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Density and temporal dynamics of macroplastics in an urban river, Central Brazil

Densidade e dinâmica temporal de macroplásticos em um rio urbano, Brasil Central

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ABSTRACT

Macroplastic pollution in riverine systems is a growing concern, particularly in neotropical rivers draining urban and agricultural areas. These environments act as vectors for the transport and deposition of plastic waste, thereby compromising water quality and ecosystem services. This study assessed the influence of temporal variation (seasonal and intraseasonal), spatial variation (along the river stretch), source, and deposition site on the density of macroplastics (>3 cm) in the Meia Ponte River, Goiás, located in the upper section of the Paraná River basin, Central Brazil. Four sampling campaigns were conducted between 2023 and 2024 at three main channel points, covering areas upstream and downstream of the Goiânia metropolitan region. The macroplastics were visually identified and classified *in situ* by source and deposition site. Density was analyzed using the Kruskal-Wallis and Dunn's *post-hoc* tests. A total of 2,024 items were recorded, yielding a total density of 40.4 items.m^{-2}. Significant differences were observed among the categories of seasonality, intraseasonality, and source ($p<0.05$). It is concluded that temporal variation (seasonal and intraseasonal) and source are the modulating factors of macroplastic dynamics in the sampled river.

Keywords: seasonality; fishing; mixed plastic sources; Meia Ponte River; Goiás.

RESUMO

A poluição macroplástica em sistemas fluviais é uma preocupação crescente, especialmente em rios neotropicais que atravessam áreas urbanas e agrícolas. Esses ambientes atuam como vetores de transporte e deposição de resíduos plásticos, comprometendo a qualidade da água e os serviços ecossistêmicos. Este estudo avaliou a influência da variação temporal (sazonal e intrassazonal), espacial (ao longo do trecho do rio), da origem e do local de deposição sobre a densidade de macroplásticos (>3 cm) no rio Meia Ponte, Goiás, localizado na seção superior da bacia do rio Paraná, Brasil Central. Foram realizadas quatro campanhas entre 2023 e 2024 em três pontos do canal principal, abrangendo áreas a montante e a jusante da região metropolitana de Goiânia. Os macroplásticos foram identificados e classificados *in situ*, visualmente, por origem e local de deposição. A densidade foi analisada por meio dos testes de Kruskal-Wallis e *post-hoc* de Dunn. Foram registrados 2.024 itens, com densidade total de 40,4 itens·m^{-2}. Foram observadas diferenças significativas entre as categorias de sazonalidade, intrassazonalidade e origem ($p<0,05$). Conclui-se que a variação temporal (sazonal e intrassazonal) e a origem são fatores moduladores da dinâmica dos macroplásticos no rio amostrado.

Palavras-chave: sazonalidade; pesca; fontes mistas de plástico; rio Meia Ponte; Goiás.

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Introduction

Watercourses are one of the main sources of human sustenance. However, they function both as carriers and as reservoirs for different types of waste, among which are plastics (Jiang et al., 2021; van Emmerik et al., 2023). Plastic waste pollution in freshwater environments is a growing global concern, as it influences environmental quality and poses a potential risk to human health (Pinto et al., 2024) while increasing the vulnerability of aquatic species (Murphy et al., 2023). Despite international efforts and the creation of regulatory frameworks, the presence of plastic in the environment remains a challenge. Plastic emission into the aquatic environment is projected to reach between 20 and 53 $Mt.year^{-1}$ by 2030 (Borrelle et al., 2020). This situation requires that concrete measures be implemented, considering, among others, the Global Agreement on Plastic Pollution proposed by the Intergovernmental Negotiating Committee (INC-5) in South Korea (United Nations Environment Programme, 2024).

