

THE USE OF FLOATING MACROPHYTES AS A BIOLOGICAL ALTERNATIVE FOR WATER QUALITY IMPROVEMENT IN EUTROPHIC ENVIRONMENTS

USO DE MACRÓFITAS FLUTUANTES COMO ALTERNATIVA BIOLÓGICA PARA MELHORIA DA QUALIDADE DA ÁGUA EM AMBIENTES EUTROFIZADOS

USO DE MACRÓFITAS FLOTANTES COMO ALTERNATIVA BIOLÓGICA PARA MEJORAR LA CALIDAD DEL AGUA EN AMBIENTES EUTRÓFICOS

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ABSTRACT

The urban streams in the Amazon are experiencing eutrophication due to sewage discharge, which threatens the diversity and abundance of aquatic fauna, as well as human health. Macrophytes have the ability to absorb high nitrogen compounds from the water. Little is known about the decontamination effects of Amazonian macrophyte species. This study aims to evaluate the physicochemical variables of water from an urban stream after treatment with native macrophytes. The experiment was conducted at the Federal Institute of Amazonas, Tabatinga *Campus*. Two hundred liters of water were collected from the Buriti stream, near the municipal public landfill. The polluted water was transferred to 20-liter aquariums in duplicates, and the treatments used were four species of floating macrophytes: *Pistia stratiotes*, *Salvinia auriculata*, *Azolla filiculoides*, and *Eichhornia azurea*. The macrophyte density used in the aquariums was $20 \pm 1 \text{ g l}^{-1}$. Dissolved oxygen, pH, total ammonia, nitrite, conductivity, dissolved solids, and aquarium temperature were monitored over seven days. The eutrophic water treated with the four experimental macrophyte species showed a reduction in total nitrite and an increase in pH within 24 and 72 hours, respectively. *Eichhornia azurea* decreased electrical conductivity and total solids in the water within 24 and 48 hours, respectively. *Pistia stratiotes* was the macrophyte with the greatest reduction in total ammonia. *Salvinia auriculata* was the only experimental species that did not reduce total ammonia in the water. Overall, *Eichhornia azurea*, followed by *Pistia stratiotes*, were the most efficient macrophytes for water treatment, altering pH, electrical conductivity, total dissolved solids, ammonia, and total nitrite. In this sense, the macrophytes *Eichhornia azurea* and *Pistia stratiotes* can be biological alternatives for the treatment and improvement of the physicochemical variables of water in an eutrophic environment.

Keywords: Nitrogen Compounds; Streams; Aquatic Plants; Pollution.

RESUMO

Os igarapés urbanos da Amazônia apresentam eutrofizações com o lançamento de esgoto, colocando em risco a diversidade e abundância da fauna aquática, além da saúde humana. As macrófitas têm capacidade de absorver compostos nitrogenados elevados da água. Pouco se sabe a respeito dos efeitos de despoluição das espécies de macrófitas amazônicas. Este estudo tem como objetivo avaliar as variáveis físico-químicas da água de um igarapé urbano após tratamento com as macrófitas nativas. O experimento foi conduzido no Instituto Federal do Amazonas *Campus* Tabatinga. Foram coletados 200 litros de água do igarapé do Buriti, próximo ao lixão público municipal. A água poluída foi transferida para aquários de 20 litros, em duplicata e os tratamentos utilizados foram quatro espécies de macrófitas flutuantes *Pistia stratiotes*, *Salvinia auriculata*, *Azolla filiculoides* e *Eichhornia azurea*. A densidade de macrófitas utilizada nos aquários foi de $20 \pm 1 \text{ g L}^{-1}$. Foram monitorados o oxigênio dissolvido, pH, amônia total, nitrito, condutividade, sólidos dissolvidos e temperatura dos aquários durante sete dias. A água eutrofizada tratada com as quatro espécies macrófitas experimentais diminuíram o nitrito total e elevaram o pH da água em 24 horas e 72 horas respectivamente. A *Eichhornia azurea* diminuiu a condutividade elétrica e os sólidos totais da água em 24 horas e 48 horas respectivamente. A *Pistia stratiotes* foi a macrófita com maior redução de amônia total. A *salvinia auriculata* foi a única espécie experimental que não diminuiu a amônia total da água. No geral, a *Eichhornia azurea* seguido de *Pistia stratiotes* foram as

