Oecologia Australis (ISSN: 2177-6199)
Ahead of print (https://revistas.ufrj.br/index.php/oa/issue/view/1109/showToc)
Article ID: AO#63166
Published online: 19 June 2024

A SYNTHESIS OF KNOWLEDGE ABOUT WATER QUALITY IN THE UPPER PARANÁ RIVER FLOODPLAIN

Jonathan Rosa[1*], *Natália Miguel Carvalho*[1], *Isadora Cristina Bianchi Costa*[1], *Bárbara Angélio Quirino*[1], *João Vitor Fonseca da Silva*[2] *& Claudia Costa Bonecker*[1]

[1]Universidade Estadual de Maringá, Centro de Ciências Biológicas, Departamento de Biologia, Núcleo de Pesquisa em Limnologia, Ictiologia e Aquicultura, Programa de Pós-Graduação em Ecologia de Ambientes Aquáticos Continentais. Av. Colombo, 5790, CEP 87020-900. Maringá, PR, Brazil.

[2]Universidade Estadual de Maringá, Centro de Ciências Biológicas, Departamento de Biologia, Programa de Pós-Graduação em Biologia Comparada. Av. Colombo, 5790, CEP 87020-900. Maringá, PR, Brazil.

E-mails: jonathandarosa95@gmail.com (*corresponding author); nathyelycarvalho@gmail.com; isadorabianchi10@gmail.com; barbara_aq@hotmail.com; joaovitorbio@live.com; claudiabonecker@gmail.com.

Abstract: Good water quality is essential for human activities, including recreation, water supply, agriculture, industry, and for maintenance of biodiversity. However, the high demand for resources has led to a reduction in the availability and quality of water. Hence, the objective of study was to make a synthesis of knowledge about water quality in a floodplain located in the basin with the highest population concentration in Brazil (Upper Paraná River floodplain), which is influenced by different anthropogenic impacts. We performed a literature search on the Google Scholar, Scopus and Web of Science databases using the following combination of keywords and operators: (Limnology OR Cyanobacteria OR Water quality) AND ("Paraná River Floodplain"). Were identified 58 publications from 1997 to 2023, and collected the following information from each article: publication year; nationality of the journal published;

study approach; type of environment; period of study; parameter of study and predictor variables. The generalised linear model showed a significant increase in the number of publications over time. The articles were mainly published in international journals and used the field approach, with an emphasis on studies carried out in lentic environments during a short period (< 10 years). Cyanobacteria and abiotic variables were the most frequently used parameters of study, while the predictor variables with the greatest influence on the studies were phosphorus, nitrogen and water transparency. Thus, considering that in the studied region, water is used for several ecosystem services, it is concerning that the results still show a gap in studies on this topic in this region.

Keywords: cyanobacteria; ecological indicators; eutrophication; freshwater; nutrients.

INTRODUCTION

Although water is an essential element for life on earth, its availability and quality are threatened by various factors, such as population and economic growth, urbanization, river damming and pollution (Duh *et al*. 2008; Akhtar *et al*. 2021). Several of these factors lead to changes in land use, which are one of the main causes of altered water quality in natural environments. For example, some cultures use fertilizers to increase production, which then run off into nearby watercourses (rivers and lakes), increasing the risk of eutrophication and loss of biodiversity (Bhateria & Jain 2016, Lechinovski *et al*. 2022). In this context, monitoring water quality is fundamental, in addition to subsidizing environmental conservation initiatives and contributing to public policies for planning and managing hydric resources (Guedes *et al*. 2012, Noori *et al*. 2019), and to evaluate water quality, different parameters can be analysed, such as nutrients (phosphorus and nitrogen), dissolved oxygen, trace elements (e.g. lead and copper), toxic algal blooms (cyanobacteria) and microplastic pollution (Vasistha & Ganguly 2020).

Among the floodplains in Brazil associated with large rivers is the upper Paraná River, located in the watershed with the highest population concentration in Brazil, impacted by the large input of nutrients from industrial and agricultural effluents, as well as the construction of several dams on its course (Algarte *et al*. 2006, Agostinho *et al*. 2018). The Upper Paraná River floodplain is located at the top of the Environmental Protected Area of the Paraná River Island and Várzea, and stretches between the Porto Primavera Dam (upstream) and the beginning of the Itaipu Reservoir, represents the last undammed stretch of the Paraná River, with 230 km in length. This region presents a greater diversity of habitats, including numerous secondary channels, interconnected and isolated lakes, and the main channels of the Paraná, Baia and Ivinhema rivers (Agostinho *et al*. 2007, Granzotti, *et al*. 2018).

Wetlands, such as floodplains, are one of the ecosystems most threatened by the social and economic demands of society, although they are extremely important. The dynamics of this ecosystem provide the society the regulation and purification of water, erosion control, waste treatment, disease control, drinking water for consumption and irrigation, food production (fish, shrimp, oysters and vegetables), energy production and cultural services (tourism and recreation) (Petsch *et al*. 2023). One way of contributing to the preservation and conservation of this ecosystem is to obtain information on their structure and functioning, and to find gaps in knowledge and consequently encourage studies that add information for a better understanding of their dynamics (Agostinho *et al*. 2008). One way of contributing to the preservation and conservation of this ecosystem is to obtain information on their structure and functioning, and to find gaps in knowledge and consequently encourage studies that add information for a better understanding of their dynamics (Agostinho *et al*. 2008). In this context, scientometric studies stand out as a quickest and effective method for knowledge synthesis, by measuring, quantifying, compiling, and synthesizing information. These studies also provide a way to visualise the technical and scientific efforts made to date, to highlight trends in the process of advancing knowledge (Dalpé 2002).

There are few scientometric studies performed in the upper Paráná river floodplain. For example, Osório & Rodrigues (2021) carried out a scientometric search to identify the studies conducted in this region until 2018, independent of their approach. Bertoncin et al. (2022) analysed the studies with aquatic macroinvertebrates in this floodplain published until 2020. Finally, Ruaro et al. (2020) carried out a systematic review to identify trends and gaps in studies on non-native populations in this region and to identify which population ecology topics are predominant in the studies. However, a review of water quality in this region was not made, although it is important because the results can contribute to environmental conservation in the context of water resource planning and management policy, since this water is used for human supply. In addition, understanding the gaps in knowledge about water quality in the Upper Paraná River region could boost scientific production in the region, which is important economically, socially, and environmentally. Thus, the aim of this study was to synthesise knowledge about water quality in the last dam-free stretch of the upper Paraná River floodplain using a systematised search of the literature.

MATERIAL AND METHODS

Literature search

A systematic search was performed to identify and update information on water quality in the last dam-free stretch of the upper Paraná River floodplain. This bibliometric research was performed in the Google Scholar, Scopus and Web of Science databases, using the following combination of keywords and operators: (Limnology OR Cyanobacteria OR Water Quality) AND (“Paraná River Floodplain”), while the Scopus database used the combination ({Limnology} OR {Cyanobacteria} OR {Water Quality}) AND ({Paraná River Floodplain}). The equations used for the literature research were based on the study by Ferreira *et al*. (2023), who analysed the main scientific literature databases. The keywords used in the search were analysed in the titles, abstracts, keywords and the entire text of the studies. The literature search

Oecologia Australis (ISSN: 2177-6199)
Ahead of print (https://revistas.ufrj.br/index.php/oa/issue/view/1109/showToc)
Article ID: AO#63166
Published online: 19 June 2024

was not limited in time, so all references published up to December 2023 were considered. The use of different bases (Google Scholar, Scopus and Web of Science) increases the search performance for articles about water quality and helps reduce the possibility of having biased results (Ferreira *et al*. 2023).

Both observational and experimental studies were used, but grey literature was not considered.

Data extraction

A database was created with all the references offered by the databases according to the search terms. Subsequently, a manual sorting process which consisted of the reading the full articles was carried out according to the specificity of our study, excluding duplicate references present in more than one database, references unrelated to our study topic (water quality) and references outside our study area (last dam-free stretch of the upper Paraná River floodplain).

The selected references were read completely, and the following information was obtained: year of publication; nationality of the journal published; study approach; parameter of study; type of environment; duration of the study; predictor variables.

