huszar, V.L., & Nabout, J.C., 2016. Comparing the effects of landscape and local environmental variables on taxonomic and functional composition of phytoplankton communities. J. Plankton Res. 38(5), 1334-1346. http://dx.doi.org/10.1093/plankt/fbw062.

Margalef, R., 1983. Limnología. Barcelona: Ediciones Omega, S.A.

Medeiros, G., Padial, A.A., Amaral, M.W.W., Guicho, R., Pilatti, M.C., Sampaio, S.C., Ludwig, T.A.V., Bueno, N.C., & dos Reis, R.R., 2022. Exploring key determinants of the periphytic diatom community in a Southern Brazilian micro-watershed. Water 14(23), 3913. http://dx.doi.org/10.3390/w14233913.

Medeiros, G., Padial, A.A., Wedig Amaral, M.W., Ludwig, T.A.V., & Bueno, N.C., 2020. Environmental variables likely influence the periphytic diatom community in a subtropical lotic environment. Limnologica 80, 125718. http://dx.doi.org/10.1016/j.limno.2019.125718.

Mihaljevic, J.R., 2012. Linking metacommunity theory and symbiont evolutionary ecology. Trends Ecol. Evol. 27(6), 323-329. PMid:22341499. http://dx.doi.org/10.1016/j.tree.2012.01.011.

Mohan, B., & Piryadarshinee, S., 2023. Phytoplankton as bio indicators of water quality in two perennial lakes of Coimbatore district, Tamil Nadu, India. Int. J. Entomol. Res. 8, 10-17.

Mohd-Din, M., Hii, K.S., Abdul-Wahab, M.F., Mohamad, S.E., Gu, H., Leaw, C.P., & Lim, P.T., 2022. Spatial-temporal variability of microphytoplankton assemblages including harmful microalgae in a tropical semi-enclosed strait (Johor Strait, Malaysia). Mar. Environ. Res. 175, 105589. PMid:35228143. http://dx.doi.org/10.1016/j.marenvres.2022.105589.

Moresco, G.A., Bortolini, J.C., Dias, J.D., Pineda, A., Jati, S., & Rodrigues, L.C., 2017. Drivers of phytoplankton richness and diversity components in Neotropical floodplain lakes, from small to large spatial scales. Hydrobiologia 799(1), 203-215. http://dx.doi.org/10.1007/s10750-017-3214-3.

Moresco, G.A., Bortolini, J.C., Rodrigues, L.C., Jati, S., & Machado Velho, L.F., 2020. A functional deconstructive approach to mixotrophic phytoplankton responds better to local, regional and biogeographic predictors than species. Austral Ecol. 45(2), 249-263. http://dx.doi.org/10.1111/aec.12852.

Naselli-Flores, L., & Padisák, J., 2016. Blowing in the wind: how many roads can a phytoplanktont walk down? A synthesis on phytoplankton biogeography and spatial processes. Hydrobiologia 764(1), 303-313. http://dx.doi.org/10.1007/s10750-015-2519-3.

Nobre, R.L.G., Caliman, A., Cabral, C.R., de Carvalho Araújo, F., Guerin, J., Dantas, F.D.C.C., & Carneiro, L.S., 2020. Precipitation, landscape properties and land use interactively affect water quality of tropical freshwaters. Sci. Total Environ. 716, 137044. PMid:32059302. http://dx.doi.org/10.1016/j.scitotenv.2020.137044.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., & Oksanen, M. J., 2020. Package 'vegan'. Community ecology package, version 2.5-7. Vienna: R Foundation for Statistical Computing.

Ormerod, S.J., Durance, I., Hatton-Ellis, T.W., Cable, J., Chadwick, E.A., Griffiths, S., Jones, T.H., Larsen, S., Merrix, F.L., Symondson, W.O.C., Thomas, R.J., & Vaughan, I.P., 2011. Landscape connectivity of freshwater ecosystems: strategic review and recommendations. Bangor: CCW, 117 p., CCW ContractScience Report, no. 932.

Padial, A.A., Ceschin, F., Declerck, S.A.J., De Meester, L., Bonecker, C.C., Lansac-Tôha, F.A., Rodrigues, L., Rodrigues, L.C., Train, S., Velho, L.F.M., & Bini, L.M., 2014. Dispersal ability determines the role of environmental, spatial and temporal drivers of metacommunity structure. PLoS One 9(10), e111227. PMid:25340577. http://dx.doi.org/10.1371/journal.pone.0111227.