macrófitas mais eficientes para o tratamento da água, alterando o pH, condutividade elétrica, sólidos totais dissolvidos, amônia e nitrito total. Nesse sentido, recomendamos primeiramente a macrófita *Eichhornia azurea* e em segundo *Pistia stratiotes* como uma alternativa biológica para tratamento e melhoria das variáveis físico e químicos da água de um ambiente eutrofizado.

Palavras-chave: Compostos Nitrogenados; Igarapés; Plantas Aquáticas; Poluição.

RESUMEN

Los igarapés urbanos de la Amazonía presentan eutrofización debido al vertido de aguas residuales, poniendo en riesgo la diversidad y abundancia de la fauna acuática, además de la salud humana. Las macrófitas tienen la capacidad de absorber compuestos nitrogenados elevados del agua. Se sabe poco sobre los efectos de despolución de las especies de macrófitas amazónicas. Este estudio tiene como objetivo evaluar las variables fisicoquímicas del agua de un igarapé urbano después de su tratamiento con las macrófitas nativas. El experimento fue realizado en el Instituto Federal de Amazonas, *Campus Tabatinga*. Se recolectaron 200 litros de agua del igarapé de Buriti, cerca del vertedero municipal. El agua contaminada fue transferida a acuarios de 20 litros, en duplicado, y los tratamientos utilizados fueron cuatro especies de macrófitas flotantes: *Pistia stratiotes*, *Salvinia auriculata*, *Azolla filiculoides* y *Eichhornia azurea*. La densidad de macrófitas utilizada en los acuarios fue de $20 \pm 1 \text{ g l}^{-1}$. Se monitorearon el oxígeno disuelto, pH, amoníaco total, nitrito, conductividad, sólidos disueltos y temperatura de los acuarios durante siete días. El agua eutrofizada tratada con las cuatro especies experimentales de macrófitas redujo el nitrito total y elevó el pH del agua en 24 y 72 horas, respectivamente. *Eichhornia azurea* redujo la conductividad eléctrica y los sólidos totales del agua en 24 y 48 horas, respectivamente. *Pistia stratiotes* fue la macrófita con mayor reducción de amoníaco total. *Salvinia auriculata* fue la única especie experimental que no redujo el amoníaco total del agua. En general, *Eichhornia azurea*, seguida de *Pistia stratiotes*, fueron las macrófitas más eficientes para el tratamiento del agua, alterando el pH, la conductividad eléctrica, los sólidos totales disueltos, el amoníaco y el nitrito total. En este sentido, las macrófitas *Eichhornia azurea* y *Pistia stratiotes* pueden ser alternativas biológicas para el tratamiento y mejora de las variables fisicoquímicas del agua en un ambiente eutrofizado.

Palabras clave: Compuestos Nitrogenados; Igarapés; Plantas Acuáticas; Contaminación.

1 INTRODUCTION

Macrophytes (macro = large; phyte = plant) are visible plant species that live in aquatic environments. (Irgang; Gastal Jr., 1996). They are plants that, during the evolutionary process, migrated from the terrestrial environment to the aquatic one, developing many morphological and anatomical adaptations necessary for life in water

(Xavier *et al.*, 2021), among these adaptations are flotation, spongy tissues (aerenchyma), hollow stems, and hydrophobic hairs that repel water, as well as flowers that are generally positioned above the water (Scremin-Dias *et al.*, 1999). These plants contribute to the structuring and dynamics of most aquatic ecosystems, inhabiting a variety of environments, including freshwater and brackish waters, and demonstrating a great capacity for adaptation (Esteves, 2011).