The entry of macroplastics into continental watercourses can occur directly, through intentional disposal, or indirectly, through the transport of waste present in the watershed by storm or surface runoff (van Emmerik et al., 2023) and the action of the wind (Al-Zawaidah et al., 2021). These mechanisms, combined with poor waste management and the seasonality of the water regime, result in the input of considerable quantities of plastic, organic, and inert materials into the watercourses (Pinto et al., 2024; Wang et al., 2024). The use of watercourse banks for recreational activities, leisure, and commerce constitutes another relevant source, intensifying the entry of solid waste, especially items like plastic bags and packaging (Belarmino et al., 2014; Ma et al., 2024). Additionally, freshwater courses constitute the main transport routes for macroplastics to the marine environment (Mashamba et al., 2024; Chowdhury et al., 2025; Dalu et al., 2025).

The mobilization and transport of macroplastics in continental watercourses are influenced by fluvial hydrodynamics. During rainy periods, the increase in flow rate (discharge) not only facilitates the longitudinal movement of this waste (van Emmerik et al., 2022b; Laverre et al., 2023) but also promotes lateral flooding that redistributes it along the banks and floodplain (Roebroek et al., 2021; Pinto et al., 2024). Extreme hydrological events, such as floods, drive the concentration and dispersion of macroplastics, whose impacts extend to surface water intakes and hydroelectric dams, increasing operational and environmental risks (Vriend et al., 2023; Schreyers et al., 2025). Furthermore, this plastic waste acts as a vector for chemical pollutants and pathogenic microorganisms, which alters water quality, harms aquatic species, and affects ecological processes related to biodiversity conservation (Ferreira et al., 2024; Mashamba et al., 2024).

In watercourses, the deposition and retention of this waste tend to occur in sections with specific characteristics, such as the presence of meanders, lentic areas (slow-moving or still water), roots, branches, and riparian vegetation (Nyberg et al., 2023). These retention sites frequently accumulate floating and persistent plastic items, such as PET bottles and Styrofoam/polystyrene (Belarmino et al., 2014; Ma et al., 2024; Chowdhury et al., 2025). Furthermore, the deposition points may coincide with surface water intake areas, which increases the risk of compromising the ecosystem services associated with water regulation, water purification, and the support of aquatic biodiversity (Bel Hassen et al., 2025). These risks are aggravated in urban watercourses, as they present recurrent plastic pollution, directly impacting aquatic organisms and potentially compromising water quality for human consumption and hydroelectric generation processes (Abdullah et al., 2022; Tobaldini et al., 2023; Pinto et al., 2024).

Despite advances in understanding the interaction between watercourses and plastic waste, the spatial and temporal behavior of this waste is still poorly known (van Emmerik et al., 2023), especially in South America and in the headwater regions of watersheds (Gallitelli and Scalici, 2022). Given this, this study aims to assess the density of macroplastics in the urban stretch of the Meia Ponte River (Goiás, Central Brazil, upper Paraná River basin), considering the temporal variation (at seasonal and intraseasonal scales), the spatial variation along the sampled stretch, and the source and deposition sites of this waste.

Materials and Methods

Study area description

The Meia Ponte River is a tributary of the Paranaíba River, located in the upper section of the Paraná River basin, in Goiás, Brazil (Figure 1). It has an approximate length of 472 km, with its headwaters in the Serra dos Brandões, in the municipality of Itauçu, and its mouth in the municipality of Cachoeira Dourada, where it flows into the Paranaíba River (Oliveira and Tejerina-Garro, 2010; Goiás, 2021). The hydromorphological characteristics of the Meia Ponte River basin facilitate longitudinal connectivity but do not favor lateral connectivity, as indicated by the limited occurrence of flooding and high waters (Veiga et al., 2013). The regional climate is humid tropical (Aw) according to the Köppen-Geiger classification, characterized by two well-defined seasons: a rainy season, from October to April, and a dry season, from May to September, with an average annual precipitation of approximately 1,500 mm (Goiás, 2021).

The basin's relief is predominantly gentle to rolling, with the presence of meandering river plains, interspersed with hills and residual mounds. The dominant soils, especially in the metropolitan region of Goiânia, are deep and well-drained Latosols, associated with recent alluvial deposits formed by sands, gravels, and silty-clay lenses. The superficial layer is composed of sandy-clay material, which favors the infiltration and mobilization of particles and waste during rainfall events (Goiás, 2021).

