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MACROPHYTE NUTRIENT REMOVAL EFFICIENCY AS A SOLUTION FOR EUTROPHIC LAKE REMEDIATION: A CASE STUDY NATURE PARK "PALIĆ"

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Abstract: Macrophytes represent important components of the aquatic ecosystem, providing ecosystem services and mediating nutrient cycling and storage. The aim of this study is to evaluate nitrogen (N) and phosphorus (P) concentrations in aboveground and belowground biomass. The biofilter potential of these three species was evaluated in the context of the shallow eutrophic Lake Palić. Results indicate that most accumulated N is in the belowground biomass, indicating rhizomes and root system as a reservoir of nutrients supporting regrowth. While the P content is different from spatial variability and is mostly related to the concentration of phosphorus in the soil, higher concentrations of P in the underground biomass were more precisely observed in localities where the soils in the immediate vicinity are richer in phosphorus. These findings highlight the ecological function of macrophytes in nutrient cycling and their potential for phytotechnology to lower nutrient loads and sustain ecosystem services in freshwater systems.

Keywords: eutrophic lake, *Phragmites australis, Typha latifolia*, *Carex vesicara,* reedbed management

INTRODUCTION

Shallow lakes are usually located in lowland areas near populated areas, which makes them extremely sensitive to anthropogenic influence. They also provide numerous ecosystems and social services (Meerhoff and Jeppesen, 2009). However, shallow stagnant waters such as lakes, ponds and swamps are most sensitive to the process of eutrophication (Janse J.H., 2005). In these ecosystems, macrophytes play a significant role, and are particularly important for nutrient cycling in lakes and for stabilizing clean water in eutrophic lakes (Swe *et al.*, 2021). In shallow lakes, macrophytes can reduce algal growth and thus affect water clarity, partly through nutrient uptake. In this way, macrophytes have an essential ecological function by modifying the physical and chemical environment of the lake (Pastor *et al.*, 2023). Anthropogenic influence, most often the discharge of industrial and city sewage, agricultural and other activities affect the increase of nutrients in the lake (Schierup and Larsen, 1981), which leads to excessive nitrogen (N) and phosphorus (P) input into aquatic habitats causing eutrophication and resulting in significant changes in nutrient cycles and productivity within these ecosystems (Wang *et al.*, 2025).

On the territory of the Republic of Serbia, the problem of anthropogenic eutrophication has been registered in many water bodies. A unique case is represented by the shallow Pannonian Lake of the "Palić Lake" Nature Park. Palić Lake is a sensitive and unstable ecosystem. It belongs to the group of shallow, warm and non-stratified lakes where any increase in nutrients is the basis for the process of eutrophication (Rudić Ž., 2015). Earlier findings indicate hypereutrophication of the lake and increased content of nutrients in riparian soils (Caković *et al.,* 2021; Caković *et al.*, 2023), which served as a starting point for the analysis of nutrients in macrophytes along the lake shore.

The aim of this study is to quantify the concentration of total nitrogen (N) and phosphorus (P) in the aboveground and belowground biomass of *Phragmites australis (Cav.) Stend., Typha latifolia L., Carex vesicara L*. from the Palić Nature Park area, as well as to compare the differences in N and P distribution between aboveground and belowground biomass among these species. The results obtained may serve as guidelines for further research and monitoring, thereby supporting the development of effective management strategies and maintenance measures of reed stands to reduce nutrient concentrations in the lake.

Proper (Asaeda and Karunaratne, 2000; Vymazal, 2011) and timely harvest (Hansson and Fredriksson, 2004; Grosshans *et al.*, 2014; Wang *et al.,* 2021) prevents the transfer of nutrients accumulated in the aboveground parts into the underground organs and sediment, but excessive removal may weaken reed stands and lead to shoreline erosion.

MATERIAL AND METHODS

Study area

Lake Palić is a shallow, semi-static lake in the steppe area and belongs to the rare and well-preserved steppe lakes of the Pannonian Basin (Figure 1) (JP Palić—Ludaš, 2014). Lake Palić and part of the tourist zone have been protected since 1996 and have been declared the National Park "Palić" (Official Gazette of the Republic of Serbia, 37/2017). The "Palić" nature park is located in the north of Vojvodina, south of the Palić settlement, 7 km southeast of the city of Subotica. It covers an area of 712.36 ha with a protection zone of 1698.13 ha (JP Palić—Ludaš, 2014).

