



Dynamics of urban greening in public squares: sustainable planning and the provision of ecosystem services in urban centers

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Abstract

Urban greening in public squares is a vital component of urban green infrastructure, which provides essential ecosystem services that promote human well-being and biodiversity conservation. However, the effectiveness of these benefits is intrinsically linked to technical criteria for species selection, which are frequently neglected in municipal planning. In this context, we evaluated the temporal dynamics of urban greening in public squares in the town of Jataí, Goiás state, Brazil, by comparing floristic parameters and the provision of ecosystem services between two surveys (2010 and 2024). A complete floristic census of 14 public squares was conducted, and species were classified according to origin (native or exotic), provision of edible fruits (edible or inedible), and deciduousness (evergreen, semideciduous, or deciduous). The results showed changes in floristic composition and diversity over time. Although no differences in total abundance were found (range: 1,030–1,274 individuals), a significant increase in species richness (range: 79–121) was observed. Consistently, diversity profiles based on Hill numbers also indicated higher effective numbers of species in 2024 compared to 2010. The most representative families in both years were Arecaceae, Bignoniaceae, and Fabaceae, while the most abundant and frequent species were *Syagrus oleracea*, *Cenostigma pluviosum*, and *Moquilea tomentosa*. In 2010, there was a tendency toward higher density of native trees, but by 2024 this pattern had shifted to an equivalent density of native and exotic trees, while species richness increased significantly for both origins. A similar trend was found for deciduous species, with increases in both parameters, especially richness. In contrast, for individuals with edible fruits, density increased in 2024, while species richness remained stable. The results indicate that, despite positive advances in density and species richness, urban greening management has prioritized exotic and deciduous species to the detriment of ecosystem attributes fundamental to sustainable planning, such as permanent shading and the valuation of the regional flora. The findings highlight a critical gap in technical planning, underscoring the urgent need to integrate ecological criteria into species selection. This shift is essential to ensure the provision of vital ecosystem services and to foster more functional and sustainable urban landscapes.

Keywords Cerrado · Tree species · Monitoring · Deciduousness · Biogeographic origin · Fruit supply

Introduction

Currently, more than half of the world's population lives in urban areas, and estimates indicate that by 2050, approximately 68% of the global population will be concentrated in cities, representing an increase of 2.2 billion people in urban environments (ONU-Habitat 2022). In Brazil, this trend is even more pronounced, with approximately 87% of the 213.4 million inhabitants living in urban areas (IBGE 2025). However, this accelerated urban expansion is not accompanied by a proportional green infrastructure, as evidenced by

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data from MapBiomass (2024), which show that the national average for urban afforestation is only 28.2% of territories with green cover. From an environmental viewpoint, this accelerated urban expansion with low vegetation cover tends to intensify various environmental impacts in cities, such as increased soil impermeability, gas emissions, and temperature (Minaki & Amorim 2012). Consequently, population growth in cities not only intensifies the demand for natural resources, but also triggers serious ecological consequences, including the loss of biodiversity and alteration of other ecosystem services (Parmar et al. 2016).

To mitigate the effects of degradation and promote urban sustainability, urban greening is recognized as an essential provider of ecological functions and ecosystem services in cities. These services are fundamental to the quality of urban life, and are classified into four main categories: provisioning, regulation, cultural, and supporting (Millennium Ecosystem Assessment 2005). Thus, tree vegetation can provide habitats, purify air and water, regulate climate, sequester carbon, and offer aesthetic and recreational benefits (Mexia et al. 2018). In addition to aesthetics, its functions include thermal regulation, improvement of air quality, and promotion of human well-being. When implemented in streets, avenues, sidewalks, squares, and parks, urban greening becomes central to creating healthier and more biodiverse spaces. This role is even more relevant, as trees act as acoustic barriers, promote climate stability, and serve as shelter and food source for local fauna (Nucci 1996; Albertin et al. 2011). Thus, in addition to these benefits, the increase in urban green areas can provide fruits during periods of crisis (Dümpelmann 2020), reinforcing their ecological and social role in urban centers.

Despite its importance, the effectiveness of urban greening is conditioned by strategic planning that integrates local characteristics and long-term ecological dynamics, aiming at synergy, especially between biodiversity and human well-being (Miguez et al. 2025). Historically, greening management has lacked adequate planning, in which the preferences of the population prevail over those of managers, and management practices that do not favor local biodiversity are adopted, such as the use of exotic species (Shackleton et al. 2015). The use of these species, motivated by their rapid growth and/or aesthetic value, has replaced native species, which can cause an ecological imbalance and impact biodiversity in these urban environments (Resende and Santos 2010). This practice is particularly critical in biomes with high biodiversity and ecological specificity, such as the Brazilian Cerrado, where the introduction of exotic species can reduce the capacity of urban areas to function as refuges for local fauna, promoting ecological connectivity and natural processes (Barros et al. 2010). Thus, the appropriate choice of species for urban greening is essential for maintaining ecosystem services in the urban environment.

Urban squares, in the context of urban greening, stand out as multifunctional spaces, integrating social, historical, cultural, ecological and identity aspects, and are seen as a symbol of sociability in the urban landscape (Viezzer et al. 2016; Oliveira Júnior and Orlando 2023). They contribute to landscaping, air quality, and environmental education (Viezzer et al. 2016), providing interaction between people and the natural environment, and enabling recreation and rest activities (Amaral and Guilherme 2014). In this context, to support sustainable planning and the maintenance of ecosystem services, it is essential to characterize and monitor tree cover over time through floristic surveys (De Sousa et al. 2019; Batista et al. 2023). The basis of these studies is the census, in which individual plants are identified and quantified (Dos Santos et al. 2015). This knowledge also supports complementary analyses, essential for understanding the ecological processes that indicate the management and sustainability of urban greening, such as knowledge of the species origin (i.e., native or exotic) (da Silva et al. 2008; De Freitas et al. 2020; Batista et al. 2023); and the diversity and homogeneity of species composition (de Lima Neto et al. 2021). Additionally, recent studies have incorporated functionally relevant ecological aspects, such as dispersal and pollination syndromes (Batista et al. 2023). Thus, urban greening planning should consider not only the composition of the tree community (Hernández and Villaseñor 2018), but also the ecological attributes that maintain the functioning and provision of ecosystem services (Brasil 2025).

Although temporal monitoring is essential for evaluating changes in the composition of species and their functions, a scientific gap persists due to the scarcity of long-term studies analyzing floristic dynamics and the ecological consequences of management decisions, limiting the capacity to develop adaptive strategies for urban greening (Batista et al. 2023). In this scenario, the need for technical and monitored planning, though widely recognized in literature, has gained new prominence on the Brazilian national agenda with the recent launching of the National Urban Afforestation Plan (PlaNAU) (Brasil 2025). This is the first federal planning instrument entirely dedicated to the topic, establishing guidelines, goals, and strategies to expand tree cover in Brazilian cities by 2045. PlaNAU proposes greening as an essential infrastructure and a Nature-Based Solution, with the objectives of promoting urban biodiversity, generating socio-environmental and climatic benefits, and prioritizing the use of adapted native species (Brasil 2025). The plan reinforces the need to integrate technical and ecological criteria into planning, overcoming fragmented approaches.

Given this gap and the urgency established by the PlaNAU, this study aimed to evaluate the temporal dynamics of woody flora in urban spaces in the town of Jataí, Goiás state, Brazil, based on surveys conducted in 2010 and 2024.

Specifically, the study sought to answer the following questions: (i) How did the composition of the tree flora, in terms of abundance, species richness, and diversity, change between the surveys? (ii) Did the abundance and richness of species associated with key ecosystem services, such as thermal comfort (evaluated here by the species deciduousness), and the provision of food resources (edible fruits for the population), change in the evaluated time interval? (iii) Were there changes in urban greening management, inferred by alterations in the proportions of native versus exotic species and deciduous versus evergreen species?