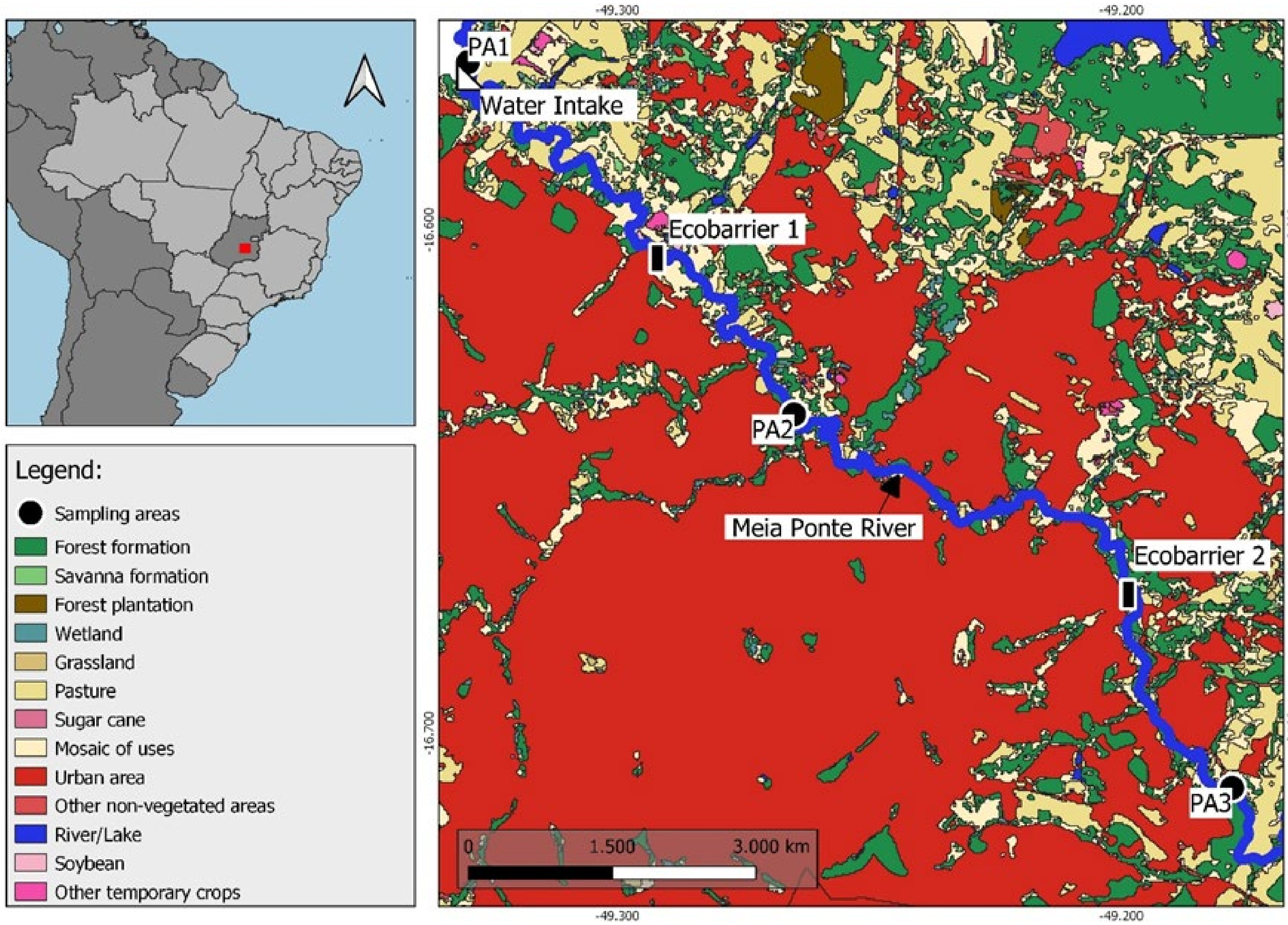

Figure 1 – Land use and location of sampling points along the main channel of the Meia Ponte River in the Goianira (PA1), Goiânia (PA2), and Senador Canedo (PA3) municipalities in the Upper Paraná River basin, Goiás, Central Brazil, 2023–2024.
Source: QGIS Desktop version 3.14, 2025. Collection 9, MapBiomas. Land use and land cover, 2025.

