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ARTICLE

Green infrastructure of Brazilian bike paths: cyclists' perception and afforestation in Rio de Janeiro City

Infraestrutura verde das ciclovias brasileiras: percepção dos ciclistas e arborização na cidade do Rio de Janeiro

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Abstract
The urgency of enhancing environmental quality, promoting a green economy, and forging a new societal paradigm falls upon the managers of Brazilian cities. It is crucial to promote sustainable transportation modes. Thus, the present study aims to assess Brazilians' perception of urban bike paths and to assess the vegetation planted along bike paths in Rio de Janeiro City. Accordingly, a survey was conducted with cyclists from various Brazilian cities mainly located in the Atlantic Forest biome. A survey about the green structure in Rio de Janeiro's bike paths was also carried out to assess its impact on infrastructure and potential issues. A questionnaire consisting of eighteen carefully formulated questions was applied to the Google Forms platform. Clearly, participants acknowledge greenery as a strategy to provide crucial benefits to people, such as heat reduction and shade creation, as well as pointed out challenges like problems arising from improper root-growth in some plant species and public lighting reduction. In total, 30 plant species were identified on Rio de Janeiro's bike paths; *Terminalia catappa* and *Pachira aquatica* were the most common ones. Leaf fall, pavement breakage and species with large fleshy fruits that can cause bike accidents are among the problems caused by the identified plant species.
Keywords: urban greenery, urban mobility, environment, ecological landscaping.

Resumo
A urgência em melhorar a qualidade ambiental, promover a economia verde e forjar um novo paradigma social recai sobre os gestores das cidades brasileiras. É crucial promover modos de transporte sustentáveis. Assim, os objetivos do presente estudo são avaliar a percepção dos brasileiros sobre ciclovias urbanas e avaliar a vegetação plantada ao longo das ciclovias na cidade do Rio de Janeiro. Nesse sentido, foi realizada uma pesquisa com ciclistas de diversas cidades brasileiras localizadas principalmente no bioma Mata Atlântica. Também foi realizado um levantamento sobre a estrutura verde das ciclovias do Rio de Janeiro para avaliar seu impacto na infraestrutura e potenciais problemas. Um questionário composto por dezoito questões cuidadosamente formuladas foi aplicado na plataforma Google Forms. Os participantes reconhecem a vegetação como uma estratégia para proporcionar benefícios cruciais às pessoas, tais como a redução do calor e a criação de sombra, bem como apontaram desafios como problemas decorrentes do crescimento inadequado das raízes em algumas espécies de plantas e da redução da iluminação pública. No total, foram identificadas 30 espécies de plantas nas ciclovias do Rio de Janeiro; *Terminalia catappa* e *Pachira Aquatica* foram as mais comuns. Queda de folhas, quebra de calçamento e espécies com frutos grandes e carnudos que podem causar acidentes de bicicleta estão entre os problemas causados pelas espécies vegetais identificadas.
Palavras-chave: vegetação urbana, mobilidade urbana, paisagismo ecológico, meio ambiente.

Introduction

Estimates show that the global urban population will account for 68% of the world's inhabitants by 2050, and over 500 cities will house more than one million people, despite the eight urban mega-regions that will hold populations exceeding 20 million people (ONU, 2022). Nowadays, the Brazilian population is close to 215 million people, and a significant fraction of it is living in major metropolises, such as São Paulo, Rio de Janeiro, Brasília, and Salvador. High population density in cities is clear, since 17 municipalities in the country have populations exceeding one million inhabitants, and they concentrate 21.9% of the Brazilian population, i.e., 46.7 million people (IBGE, 2022). Transportation is one of the main challenges associated with these large cities since it is highly polluting, and its infrastructure is inefficient. Rêgo (2022) mentions that cycle paths and cycle lanes reduce traffic problems and are a sustainable alternative for urban mobility.

The significant concentration of vehicles and people in a few municipalities results in substantial traffic jam, fuel consumption, energy expenditure, toxic gas emissions, water pollution, and higher temperatures, among other factors contributing to public health deterioration. Proper pavement and greenery planning along bike paths could encourage more frequent cycling. According to Abramet (2022), traffic violence represents one of the leading causes of death worldwide, and the total number of serious accidents involving cyclists in Brazil increased by 30% in the first five months of 2021 in comparison to the same period in 2020. In absolute numbers, there were 5,022 incidents with bikes in 2020 and 6,792 in 2021.