Basic information on the size of the lake, climatic conditions of the study area, geology, as well as data on soil and other relevant characteristics are given in Table 1.

The NP "Palić" is located on the eastern European bird migration route and is an important habitat for resting, feeding and wintering waterfowl. Around 210 species of birds have been recorded on this site, of which over 100 species nests, which makes this

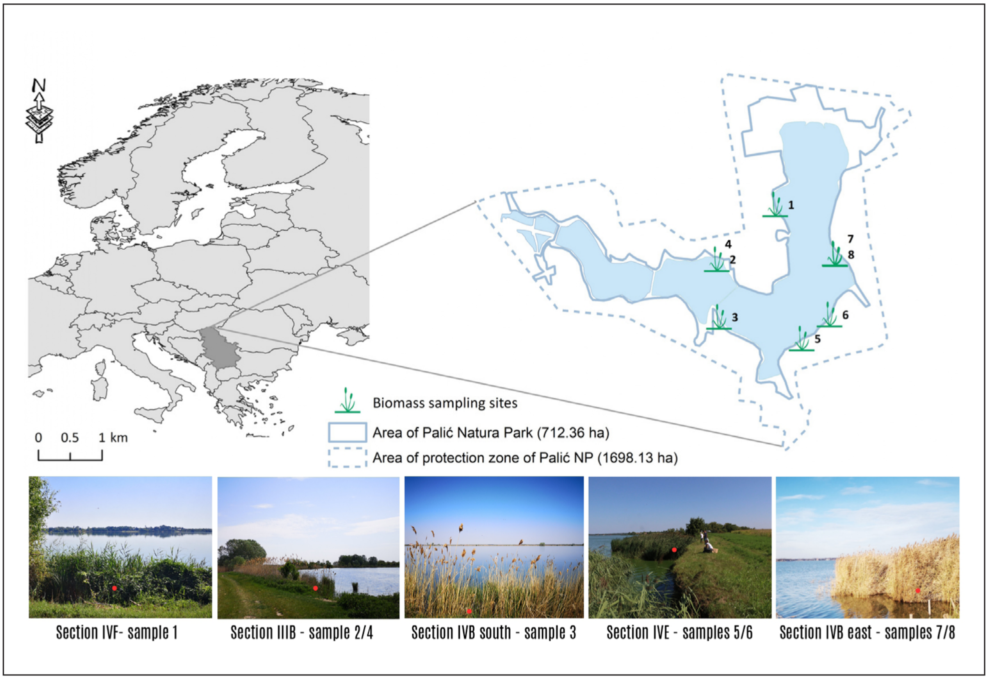

Figure 1. Study area
Slika 1. Istraživano područje

area internationally important. The place has both national protection and international recognition, having been classified as an Important Bird Area (IBA) (https://datazone.birdlife.org/about-our-science/ibas). Furthermore, this area was nominated in 2020 as part of the Natura 2000 network of sites. Natura 2000 is a network of protected areas that stretches across all 27 EU countries, providing long-term protection for Europe's most valuable and endangered species and habitats (https://europa.rs/natura-2000-zastita-prirode-po-eu-standardima/, https://www.eea.europa.eu/themes/biodiversity/natura-2000/the-natura-2000-protected-areas-network). The wealth of this area is distinguished by the fact that it is classified as an important botanical area (IPA - Important Plant Areas).

Table 1. Characteristics of the study area NP "Palić"
Tabela 1. Karakteristike istraživanog područja PP "Palić"

Area of water body	579.77 ha
Length of shoreline	28.08 km
Average lake depth	≈2 m
Soil type	Calcic Chernozem; Arenic Chernozem
Geomorphology	Loess; Sand
Climate	Temperate climate
Precipitation	568.3 mm

METHODOLOGY

The dominant macrophyte species included in this study were *Phragmites australis (Cav.) Stend., Typha latifolia L., Carex vesicara L.* Aboveground and belowground biomass samples were collected in the summer of 2020. Samples were taken at representative locations (where anthropogenic impact was observed, near agricultural areas).