The sampled stretch of the watercourse extends for 38.3 km along the metropolitan region of Goiânia, draining rural areas of the municipality of Goianira, to the north, and the municipality of Senador Canedo, to the south. Along this stretch, three sampling points were delineated: the first (PA1) located on the right bank upstream of the metropolitan area of Goiânia (16°34'0.037″S, 49°19'47″W and 709 m AMSL), constituting the reference point expected to be free from macroplastics originating in the city of Goiânia; the second (PA2) located on the right bank, approximately in the middle of the stretch along the aforementioned metropolitan area (16°38'12″S, 49°15'54″W and 699 m AMSL); and the third (PA3) positioned on the left bank downstream of the metropolitan area of Goiânia (16°42'39″S, 49°10'41″W and 680 m AMSL). These last two points are under the influence of macroplastic input originating from the city of Goiânia.

At PA1, on the right bank, there is the presence of riparian forest and surrounding patches of Cerrado (Brazilian savanna). On the right bank, there are also floodplain areas that become inundated during the rainy season under the influence of the Meia Ponte River and the São Domingos stream. On the left bank, pasture is predominant. On both banks, there is a presence of grasses and water hyacinths (*Eichhornia* spp.).

Between sampling points PA1 and PA2, a raw water pumping station used for the water supply of the city of Goiânia is located, as well as an ecobarrier that prevents the movement of floating solid waste. This barrier is formed by 50 L containers attached to a rope extending from one bank to the other.

PA2 is located on the right bank. It features a riparian forest, which, in some parts, has trees partially overhanging the watercourse, and a flood area resulting from the construction of a dam that prevents water from flooding adjacent residential areas. On the left bank, the riparian forest is fragmented with the presence of pastures. On the right bank, there is a presence of grasses, climbing plants, and water hyacinths

(*Eichhornia* spp.) during the dry season. Between PA2 and PA3 there is a second ecobarrier with a shape and installation like the one previously described.

PA3, located on the left bank (Figure 2), features an uneven terrain with a riparian forest that extends beyond the sampling point and, in the surrounding area, patches of Cerrado. The right bank is also elevated and uneven. The vegetation is composed of Cerradão (dense forest-like savanna) that extends beyond the sampled stretch. Both banks are fragmented with the presence of waste of diverse sources, constituting induced and/or modified technogenic deposits. There is an isolated presence of water hyacinths (*Eichhornia* spp.), observed in November 2023.

Data collection and analysis

The field campaigns occurred in four distinct periods throughout a regional seasonal cycle, covering the dry (campaigns in May and August) and the rainy season (campaigns in November and February), between November 2023 and August 2024 (Figure 3). The sampling took place on a single day in the downstream (PA3) to upstream (PA1) direction. At each sampling point, an area of 50 m^2 was delimited: 10 m in the longitudinal direction to the watercourse and 5 m in the transverse direction toward the riparian forest and influenced by lateral flooding. Along the 10 m longitudinal stretch, transects were demarcated every meter, using a plastic rope.

Figure 2 – Sampling point PA3 (Senador Canedo municipality) on the Meia Ponte River, Goiás, Central Brazil, during the rainy season (February 2024, left) and the dry season (August 2024, right).
Photo: Maycon Winnicius Barreira de Souza-Coelho.

Figure 3 – Macroplastics deposited on the main channel bank of the Meia Ponte River at PA1 during the rainy season (February 2024, left) and the dry season (August 2024, right).
Photo: Maycon Winnicius Barreira de Souza-Coelho.