Materials and methods

Study area

The study was conducted in the town of Jataí, in southwestern state of Goiás, Brazil ($17^{\circ}52'53''$ S and $51^{\circ}43'45''$ W) (Fig. 1). Elevation of the urban perimeter ranges from 652 to 860 m a.s.l., the predominant climate is Aw, tropical savanna, with average annual rainfall of 1,649.5 mm and average

annual temperature of 22°C , considering the historical average between the years 1961 and 1990 (Silva et al. 2020).

Although Jataí is located in the transition zone between the Cerrado and Atlantic Forest, vegetation types typical of the Cerrado biome predominate in the surroundings and in the city's green areas, on predominantly acidic soils with low natural fertility.

Sampling

The vegetation survey was carried out in 2010 and 2024 in 14 urban squares (Table 1; Fig. 1), out of the 60 existing squares, all located within the urban area of Jataí and distributed throughout its urban perimeter, which were previously selected based on the relevance of visitation frequency (Amaral and Guilherme 2014). Species richness and abundance were recorded in each square in 2010 and in 2024. The public squares studied vary in size, from 899 to 21,700 m^2 (Table 1), and are generally square. The dimensions of the squares remained unchanged between the surveys.

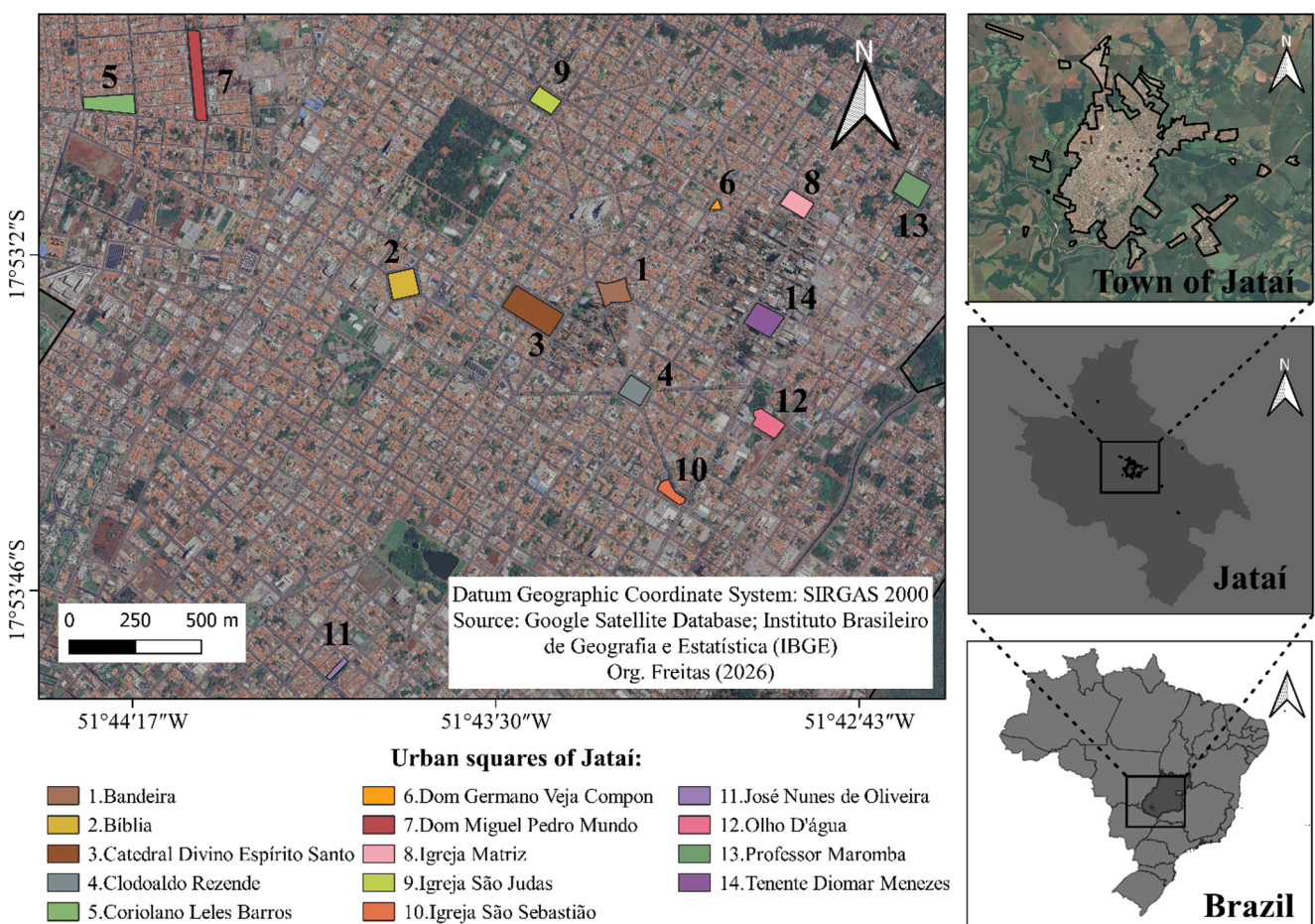


Fig. 1 Urban area in the town of Jataí, Goiás State, Brazil, showing the spatial distribution of the 14 sampled public squares

Table 1 Urban squares, area (m²), total number of individuals (abundance: Abun.), total number of species (richness: Ric.), and variation (+/-) between surveys conducted in 2010 and 2024 in urban squares in the town of Jataí, GO state, Brazil

Urban squares	Area (m ²)	2010		2024		(+/-)	
		Abun.	Ric.	Abun.	Ric.	Abun.	Ric.
1. Bandeira	4,050	102	22	87	23	-15	1
2. Bíblia	10,816	77	16	72	18	-5	2
3. Catedral Divino Espírito Santo	21,700	50	11	94	19	44	8
4. Clodoaldo Rezende	7,031	83	14	49	12	-34	-2
5. Cloriolando Leles Barroso	11,773	143	4	156	24	13	20
6. Dom Germano Veja Compon	1,044	19	3	21	5	2	2
7. Dom Miguel Pedro Mundo	13,845	125	37	153	40	28	3
8. Igreja Matriz	6,996	104	15	112	27	8	12
9. Igreja São Judas	1,840	49	10	24	11	-25	1
10. Igreja São Sebastião	899	9	4	17	6	8	2
11. José Nunes de Oliveira	1,083	17	4	13	2	-4	-2
12. Olho d'água	3,773	133	13	159	24	26	11
13. Professor Maromba	10,976	51	6	102	22	51	16
14. Tenente Diomar Menezes	9,405	68	18	215	51	147	33
Total		1030	79	1274	121	244	42

In each square, species richness and abundance were recorded by surveying all woody and arborescent plants (including palm trees). In general, species identification was carried out on site, and for those not identified, photographic records were made and botanical identification was conducted with the help of specialists, specific literature, and internet pages (Reflora, virtual herbaria). The nomenclature of species and their origin were verified (native and non-native to Brazilian biomes) in Flora 2020 (<https://flora.dobrasil.jbrj.gov.br>).