Data analysis

A Generalised Linear Model (GLM) analysis (Logan, 2010) was performed to determine the relationship between the number of publications (response variable) and the years of publication (fixed effect) using the Poisson distribution. The data was checked for normality and homogeneity of variance to meet the conditions for multiple regression.

Were used graphs and descriptive statistics to estimate the comparison between some factors, such as the number of articles by journal nationality, the number of field or experimental articles, the type of environment, the duration of the study (long duration > 10 years or short duration < 10 years) and the parameter of study used. A word cloud was created to verify the most frequent predictor variables in the articles evaluated. This word cloud is a visual representation that considers the frequency of words as a degree of importance, i.e. the bigger the word, the greater the effect. In addition, posteriori, a report was carried out on the species of cyanobacteria cited in the articles because this was the most widely used parameter of study.

The GLM analysis and all the graphs were performed in the R software version 3.3.1 using the "nlme" package and the "ggplot2" package, respectively (R Development Core Team, 2013).

RESULTS

A total of 58 published studies on water quality were recorded in the floodplain (Figure 1), with a higher concentration in the sub-basins of the Paraná, Baia and Ivinhema Rivers (Figure 2; Table S1- Supplementary material). The first studies were published in 1997 and the most recent in 2023. The generalised linear model (GLM) showed a significant increase in the number of publications over the years (z-value = 1.9; p = 0.04 Figure 3).

Oecologia Australis (ISSN: 2177-6199)
Ahead of print (https://revistas.ufrj.br/index.php/oa/issue/view/1109/showToc)
Article ID: AO#63166
Published online: 19 June 2024

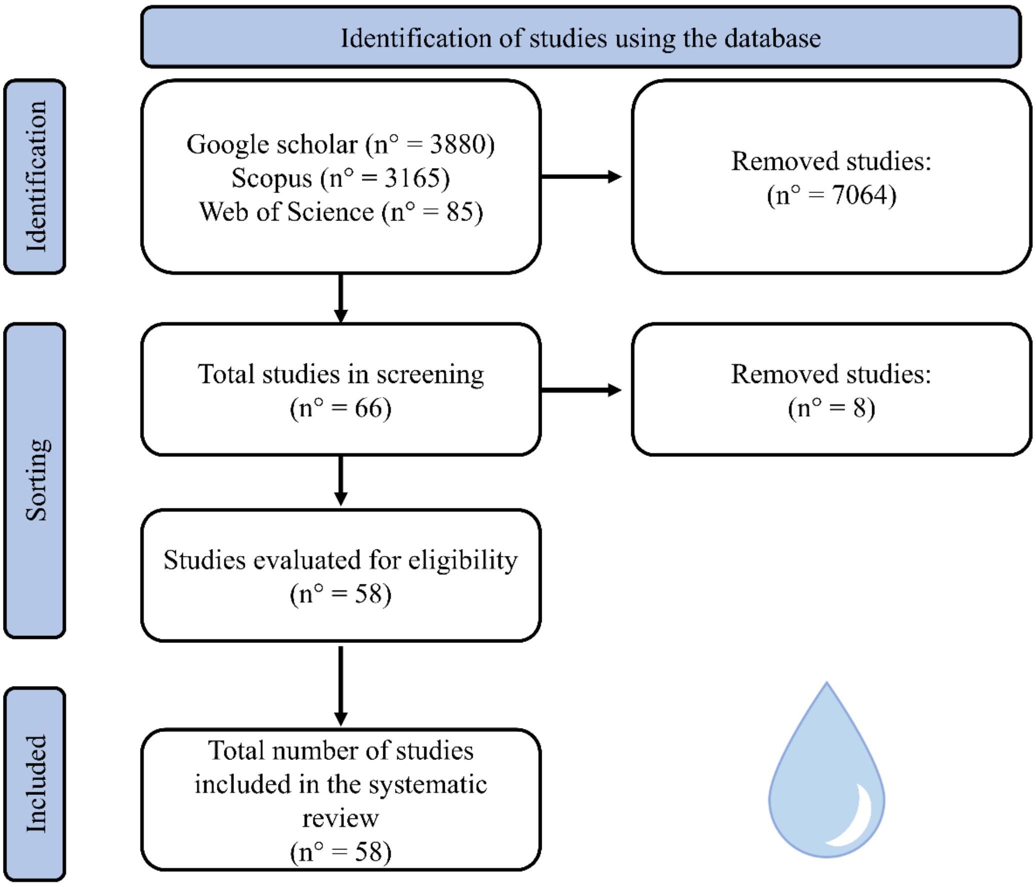

Figure 1. Steps of the systematic review based on the adapted PRISMA flow diagram (Moher *et al*., 2009) summarizing the phases of inclusion and exclusion of studies.

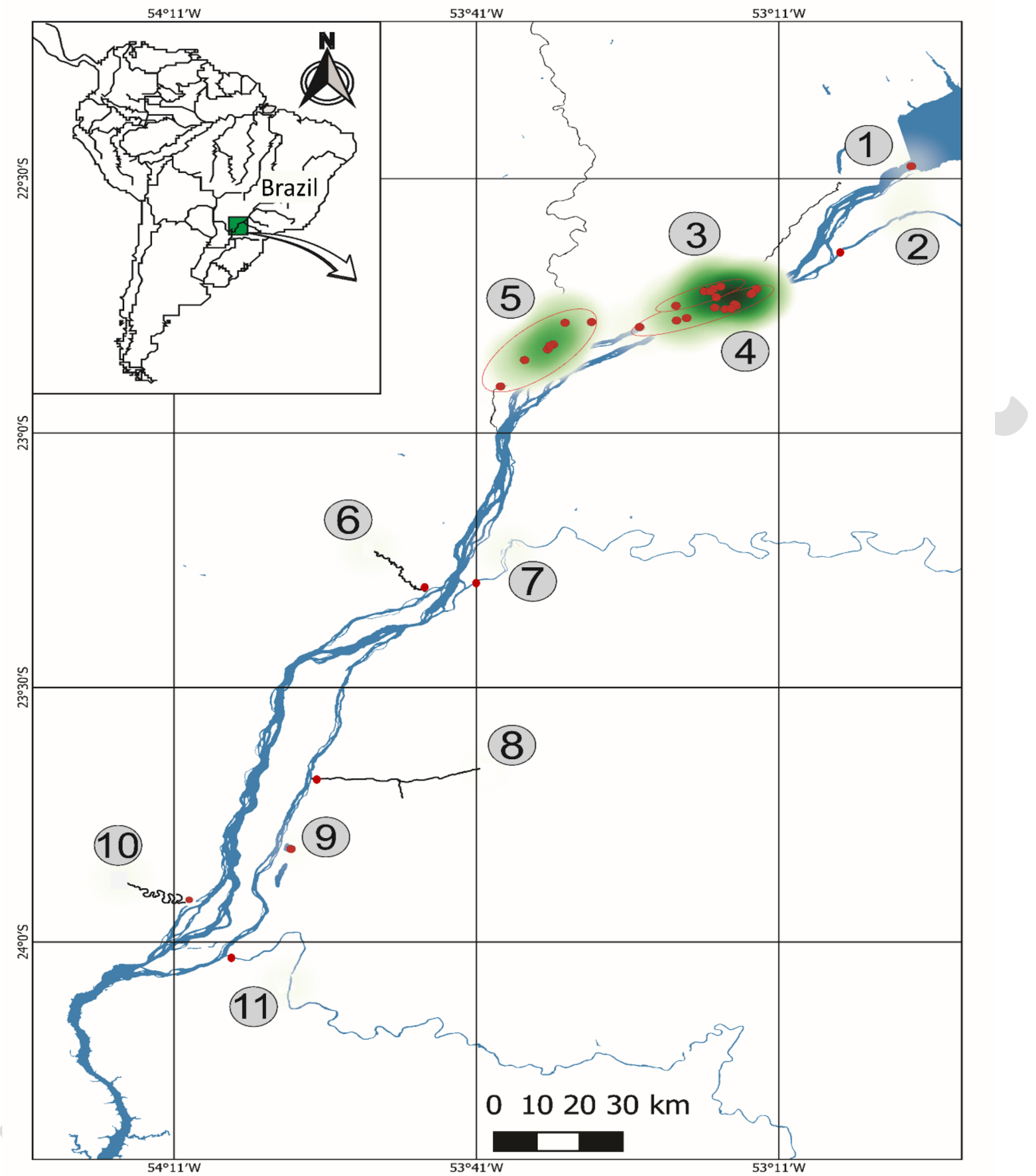

Figure 2. Map showing the sites where water quality was analysed in the upper Paraná River floodplain. 1: Paraná river, downstream of the Porto Primavera reservoir; 2: Paranapanema River, downstream of the Rosana reservoir; 3: Baia River sub-basin; 4: Paraná River sub-basin; 5: Ivinhema River sub-basin; 6: Amambai River; 7: Ivai River; 8: Paracai River; 9: Paraná River; 10: Iguatemi River; 11: Piquiri River. The red dots represent the sampling points. The green colour indicates the concentration in the number of studies, where the higher shades of green represent a higher number of studies. The red ellipses delimit the regions with the highest number of studies (3. Baia River, 4. Paraná River and 5. Ivinhema River).