In each sampling area and along each transect, macroplastics were visually identified and quantified (abundance) *in situ* without being removed. This latter procedure allowed for the eventual recounting of macroplastics in subsequent collections (Belarmino et al., 2014) and the evaluation of the effect of natural removal or flushing by the watercourse. The non-removal of macroplastics can result in inaccurate or overestimated counts, introducing a bias. However, as the method was the same in all collections, it is assumed that the bias is constant and does not interfere with comparisons (Krebs, 1989). The individual characterization of macroplastics (>3 cm) was performed considering seasonality (the rainy or dry period in which the item was quantified), intraseasonality (campaigns C1–C4), and location along the river stretch (PA1–PA3). To determine the probable source of macroplastics, the adapted classification by Belarmino et al. (2014) was used (Table 1). For the classification by deposition location within the sampling area, the adapted protocol developed by González-Fernández and Hanke (2017) and van Emmerik et al. (2018) was followed. Subsequently, based on the quantifications, the macroplastic density was calculated considering the sampling area of 50 m² and expressed in items.m^{-2}.

The collected data were tabulated and organized into a matrix for analysis, considering the density of macroplastic items (items.m^{-2}) by categorical variable: seasonality (rainy and dry periods), intraseasonality (C1, November; C2, February; C3, May; C4, August), spatial variation (PA1, PA2, and PA3), probable source (quick use, domestic, mixed, and fishing), and deposition environment (floating, riverbank, roots, and branches). Initially, the density values were submitted to a Shapiro-Wilk normality test ($p=0.05$). Subsequently, due to the non-normality of the data, a Kruskal-Wallis analysis (chi-squared method corrected for ties) was performed between the item density per categorical variable, followed by a Dunn *post-hoc* analysis (Dunn, 1964) with the sequential Holm-Bonferroni method for multiple comparison correction (Dinno, 2015). All statistical analyses were performed using Past 5.3 software (Hammer et al., 2001).

Table 1 – Macroplastic classification by probable source (adapted from Belarmino et al., 2014).

Source	Common items
Quick	Cigarette butts, plastic dishes (disposable or not), plastic sticks, package seals, straws, and rope
Domestic	Toys, cotton swabs, Styrofoam, nylon tape/strap, nonwoven fabric face masks, nonwoven fabrics, vehicle accessories, and polyvinyl chloride (PVC) tubing
Mixed	Polyethylene terephthalate (PET) bottles, plastic caps, plastic bags in general, long-life/general packaging, bubble wrap, and informational leaflets
Fishing	Nylon lines, plastic rods, nylon nets, and spools

Results and Discussion

The sampling resulted in a total of 2,024 macroplastic items and a total density of 40.4 items.m^{-2}, the quantities and densities of which by categorical variable are indicated in Table 2. However, the values presented in Table 2 are estimates and not exact values, since the sampling method did not include the removal of macroplastics from the deposition sites. Nevertheless, this does not interfere with the comparisons made (Krebs, 1989).

The results of the Kruskal–Wallis test indicated statistically significant differences for the variables of seasonality, intraseasonality, and source of macroplastics (Table 3). Regarding temporal variation, the density and variability of macroplastics in the rainy period were higher than those recorded in the dry season (Figure 4A). At the intraseasonal scale, campaign C1 (start of the rainy season) presented the highest density and variability values, differing significantly from campaign C4 (end of the dry season; Figure 4B; Table 3). These results indicate that precipitation and the consequent increase in flow rate (discharge) promote the transport and redistribution of macroplastics along the main channel (Roebroek et al., 2021; van Emmerik et al., 2023; Pinto et al., 2024). Conversely, the reduction in rainfall and flow rate during the dry season favors the progressive accumulation of macroplastics on the riverbanks, branches, and roots of the riparian forest, due to deposition processes characteristic of low-energy environments (Schwenk et al., 2025).