Species characterization

The density of individuals (individuals per hectare) and species richness were calculated for the years 2010 and 2024. Density and richness were grouped into the following categories: origin (native or exotic), ecosystem services (fruit supply), and ecological characteristics (deciduousness categories). Native species were defined as those that occur naturally in the Cerrado phytogeographical domain (i.e., species whose natural distribution includes the Cerrado, even when they also occur in other Brazilian biomes). Exotic species were defined as those that do not occur naturally in the Cerrado, including naturalized and cultivated species (De Freitas et al. 2020) (Table S1). This criterion was adopted to ensure that our classification reflects the regional native flora relevant to the study area. Species were defined as fruit supply plants if their fruits were suitable for human consumption and were therefore treated as an ecosystem supply service (Burkhard et al. 2012). Regarding deciduousness, species were classified as deciduous, semideciduous (i.e., tree species in which leaf fall coincides with bud burst and new leaf flush at the beginning of the rainy season, and

crowns are rarely completely leafless for more than a few days), and evergreen (Carvalho 2003, 2006, 2008, 2010).

Data analysis

To characterize species diversity in the two surveys, we used the first three Hill numbers: ⁰D (species richness), ¹D (the effective number of species accounting for their relative abundances), and ²D (the effective number of common species, which gives more weight to abundant and less weight to rare species). These metrics were estimated using incidence-based rarefaction and extrapolation (Chao et al. 2014; Hsieh et al. 2016).

Density of individuals (density: ind/ha) and species richness were compared between the two surveys (2010 vs. 2024) using paired analyses ($\alpha=0.05$). Paired differences were defined as [value in 2024 - value in 2010], so that positive test statistics and positive mean differences indicate increases over time, whereas negative values indicate decreases. The same paired tests were applied to assess temporal changes in the density and richness of ecosystem services and ecological traits (i.e., species origin, deciduousness, and fruit type).

Within each survey year (2010 and 2024), differences between two independent groups (e.g., native vs. exotic species, edible vs. inedible fruits) were assessed using Wilcoxon rank-sum tests ($\alpha=0.05$). Differences among more than two categorical groups (e.g., deciduousness classes) within each year were assessed using Kruskal–Wallis tests ($\alpha=0.05$).

We generated boxplots to show the results of variables between years (2010 and 2024) and across categories within the same year, displaying the median, interquartile ranges (IQR), and whiskers extending to 1.5 x IQR (McGill et al.

1978). All statistical and graphical analyses were performed in the R environment (R Core Team 2025).

Results

Floristic composition of greening of urban squares

Considering all squares, in the 2010 survey 1,030 individuals were sampled, distributed among 79 species and 33 families, whereas eight individuals corresponding to six morphospecies could not be identified at the species level (Table S1). In turn, in 2024, an increase in both the number of individuals and richness of species and families was recorded, with 1,274 individuals, distributed among 121 species and 39 families (Table S1). Nine squares showed increases in abundance, while twelve showed increases in richness (Table 1).

The diversity profiles based on Hill numbers indicated an increase in species richness from 2010 to 2024 (Fig. 2). The total number of species was higher in 2024, and the rarefaction/extrapolation curves for 0D (species richness) were uniformly above those for 2010 (Fig. 2), indicating that a greater number of species is expected in 2024 for a given sample size. The curves for 1D and 2D showed similar pattern, with higher values in 2024 across most of the sampling range (Fig. 2), indicating an increase not only in species richness (0D), but also in the effective number of common (1D) and dominant (2D) species between surveys. The density of individuals did not differ significantly between years ($t=0.70$; $p=0.4961$; Fig. 3a), whereas, consistent with the Hill-number results, species richness was significantly higher in 2024 than in 2010 ($t=2.95$; $p=0.0112$; Fig. 3b).

The species *Syagrus oleracea* had the highest abundance in both years (430 in 2010 and 270 in 2024) (Table S1). The ten most abundant species comprised 76.3% of all individuals in 2010, showing a reduction to 59.3% by 2024. Among these, *Cenostigma pluviosum* and *Moquilea tomentosa* were the second and third most abundant species respectively, in both years. Arecaceae, Fabaceae, and Bignoniaceae were the most abundant families in both years, with the latter showing the greatest increase compared to 2010. These three families also represented the largest number of species in 2024, respectively in the order Fabaceae (21 spp.), Arecaceae (19 spp.), and Bignoniaceae (9 spp.).

Ecological aspects and associated ecosystem services

In 2010, the urban tree community showed a marginal trend toward higher density of native individuals compared to exotic ones ($W=58.5$, $p=0.0731$; Fig. 4a), whereas in 2024 there was no difference in density between origins ($W=100.5$, $p=0.9268$; Fig. 4a). Temporal comparisons revealed no significant change in the density of native ($t=-1.07$, $p=0.3080$; Fig. 4a) or exotic individuals ($t=1.84$, $p=0.0891$; Fig. 4a) between surveys, although exotic species showed a marginal tendency toward higher density in 2024 compared with 2010. Regarding species richness, native and exotic species did not differ significantly in either survey (2010: $W=139.5$, $p=0.0532$; 2024: $W=132.5$, $p=0.1174$; Fig. 4b), with a marginal trend toward higher richness of exotic species in 2010. However, species richness increased significantly for both origins between 2010 and 2024 (native: $t=3.42$, $p=0.0045$; exotic: $t=2.51$, $p=0.0261$; Fig. 4b).

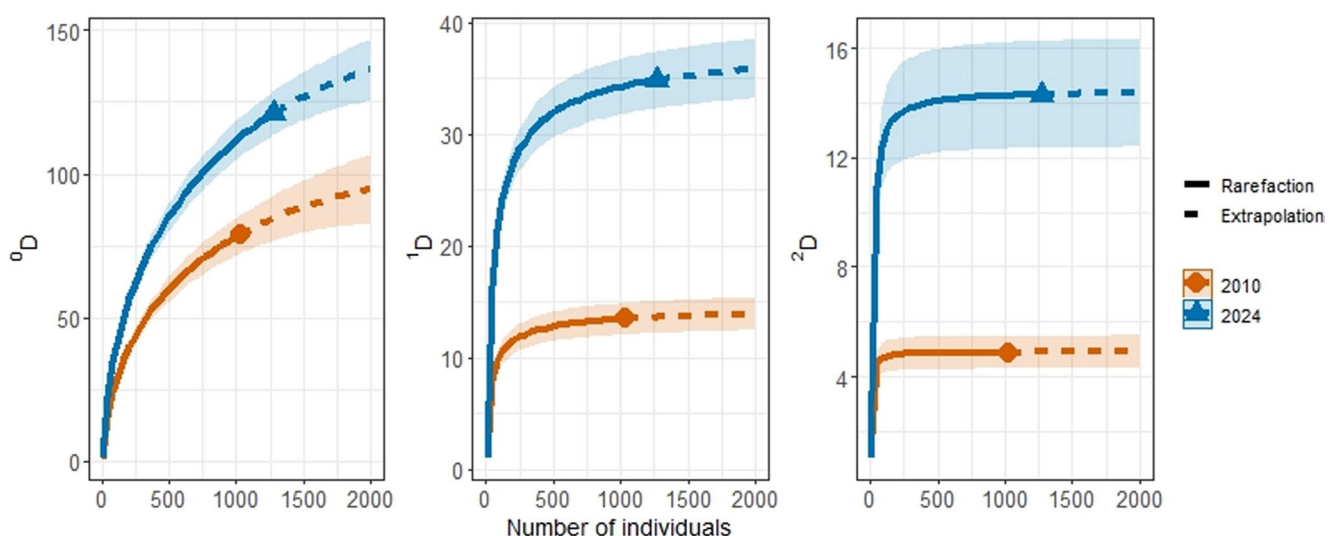


Fig. 2 Rarefaction (solid lines) and extrapolation (dashed lines) curves with 95% confidence intervals for Hill numbers of order 0D , 1D , and 2D of tree species recorded in two surveys conducted in 2010 (red) and 2024 (blue) in urban squares in Jataí, Goiás state, Brazil