Aquatic macrophytes are primary producers and provide habitat and refuge for periphyton, zooplankton, insects, fish, frogs, birds, and mammals (Araújo-Lima *et al.*, 1986; Meschiatti *et al.*, 2000; Bornette; Puijalon, 2009). Studies show the importance of the presence of aquatic macrophytes as an explanatory factor for the increase in aquatic diversity (Sánchez-Botero; Araújo-lima, 2001; Albertoni *et al.*, 2007; Dornfeld; Gessner, 2005, Pelicice *et al.*, 2008; Batista-Silva *et al.*, 2011). In addition, they are used as a place for reproduction and feeding by these organisms (Pompêo, 2017).

Aquatic plants also play key roles in biogeochemical cycles, such as in the production of organic carbon and the mobilization of phosphorus, directly influencing hydrology and sediment dynamics through their effects on water flow in freshwater ecosystems (Demarty; Prair, 2009; Marinho *et al.*, 2010; Esteves; Suzuki, 2013). Additionally, macrophytes also play the role of environmental bioindicators, indicating the biotic or abiotic condition of a water body. In the case of eutrophication (excess organic matter), the high production of macrophytes indicates a higher degree of pollution, as they thrive better in environments with high nutrient concentration (Brandão; Jesus, 2023).

In Amazonian urban centers, the lack of sanitation is directly linked to the pollution of water resources (França *et al.*, 2024). The vast majority of municipalities do not have sewage treatment systems (Dib *et al.*, 2022). The accumulation of dissolved nutrients, especially nitrogen (N) and phosphorus (P), can cause eutrophication and the entire process of water body pollution, leading to a turbid coloration and very low levels of dissolved oxygen. This has a significant impact on aquatic ecosystems, such as the loss of biodiversity (Esteves, 2011).

In order to meet legal requirements for the discharge of effluents into water bodies, it is necessary to seek alternative treatment methods that are cost-effective, ecological, and capable of complying with standard limits (França *et al.*, 2024). The use of aquatic

macrophytes has been explored in many studies for wastewater treatment, and they have shown excellent results in reducing pollutant levels in effluents (Silva, 2018). Furthermore, macrophytes have been widely used as biofilters, helping in the removal of nutrients, such as the ability to capture nitrogen from effluents and release it with lower contaminant levels into receiving bodies. This happens because the plants absorb nitrogen in its inorganic forms, such as ammonia (NH_3) or nitrate (NO_3^-), or even in its organic form present in urea ($\text{CO}(\text{NH}_2)_2$) (Nuvolari *et al.*, 2003; Diniz *et al.*, 2005). The use of macrophytes maximizes the process of water decontamination in an economical, short-term, and controlled manner (Dias *et al.*, 2016)

In this context, effluent treatment systems using macrophytes can be viable for urban areas and also minimize the impacts on aquatic ecosystems. Despite numerous studies demonstrating the efficiency of aquatic plants in treating domestic effluents (Ennabili *et al.*, 1998; Lin *et al.*, 2005; Greenway, 2005; Hadad *et al.*, 2006), there are few studies on the use of these vegetables in effluent treatment in Brazil (Zaniboni-Filho *et al.*, 1997; Sipaubá-Tavares *et al.*, 2002; Henry-Silva; Camargo, 2006). In this study, the efficiency of free-floating macrophytes such as *Pistia stratiotes*, *Salvinia auriculata*, *Azolla filiculoides*, and *Eichhornia azurea* in treating the water of an eutrophic stream in the municipality of Tabatinga, Amazonas, was investigated.

2 MATERIAL AND METHODS

2.1 STUDY ÁREA

The municipality of Tabatinga is located in the Alto Solimões microregion, in the western part of the state of Amazonas, Brazil, on the border with Peru and Colombia. The climate in the region is equatorial humid, with an average temperature of 25.9°C and annual rainfall exceeding 2.500 mm (Coutinho *et al.*, 2018). The population of Tabatinga is 71,317 inhabitants, and the Gross Domestic Product is R\$ 533.610,70 million, with the main economic activities focused on fishing and agriculture (IBGE, 2022).