Table 2 – Quantity and density (items.m^{-2}) of macroplastics recorded in the Meia Ponte River, Goiás, Central Brazil, stratified by seasonality, intraseasonality, sampling points, source, and deposition site categories (2023–2024).

Variable	Category	Quantity	Density
Seasonality	Rainy	727	14.5
	Dry	1,297	25.9
Intraseasonality	C1	660	13.2
	C2	67	1.3
	C3	647	12.9
	C4	650	13.0
Sampling point	PA1	860	17.2
	PA2	455	9.1
	PA3	709	14.2
Source	Mixed	1,371	27.4
	Domestic	48	1.0
	Quick	257	5.1
	Fishing	348	7.0
Deposition site	Riverbank	1,220	24.4
	Branches	379	7.6
	Roots	210	4.2
	Floating	215	4.3
Total	-	**2,024**	**40.4**

Table 3 – Statistics from the Kruskal–Wallis and Dunn's *post hoc* tests for multiple comparisons of macroplastic densities across categorical variables, Meia Ponte River, Goiás, Central Brazil (2023–2024). Significant differences (p<0.05) are shown in bold. C1–C4 = sampling campaigns.

Categorical variable	Kruskal–Wallis		Dunn				
Seasonality	Hc (chi²)	5.585		Rainy	Dry		
	p	**0.018**	Rainy	-			
			Dry	**0.018**	-		
Intraseasonality	Hc (chi²)	**9.935**		C1	C2	C3	C4
	p	**0.016**	C1	-			
			C2	0.369	-		
			C3	0.075	0.775	-	
			C4	**0.001**	0.281	0.224	-
Sampling point	Hc (chi²)	0.498	-				
	p	0.780					
Source	Hc (chi²)	28.690		Mixed	Domestic	Quick	Fishing
	p	**0.000**	Mixed	-			
			Domestic	**0.000**	-		
			Quick	**0.017**	**0.024**	-	
			Fishing	0.742	**0.010**	0.314	-
Deposition site	Hc (chi²)	2.662	-				
	p	0.447					

In turn, the transition between the rainy period and the start of the dry season, represented by the intermediate campaigns (C2 and C3), suggests a balance between transport and deposition processes, resulting in more homogeneous densities along the watercourse (van Emmerik et al., 2022a). This trend reaffirms the influence of seasonality and fluvial hydrodynamics in modulating the retention and displacement of macroplastics, a phenomenon documented in both tropical (Vorsatz et al., 2023; Gupta et al., 2024; Schreyers et al., 2024) and subtropical systems (Mashamba et al., 2024; Chowdhury et al., 2025; Dalu et al., 2025).

The source of macroplastics in the Meia Ponte River differs significantly among the analyzed categories (Figure 4C; Table 3). The "Domestic" category (toys, cotton swabs, and Styrofoam, among others) registered the lowest density among all, and differs significantly from the "Fishing" category (highest density and variability), which was followed by "Mixed" (intermediate values) and "Quick" (low values). Differences are also observed between "Mixed" and "Quick." The high density of items in the "Fishing" category (lines, nets, rods, and spools) is directly associated with local fishing activity. The diverse ichthyofauna of the Meia Ponte River, which includes 64 native and exotic species and covers some of commercial value (Oliveira and Tejerina-Garro, 2010), attracts fishermen, resulting in a point source of macroplastic pollution via direct disposal. These items are frequently found retained on riverbanks and in the riparian forest, especially in backwater areas and easily accessible points (Silva et al., 2008; Belarmino et al., 2014), as observed at PA1 on the Meia Ponte River (Figure 5).