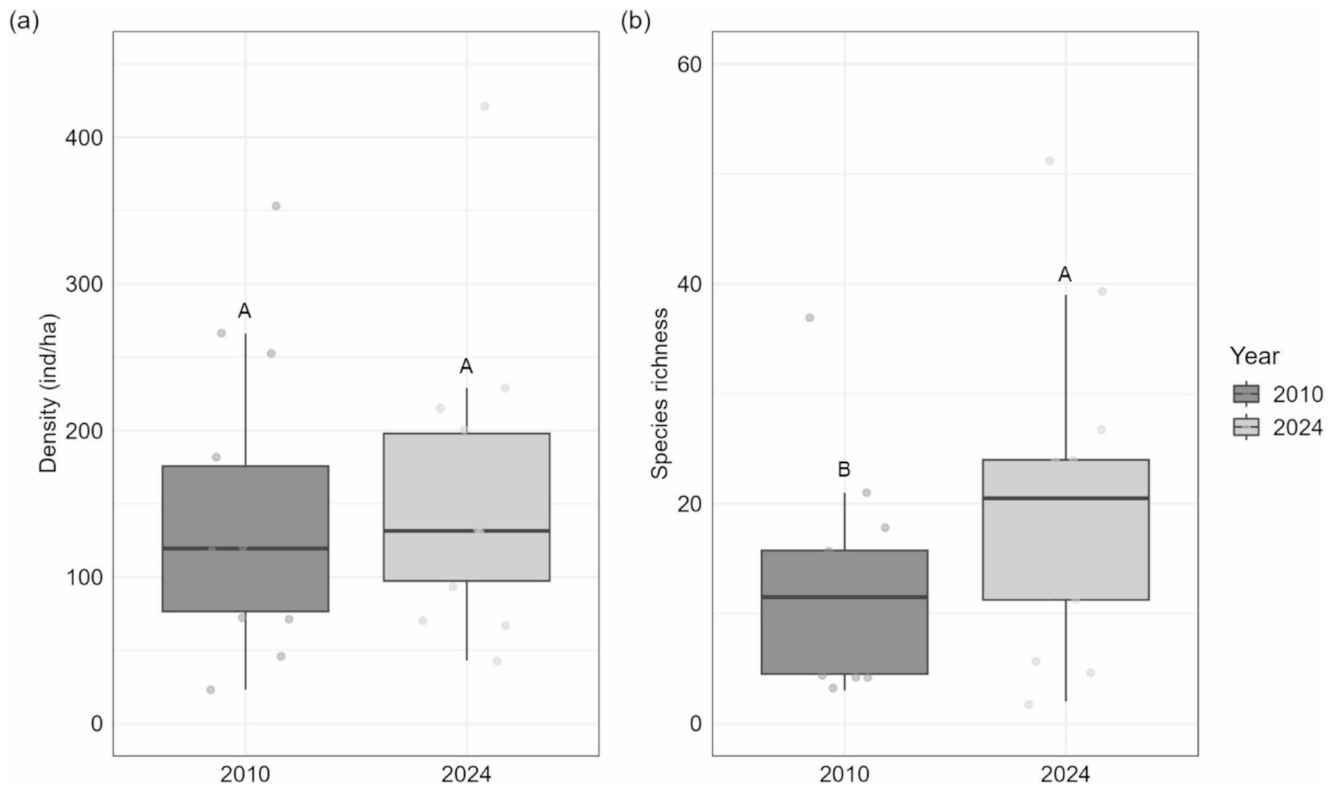


Fig. 3 Density (a) and species richness (b) per urban squares in Jataí, Goiás state, Brazil. The boxes represent the interquartile range (from the first to the third quartile), with the horizontal black line indicating

the median, and the whiskers extending to 1.5 times the interquartile range. Different letters indicate significant differences between years

When considering the five most abundant native and exotic species in each survey, the relative contribution of native species decreased (92.0% in 2010 to 76.7% in 2024), whereas the relative contribution of exotic species remained similar between years (41.0% in 2010 to 39.0% in 2024) (Table 2). Notable increases among exotics included *Mangifera indica* (8 to 43) and *Wodyetia bifurcata* (0 to 49) (Table 2); while *Ficus benjamina* decreased markedly (29 to 3). Among native species, *Syagrus oleracea* remained dominant but declined (430 to 270); *Myroxylon peruiferum* (0 to 41) and *Syagrus romanzoffiana* (4 to 40) increased (Table 2); and *Attalea phalerata* decreased substantially (19 to 1). Among the native species, only one was exclusive to the Cerrado phytogeographical domain (*Caryocar brasiliense*), whereas seven were exclusive to the Amazon and four were exclusive to the Atlantic Forest, while the remaining native species occurred in two or more Brazilian phytogeographical domains (Table S1).

Tree deciduousness also showed changes over the years. For density of individuals, evergreen species had higher values than deciduous and semideciduous species in both years (2010: $t=2.51$, $p=0.0009$; 2024: $t=2.50$, $p=0.0032$) (Fig. 5a). The pattern was species richness differed: in 2010, evergreens were the richest and semideciduous trees the least, while deciduous trees did not differ ($t=2.50$, $p=0.0044$) (Fig. 5b); on the other hand, in 2024

the richness of deciduous species equaled that of evergreens and was greater than that of semideciduous species ($t=2.50$, $p=0.0021$) (Fig. 5b). In the temporal comparison, the density of deciduous species tended to increase from 2010 to 2024 ($t=1.93$, $p=0.0758$), while the values for evergreens ($t=0.23$, $p=0.8187$) and semideciduous species ($t=-1.49$, $p=0.1609$) remained constant (Fig. 5a). Regarding richness, there was an increase in the number of deciduous and evergreen species (deciduous: $t=3.22$, $p=0.0066$; evergreen: $t=2.94$, $p=0.1130$), with no change for semideciduous species ($t=0.14$, $p=0.8879$) (Fig. 5b).

For the five most abundant species, semideciduous and evergreen categories decreased from 2010 to 2024 (Table 3), whereas deciduous species increased their relative contribution (6.8% to 13.6%). *Cenostigma pluviosum* was the most abundant semideciduous species and *Syagrus oleracea* was the most abundant evergreen species in both surveys (Table 3). The shift toward a higher contribution of deciduous species was driven mainly by increases in the abundance of *Myroxylon peruiferum* (0 to 41) and *Tabebuia roseoalba* (8 to 29) (Table 3).

The temporal dynamics for fruit supply revealed distinct responses. In 2010, there was no difference in density between edible and inedible fruits ($W=64.5$, $p=0.1292$) (Fig. 6a). However, in 2024, plants with inedible fruits had a higher density