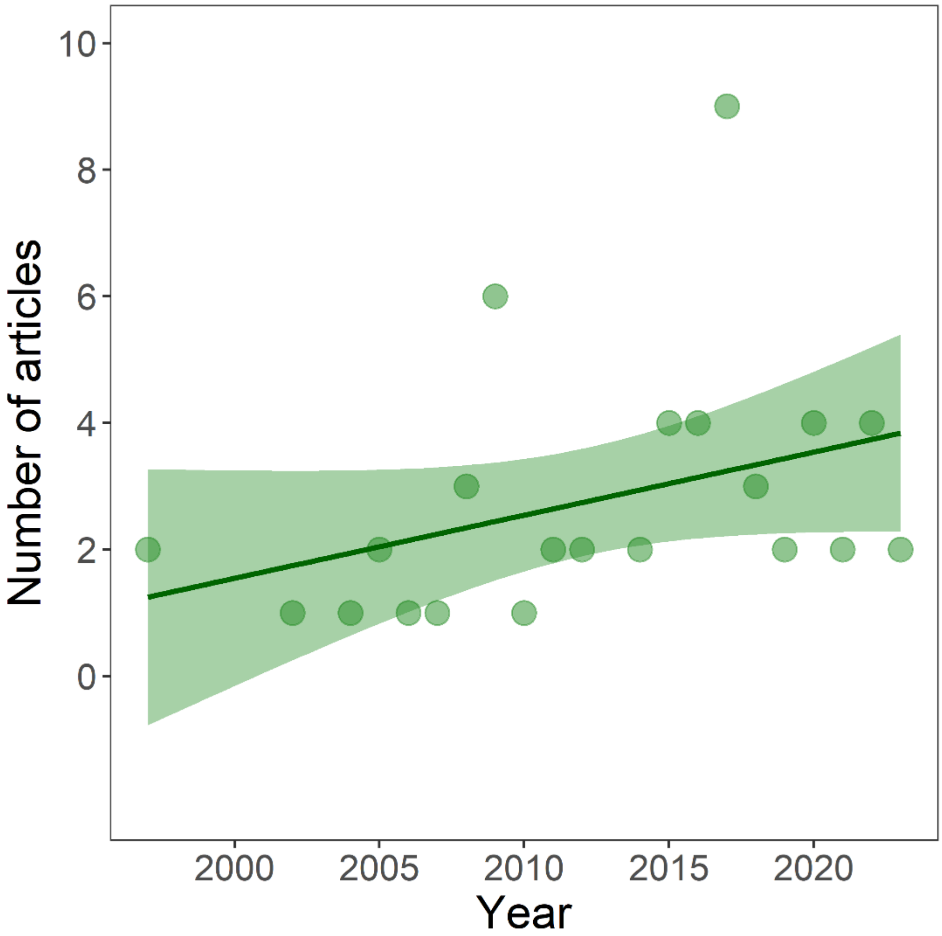

Figure 3. Results of the generalised linear model showing the relationship between the number of articles published and the years of publication. The shaded band represents the standard error.

Most of the studies analysed were published in international journals. However, this difference was relatively small, with 32 articles originating from international sources and 26 from national publications (Figure 4A). When we analysed the approach of the studies, we observed that the majority were performed in the field (51 articles), while a smaller number (7 articles) used an experimental approach (Figure 4B).

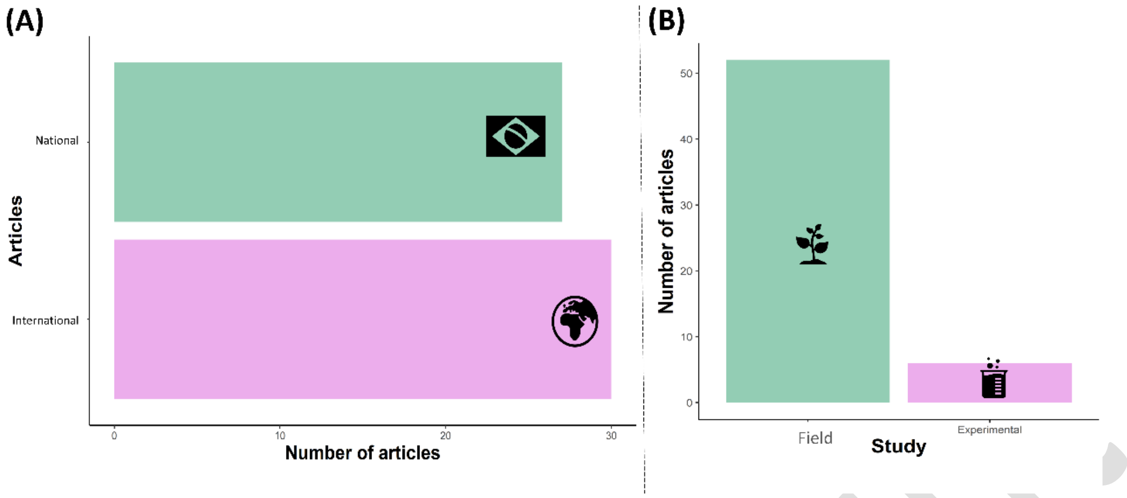

Figure 4. Number of articles published in national and international journals (A) and number of articles with field or experimental approaches (B).

Based on the literature search, it was possible to identify that different study parameters were used to evaluate water quality, such as cyanobacteria, abiotic variables (e.g. nutrients), fish, zooplankton, macroinvertebrates and macrophytes (Figure 5). Cyanobacteria were the most widely used parameter of study to indicate water quality, both in field and experimental approaches, with 126 species recorded in studies performed in the upper Paraná River floodplain, of which 44 genera are recognised for their toxic potential (Table S2). On the other hand, macroinvertebrates and macrophytes were the lowest studied parameters.

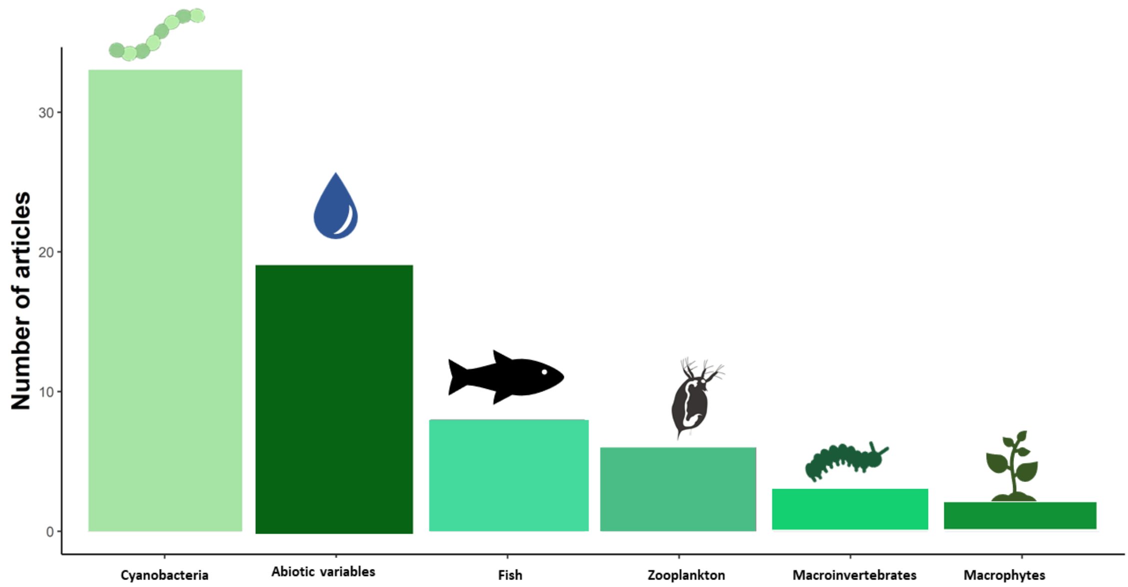

Figure 5. Variables and test organisms used in studies on water quality in the upper Paraná River floodplain between 1997 and 2023.