Pellowe-Wagstaff, K.E., & Simonis, J.L., 2014. The ecology and mechanisms of overflow-mediated dispersal in a rock-pool metacommunity. Freshw. Biol. 59(6), 1161-1172. http://dx.doi.org/10.1111/fwb.12337.

Peng, C., Zou, W., Li, D., Li, G., & Bi, Y., 2022. Distinct effects of sediment regulation on phytoplankton community assembly in the tributaries and mainstream of the Three Gorges Reservoir. J. Clean. Prod. 368, 133082. http://dx.doi.org/10.1016/j.jclepro.2022.133082.

Peres, K.K., Guicho, R., Medeiros, G., Amaral, M.W.W., da Silva, T.T., Pilatti, M.C., Prior, M., & Bueno, N.C., 2022. Environmental fragility as an indicator of the risk of contamination by human action in watersheds used for public supply in western Paraná, Brazil. Environ. Earth Sci. 81(20), 486. http://dx.doi.org/10.1007/s12665-022-10619-y.

Peter, A.P., Khoo, K.S., Chew, K.W., Ling, T.C., Ho, S.H., Chang, J.S., & Show, P.L., 2021. Microalgae for biofuels, wastewater treatment and environmental monitoring. Environ. Chem. Lett. 19(4), 2891-2904. http://dx.doi.org/10.1007/s10311-021-01219-6.

Pourfallah Koushali, H., Mastouri, R., & Khaledian, M.R., 2021. Impact of precipitation and flow rate changes on the water quality of a Coastal River. Shock Vib. 2021, 1-13. http://dx.doi.org/10.1155/2021/6557689.

R Core Team, 2022. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Retrieved in 2023, June 30, from https://www.R-project.org/

Radbruch, L., De Lima, L., Knaul, F., Wenk, R., Ali, Z., Bhatnaghar, S., Blanchard, C., Bruera, E., Buitrago, R., Burla, C., Callaway, M., Munyoro, E.C., Centeno, C., Cleary, J., Connor, S., Davaasuren, O., Downing, J., Foley, K., Goh, C., Gomez-Garcia, W., Harding, R., Khan, Q.T., Larkin, P., Leng, M., Luyirika, E., Marston, J., Moine, S., Osman, H., Pettus, K., Puchalski, C., Rajagopal, M.R., Spence, D., Spruijt, O., Venkateswaran, C., Wee, B., Woodruff, R., Yong, J., & Pastrana, T., 2020. Redefining palliative care: a new consensus-based definition. J. Pain Symptom Manage. 60(4), 754-764. PMid:32387576. http://dx.doi.org/10.1016/j.jpainsymman.2020.04.027.

Reynolds, C.S., 2006. The ecology of phytoplankton. Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511542145.

Rocha, B.S., Souza, C.A., Machado, K.B., Vieira, L.C.G., & Nabout, J.C., 2020. The relative influence of the environment, land use, and space on the functional and taxonomic structures of phytoplankton and zooplankton metacommunities in tropical reservoirs. Freshw. Sci. 39(2), 321-333. http://dx.doi.org/10.1086/708949.

Rodrigues, L.C., Pivato, B.M., Vieira, L.C.G., Bovo-Scomparin, V.M., Bortolini, J.C., Pineda, A., & Train, S., 2018. Use of phytoplankton functional groups as a model of spatial and temporal patterns in reservoirs: a case study in a reservoir of central Brazil. Hydrobiologia 805(1), 147-161. http://dx.doi.org/10.1007/s10750-017-3289-x.

Salton, F.G., Morais, H., & Lohmann, M., 2021. Períodos secos no estado do Paraná. Rev. Bras. Meteorol.

36(2), 295-303. http://dx.doi.org/10.1590/0102-77863620163.

Silva, M.J.L., Pilatti, M.C., Bortolini, J.C., Baumgartner, G., & Bueno, N.C., 2023a. Chlorophyceae and Trebouxiophyceae (Chlorophyta) in lotic environments in the area of influence of the Baixo Iguaçu Hydroelectric Plant, Paraná State, Brazil. SciELO Preprints. In press.