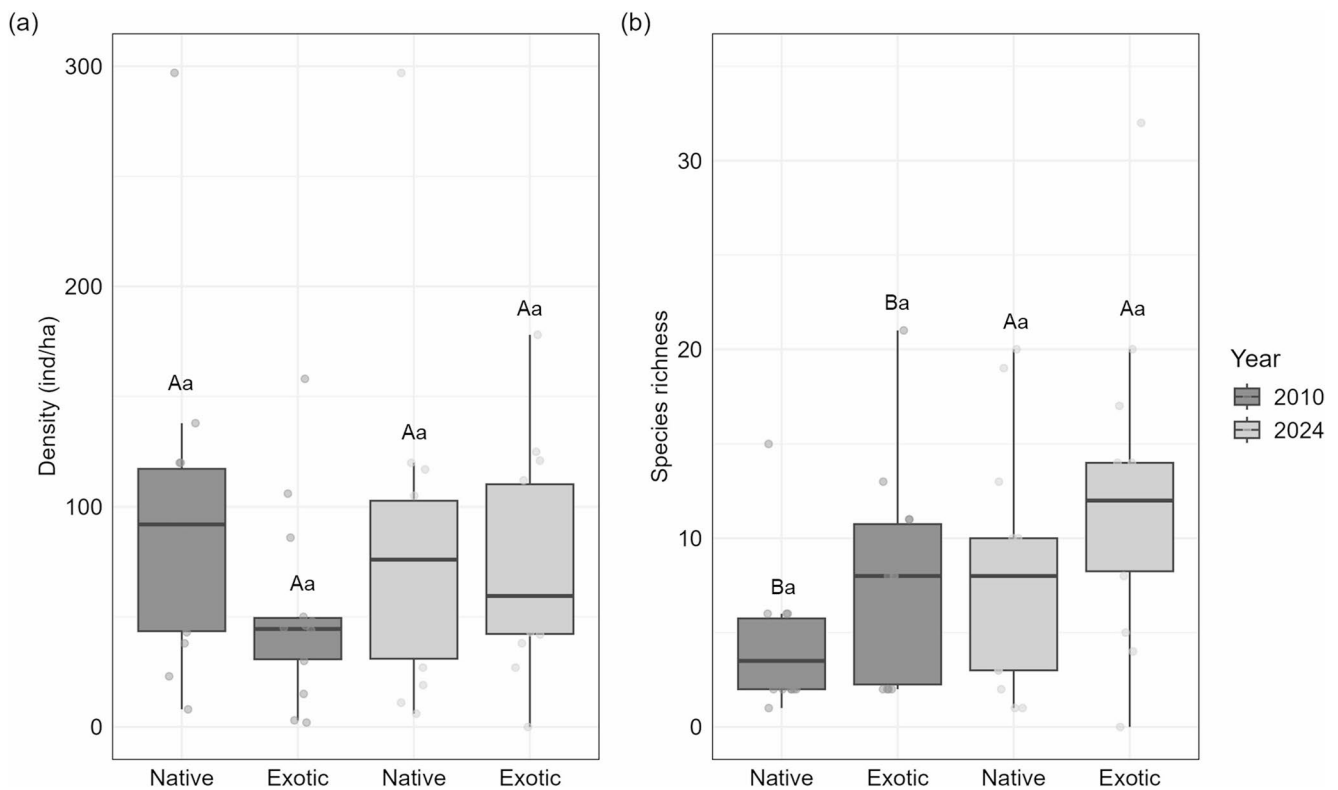


Fig. 4 Density (a) and species richness (b) of native and exotic plants per urban squares in Jataí, Goiás state, Brazil. The boxes represent the interquartile range (from the first to the third quartile), with the horizontal black line indicating the median, and the whiskers extending

to 1.5 times the interquartile range. Different capital letters indicate significant differences between years in the same category, while different lower-case letters indicate difference between categories in the same year

Table 2 Five most abundant species (number of individuals) in each origin category (exotic and native) for each survey (2010 and 2024)

Origin category	Species	2010	Species	2024
Native	<i>Syagrus oleracea</i>	430	<i>Syagrus oleracea</i>	270
	<i>Cenostigma pluviosum</i>	158	<i>Cenostigma pluviosum</i>	136
	<i>Attalea phalerata</i>	19	<i>Myroxylon peruiferum</i>	41
	<i>Triplaris americana</i>	10	<i>Syagrus romanzoffiana</i>	40
	<i>Jacaranda cuspidifolia</i>	8	<i>Tabebuia roseoalba</i>	29
	<i>Moquilea tomentosa</i>	48	<i>Moquilea tomentosa</i>	68
	<i>Ficus benjamina</i>	29	<i>Wodyetia bifurcata</i>	49
Exotic	<i>Tabebuia rosea</i>	26	<i>Mangifera indica</i>	43
	<i>Roystonea oleracea</i>	21	<i>Handroanthus impetiginosus</i>	40
	<i>Caryota urens</i>	19	<i>Handroanthus chrysotrichus</i>	37

than those with edible fruits ($W=34.0$, $p=0.0035$) (Fig. 6a). Regarding species richness, the number of species with inedible fruits was higher in both 2010 and 2024 (2010: $W=162.0$, $p=0.0033$; 2024: $W=151.5$, $p=0.0145$) (Fig. 6b). In the

comparison between 2010 and 2024, the density of edible ($t=-0.68$, $p=0.5055$) and inedible fruits remained the same ($t=1.25$, $p=0.2325$) (Fig. 6a). Species richness increased from 2010 to 2024 for both fruit supply categories (edible: $t=3.09$, $p=0.0085$; inedible: $t=2.69$, $p=0.0184$) (Fig. 6b).

The proportion of individuals among the five most abundant species decreased in both fruit categories from 2010 to 2024 (inedible: 27.4% to 26.2%; edible: 43.9% to 29.7% (Table 4). Among inedible fruit species, abundance increased for *Wodyetia bifurcata* (0 to 49), *Myroxylon peruiferum* (0 to 4) and *Handroanthus impetiginosus* (9 to 40) (Table 4). For edible fruit species, although their relative abundance declined overall, several species increased: *Mangifera indica* (8 to 43), *Syagrus romanzoffiana* (4 to 40), *Persea americana* (0 to 13) and *Inga laurina* (1 to 12) (Table 4).

Discussion

The results of this study indicate a temporal change in the urban tree community structure, with 24% increase in the abundance of individuals and a significant 53% increase in species richness. This result was reflected in increased diversity, indicating a reduction in the dominance of a few species