The collected samples were first dried to constant weight, then ground to fine homogenization, and finally processed in the laboratory for the determination of total nitrogen (N) and phosphorus (P). The following methods were applied: 1. Determination of nitrogen according to the Ansttet 1956 method in the modification of Ponomarjeva and Nikolajeva (Ponomareva and Plotnikova, 1975), 2. Determination of phosphorus in plant material according to the method from the publication S a r i ć *et al.* 1986.

Statistical analysis

Descriptive statistics and Box–Whisker plots were used to illustrate the data distribution for nitrogen (N) and phosphorus (P). The normality of the data was tested prior to further analysis. Depending on the distribution, the paired Student's *t*-test and the Mann–Whitney *U* test was applied to assess the significance of differences between aboveground and belowground biomass.

RESULTS

The analysis of nitrogen and phosphorus content in biomass samples yielded significant results that indicate variations in nutrients between the aboveground and belowground parts of the biomass (Table 2).

Figure 2 shows the concentration of total phosphorus in relation to the macrophyte species. *Typha spp*. has average values of total P higher in belowground than aboveground biomass, with a range of about 0.8 to 1.3 %. *Phragmites australis* shows considerable variability in belowground biomass, with one outlier above 1.6 %, while aboveground biomass has lower and more uniform values (0.3–1.5 %). *Carex vesicara* has relatively uniform P values in above-ground and below-ground biomass, with less dispersion and values around 0.8 – 1 %. For all species, the underground biomass contains higher concentrations of phosphorus compared to the above ground, except for *C. vesicara* where the difference is minimal.

The nitrogen levels in *Typha latifolia* are rather stable and range between 2.0 % and 2.8 %. Aboveground biomass has a little less variation, while below-ground biomass has values that are the same or a little greater, but still in a restricted range. *P. australis* showed the most variation. The nitrogen content varies from approximately 2.0 % to around 3.7–3.8 %. Parts that are above and below the ground have a wide variety of values. Belowground biomass tends to have more nitrogen than aboveground biomass. In *Carex vesicara*, nitrogen values are in a smaller range (around 2.4–2.6%), and there isn't a lot of variation between the aboveground and belowground biomass.

Table 2. Nitrogen and phosphorus concentrations in aboveground and belowground biomass
Tabela 2. Koncentracija azota i fosfora u nadzemnoj i podzemnoj masi

Sample no.	Sector	Species	N (%)	P2O5 (%)	Part of biomass
1.	IVF	*Typha latifolia L.*	2.11	0.98	Aboveground
	IVF	*Typha latifolia L.*	2.63	0.91	Belowground
2.	IIIB	*Typha latifolia L.*	2.00	1.27	Aboveground
	IIIB	*Typha latifolia L.*	2.51	0.93	Belowground
3.	IVB	*Carex vesicara L.*	2.40	0.99	Aboveground
	IVB	*Carex vesicara L.*	2.64	0.79	Belowground
4.	IIIB	*Phragmites australis (Cav.) Stend.*	1.99	1.62	Aboveground
	IIIB	*Phragmites australis (Cav.) Stend.*	2.65	0.71	Belowground
5.	IVG	*Phragmites australis (Cav.) Stend.*	2.09	0.16	Aboveground
	IVG	*Phragmites australis (Cav.) Stend.*	2.42	0.3	Belowground
6.	IVB	*Phragmites australis (Cav.) Stend.*	3.09	0.71	Aboveground
	IVB	*Phragmites australis (Cav.) Stend.*	3.69	1.55	Belowground
7.	IVB east	*Typha latifolia L.*	2.53	1.06	Aboveground
	IVB east	*Typha latifolia L.*	2.47	1.21	Belowground
8.	IVB east	*Phragmites australis (Cav.) Stend.*	2.93	0.42	Aboveground
	IVB east	*Phragmites australis (Cav.) Stend.*	2.96	0.51	Belowground