The municipality is densely drained by several streams and faces insufficient urban infrastructure in relation to population growth, as well as a lack of maintenance and conservation of the urban streams (Oliveira *et al.*, 2023).

2.2 WATER COLLECTION

The water for this study (200 liters) was collected from the Buriti stream (4°13'6.42"S and 69°55'10.99"O). This stream receives leachate from the public landfill of Tabatinga and exhibits eutrophication with physicochemical characteristics unsuitable for the survival of most aquatic animals (Garcez *et al.*, 2024). The collection, preservation, and transportation of the water from the stream followed the standards set by the American Public Health Association. (APHA, 2005).

2.3 COLLECTION OF FLOATING MACROPHYTES

Four species of free-floating macrophytes, known as water lettuce (*Pistia stratiotes*), water spangle (*Salvinia auriculata*), azolla (*Azolla filiculoides*), and water hyacinth (*Eichhornia azurea*), were selected. The macrophytes were collected from the Brilhante stream (4°14'30.70"S and 69°56'15.36"O). At each collection point, a 1 m² square was randomly thrown over the macrophyte bed, and all material within the area of the square was placed into plastic bags, labeled, and transported to the Educational Units Production Sector of the Federal Institute of Education, Science, and Technology – IFAM, Tabatinga Campus.

2.4 EXPERIMENTAL SETUP

Ten 20-liter aquariums were used, containing water collected from the eutrophic stream. As treatments, each of the floating macrophyte species (*Pistia stratiotes*, *Salvinia auriculata*, *Azolla filiculoides*, and *Eichhornia azurea*) was used in duplicate. A treatment without macrophytes was maintained as a control. The macrophyte culture took place over seven days (168 hours), and their ability to improve water quality was evaluated daily through physicochemical variables. The wet mass density of the macrophytes used in each aquarium was $20 \pm 1 \text{ g l}^{-1}$. The aquariums were kept on a table with five hours of sunlight exposure, at room temperature ($28.72 \pm 1.87 \text{ °C}$) and a natural photoperiod.

2.5 PHYSICOCHEMICAL VARIABLES

The physicochemical variables of the water in the aquariums were monitored daily at 4:00 PM. Data on dissolved oxygen concentration and water temperature were collected using a YSI® ProDO digital oxygen meter. Electrical conductivity, pH, and total solids data were collected using a JQ-006® digital multiparameter meter. Total ammonia (NH_3) and nitrite (NO_2^-) were also measured using Labcon Test® colorimetric kits.

2.6 DATA ANALYSIS

A descriptive research methodology was adopted, using Microsoft Excel® 1.0/2016 (64Bits) software to assist in data tabulation and graph creation. For the effects of the macrophytes on water quality after 168 hours, the data were subjected to analysis of variance (ANOVA) and Tukey's mean test for multiple comparisons. All statistical analyses were performed considering a significance level of 5%. Data processing and analysis were carried out using Statistica 7.1® software. (Statsoft Inc., Tulsa, OK, USA, 2007).

3 RESULTS

The physicochemical variables of the water were altered after treatment with macrophytes (Table 1), improving the overall water quality. *Pistia stratiotes* increased the pH and reduced total dissolved solids, along with ammonia and total nitrite levels ($p < 0.05$). *Salvinia auriculata* increased the pH and reduced total nitrite ($p < 0.05$). *Azolla filiculoides* increased the pH and reduced ammonia and total nitrite levels ($p < 0.05$). Lastly, *Eichhornia azurea* increased the pH, decreased electrical conductivity, total dissolved solids, ammonia, and total nitrite ($p < 0.05$).

Table 1. Physicochemical variables of the water from an eutrophic stream treated for 168 hours with four species of free-floating macrophytes.