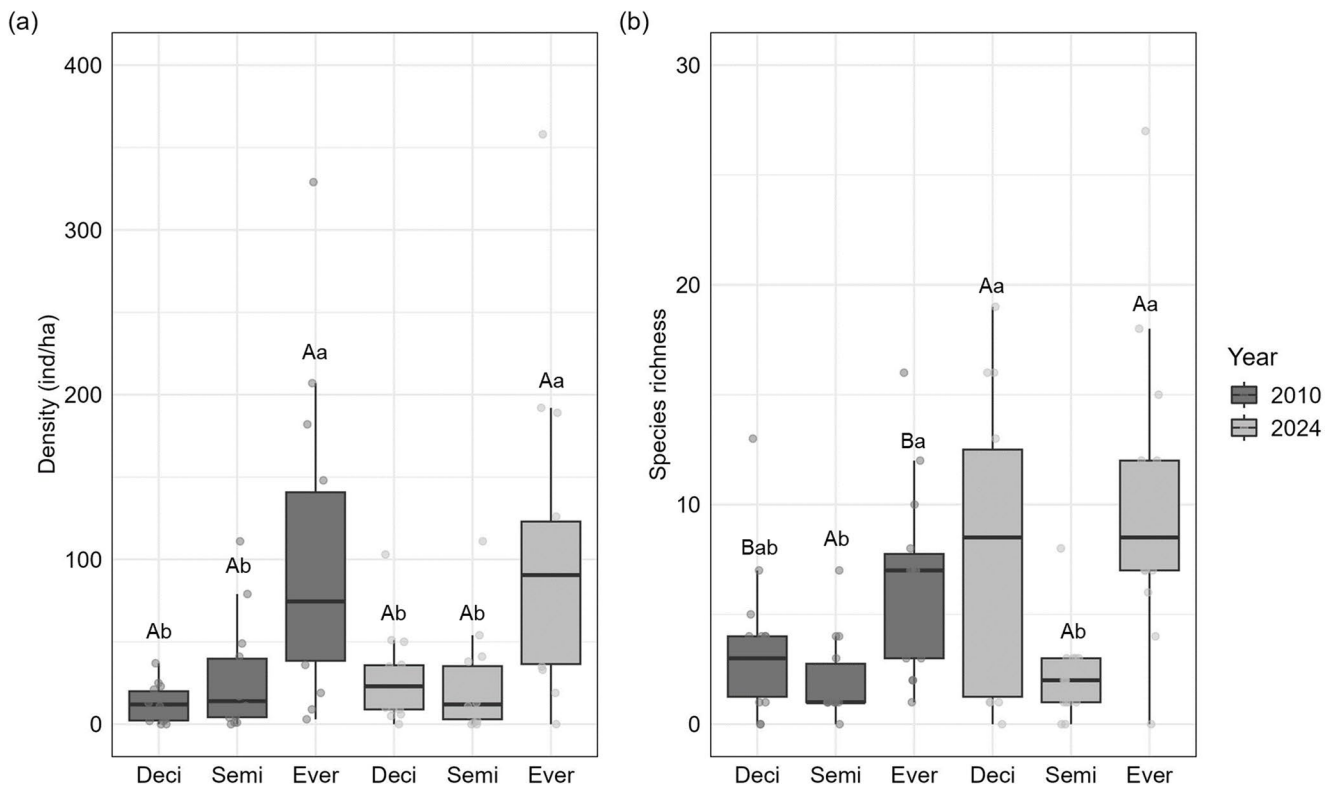


Fig. 5 Density (a) and species richness (b) of tree plants classified into three deciduousness categories (deci: deciduous; semi: semideciduous; ever: evergreen) per urban squares in Jataí, Goiás state, Brazil. The boxes represent the interquartile range (from the first to the third quartile), with the horizontal black line indicating the median, and the

whiskers extending to 1.5 times the interquartile range. Different capital letters indicate significant differences between years in the same category, while different lower-case letters indicate difference among categories in the same year

and an increase in tree species over time in the squares. Despite these changes, the analysis of ecological aspects, such as the species origin (native vs. exotic), deciduousness, and fruit supply to the population, revealed opportunities for management. Specifically, the need to prioritize native Cerrado species and select those with functional attributes that maximize the provision of essential ecosystem services, notably the provision of shade by evergreen species and the potential provision of food resources through fruit-supply trees.

Changes in floristic composition

The significant increases in species richness and diversity between the surveys indicate a positive trend in the management of urban square greening. Importantly, the size of the urban squares remained unchanged between 2010 and 2024, ensuring that the observed changes in richness and diversity are not confounded by variation in area. The diversity profiles based on Hill numbers indicate a consistent increase in tree diversity in Jataí's public squares over time. This pattern reflects not only higher species richness (0D), but also an increase in the effective number of typical (1D) and common (2D) species, suggesting a structurally more complex and

compositionally richer community. At the scale of individual squares, most squares also showed higher species richness in 2024, although some still exhibited comparatively low richness, indicating priority areas for targeted planting and management interventions. This favorable comparative position reinforces the effectiveness of the management practices adopted and highlights the role of squares in maintaining and/or increasing floristic diversity in urban environments. Greater floristic diversity, as observed, is a desirable attribute, as it provides higher phytosanitary resilience by reducing the risks of epidemics and widespread predation (Oliveira et al. 2024) and creates more dynamic and aesthetically attractive landscapes throughout the seasons (Silva 2012).

Despite increased richness and diversity, three species maintained high abundance over time: *Syagrus oleracea*, *Cenostigma pluviosum*, and *Moquilea tomentosa*. Even with a 37% reduction from 2010 to 2024, *S. oleracea* remained the most abundant in both surveys. Although originating in the Cerrado and Caatinga biomes, this species has a broad geographic distribution, as it occurs in all five regions of Brazil. Its presence is frequently observed in urban greening in the states of Goiás (Amaral and Guilherme 2014; Ferreira et al. 2024a, b), Tocantins (Silva et al. 2019), and Mato Grosso

Table 3 Five most abundant species (number of individuals) in each deciduousness category (semideciduous, deciduous or evergreen) for each survey (2010 and 2024)

Deciduousness category	Species	2010	Species	2024
Deciduous	<i>Tabebuia rosea</i>	26	<i>Myroxylon peruiferum</i>	41
	<i>Lagerstroemia indica</i>	17	<i>Handroanthus impetiginosus</i>	40
	<i>Handroanthus chrysotrichus</i>	10	<i>Handroanthus chrysotrichus</i>	37
	<i>Handroanthus impetiginosus</i>	9	<i>Tabebuia roseoalba</i>	29
	<i>Delonix regia</i>	8	<i>Tabebuia rosea</i>	26
	<i>Cenostigma pluviosum</i>	158	<i>Cenostigma pluviosum</i>	136
Semi-deciduous	<i>Spachea lactescens</i>	7	<i>Tecoma stans</i>	5
	<i>Leucaena leucocephala</i>	3	<i>Thevetia peruviana</i>	5
	<i>Genipa americana</i>	3	<i>Leucaena leucocephala</i>	4
	<i>Bixa orellana</i>	2	<i>Pleroma granulosum</i>	4
	<i>Syagrus oleracea</i>	430	<i>Syagrus oleracea</i>	270
	<i>Moquilea tomentosa</i>	48	<i>Moquilea tomentosa</i>	68
Evergreen	<i>Ficus benjamina</i>	29	<i>Wodyetia bifurcata</i>	49
	<i>Roystonea oleracea</i>	21	<i>Mangifera indica</i>	43
	<i>Attalea phalerata</i>	19	<i>Syagrus romanzoffiana</i>	40

do Sul (Aoki et al. 2020). The recurrence of this palm tree is attributed to its rapid growth, the ease of production and nursery production (i.e., seedlings are readily available), and especially to the fact that its fruits and palm hearts are appreciated and used in regional cuisine (Amaral and Guilherme 2014). Furthermore, Arecaceae species have high ornamental and commercial potential, given their showy foliage that adds beauty to the landscape (Barros et al. 2010; Batista and Guarim Neto 2015) and are therefore commonly found in urban squares (Silva et al. 2018; Soares et al. 2022).

Regarding *C. pluviosum*, the high abundance observed in this study is consistent with previous studies from different locations in Brazil, such as in the states of Paraná (Lima et al. 2007; Cayres et al. 2017); Mato Grosso do Sul (Pestana et al. 2011) and Goiás (Batista et al. 2023). Although native to Brazil, *C. pluviosum* is not endemic and has wide distribution throughout the Brazilian territory, occurring in five of the six Brazilian biomes, with the exception only of the Southern Pampas (Gaem 2020). Its high abundance observed in this study is due to its exuberant flowering, its wide canopy that provides dense shade, and its high adaptability to the urban environment (Bernardes et al. 2019),

characteristics that have consolidated it as a traditional species in Brazilian landscaping.

M. tomentosa, a species native to the Atlantic Forest, has also been frequently documented in urban greening (Pires et al. 2010; Silva et al. 2015; Silva and Borges 2018) and was the most abundant species recorded in street-tree surveys in Jataí, GO (Batista et al. 2023). Its use is associated with its dense canopy, which results in dense shade (Machado et al. 2006). The high abundance of this species in squares and streets of Jataí is mainly related to the regular supply of seedlings by the municipality's Department of Environment and Urban Planning. Thus, the successful establishment and high frequency of these three species in urban greening demonstrate the importance of prioritizing similar functional attributes, such as wide canopy for shading, ornamental or cultural value, and adaptability in the use of other species. This model can be applied to incorporate, for example, a larger set of native Cerrado species with these characteristics, thus promoting an improvement in regional floristic diversity.

Fabaceae was the species-richest family in the squares of Jataí and is also highly representative in the Cerrado flora (Santos and Silva 2025), with more than 43% of its species occurring in this biome (Santos and Silva 2025). In our survey, more than 57% of Fabaceae were native, which may relate to the family's broad functional diversity and ecological roles (Silva et al. 2018). Although Bignoniaceae is less diverse than Fabaceae at the biome scale, it showed local relevance, likely due to its ornamental value, as also reported in regional (Souza et al. 2015) and international (Saensouk et al. 2025) surveys. In our data, this pattern was largely driven by "ipês" tree species, especially *Handroanthus impetiginosus*, widely used in squares and parks (Oliveira et al. 2024; Ferreira et al. 2024a, b).