Ribeiro et al. (2023) consider that heat and high temperatures disfavor the use of bicycles for daily activities, with the position being observed in wooded areas, where the shading of surfaces prevents direct sunlight, making bicycle travel more pleasant. Modern managers aiming to improve urban quality of life should prioritize the creation of more biophilic projects and cities. The term "Biophilic City" refers to cities immersed in nature, with several visible and accessible natural systems for all (Beatley, 2011). These spaces' construction in Brazilian cities can be combined with actions aimed at implementing green infrastructure in them. Bike paths are perfect spaces for such integration since they have many open areas along their route that can be used for urban greening, gardens, and orchards, and to form true urban ecological corridors to help improve urban ecosystems (Vargas-Maldonado et al., 2021).

Thus, the aims of the present study were to 1) diagnose Brazilians "perception of the green infrastructure in urban bike paths by assessing environmental awareness levels and information about citizens" needs, as well as by collecting critiques and suggestions to help develop future management plans, urban transportation strategies, and landscaping projects; 2) survey the species used in bike paths' green infrastructure in Rio de Janeiro City and discuss species-associated issues and possible solutions to them. It is worth noting that a significant portion of these projects do not distinguish between urban vegetation planted on sidewalks and that planted on cycle paths, a fact that highlights the relevance of this study for planning these projects in Brazilian cities.

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Materials and Methods

Brazilians cyclists' perception diagnosis

Semi-structured questionnaires created on Google Forms were applied and distributed through social networks between November and December 2022 to Brazilian citizens. Adults interested in participating in the survey answered open and objective questions about their perception of bike paths' infrastructure and urban green areas. There were no specific criteria for selecting volunteers, except for being urban bike path users. For this research, urban cycle paths were considered cycle paths, cycle lanes, and cycle paths. Respondents also had the opportunity to read and approve a pre-research consent form. It was explained that every part related to urban greening was considered green infrastructure, while the construction part, foundations, pipes, telephone cables, and electrical grid, among others, was called gray infrastructure.

For data collection, sixteen (16) questions were sent to each volunteer, with clear and objective questions, aiming to detect citizens' concerns and assess their opinion on urban trees, ornamental plants, and cycle path infrastructure. The questionnaires were sent through social networks, based on the methodology adopted by Maistro and Ferraz (2018). The questionnaire addressed aspects such as 1) Gender; 2) Age group; 3) Educational level; 4) Number of bicycles at home; 5) Perception of the level of urban vegetation in the city; 6) Perception of the existence of ornamental plants on the city's cycle paths; 7) Perception of the existence of urban trees on the city's cycle paths; 8) Perception of the use of vegetation on the cycle paths in a neighborhood; 9) Main disadvantages regarding urban trees on the cycle paths in a neighborhood; 10) Cyclists' perception of the advantages of using trees and ornamental plants on the cycle paths; 11) Who do residents complain to about problems with bike paths? 12) Who is responsible for planting trees and ornamental plants in your city? 13) How do you contribute to urban landscaping in your city? 14) What could be done to encourage the use of vegetation and ornamental plants on bike paths? 15) Where do the trees you would like to see planted on bike paths come from? and 16) What are the main needs of bike paths? In total, 150 individuals from 48 cities in 10 Brazilian states and the Federal District answered the questionnaire. Since there was no specific filter in this study, some cities did not belong to the Atlantic Forest biome, but most of the responding citizens lived in the Atlantic Forest biome (Fig. 1). Respondents were not required to answer all questions if they had any questions.

The responses received made it possible to outline the profile of residents and document the perception of these Brazilians about urban vegetation and cycle paths in their cities, without the application of any program for prior screening of responses (Table 1).