The "Mixed" category (PET bottles, food packaging, and plastic bags) comprises items of ambiguous origins, potentially deriving from both domestic and quick-use sources (Belarmino et al., 2014). The "Quick" category (cigarette butts, plastic utensils, and straws) is for recreational or short-duration use. The types of items that make up both categories are widely utilized by the human population (urban or non-urban), and their management becomes deficient, considering that their production and disposal surpass mitigation efforts (Borrelle et al., 2020). Both "Mixed and "Quick" items enter the watercourse through point sources, via direct disposal by users during recreational activities such as fishing (Belarmino et al., 2014; Ma et al., 2024). However, "Mixed" items also have a diffuse entry route, being transported from urban areas to the watercourse by surface runoff during rainy periods (Roebroek et al., 2021; van Emmerik et al., 2023; Pinto et al., 2024) or by wind action, in the case of plastic bags and light packaging (Al-Zawaidah et al., 2021).

The low density of "domestic" items (toys, cotton swabs, and Styrofoam, among others) runs contrary to expectations. Domestic plastic waste is documented as being part of constructed technogenic deposits (landfills, waste bodies, etc.) between 0.30 and 0.35 m deep on the bank of the Meia Ponte River and another on the Palmito stream, a tributary of the Meia Ponte River, with the presence of bottles and plastic bags, Styrofoam, and rubber, among others (Rubin et al., 2008).