Ecological aspects and provision of ecosystem services

The results of this study revealed an increase in the use of exotic species in the greening of urban squares over time, a pattern consistent with urban greening in several Brazilian counties (Paiva 2009; Pires et al. 2010; Moura et al. 2020; Ferreira et al. 2024a, b). Although the marginal difference in native versus exotic individual density observed in 2010 was no longer evident in 2024, the density of exotic species showed a marginal tendency to increase over time, and species richness increased over time. This result highlights a direct challenge to the implementation of the National Urban Afforestation Plan guideline (PlaNAU), which is the prioritization of native species and the control of exotic species (Brazil 2025). The increase in exotic species richness can be attributed to the concept of "tropical landscaping", which has resulted in the use and commercialization of few species

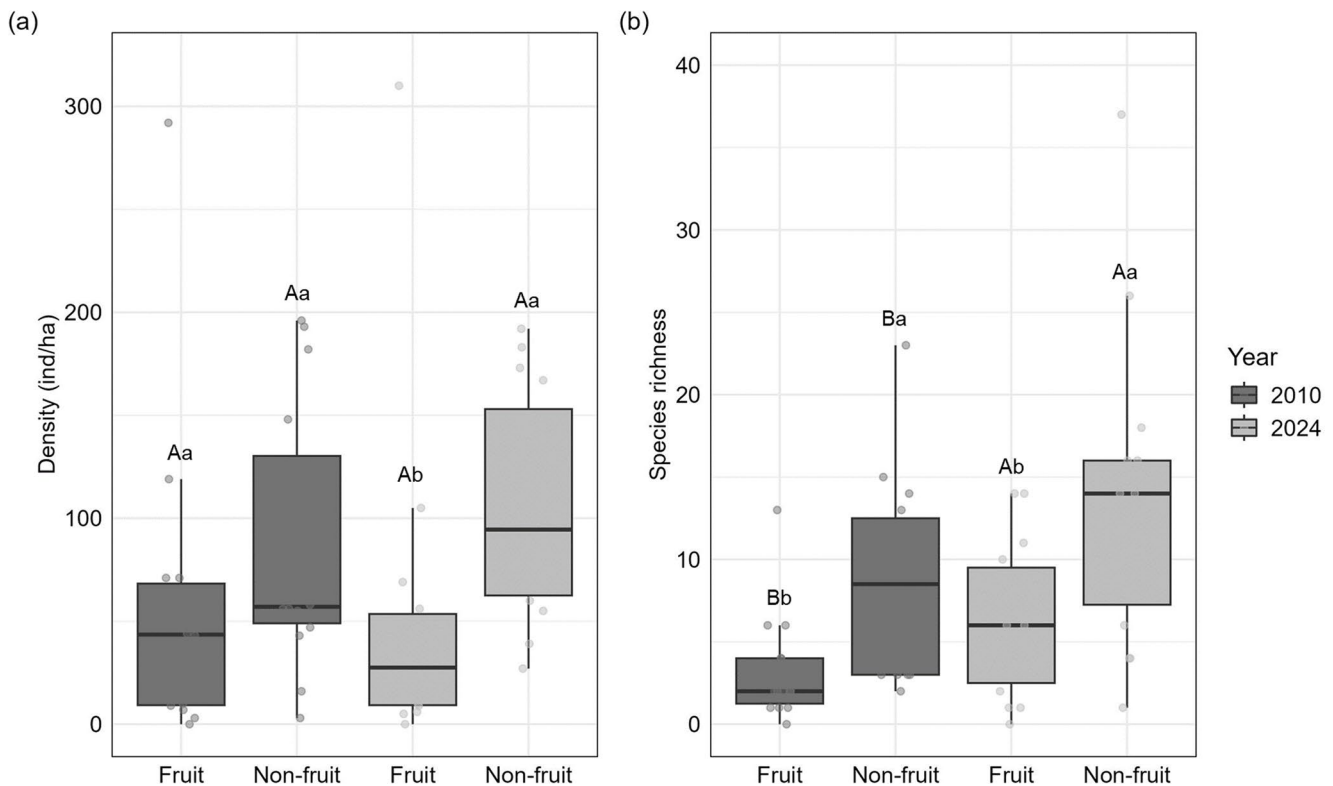


Fig. 6 Density (a) and species richness (b) of tree plants with fruit supply (fruit) and non-fruit supply (non-fruit) per urban squares in Jataí, Goiás state, Brazil. The boxes represent the interquartile range (from the first to the third quartile), with the horizontal black line indicating

the median, and the whiskers extending to 1.5 times the interquartile range. Different capital letters indicate significant differences between years in the same category, while different lower-case letters indicate difference between categories in the same year

Table 4 Five most abundant species (number of individuals) in each fruit supply category (fruit and non-fruit) for each survey (2010 and 2024)

Fruit supply category	Species	2010	Species	2024
Fruit	<i>Syagrus oleracea</i>	430	<i>Syagrus oleracea</i>	270
	<i>Mangifera indica</i>	8	<i>Mangifera indica</i>	43
	<i>Hymenaea courbaril</i>	5	<i>Syagrus romanzoffiana</i>	40
	<i>Psidium guajava</i>	5	<i>Persea americana</i>	13
	<i>Citrus ×limon</i>	4	<i>Inga laurina</i>	12
Non-fruit	<i>Cenostigma pluviosum</i>	158	<i>Cenostigma pluviosum</i>	136
	<i>Moquilea tomentosa</i>	48	<i>Moquilea tomentosa</i>	68
	<i>Ficus benjamina</i>	29	<i>Wodyetia bifurcata</i>	49
	<i>Tabebuia rosea</i>	26	<i>Myroxylon peruiferum</i>	41
	<i>Roystonea oleracea</i>	21	<i>Handroanthus impetiginosus</i>	40

(Ignatieva 2012), contributing to the homogenization of urban afforestation in some regions (McKinney 2006). However, the significant reduction in the abundance of *Ficus benjamina*, an exotic species with an aggressive root system that has caused damage to sidewalks and infrastructure (Júnior et

al. 2008; Nascimento and Guedes 2016), may indicate more careful management in the selection of exotic species, at least for those that have been identified as posing an imminent risk. Despite this positive sign, the increase in exotic species richness and their continued use in urban greening, combined with their high individual density, may increase ecological risks, including potential impacts on local biotic interactions and ecosystem functioning (Simberloff and Rejmánek 2011) and the establishment of bioinvasions, since many species considered invasive in Brazil were initially introduced as ornamentals (Zenni 2014), a fact unknown to the population and public authorities (Rufino et al. 2019).

In addition to ecological damages, the use and consequent increase in the use of exotic species can lead to a lack of knowledge and devaluation of regional flora, which, when used, reinforces regional identities (Heiden et al. 2006) and generally presents better adaptation to edaphoclimatic conditions, conferring greater resilience to pests and diseases, which can contribute to the biodiversity and genetic heritage of the Cerrado biome (Cavalcante et al. 2017). Therefore, encouraging the use of native species is crucial for biodiversity conservation, ecological sustainability, and the resilience of urban greening, which is a fundamental pillar for the success of the PlaNAU.