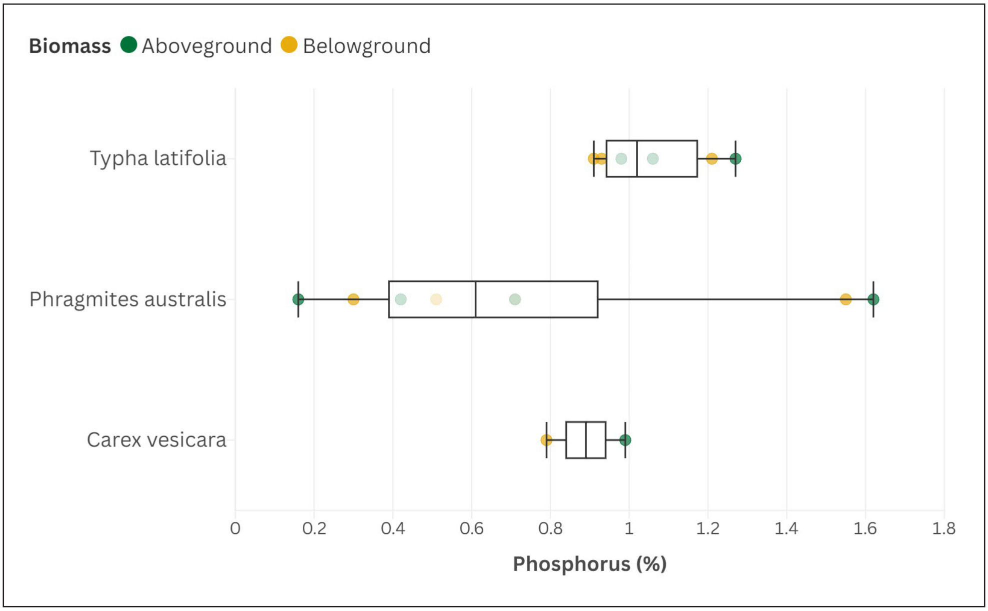

Figure 2. Distribution of phosphorous levels in aboveground and belowground biomass
Figure 2. Distribucija nivoa fosfora u nadzemnoj i podzemnoj biomasi

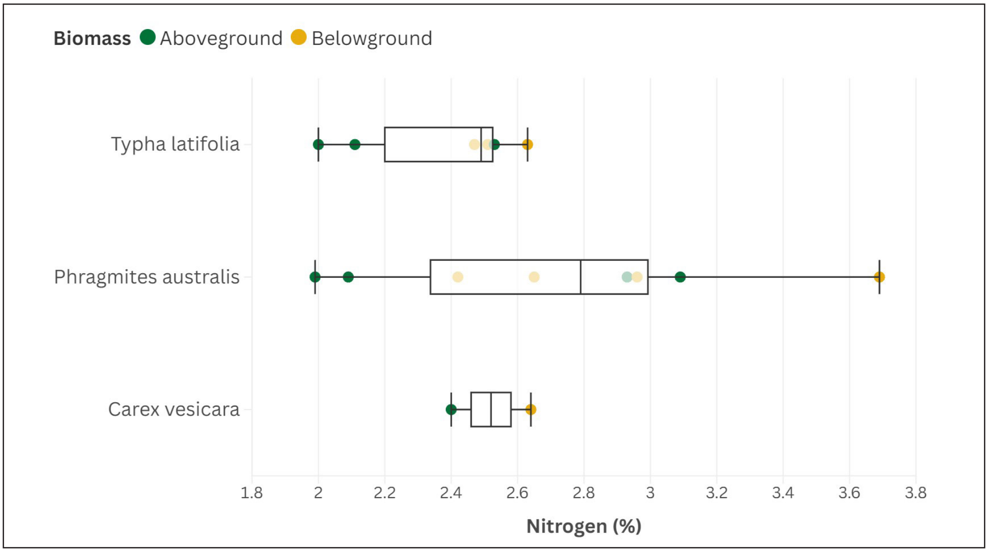

Figure 3. Distribution of nitrogen levels in aboveground and belowground biomass.
Figure 3. Distribucija nivoa azota u nadzemnoj i podzemnoj biomasi

Using *jamovi Software* (Version 2.6) (Jamovi 2024; R Core Team,2024), Student's t-test and Mann-Whitney U test were conducted to determine if there was a difference in nutrient uptake between aboveground and belowground biomass (Table 3.). There is no statistically significant difference in nitrogen uptake between the aboveground and belowground biomass (Student's t: $t = -1.68$, $df = 14$, $p = 0.12$), which is also confirmed by the Mann-Whitney U test ($U = 16$, $p = 0.10$). However, the mean difference (–0.35) shows that the underground biomass accumulates slightly more nitrogen. Phosphorus analysis shows that there is no difference between parts of the biomass ($p > 0.5$), and the mean difference (0.04) indicates almost identical values of phosphorus uptake in the aboveground and belowground parts of the biomass.