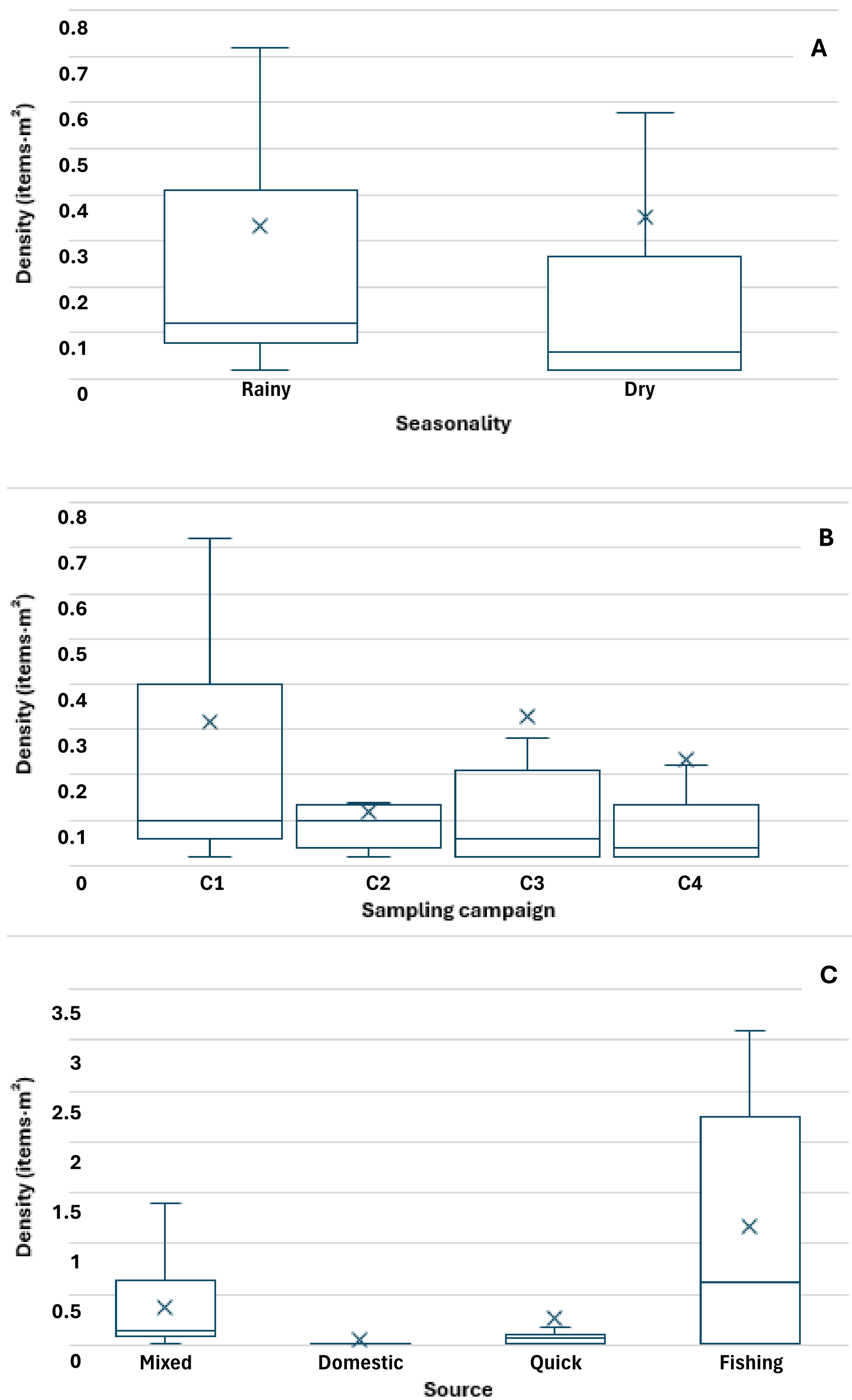

Figure 4 – Boxplot analysis of macroplastic density in the Meia Ponte River, Goiás, Central Brazil (2023–2024), displaying categories for seasonality (A), intraseasonality (B), and source (C). X=mean.

Figure 5 – Recreational activity (fishing) recorded at PA1 on the Meia Ponte River, Goiás, Central Brazil, during the 2024 dry season.
Photo: Maycon Winnicius Barreira de Souza-Coelho.

Both locations are in the same upper section of the basin sampled in this study. A possible explanation for this reduction is the implementation of public waste management policies in Goiânia, such as the Voluntary Collection Points (Pontos de Entrega Voluntária — PEV; Matida and Santos, 2022) and the "Catatreco" (Almeida and Pfeiffer, 2022), which may have reduced improper disposal in the basin.

The homogeneous distribution of macroplastics among the sampling points (PA1, PA2, PA3) can be attributed to the ecobarriers installed by the municipal administration (upstream of PA2 and PA3 in this study), which continuously retain floating material with removal occurring biweekly (Goiânia, 2020). Furthermore, the absence of differences in deposition locations (riverbank, branches, roots, and floating) is likely related to the hydromorphology of the Meia Ponte River basin. This watercourse is incised, with abrupt banks, which limit overflow and lateral connectivity with the riparian forest (Veiga et al., 2013). This morphology concentrates waste dynamics in the main channel and inhibits the formation of distinct retention points.

Conclusion

This study indicates that, of the five variables considered, temporal variation (seasonal and intraseasonal) and source are key influencers in the dynamics of macroplastic density in the sampled watercourse. The alternation of rainy and dry periods, characteristic of the regional climate, modulates the deposition and transport of macroplastics.

Macroplastics categorized as "Fishing" (lines, nets, rods, and spools), "Mixed" (PET bottles, food packaging, and plastic bags), and "Quick" (cigarette butts, plastic utensils, and straws) exhibit densities predominant over "Domestic" items (toys, cotton swabs, and Styrofoam, among others). This disparity is attributed to their intense production, consumption, and disposal by human populations.

The findings regarding the interaction of macroplastics with the aquatic environment can be extrapolated to other watercourses that exhibit characteristics like the sampled one: urban drainage influence, well-defined dry and rainy seasonality, and location in the upper section of the basin.

These results contribute to the understanding of the interaction of macroplastics with the aquatic environment under little-known conditions. These conditions are represented in this study by the spatial and temporal scale of the sampling and the location of the waterway in the upper section of a watershed. Further macroplastic studies are necessary to better comprehend the interaction of this type of waste with the aquatic environment, considering, in addition to the indicated conditions, the presence of installed ecobarriers and the deposition of macroplastics in the watercourse sediment and in lentic environments.

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Authors' Contributions

Souza-Coelho, M.W.B.: conceptualization, methodology, data curation, formal analysis, writing – original draft, writing – review & editing. **Alves**, I.V.S.: methodology, data curation, and formal analysis. **Tejerina-Garro**, F.L.: conceptualization, formal analysis, supervision, validation, writing – review & editing.

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