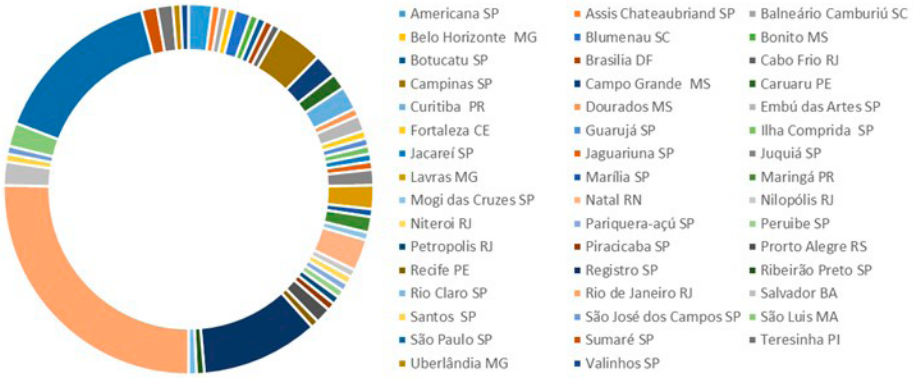

Fig. 1. Distribution of citizens residing in the cities that responded to the questionnaire.

Table 1. Social Profile of Interviewed Citizens.

Variable	%
Gender	
Non-Binary	0.7
Female	50.0
Male	49.3
Age Range	
18 - 30 years	21.0
31 - 40 years	25.0
41 - 50 years	27.7
51 - 60 years	18.3
Above 61 years	8.1
Education	
Completed Primary	0.7
Completed High School	6.0
Incomplete Higher Education	7.9
Completed Higher Education	31.1
Postgraduate	

All 150 participants lived in urban centers within the Atlantic Forest domain, and they voluntarily answered the questionnaire. Because ornamental plants attract the attention of the population and are planted by the population in cities, we chose to include this item in the evaluation.

Subsequently, the collected data were processed in a Microsoft Excel 2007 spreadsheet and results were presented through descriptive statistics.

Survey on green infrastructure of bike paths in Rio de Janeiro City

A survey on tree vegetation was conducted in five bike path stretches in Rio de Janeiro municipality. These stretches were considered continuous and each one of them covered 800 m. They were chosen for being the busiest stretches in each assessed neighborhood, namely: Lagoa Rodrigo de Freitas, Humaitá, Botafogo, Gávea, and Leblon. Pavement and streets-associated bike paths were assessed, not including for squares and parks (Fig. 2).

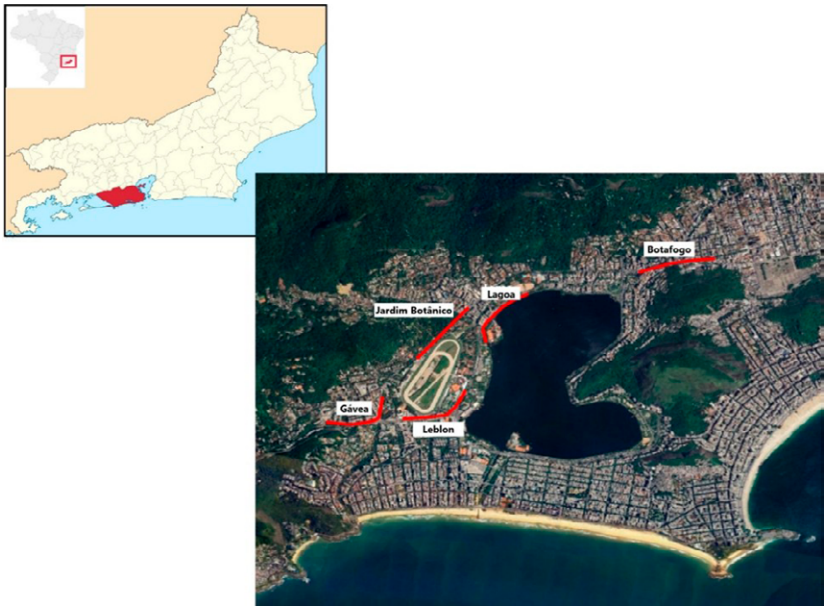

Fig. 2. Location of cycle paths in the city of Rio de Janeiro-RJ.