The normality test confirmed that N ($W = 0.95$, $p = 0.73$) and P_2O_5 ($W = 0.90$, $p = 0.37$) were normally distributed ($p > 0.05$), allowing the application of the subsequent tests.

Table 3. Statistical analysis of differences in nitrogen and phosphorus uptake between aboveground and belowground biomass (Student's t-test and Mann-Whitney U test).
Table 3. Statistička analiza razlika u usvajanju azota i fosfora između nadzemne i podzemne biomase (Student's t-test i Mann-Whitney U test).

Variable	Statistics	Value	df	p value	Mean difference	SE difference
N content	Student's t-test	-1.68	14	0.12	-0.35	0.21
	Mann-Whitney U test	16.0		0.10	-0.42	
P content	Student's t-test	0.17	14	0.86	0.04	0.21
	Mann-Whitney U test	27.5		0.67	0.07	

Note: Ha $\mu_{Aboveground} \neq \mu_{Belowground}$
df – degrees of freedom

DISCUSSION

Different scientific studies confirm the significant role of macrophytes in the functioning of aquatic ecosystems (Burks *et al.*, 2006; Bornette and Puijalon, 2009; Thomaz *et al.*, 2025 These plants also provide protection for various wildlife and birds. Birds often nest in the macrophyte zone, and waterfowl use the seeds, rhizomes and stems of macrophytes for food (Tilley and John, 2012).

With roots and underground rhizomes controlling absorption and storage, and shoots controlling distribution through transpiration, gas exchange, photosynthesis, and nutrient transport, wetland plants have unique structures for effective nutrient acquisition (Wu *et al.*, 2025).

The results obtained in this study confirm the importance of macrophytes in lake ecosystems, as they indicate that *Phragmites australis*, *Typha latifolia* and *Carex vesicara* species accumulate nutrients in their aboveground and belowground biomass. Likewise, results of sediment indicate nutrient absorption in same location (Leković I., 2022).

The obtained results indicate differences in the accumulation of phosphorus and nitrogen between the investigated species and between aboveground and belowground plant organs. Based on the results of phosphorus uptake in aboveground and belowground biomass are almost uniform, it can be concluded that the distribution of this nutrient depends on the specific conditions at the sampling location. In comparison with the previous research carried out by Caković *et al.*, 2021 on the concentration of nutrients in the soil in the same area, the obtained results can be better viewed and interpreted. Higher concentrations of phosphorus in the above-ground part of macrophytes were recorded in the samples collected from the western shore of the IV sector of Lake Palić, as well as from the third sector. However, samples from the east coast of sector IV show a higher phosphorus content in the underground parts of the biomass. At those locations, the concentration of phosphorus in the soil exceeds 25 mg/100 g. According to the classification (Ninkov J., 2023), concentrations above 25 mg/100g indicate high values, while values greater than 50 mg/100g have a toxic effect. Based on our previous research, it can be observed that nearby soil and sludge samples with phosphorus concentrations above 40 mg/100g also showed increased phosphorus accumulation in plant biomass (Caković *et al.,* 2021; Leković 2022).

Results indicate that species differed in the distribution and variability of nitrogen concentration in both aboveground and belowground biomass. At *Typha* species, the values remain relatively constant, indicating minor variations between the aboveground and belowground biomass. This observation corresponds with the conclusions of Kuusemets and Lõhmus (2005), who emphasize that *Typha sp.* efficiently absorbs nutrients and indicates consistent nitrogen accumulation due to its rapid development and high productivity. Furthermore, research by Li *et al.* (2009) demonstrates that aquatic environments with elevated nitrogen concentrations, particularly under stress conditions, can impede the root development of *Typha* species. These findings indicate that elevated nutrient concentrations, rather than facilitating the growth of belowground biomass, may negatively affect its development. Accordingly, timely harvesting of *Typha* species is essential to avert an excessive accumulation of nutrients in the biomass. Eliminating the aboveground parts of the plant enables more efficient mitigation of nitrogen return into the system via the decomposition of plant waste, thereby reducing the possibility of additional eutrophication in lakes.