Given the diversity of environments found in the floodplain, it was observed that some studies evaluate water quality in both lotic and lentic environments, but in general, the number of studies in lentic environments (47 studies) is higher than in lotic environments (25 studies) (Figure 6).

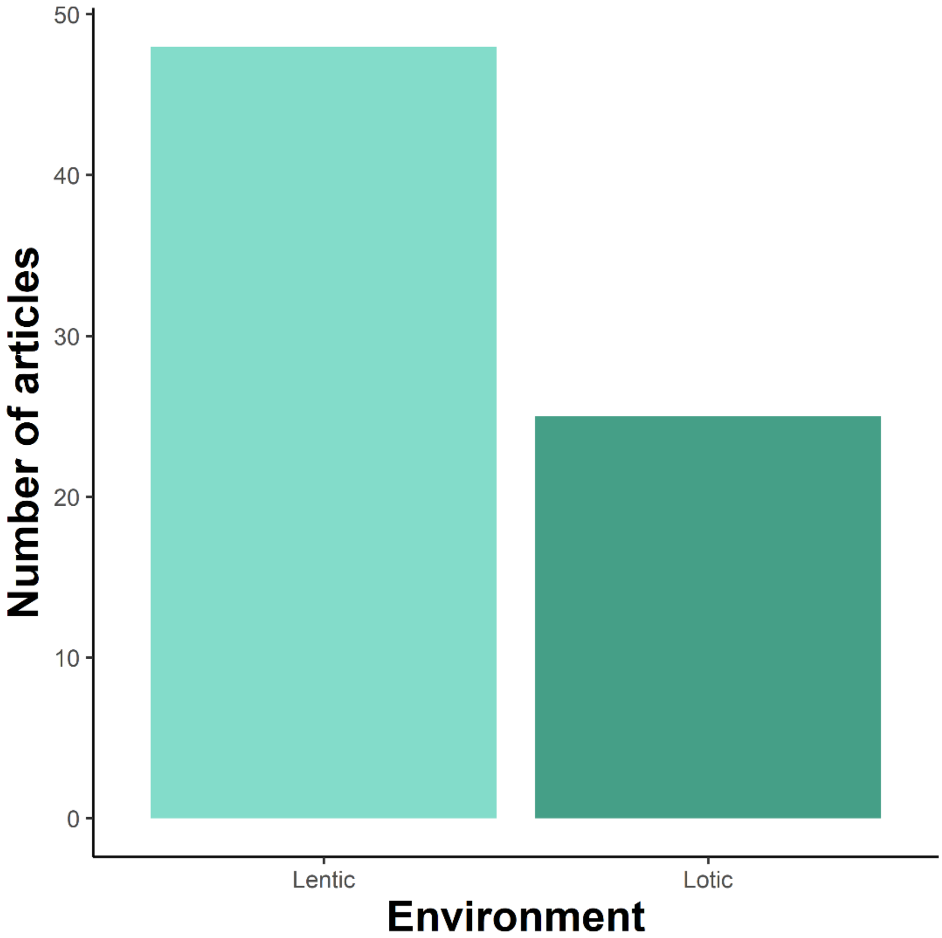

Figure 6. Number of articles carried out on lentic and lotic environments in the upper Paraná River floodplain.

Concerning the duration of the studies, the majority of the studies are of short duration (< 10 years) (Figure 7); on the other hand, only 12 studies used long-term data.

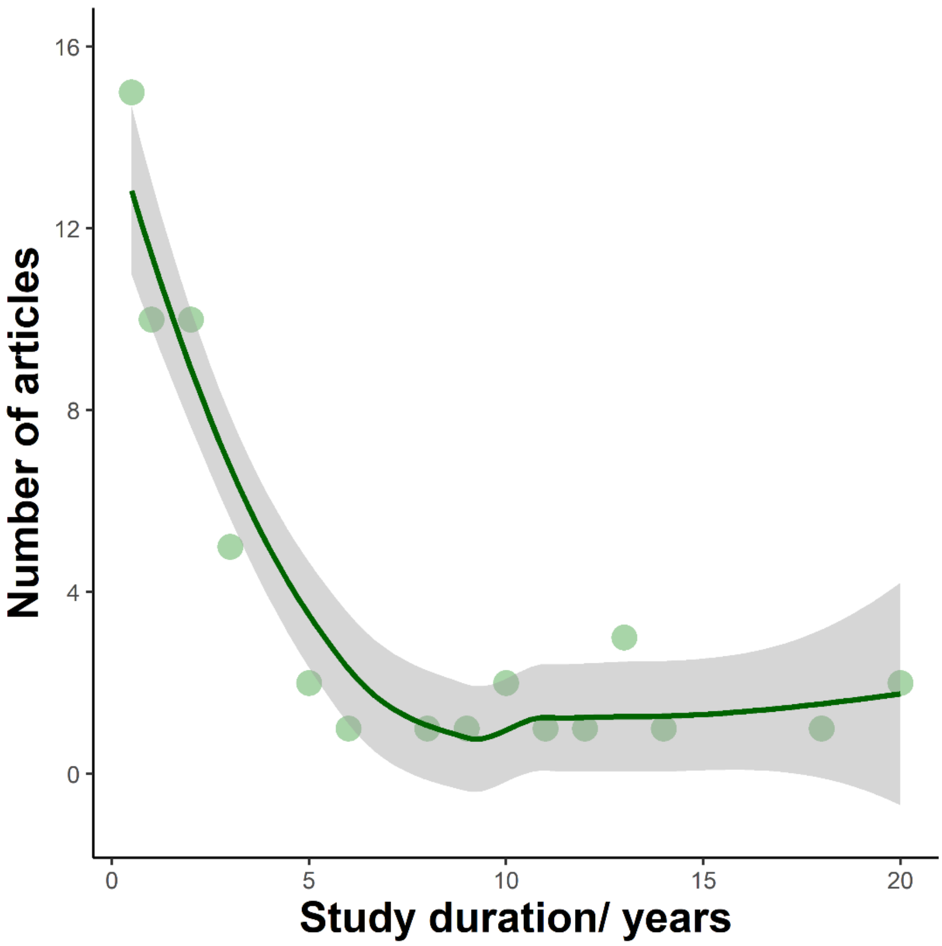

Figure 7. Duration of the study of articles on water quality in the upper Paraná River floodplain between 1997 and 2023.

The variables that most frequently explained the water quality of the floodplain environments were nitrogen, phosphorus, chlorophyll, water transparency, and oxygen. (Figure 8). On the other hand, some of the explanatory variables least reported as significant in the studies were microplastics and trace elements (e.g. mercury) (Figure 8).