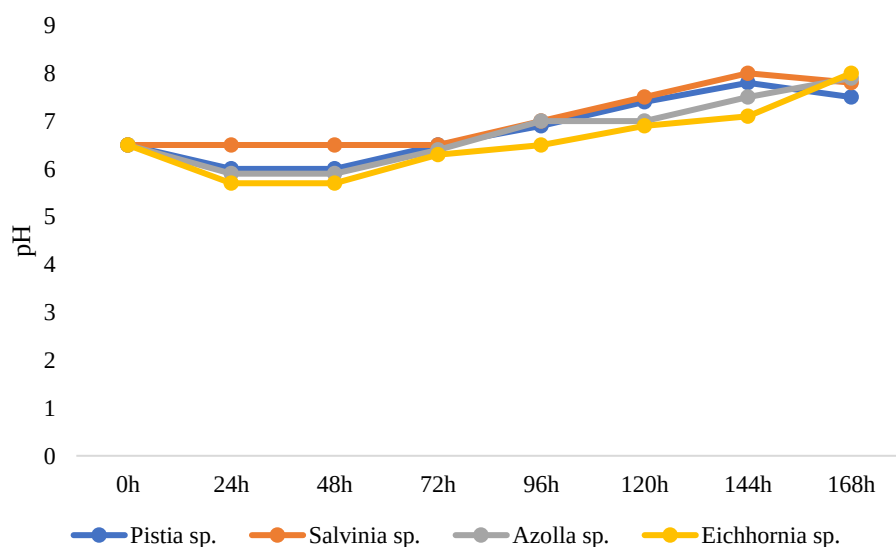
Parameters	Eutrophic stream	Treatment after 168 hours				p-value
		<i>Pistia sp.</i>	<i>Salvinia sp.</i>	<i>Azolla sp.</i>	<i>Eichhornia sp.</i>	
pH	6,50 ±0,00 ^b	7,65±0,15 ^a	7,75±0,10 ^a	7,70±0,20 ^a	7,75±0,45 ^a	0,0219
DO (mg l ⁻¹)	1,00±0,00	1,25±0,25	1,00±0,00	0,75±0,25	1,00±0,00	0,3977
EC (μS cm ⁻¹)	476,50 ±5,50 ^a	424,00±1,00 ^{ab}	436,50±3,50 ^{ab}	469,50±0,50 ^a	296,00±0,40 ^b	0,0001
TDS (mg l ⁻¹)	237,50±1,50 ^a	212,00±2,00 ^c	220,00±0,00 ^b	231,00±1,00 ^a	149,50±0,50 ^d	0,0000
Ammonia (mg l ⁻¹)	6,50±0,00 ^a	0,25±0,00 ^c	6,50±0,00 ^a	0,75±0,25 ^{bc}	1,00±1,00 ^b	0,0000
Nitrite (mg l ⁻¹)	1,00±0,00 ^a	0,00±0,00 ^c	0,25±0,00 ^b	0,00 ±0,00 ^c	0,00±0,00 ^c	0,0000
Temp. (°C)	28,50 ±0,50	27,00 ±1,00	27,00 ±1,00	27,75±0,25	27,75±0,25	0,5560

The values are expressed as mean ± standard error. pH: Hydrogen ion potential; DO: Dissolved oxygen concentration in water; EC: Electrical conductivity; TDS: Total dissolved solids; Temp: Temperature. Different letters in the same row indicate differences in means due to the treatments, according to Tukey's multiple comparisons test ($p < 0.05$).

Source: Authors.