Regarding regulatory ecosystem services, i.e., the deciduousness of species, a significant change in the functional composition of the community was observed, with a marked increase in the abundance and richness of deciduous species. In the context of climate change and rising temperatures, providing shade becomes a primary service, representing one of the main reasons for using tree species in urban landscaping (Munduruku et al. 2019; Mussama et al. 2025), aiming at thermal comfort in squares and public roads by reducing temperature and conserving humidity (Martini et al. 2014; Souza et al. 2024). Nevertheless, the increased use of deciduous species may reflect a prioritization of seasonal aesthetics over permanent thermal comfort; however, this relationship is not direct. The prominence of evergreen palm trees such as *Syagrus oleracea*, *Wodyetia bifurcata*, and *Syagrus romanzoffiana* among the species with the highest numbers of individuals in the surveyed squares illustrates this complexity. Although palm trees can attenuate solar radiation, their contribution to thermal comfort is often lower in comparison with trees with broad, dense canopies, due to variables such as canopy architecture, leaf density, and shade projection area (Ribeiro et al. 2019). Sá Roriz et al. (2021) report, for example, that a single *Pachira aquatica* individual provided thermal benefits equivalent to 22 *S. oleracea* individuals. Thus, the use of palm trees must be planned and cannot be considered a substitute for canopy trees in providing effective shading.

Regarding the provisioning service, the dynamics of species with edible and inedible fruits indicated an increase in species richness in both categories, but the abundance of individuals remained stable for edible fruit trees and increased for inedible ones. The use of fruit species in urban landscaping, as exemplified by the increase in *Mangifera indica*, is a practice surrounded by debate for decades (Dias 1996; Santos and Teixeira 2001; Araújo and Pires 2009). On the one hand, these species beautify the landscape, attract birds, and can provide food (Marques et al. 2021). On the other hand, they can cause accidents, suffer vandalism, attract unwanted animals, and, paradoxically, lead to mistreatment of wildlife, such as the stoning of birds (Marques et al. 2024). Thus, the incorporation of fruit-bearing species into the afforestation of squares, like any other species, requires planning, knowledge about the species and the location, as well as the development of appropriate management and conservation strategies to maximize their benefits and mitigate their drawbacks. These strategies should also include public education and outreach to discourage harmful interactions with wildlife and to align management measures with local social behavior. Overcoming this impasse finds direct support in the PlaNAU (Brazil 2025), which provides an ideal framework for municipalities to develop management protocols that optimize the use of fruit-bearing species, transforming a

potential conflict into a concrete opportunity for food provision and connection with nature.

Guidelines for integrated urban greening planning

The results of this study offer valuable insights to guide the management of urban greening programs. Consistent with the issues discussed above, the observed increase in exotic species underscores the need to prioritize evidence-based species selection and planting guidelines to minimize ecological risks (Simberloff and Rejmánek 2011; Zenni 2014). In addition to the ecological impacts, this practice may perpetuate the devaluation of regional flora and reduce opportunities for incorporating Cerrado native species into urban green spaces, while sustaining a seedling market focused on a limited portfolio of species, often dominated by exotic species (Camillo and Tombolato 2016), to the detriment of native species (Schenkel et al. 2025). Moreover, our findings indicate that Cerrado-exclusive species are underrepresented even among the native species used in Jataí's squares, whereas broadly distributed taxa and species typical of other Brazilian biomes are relatively more frequent. This pattern reinforces the need for urban greening guidelines that not only increase the overall use of native species but also prioritize those that are typical or endemic to the Cerrado. Breaking this pattern requires generating demand for native species. Thus, given the significant landscape potential of the Cerrado flora (Neto et al. 2010; Soares 2022), investments in research and the structuring of public and private nurseries are necessary to meet this demand. Such a change would bring additional socioeconomic gains, strengthening local production chains, such as that of seed collectors, a market that generated more than R\$ 1.8 million in Brazil only in the Xingu Seed Network in 2024 (Rede de Sementes do Xingu 2025). The increasing prevalence of deciduous species in the landscaping of public squares, as documented, should be analyzed from two main perspectives: the impacts on thermal comfort and the implications for management. Seasonal leaf fall, a natural process that in native ecosystems is beneficial for soil moisture conservation and nutrient cycling (Lopes et al. 2009; Mateus et al. 2013), is often perceived as “dirt” in the urban context (Gross et al. 2012; Moura et al. 2020). Consequently, the increase in the proportion of deciduous species raises the demand for sweeping and cleaning services to prevent drainage obstruction, implying higher operational and labor costs for public administration. This does not suggest the exclusion of deciduous species, many of which, such as the “ipês” (Bignoniaceae family), have undeniable aesthetic and cultural value, but it highlights the imperative need for technical, economic, and logistical planning that considers these management aspects. From the perspective

of provisioning services, edible fruit species are considered a potential asset for urban squares, contingent upon their use being guided by appropriate planning and management. The stability in the abundance of individuals with edible fruits, contrasting with the increase in species richness in this category, highlights the inherent complexity of using fruit trees in landscaping. The discussion about their benefits (beautification, attraction of birds, and food potential) and disadvantages (risk of accidents, vandalism, and attraction of unwanted fauna) is long-standing (Santos and Teixeira 2001; Araújo and Pires 2009; Marques et al. 2021). Overcoming this potential conflict requires moving beyond simple species choice and developing integrated management protocols that consider phenology and reproductive traits. In particular, fruit size and mass should be considered because larger/heavier fruits pose a higher risk of injury or property damage when they fall; thus, in public squares, priority should be given to species with smaller/lighter fruits and shorter fruiting periods to reduce both impact severity and the duration of exposure to falling-fruit incidents (Santos and Teixeira 2001; Gonçalves 2004; Moretti and Nishihata 2023). Furthermore, it is crucial to establish procedures for harvesting, sanitization, and safe distribution, coupled with environmental education programs that discourage vandalism and intentional physical damage to trees (e.g., branch breaking) and promote responsible use, maximizing potential benefits for food security (Tomasini and Sattler 2006). The attraction of wildlife, an expected consequence, also requires the inclusion of professionals in the field in planning and management. Finally, multidisciplinary investigations are needed to assess the quality and sanitary safety of fruits in urban environments subject to pollution (Manica 1997; Gonçalves 2008), and these results should be widely disseminated in an accessible manner.

Conclusions

This study demonstrates that urban greening in public squares, although it has advanced in species richness and diversity, still lacks fundamental ecological principles and national strategic guidelines. The analysis of the temporal dynamics of urban greening demonstrated that the quantitative increase in species diversity did not translate into a qualitative improvement in the capacity of the tree community to provide ecosystem services. Although a significant increase in species richness and diversity was observed between the surveys, a positive indicator of ecological diversity, the analysis of ecological aspects revealed that management prioritized species with low potential for the provision of essential ecosystem services. A critical transition in management was observed, in which a tendency toward dominance of native species was replaced by equivalence with exotic species, while the

number of deciduous species increased significantly, compromising the provision of permanent shading. Additionally, the abundance of edible fruits remained stable. The findings of this study reveal that quantitative evolution was not accompanied by adequate ecological criteria. Therefore, they reinforce the urgent need for municipal planning to align with the PLANAU, prioritizing the regional flora of the Brazilian Cerrado and selecting species based on their functional attributes to guarantee the provision of ecosystem services fundamental to urban sustainability and Cerrado conservation.

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Author contributions All authors contributed to the conception, design, analysis, interpretation, and documentation of the study. Material preparation and data collection were carried out by J. de O., F. (A) G. G., J. S. O., L. (B) L., E. V. E. de J. A., E. M. da S., W. (C) F., C. R. A., and (D) L. M. Statistical analyses were performed by D. L. M. The first draft of the manuscript was written by J. de O., M. S. de F., and A. R. D. All authors reviewed previous versions of the manuscript and approved the final version.

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Data availability Data generated and analyzed during the current study are available from the corresponding author upon request.

Declarations

Competing interests The authors declare no competing interests.

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