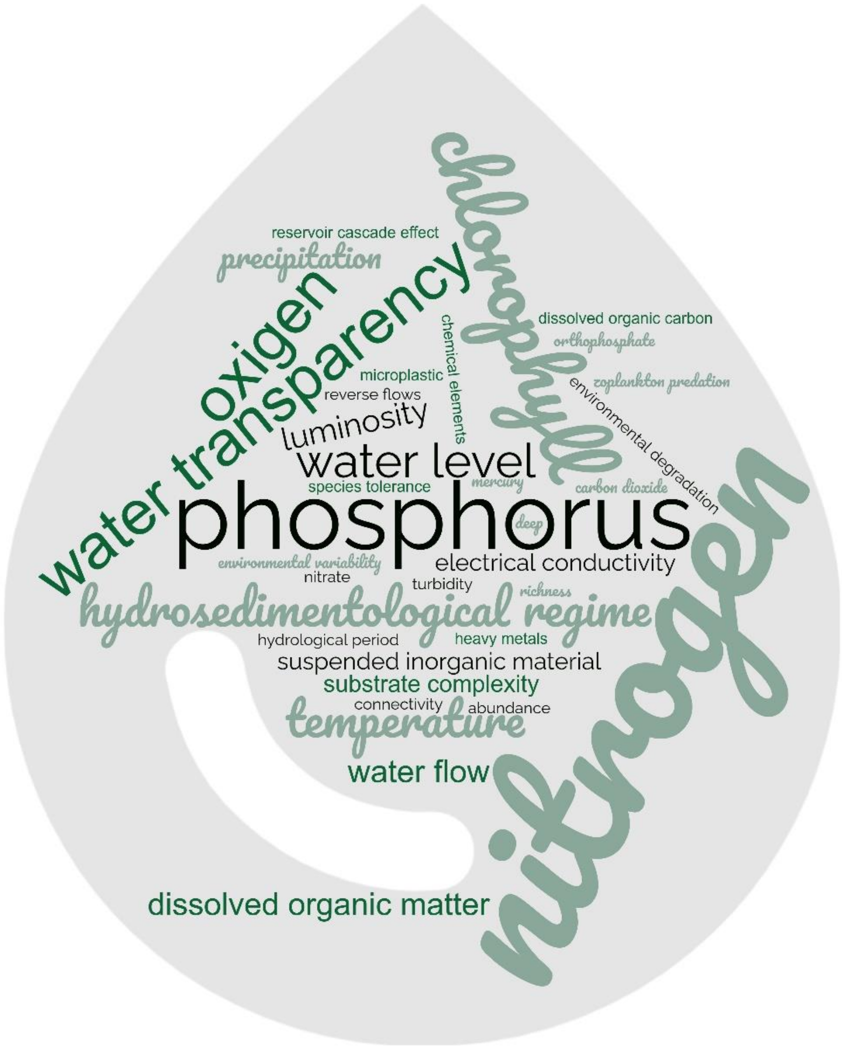

Figure 8. Explanatory variables of studies on water quality in the upper Paraná River floodplain between 1997 and 2023. Larger words indicate greater frequency in the studies.

DISCUSSION

The study demonstrated trends in the increase of the number of publications related to water quality in the environments of the upper Paraná River plain over time, although it is important to emphasise that there is still a knowledge gap. This is evident when we compare the results of Osório & Rodrigues (2021), who performed a search in the Web of Science database of all studies carried out in this same floodplain between 1995 and 2018, and found a total of 435 published articles. In contrast, our search, which focused exclusively on water quality, identified only 58 studies. However, it is important to note that Osório & Rodrigues (2021) used different keywords, databases and years, since their aim of their research was to record any type of study carried out on the Upper Paraná River floodplain, regardless of the approach. This shows that the number of studies on water quality recorded in our search is relatively low when compared to the total number of studies carried out in this area of study up to 2018.

The largest number of publications found in our search were in international journals. The publication of articles in international journals provides some advantages for authors and readers, such as a greater reach for the results and conclusions obtained, and consequently an advance in the distribution of knowledge, since the English language is the universal language of science (Ilyosovna 2020), a fact that contributed to this result. In addition, the journals that publish studies in the field of aquatic ecology that have a high impact factor are international and only publish manuscripts written in English, as the publishers recognise that the maximum number of readers and citations can be reached with this language (Garfield 2002, Martens 2015).

Most of the studies used the field approach, and there were fewer experimental studies. The first approach is commonly used and aims to describe reality (Aragão 2011), establishing a relationship between the response and explanatory variables, as well as involving the collection of standardised data (Fontelles *et al*. 2009). On the other hand, experimental research is not very common, due to the lack of physical structure and equipment, and the potential for operational problems during the experiment, which affect the timescale of the studies. Although, in some cases, this is the only alternative to answering a cause-and-effect relationship. However, it is important to highlight that some relationships cannot be interpreted by experimental approaches, as the process to be investigated is more complex, requires more study time and financial resources (Aragão 2011, Freire & Patussi 2018).

The studies on water quality in the floodplain of the upper Paraná River were mostly performed in lentic environments, primarily because these studies typically involved communities that are more diverse in this type of environment (Agostinho *et al*. 2004). In addition, lakes, both isolated and temporary, and permanently connected to other environments, are distributed along the entire floodplain and in greater numbers than lotic environments. Thus, lentic environments are more focused on research with different biological groups (e.g. phytoplankton and fish), and consequently their studies provide inferences about water quality (Pineda *et al*. 2017, Lopes *et al*. 2022). In addition, the residence time of water in lakes is related to water quality, since it affects the water's chemical composition and is closely related to the efficiency of nutrient utilization by algae (Hilton *et al*. 2006). A long water residence time is an important factor that contributes to the possibility of eutrophic events and increased occurrence of cyanobacterial blooms (Soares *et al* 2008). However, when the water retention time is reduced, and consequently the water flow in the environment is high, the algae are unable to reach maximum biomass and utilise all the available nutrients (Hilton *et al*. 2006).

In this floodplain, studies on biological communities started in 1986, but intensified with systematic sampling from 2000 onwards, with the creation of the long-term ecological research programme (PELD-PIAP), which monitors different aquatic communities (e.g. phytoplankton, periphyton, protozoa, zooplankton, ostracods, benthic macroinvertebrates, aquatic macrophytes, riparian vegetation and fish) (Brito *et al*. 2020, PELD-PIAP). In fact, the most studied areas on the floodplain, the Paraná River subsystem, the Baía River and the Ivinhema River, correspond to the monitoring points of the PELD programme. This project's database is widely used by students on the Postgraduate Programme in Ecology of Continental Aquatic Environments to write theses and dissertations, and consequently to publish articles in national and international journals. However, this monitoring programme is relatively new and has been running for 23 years, which may contribute to the lower number of long-term studies, as only studies carried out since 2010 have been able to take a long-term approach.

The majority of the works evaluated were short term, due to the aims of the research and the lack of funding. Long-term studies require intense and continuous investment, qualified professionals and questions aimed at monitoring a process and/or event. Based on this, a robust database is built up with systematised and standardised information that makes it possible to understand natural and anthropogenic influences on biodiversity and water quality, and to assess trends in the reduction of these ecosystem components (PELD 2017, Bonecker *et al*. 2020, Costa *et al*. 2020, Higuti *et al*. 2020). Pineda *et al*. (2020) performed a long-term study on the floodplain of the upper Paraná River using a database of phytoplankton species from 1993 to 2018 and were able to assess a positive effect of the installation of a protection area on the biodiversity of some aquatic communities and water quality in general, as they observed a reduction in the dominance of cyanobacteria over time.

Cyanobacteria were the main organisms used to indicate water quality in the studies. Phytoplankton species are widely used as an indicator to determine the level of nutrients in the water, which is the basis for preparing and monitoring strategies for aquatic environments (Bhateria & Jain 2016), due to their sensitivity and rapid ability to respond to environmental changes (El-Kassas & Gharib 2016). Among the groups of planktonic algae, cyanobacteria are particularly important because they are generally responsible for the formation of algal blooms, which lead to a change in water color (Huisman *et al.* 2018) and increased turbidity (Foster *et al*. 2020), effects that are visible to the naked eye. In addition, they can lead to depleted oxygen concentrations and the production of toxic secondary metabolites that alter food webs (Paerl & Huisman 2009), harming the various uses of water and cause a series of changes in the planktonic and benthic microbiota (Paerl & Otten 2013, Huisman *et al*. 2018). The formation of blooms of species that produce cyanotoxins negatively influences some ecosystem services, such as water potability, fishing and recreational activities (Plaas & Plaer 2020).