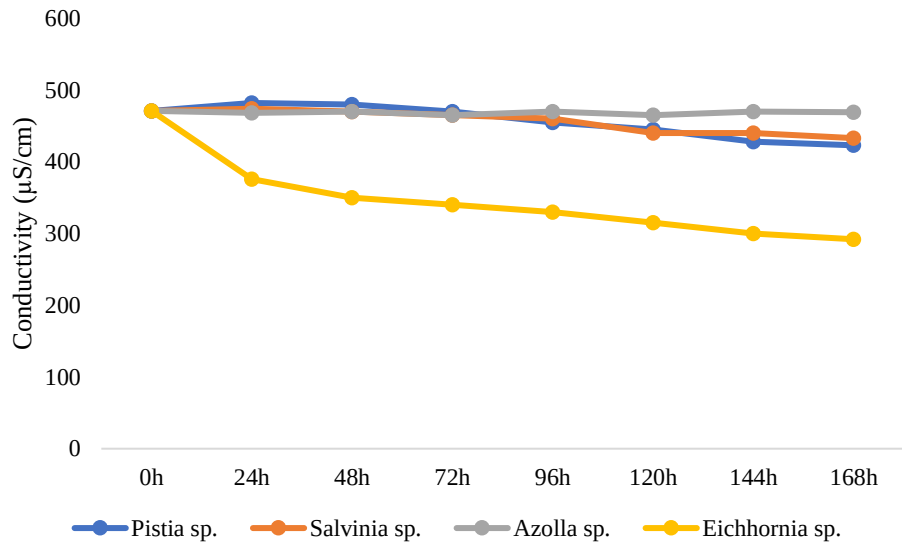
It was observed that the pH of the water increased after 72 hours for all the macrophytes (Figure 1). *Eichhornia azurea* reduced the electrical conductivity of the water within 24 hours (Figure 2). *Eichhornia azurea* also decreased the total solids in the water within 48 hours (Figure 3). *Pistia stratiotes* was the macrophyte with the greatest reduction of total ammonia, and *Salvinia auriculata* was the only experimental species that did not reduce the total ammonia in the water (Figure 4). Finally, all the macrophytes reduced the total nitrite after 24 hours (Figure 5).

Figure 1. Daily monitoring of the pH of the eutrophicated water treated with four species of free-floating macrophytes.



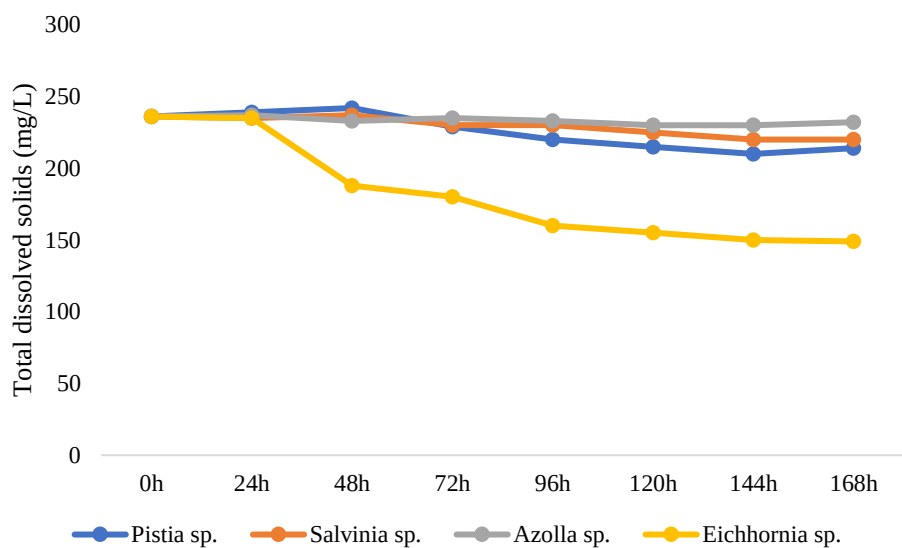
Source: Prepared by the authors.

Figure 2. Daily monitoring of electrical conductivity of eutrophicated water treated with four species of free-floating macrophytes.