Silva, L.B., Souza, C.A., Vieira, L.C.G., Antonio, E.V.R., & Couto Junior, A.F., 2023b. Local and regional determinants of phytoplankton communities in water reservoirs from the Cerrado biome. Acta Limnol. Bras. 35, e1. http://dx.doi.org/10.1590/s2179-975x5021.

Sistema de Tecnologia e Monitoramento Ambiental do Paraná – SIMEPAR, 2023 [online]. Retrieved in 2023, June 30, from http://www.simepar.org/

Sun, J., 2003. Geometric models for calculating cell biovolume and surface area for phytoplankton. J. Plankton Res. 25(11), 1331-1346. http://dx.doi.org/10.1093/plankt/fbg096.

Tabrez, S., Zughaibi, T.A., & Javed, M., 2022. Water quality index, *Labeo rohita*, and *Eichhornia crassipes*: suitable bio-indicators of river water pollution. Saudi J. Biol. Sci. 29(1), 75-82. PMid:35002395. http://dx.doi.org/10.1016/j.sjbs.2021.10.052.

Tang, W., Pei, Y., Zheng, H., Zhao, Y., Shu, L., & Zhang, H., 2022. Twenty years of China's water pollution control: experiences and challenges. Chemosphere 295, 133875. PMid:35131279. http://dx.doi.org/10.1016/j.chemosphere.2022.133875.

Thompson, P.A., O'Brien, T.D., Paerl, H.W., Peierls, B.L., Harrison, P.J., & Robb, M., 2015. Precipitation as a driver of phytoplankton ecology in coastal waters: a climatic perspective. Estuar. Coast. Shelf Sci. 162, 119-129. http://dx.doi.org/10.1016/j.ecss.2015.04.004.

Utermohl, H., 1958. Zur Ver vollkommung der quantitativen phytoplankton-methodik. Mitt Int Verein Theor Angew Limnol. 9, 39.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., & Cushing, C.E., 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37(1), 130-137. http://dx.doi.org/10.1139/f80-017.

Viana, D.S., & Chase, J.M., 2019. Spatial scale modulates the inference of metacommunity assembly processes. Ecology 100(2), e02576. PMid:30516271. http://dx.doi.org/10.1002/ecy.2576.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., & Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467(7315), 555-561. PMid:20882010. http://dx.doi.org/10.1038/nature09440.

Wojciechowski, J., Heino, J., Bini, L.M., & Padial, A.A., 2017. The strength of species sorting of phytoplankton communities is temporally variable in subtropical reservoirs. Hydrobiologia 800(1), 31-43. http://dx.doi.org/10.1007/s10750-017-3245-9.

Xu, S., Li, S.-L., Zhong, J., & Li, C., 2020. Spatial scale effects of the variable relationships between landscape pattern and water quality: example from an agricultural karst river basin. Agric. Ecosyst. Environ. 300, 106999. http://dx.doi.org/10.1016/j.agee.2020.106999.

Yang, Y., Chen, H., Abdullah Al, M., Ndayishimiye, J.C., Yang, J.R., Isabwe, A., Luo, A., & Yang, J., 2022. Urbanization reduces resource use efficiency of phytoplankton community by altering the environment and decreasing biodiversity. J. Environ. Sci. 112, 140-151. PMid:34955197. http://dx.doi.org/10.1016/j.jes.2021.05.001.

Yaqoob, M.M., Somlyai, I., Berta, C., Bácsi, I., Al-Tayawi, A.N., Al-Ahmady, K.K., Mohammed, R.H., Alalami, O., & Grigorszky, I., 2023. The impacts of land use and seasonal effects on phytoplankton taxa and physical-chemical variables in the Tigris River within the city of Mosul. Water 15(6), 1062. http://dx.doi.org/10.3390/w15061062.

Zhang, Y., Ma, R., Chu, H., Zhou, X., Yao, T., & Zhang, Y., 2022. Evaluation of the performance of different membrane materials for microalgae cultivation on attached biofilm reactors. RSC Advances 12(3), 1451-1459. PMid:35425202. http://dx.doi.org/10.1039/D1RA07335D.

Zhao, Z., Liu, G., Liu, Q., Huang, C., & Li, H., 2018. Studies on the spatiotemporal variability of river water quality and its relationships with soil and precipitation: a case study of the mun river basin in Thailand. Int. J. Environ. Res. Public Health 15(11), 2466. PMid:30400628. http://dx.doi.org/10.3390/ijerph15112466.

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