The increased frequency, severity and duration of these blooms are closely associated with anthropogenic actions and global warming (Pinto *et al*. 2023). In the studies analysed, despite the fact that a large number of species producing cyanotoxins have been recorded in the region, the occurrence of blooms is not frequent, and this is primarily due to the oligotrophic nature of the water bodies within the Upper Paraná River floodplain. In addition, the mass proliferation of cyanobacteria is influenced not only by the high concentration of nutrients, but by a number of factors, such as water column stability, water retention time, carbon availability and temperature (Jeppesen *et al*. 2009, Sondergaard *et al*. 2011).

One of the keywords used in the search for articles on water quality was the word cyanobacteria, since it is a group widely used to indicate the concentration of nutrients in water (Bhateria & Jain 2016). This choice could influence the results regarding the study parameters used to evaluate water quality and represent a potential limitation. For this reason, we combined the keywords Limnology OR Cyanobacteria OR Water quality to reduce any bias on the results. Furthermore, restricting the search to only 'water quality' might yield similar trends in the results. However, we recognised that the selection of keywords is a crucial step to understand the results.

Studies on macroinvertebrates and macrophytes as mediators of water quality still need to be intensified, since changes in the structure of these communities can be important as an indicator of the quality of an environment (Hildrew & Giller 1995, Galdean *et al*. 2000; Rosa *et al*. 2022). These organisms are efficient at responding to habitat changes (Armitage & Pardo 1995, Rosa *et al*. 2024). Plecoptera, for example, are only found in waters with very good quality (Galdean *et al*. 2000). However, many studies involving macroinvertebrates as bioindicators of water quality are experimental, an approach that was little used in the studies analysed (Kelly *et al*. 2020, Lohs *et al*. 2023), which may explain the low number of articles found using invertebrates.

Aquatic macrophytes are also efficient indicators of water quality, since up to a certain threshold of external nutrient input, they act as purifying filters for aquatic environments (Diniz *et al*. 2005). In addition, the distribution of morphological groups is related to environmental conditions. Stefanidis & Papastergiadou (2019) observed that the occurrence and density of rooted submerged macrophytes were related to water transparency, conductivity and alkalinity;

while rooted macrophytes with floating leaves were related to waters enriched in nitrogen and phosphorus.

Total phosphorus and nitrogen concentrations, as well as water transparency, were the most frequent explanatory variables in studies on water quality in this floodplain. These variables, as well as dissolved oxygen, pH and temperature, are used to create indices that are crucial to understanding the water quality of water bodies (Chang *et al*. 2020). In general, these variables also influence the distribution and abundance of aquatic groups and species that can indicate water quality (Akane Murakami & Rodrigues 2009, Vieira da Silva *et al*. 2022). Phosphorus and nitrogen are limiting nutrients for photosynthesizing species and their enrichment in aquatic ecosystems is related to the process of eutrophication, leading to excessive growth of phytoplankton algae (Lewis *et al*. 2011) and, consequently, a chain imbalance in communities at higher trophic levels, resulting in a loss of water quality, biodiversity, and ecosystem services.

Trace elements and microplastics have not been the parameter of many studies in the upper Paraná River floodplain, but their effects should be emphasised. Trace elements are considered toxic and have bioaccumulative potential and can enter the water body through consumer and industrial waste or released and carried from the soil by acid rain (Verma & Dwivedi 2013). In our search, we found only one study on trace elements, which was carried out by Moraes *et al*. (1997) who investigated mercury concentrations in two fish species and observed that the values detected did not exceed the limits established for the emission of fish consumption (<500 ng.g-1). However, this study was performed more than twenty years ago, which highlights the lack of studies for the region.

In terms of microplastics, only two studies were found investigating the presence of microplastics. Cardozo *et al*. (2023) recorded microplastic particles in the diet of nine species of carnivorous fish, showing a positive relationship between the number of plastics and the rainy season. In contrast, da Silva *et al*. (2022) experimentally evaluated the effect of microplastic particles on planktonic trophic webs and observed that smaller microplastic particles are significantly more consumed by plankton.

In conclusion, this study provides important data on the knowledge gaps about the factors that influence water quality in the Upper Paraná River floodplain, highlighting the need to continue studies with extended durations, guaranteeing the preservation and improvement of water resources. We have identified that some communities, such as benthic macroinvertebrates and aquatic macrophytes, should be better studied in this region to understand the aquatic ecosystem overall. In addition, the limnological variables phosphorus, nitrogen and transparency can be used as tools to monitor water quality in this ecosystem, as well as the abundance of cyanobacteria. We also suggest that future studies explore the effects of pollutants such as trace elements, pesticides and microplastics, which have a high pollution potential. Therefore, it is essential that all the knowledge resulting from this scientific research is organised to serve as a base for the development of environmental policies and guidelines for ecosystem management.

ACKNOWLEDGMENTS

The author thanks the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (Nupélia) and its researchers, the Graduate Program in Ecology of Continental Aquatic Evironments (UEM), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação Araucaria for granting scholarship to J. Rosa, N. M. Carvalho, I. C. Bianchi-Costa, B.A. Quirino, and J. V. F. da Silva for financial support and infrastructure for the development of this study.

REFERENCES

Agostinho, A. A., Gomes, L. C., Thomaz, S. M., & Hahn, N. S. 2004. The upper Paraná River and its floodplain: main characteristics and perspectives for management and conservation. In: S. M. Thomaz, A. A. Agostinho & N. S. Hahn (Eds.), The Upper Paraná River and its floodplain: physical aspects, ecology and conservation. pp. 381–393.

Agostinho, A. A, Pelicice, F. M., Petry, A. C., Gomes LC., & Júlio H. F. 2007. Fish diversity in the upper Paraná River basin: habitats, fisheries management and conservation. Aquatic Ecosystem Health & Management, 10(2), 174–186. DOI: 10.1080/14634980701341719.

Agostinho, A. A., Gomes, L. C., Pelicice, F. M., Souza-Filho, E. E., & Tomanik, E. A. 2008. Application of the ecohydrological concept for sustainable development of tropical floodplains: the case of the upper Paraná River basin. Ecohydrology & Hydrobiology, 8(2–4), 205–223. DOI: 10.2478/v10104-009-0016-x.

Agostinho, A. A., Júlio-Junior, H. F., Gomes, L. C., Bini, L. M., & Agostinho, C. S. 2018. Composição, abundância e distribuição espaço-temporal da ictiofauna. In: S. E. A. M., Vazzoler, A. A. Agostinho & N. S. Hahn (Eds.), A Planície de inundação do alto rio Paraná: aspectos físicos, biológicos e socioeconômicos. Maringá: EDUEM, 1997. pp.179–208.

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. DOI: 10.3390/w13192660.

Algarte, V. M., Moresco, C., & Rodrigues, L. (2006). Algas do perifíton de distintos ambientes na planície de inundação do alto rio Paraná. Acta Scientiarum. Biological Sciences, 28(3), 243-251. DOI: 10.1590/S1519-69842009000300015

Aragão, J. 2011. Introdução aos estudos quantitativos utilizados em pesquisas científicas. Revista práxis, 3(6), 59–62. DOI: 10.25119/praxis-3-6-566.

Armitage, P. D., & Pardo, I. 1995. Impact assessment of regulation at the reach level using macroinvertebrate information from mesohabitats. Regulated Rivers: Research and management, 10(2-4), 147-158. DOI: 10.1002/rrr.3450100210.

Bank, Michael S. 2020. The mercury science-policy interface: History, evolution and progress of the Minamata Convention. Science of The Total Environment, 722, 137832. DOI: 10.1016/j.scitotenv.2020.137832.

Bertoncin, A. P. S., Tramonte, R. P., Pinha, G. D., Gentilin-Avanci, C., Oliveira, M. V. C. D., & Mormul, R. P. 2022. On the significance of wetlands: three decades of aquatic macroinvertebrate monitoring programs in a Neotropical floodplain. Acta Limnologica Brasiliensia, 34, e10. DOI: 10.1590/S2179-975X4721.