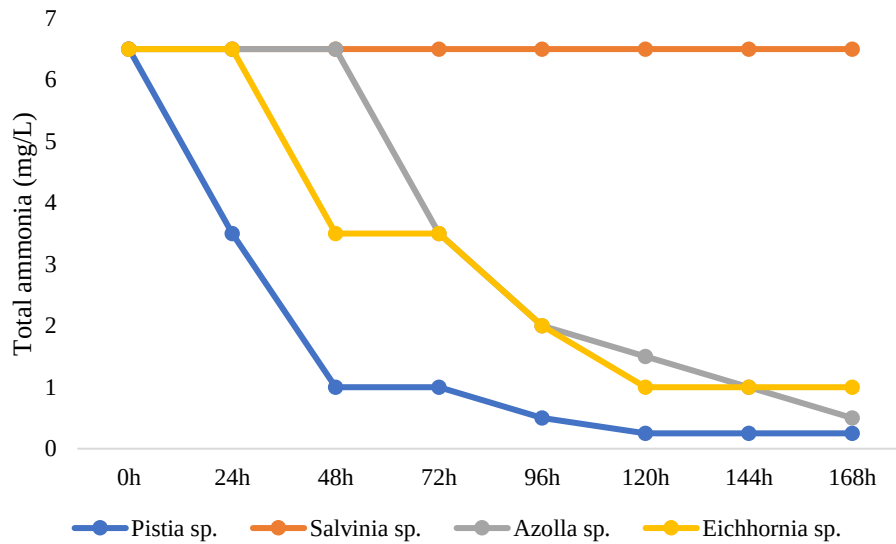
Source: Prepared by the authors.

Figure 3. Daily monitoring of total dissolved solids in eutrophic water treated with four species of free-floating macrophytes.



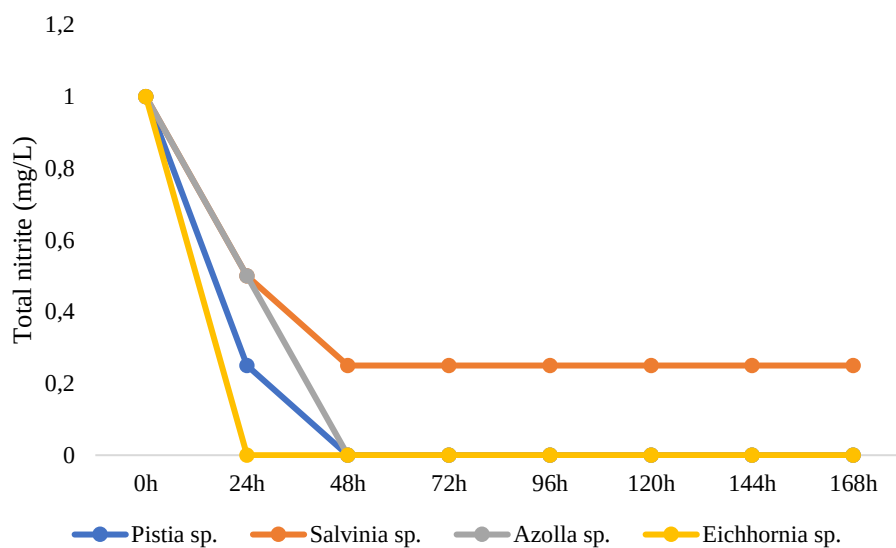
Source: Prepared by the authors.

Figure 4. Daily monitoring of total ammonia in eutrophic water treated with four species of free-floating macrophytes.



Source: Prepared by the authors.

Figure 5. Daily monitoring of total nitrite in eutrophic water treated with four species of free-floating macrophytes.



Source: Prepared by the authors.

4 DISCUSSION

This study consisted of qualitative and quantitative evaluations regarding the water quality after treatment with macrophytes, obtaining satisfactory results, especially in the removal of nitrogenous compounds. This reduction occurs through the process of

water cycling by the roots (Pompêo, 2017) and can absorb nitrogen from an eutrophic environment. One species that stood out was the mureru (*Eichhornia azurea*), which, in addition to the reduction of nitrogen compounds observed in this study, other authors claim that species of *Eichhornia* sp. have the ability to absorb total phosphorus, dissolved phosphorus, and improve water turbidity (Henry-Silva; Camargo, 2008; Biudes; Camargo, 2018). This makes it widely used in the treatment of effluents and eutrophic environments (Henry-Silva; Camargo, 2006; Silva *et al.*, 2014). In general, the increase in nitrogen, associated with sewage discharges, is harmful to the environment and aquatic biodiversity (Esteves, 2011).