The results indicate a slightly higher variability in nitrogen uptake (from 2.0% to 3.7%) in *Phragmites* species, as well as that the belowground biomass can accumulate more nitrogen than the aboveground biomass. This is confirmed by the study of Granéli *et al.,* 1992, which indicates that rhizomes function as a nitrogen storage reservoir. Ge *et al.,* 2017 indicates the distribution of nitrogen and phosphorus in *Phragmites* roots > stems > leaves > spikes, which makes reeds a promising species for the purification of nutrient-rich waters (Ennabili *et al.,* 1997).

As the results of this study indicate that *Carex* species accumulates more nitrogen in the belowground biomass than in the aboveground biomass, as confirmed by Brooker *et al.,* 2002. The same study explains that in this way the rhizome of this species does not only represent a passive reservoir of nutrients, but a significant part is subsequently translocated to the aboveground part of the plant. Thus, the early spring growth period comes from nutrients stored in the rhizomes during the winter, but most of the summer growth is due to absorption from the soil as reported by Bernard *et al.,* 1988.

Future prospects and recommendations for macrophyte management

The obtained results indicate that macrophytes (*Phragmites australis (Cav.) Stend., Typha latifolia L., Carex vesicara L.*) accumulate significant amounts of nitrogen and phosphorus in aboveground and underground biomass, which directly affects the regulation of the trophic status of aquatic ecosystems. In order to ensure a healthier ecosystem, it is necessary to use practical and ecological solutions. Effective management (harvest period and technique) is key to optimizing nutrient removal from macrophytes and aquatic ecosystems (Geurts *et al.,* 2020).

Experience in growing macrophytes has shown that nutrients and heavy metals are removed with the help of mowing. Mowing in the summer months leads to less vital vegetation. This is why these plants are most often mowed in the winter months, which affects the removal of nutrients, because in this period part of the nutrients from the shoot moves to the rhizome (Janse J.H., 2005). When the biomass is cut in the winter months and removed from the lake, a part of the organic matter of the lake is removed (Seleši Đ., 1973). The winter months are the optimal time for cutting reeds, as this is how the most nutrients are removed from aquatic ecosystems (GLNP, 2025; Wang *et al.*, 2021). Also, in addition to the removal of nutrients from the lake, harvesting in the winter months is important because that is when the ash and moisture content is the lowest, and such biomass is also used for energy purposes (Čule N., 2016; Niemiec *et al.*, 2019).

Recommendations for reed mowing (Asaeda and Karunaratne, 2000; Vymazal J. 2011; Hansson and Fredriksson, 2004; Grosshans *et al.,* 2014; Wang *et al.,* 2021) aimed at reducing and removing nutrients from the water body are as follows:

- late summer or early autumn harvest is recommanded (while the aboveground biomass is still green);
- cutting should be performed approximately 20 cm above the water level/ground, to allow reed regeneration in the next growing season;
- mosaic cutting (of up to one-third area/year) is recommanded in dense and continuous reed stands.

CONCLUSION

The results of this study indicate the significant potential of macrophyte species (*Phragmites australis (Cav.) Stend., Typha latifolia L., Carex vesicara L.*) to absorb nutrients from Lake Palic.

In this species, it was observed that the greater part of the nitrogen taken up is retained in the underground biomass, which emphasizes their potential to store and retain nutrients in the ecosystem in the long term. Also, the results of the phosphorus analysis show that its concentration in the biomass is higher in the parts of the lake where the phosphorus content in the soil is increased, where the accumulation in the underground biomass is more pronounced.

The main measure on the way to the revitalization of the lake, which is classified as hypereutrophic, is the reduction of the nutrient content in the lake. Reed bed restoration is of particular importance, as it can exert multiple beneficial impacts on the ecological quality of habitats. Proper care and regular mowing of macrophyte plants can lead to a reduction of nutrients in the lake.

These results can serve as a basis for further research aimed at a clearer understanding of the role of macrophytes in processes related to eutrophication, towards the improvement of restorative techniques in similar ecosystems, towards protection measures.

Author contributions

Conceptualization – M.C.M.; Data curation – M.C.M, J.B. and V.S..; Formal analysis – M.C.M. and V.S., Investigation – M.C.M.; Methodology–M.C.M.; Project administration – J.B.; Supervision – J.B.; Visualization – M.C.M.; Writing – M.C.M.; Writing – review and editing – J.B and V.S. All authors have read and agreed to the published version of the manuscript.

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