Bhateria, R., & Jain, D. 2016. Water quality assessment of lake water: a review. Sustainable Water Resources Management, 2, 161-173. DOI:10.1007/s40899-015-0014-7.

Bonecker, C. C., Diniz, L. P., Braghin, L. D. S. M., Mantovano, T., da Silva, J. V. F., de Fátima Bomfim, F., Moi, D. A., Deosti, S., Santos, G. N. T., Candeias, D. A., Mota, A. J. M. M., Velho, L. F. M., & Lansac-Tôha, F. A. 2020. Synergistic effects of natural and anthropogenic impacts on zooplankton diversity in a subtropical floodplain: a long-term study. Oecologia Australis, 24(2), 524-537. DOI: 10.4257/oeco.2020.2402.20.

Brito, M. A., Oliveira, D., de Araujo Mamede, M., Randig, O., & de Lacerda, F. S. 2020. Programa de pesquisa ecológica de longa duração–PELD/CNPq–desafios da gestão, avanços e perspectivas. Oecologia Australis, 24(2), 259-265. DOI:10.4257/oeco.2020.2402.02.

Cardozo, A. L. P., Yofukuji, K. Y., da Silva Júnior, R. C., de Castro-Hoshino, L. V., & Fugi, R. 2023. Plastic ingestion by carnivore fish in a neotropical floodplain: seasonal and interspecific variations. Environmental Science and Pollution Research, 30(14), 40712-40723. 2023. DOI: 10.1007/s11356-023—25135-0.

Chang, N., Luo, L., Wang, X. C., Song, J., Han, J., & Ao, D. 2020. A novel index for assessing the water quality of urban landscape lakes based on water transparency. Science of the Total Environment, 735, 139351. DOI:10.1016/j.scitotenv.2020.139351.

Costa, F. R. C., Zuanon, J., Baccaro, F. B., de Almeida, J. S., Menger, J. D. S., Souza, J. L. P., Borba, G. C., Esteban, E. J. L., Bertin, V. M., Gerolamo, C. S., Anselmo, N., & Castilho, C. V. D. 2020. Effects of climate change on central amazonian forests: a two decades synthesis of monitoring tropical biodiversity. Oecologia Australis, 24(2), 317-335. DOI: 10.4257/oeci.2020.2402.07.

da Silva, J. V. F., Lansac-Tôha, F. M., Segovia, B. T., Amadeo, F. E., Braghin, L. D. S. M., Velho, L. F. M., Sarmento, H., & Bonecker, C. C. 2022. Experimental evaluation of microplastic consumption by using a size-fractionation approach in the planktonic communities. Science of The Total Environment, 821, 153045. DOI:10.1016/j.scitotenv.2022.153045.

Dalpé, R. 2002. Bibliometric analysis of biotechnology. Scientometrics, 55(2), 189-213. DOI: 10.1023/a:1019663607103.

Diniz, C. R., de Ceballos, B. S., Barbosa, J. E. D. L., & Konig, A. 2021. Use of aquatic macrophytes as ecological solution for improvement of the water quality. Revista Brasileira de Engenharia Agrícola e Ambiental, 9, 226-230. DOI: 10.1590/1807-1929/agriambi.v9nsupp226-230.

Duh, J. D., Shandas, V., Chang, H., & George, L. A. 2008. Rates of urbanisation and the resiliency of air and water quality. Science of the total environment, 400(1-3), 238-256. DOI: 10.1016/j.scitotenv.2008.05.002.

El-Kassas, H. Y., & Gharib, S. M. 2016. Phytoplankton abundance and structure as indicator of water quality in the drainage system of the Burullus Lagoon, southern Mediterranean coast, Egypt. Environmental Monitoring and Assessment, 188, 1-14. DOI: 10.1007/s10661-016-5525-7.

Ferreira, V. G., Rosa, J., Almeida, N. M., Pereira, J. S., Sabater, L. M., Vendramin, D., Zhu, H., Martens, K., & Higuti, J. 2023. A comparison of three main scientific literature databases using a search in aquatic ecology. Hydrobiologia, 850(6), 1477-1486. DOI:10.1007/s10750-022-05067-5.

Fontelles, M. J., Simões, M. G., Farias, S. H., & Fontelles, R. G. S. 2009. Metodologia da pesquisa científica: diretrizes para a elaboração de um protocolo de pesquisa. Rev. para. med. 23(3), 1-8.

Foster, L., Muhamadali, H., Boothman, C., Sigee, D., Pittman, J. K., Goodacre, R., Morris, K., & Lloyd, J. R. 2020. Radiation tolerance of *Pseudanabaena catenata*, a cyanobacterium relevant to the first generation magnox storage pond. Frontiers in Microbiology, 11, 515. DOI: 10.3389/fmicb.2020.00515.

Freire, M. C. M., & Pattussi M. P. 2018. Tipos de estudos. IN: C. Estrela (Eds.)., Metodologia científica. Ciência, ensino e pesquisa. Artes Médicas, 3, pp.109-127.

Galdean, N., Callisto, M., & Barbosa, F. A. R. 2000. Lotic ecosystems of Serra do Cipó, southeast Brazil: water quality and a tentative classification based on the benthic macroinvertebrate community. Aquatic Ecosystem Health & Management, 3(4), 545-552. DOI: 10.1080/14634980008650691.

Garfield, E. 2003. The meaning of the impact factor. International journal of clinical and health psychology, 3(2), 363-369.

Granzotti, R. V., Miranda, L. E., Agostinho, A. A., & Gomes, L. C. 2018. Downstream impacts of dams: shifts in benthic invertivorous fish assemblages. Aquatic Sciences, 80, 1-14. DOI:10.1007/s00027-017-0541-1.

Guedes, H. A., Silva, D. D. D., Elesbon, A. A., Ribeiro, C., Matos, A. T. D., & Soares, J. H. 2012. Aplicação da análise estatística multivariada no estudo da qualidade da água do Rio Pomba, MG. Revista Brasileira de Engenharia Agrícola e Ambiental, 16, 558-563. DOI:10.1590/S1415-43662012000500012.

Higuti, J., Rosa, J., Ferreira, V. G., Almeida, N. M., Campos, R., Conceição, E. O., & Martens, K. 2020. Inter-annual variation of ostracod (Crustacea) communities in the Upper Paraná River floodplain, Brazil. Oecologia Australis, 24(2), 474-488. DOI: 10.4257/oeco.2020.2402.17.

Hildrew, AG., & Giller, PS.1995. Patchiness, species interactions and disturbance in the stream benthos. In: P. S. Giller, A. G. Hildrew & D. G. Raffaelli (Eds.), Aquatic Ecology: Scale, Pattern and Process. Blackwell Science, Boston.

Hilton, J., O'Hare, M., Bowes, M. J., & Jones, J. I. 2006. How green is my river? A new paradigm of eutrophication in rivers. Science of the Total Environment, 365(1-3), 66-83. DOI: 10.1016/j.scitotenv.2006.02.055.

Huisman, J., Codd, G. A., Paerl, H. W., Ibelings, B. W., Verspagen, J. M., & Visser, P. M. 2018. Cyanobacterial blooms. Nature Reviews Microbiology, 16(8), 471-483. DOI: 10.1038/s41579-018-0040-1.

Ilyosovna, N. A. 2020. The importance of English language. International Journal on Orange Technologies, 2(1), 22-24.

Jeppesen, E., Kronvang, B., Meerhoff, M., Søndergaard, M., Hansen, K. M., Andersen, H. E., Lauridsen, T. L., Liboriussen, L., Beklioglu, M., Özen, A., & Olesen, J. E. 2009. Climate change effects on runoff, catchment phosphorus loading and lake ecological state, and potential adaptations. Journal of environmental quality, 38(5), 1930-1941. 38(5). DOI: 10.2134/jeq2008.0113.

Kelly, L. T., Puddick, J., Ryan, K. G., Champeau, O., & Wood, S. A. 2020. An ecotoxicological assessment of the acute toxicity of anatoxin congeners on New Zealand *Deleatidium* species (mayflies). Inland Waters, 10(1), 101-108. DOI: 10.1080/20442041.2019.1626151.