Another interesting result was the increase in pH for all the evaluated macrophytes, which can be explained by the assimilation of carbon dioxide during the photosynthetic process (Esteves, 2011). Since there was no water renewal and no aeration, the dissolved oxygen remained low. This possibly could have kept the dissolved carbon dioxide elevated, but it was not measurable in this study. The increase in pH alters the equilibrium between carbonate, bicarbonate, and assimilable carbon (Tundisi; Tundisi, 2008). Although, Zimmermann *et al.*, (2020) it is stated that the pH of the water increases due to an adaptation and acclimation of the plants to the location, and that after 15 days, the pH stabilizes near neutrality. Since urban streams generally have acidity in the eutrophication process, pH is one of the main factors that affect the diversity, distribution, and interaction of aquatic macrophytes (Barbosa, 2012).

Regarding the decrease in total dissolved solids, studies indicate that macrophytes contribute to this reduction by using their roots, which retain the accumulated solids. However, it is emphasized that it is necessary to remove these plants from the water after a certain period (Zimmermann *et al.*, 2020). Other authors suggest that this reduction is also caused by the decrease in the passage of solar radiation and claim that this reduction is associated with the hydrolysis of particulate organic matter, sedimentation, and fixation in the roots of macrophytes, leading to a reduction in suspended solids (Van Der Steen *et al.*, 1998; Mohedano, 2004; Zimmo *et al.*, 2004).

Another important factor is related to electrical conductivity, which is linked to pollution sources generated by sedimentation, urban activity, and therefore to more eutrophic environments (Akaishi *et al.*, 2006). Studies indicate that there is a relationship between electrical conductivity, nutrient concentrations, and total solids, as observed in a

reservoir in Nigeria (Akinyemi; Nwankwo, 2007). This explains the reduction with *Eichhornia azurea*, which showed the ability to retain the solids from the water in its roots and consequently reduced the electrical conductivity

The results presented may suggest the use of biological filters. They are important because they are a low-cost technology in the implementation and maintenance phases (Olijnyk, 2008). In addition, it could be an alternative for the treatment of agricultural effluents (Júnior *et al.*, 2007).

The macrophytes *Eichhornia azurea* and *Pistia stratiotes* were the most suitable for effluent treatment due to their ability to remove significant amounts of organic matter from the water and their filtering potential. However, studies indicate that they can experience accelerated population growth if not properly controlled (Camargo *et al.*, 2003; Martins *et al.*, 2003). This control is important to maintain the filtering effect and the efficiencies in reducing pollutant components. It is necessary to prevent their decomposition from contributing to the increase of nitrogen and phosphorus forms again in a cycle with the natural death of the plants, as they accelerate sedimentation and raise nutrient levels during their decomposition.

Maintenance with controlled growth acts as a natural water cleaning mechanism, extracting pollutants and dissolved nutrients. The excess removed during the control of macrophytes has an excellent chemical composition and can be used as a source of green fertilization in agriculture. Since this effluent water contains high levels of organic waste and nutrients, its improper disposal represents a negative impact on the environment, potentially leading to the degradation of the water bodies it flows into (Silva *et al.*, 2014).

Finally, it would be important to implement public policies associated with the life of the streams in Tabatinga. Improving the water quality in these environments could indicate the eventual return of native species and promote public health, as there are bathing areas nearby, and many rural producers use the water for agricultural supply.

5 CONCLUSION

The use of the macrophytes *mureru* (*Eichhornia azurea*) and water hyacinth (*Pistia stratiotes*) can be viable or palliative ecological solutions for improving the water quality of aquatic bodies undergoing eutrophication.

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