Lechinovski, L., Bados, M., Rosa, J., Moda, D. B., & Bueno Krawczyk, A. C. D. D. 2022. Ecotoxicological effects of conventional herbicides and a natural herbicide on freshwater fish (*Danio rerio*). Journal of Environmental Science and Health, Part B, 57(10), 812-820. DOI: 10.1080/03601234.2022.2122664.

Lewis Jr, W. M., Wurtsbaugh, W. A., & Paerl, H. W. 2011. Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. Environmental science & technology, 45(24), 10300-10305. DOI: 10.1021/es202401p.

Logan, M. 2010. Biostatistical design and analysis using R: a practical guide. John Wiley & Sons, Chichester.

Lohs, A., Villamarín, C., Donoso, M., & Ríos-Touma, B. 2023. Behavioral and biochemical patterns in the Andean highland macroinvertebrate Nectopsyche sp. after chronic mercury exposure. Chemosphere, 340, 139791. DOI: 10.1016/j..chemosphere.2023.13979.

Lopes, T. M., Muniz, C. M., Schmitz, M. H., Dias, R. M., Rodrigues, A. C., Buzo, M. G., Couto, E. V., & Agostinho, A. A. 2022. Drivers of fish trophic guild composition in lakes of the Upper Paraná River floodplain. Aquatic Sciences, 84(2), 27. DOI:10.1007/s00027-022-00860-9.

Martens, K. 2015. Preface: emerging trends in aquatic ecology. Hydrobiologia, 750(1), 1-4. DOI: 10.1007/s10750-015-2195-3

Moraes, L. A. F., Lenzi, E., & Luchese, E. B. 1997. Mercury in two fish species from the Parana River floodplain, Parana, Brazil. Environmental Pollution, 98(1), 123-127. DOI: 10.1016/S0269-7491(97)00101-2.

Murakami, E. A., & Rodrigues, L. 2009. Resposta das algas perifíticas às alterações de temperatura e ao enriquecimento artificial de nutrientes em curto período de tempo. Acta Scientiarum Biological Sciences, 31(3), 273-284. DOI:10.4025/actascibiolsci.v31i3.1627.

Noori, R., Berndtsson, R., Hosseinzadeh, M., Adamowski, J. F., & Abyaneh, M. R. 2019. A critical review on the application of the National Sanitation Foundation Water Quality Index. Environmental Pollution, 244, 575-587. DOI:10.1016/j.envpol.2018.10.076.

Osório, N. C., & Rodrigues, L. 2021. Upper Paraná River floodplain: synthesizing knowledge over time. Acta Limnologica Brasiliensia, 33, e103. DOI:10.1590/S2179-975X9420.

Paerl, H. W., & Huisman, J. 2009. Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environmental microbiology reports, 1(1), 27-37. DOI: 10.1111/j.1758-2229.2008.00004.x.

Paerl, H. W., & Otten, T. G. 2013. Harmful cyanobacterial blooms: causes, consequences, and controls. Microbial ecology, 65, 995-1010. DOI: 10.1007/s00248-012-0159-y

Peld Piap: Pesquisas Ecológicas de Longa Duração PELD. Paraná, PR. Retrieved February 22, from, http://www.peld.uem.br/peld-historico_Pesq_ec.htm. Peld. 2017. Programa de Pesquisa Ecológica de Longa Duração completa 20 anos — Conselho Nacional de Desenvolvimento Científico e Tecnológico. Paraná, PR. (Retrieved February 22, 2024, from https://www.gov.br/cnpq/pt-br/assuntos/noticias/destaque-em-cti/programa-de-pesquisa-ecologica-de-longa-duracao-completa-20-anos).

Petsch, D. K., Cionek, V. D. M., Thomaz, S. M., & Dos Santos, N. C. L. 2023. Ecosystem services provided by river-floodplain ecosystems. Hydrobiologia, 850(12), 2563-2584. DOI: 10.1007/s10750-022-04916-7.

Pineda, A., Moresco, G. A., Paula, A. C. M. D., Nogueira, L. M., Iatskiu, P., Souza, Y. R. D., Reis, L. M., & Rodrigues, L. C. 2017. Rivers affect the biovolume and functional traits of phytoplankton in floodplain lakes. Acta Limnologica Brasiliensia, 29. DOI: 10.1590/S2179-975X7317.

Pineda, A., de Paula, A. C. M., Iatskiu, P., Moresco, G. A., Souza, Y. R., Ortega, L. A., Zanon, F. M., Zanco, B. F., Jati, S., Bortolini, J. C., & Rodrigues, L. C. 2020. A protection area in a subtropical floodplain influenced the phytoplankton taxonomic and functional diversity. Oecologia Australis, 24(2), 505-523. DOI: 10.4257/eco.2020.2402.19

Pinto, A., Botelho, M. J., Churro, C., Asselman, J., Pereira, P., & Pereira, J. L. 2023. A review on aquatic toxins-Do we really know it all regarding the environmental risk posed by phytoplankton neurotoxins?. Journal of Environmental Management, 345, 118769. DOI: 10.1016/j.jenvman.2023.118769.

Plaas, H. E., & Paerl, H. W. 2020. Toxic cyanobacteria: a growing threat to water and air quality. Environmental science & technology, 55(1), 44-64. DOI: 10.1021/acs.est.0c06653.

R Development Core Team. 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Austria, Vienna.

Rosa, J., de Oliveira, F. R., Pereira, L. F., de Melo Silva, M., & Bueno-Krawczyk, A. C. D. D. 2022. Temporal variation in Oligochaeta species composition in an anthropized stretch of a Neotropical urban river. International Journal of Limnology, 58, 6. DOI: 10.1051/limn/2022006.

Rosa, J., Muniz, C. M., Petsch, D. K., Moretto, Y., Martens, K., & Higuti, J. 2024. Local factors drive the richness, biomass and composition of benthic invertebrate communities in Neotropical reservoirs. Aquatic Sciences, 86(2), 1-14. DOI: 10.1007/s00027-024-01064-z.

Ruaro, R., Tramonte, R. P., Buosi, P. R., Manetta, G. I., & Benedito, E. 2020. Trends in studies of nonnative populations: Invasions in the Upper Paraná River Floodplain. Wetlands, 40(1), 113-124. DOI: 10.1007/s13157-019-01161-y.

Soares, M. C. S., Marinho, M. M., Huszar, V. L., Branco, C. W., & Azevedo, S. M. 2008. The effects of water retention time and watershed features on the limnology of two tropical reservoirs in Brazil. Lakes & Reservoirs: Research & Management, 13(4), 257-269. DOI: 10.1111/j.1440-1770.2008.00379.x.

Søndergaard, M., Larsen, S. E., Jørgensen, T. B., & Jeppesen, E. 2011. Using chlorophyll a and cyanobacteria in the ecological classification of lakes. Ecological indicators, 11(5), 1403-1412. DOI: 10.1016/j.ecolind.2011.03.002.

Stefanidis, K., & Papastergiadou, E. 2019. Linkages between macrophyte functional traits and water quality: insights from a study in freshwater lakes of Greece. Water, 11(5), 1047. DOI: 10.3390/w11051047.

Vasistha, P., & Ganguly, R. 2020. Water quality assessment of natural lakes and its importance: An overview. Materials Today: Proceedings, 32, 544-552. DOI: 10.1016/j.matpr.2020.02.092.

Verma, R., & Dwivedi, P. 2013. Heavy Metal Water Pollution - A Case Study. Pesquisas Recentes em Ciência e Tecnologia, 5(5), 98-99.

Vieira da Silva, M., Bortolini, J. C., & Jati, S. 2022. The phytoplankton community as a descriptor of environmental variability: a case study in five reservoirs of the Paraná River basin. Acta Limnologica Brasiliensia, 34, e1. DOI: 10.1590/S2179-975X4621.

Supplementary Material

Table S1. List of articles about water quality used in this study.
Table S2. List of cyanobacteria species recorded in the studies about on water quality in the upper Paraná River floodplain.

Submitted: 08 March 2024

Accepted: 08 June 2024

Published online: 19 June 2024

Associate Editor: Andre Andrian Padial, Rosana M Rocha