Greenery trees along the bike paths were herein identified within the maximum distance of three meters from the bike path. Field data, including plant diameter, height, mean crown diameter, distance from the trunk to the beginning of the bike path, rate of crown coverage over the bike path, and pavement damages were collected for each tree. Information about geographic distribution, leaf dehiscence, fruit size, and crown density of each species was collected from specialized literature such as Lorenzi (2020), Lorenzi (2022), and Flora do Brasil (2024).

Crown diameter measurements were taken in two directions to form a „cross-like“ shape. The mean plant diameter was calculated and the occupation area of each tree was determined. Diameter measurements were taken with the aid of measuring tape; they included circumference data that were converted into diameter. Bike path area covered by the tree crown was calculated through the following formula:

Wherein, A is the tree crown area covering the bike path; W is the bike path width (1.5 m) was the standard size for the municipality‘s bike paths); L is the total length from the beginning of the crown on the bike path to the end of it; P is the rate of the area covered by the tree crown. Tree crown rate was taken into consideration because it rarely occupies 100% of the space, as shown in (Fig. 3). In this case, the formula applied creates a rectangle based on the width multiplied by the length. However, not all of the rectangle is occupied by the tree’s canopy, so “p” is the relative percentage, ranging from 0 to 1 of the area occupied by the canopy. For example, a tree occupies a length of 5 m on a bike path with a width of 1.5 m, which would give an area of 7.5 m², but the canopy only occupies 40% of this rectangle. Therefore, we multiply by 0.4, resulting in 3m² occupied by the canopy tree.

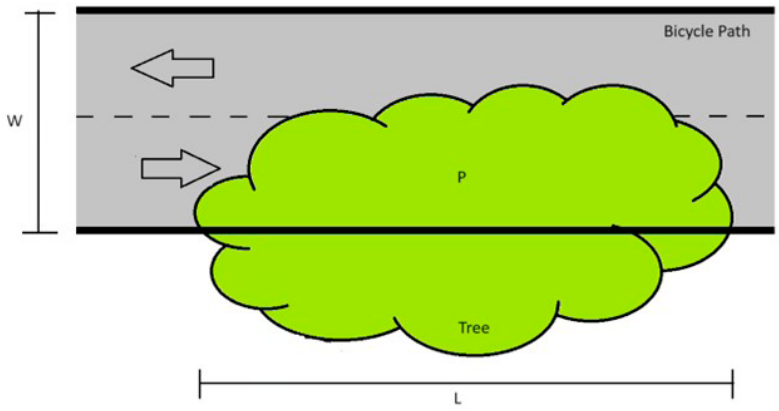

Fig. 3. Scheme for quantifying the area covered by a tree crown on a bike path segment.

Data on plants' origin, nomenclature, botanical family, leaf dehiscence, fruit size, and crown density were gathered in the studies by Lorenzi (2020) and Lorenzi (2022) and in the virtual herbarium Flora do Brasil (2024).

The species were classified by creating a presence (1) and absence (0) ranking based on five observed bike-path issues: large fruits (with 1 for large fruit and 0 for small fruit), sparse crown (with 1 for sparse crown and 0 for dense crown), dehiscent leaves (with 1 for deciduous leaves and 0 for evergreen leaves), pavement breakage (with 1 for species that damage the pavement and 0 for trees that do not damage the pavement), and invasiveness (with 1 for invasive species and 0 for non-invasive species), following the method by Bergallo Filho et al. (2021). The sum of all issues was calculated to rank the species, presenting those least recommended for use on bike lanes. Finally, we made suggestions for suitable species based on data collected in Rio de Janeiro City and information available in literature, including species already suggested in other scientific studies.

Results and Discussion

Brazilians cyclists' perception diagnosis

With respect to gender information, 0.7% of participants identified themselves as non-binary, 49.3% as female, and 50.0% as male (Table 1). This finding shows that both the older and younger populations are concerned and attentive to the quality of green spaces in their cities and to the type of transportation that has been used.

According to the data collected, the perception and concern are more remarkable among individuals with higher schooling: 85.40% of respondents had college majors or post-graduation degrees, and only 14.60% of them did not go to college or finish high school. This result may be associated with individuals who answered the questionnaire, who are likely associated with higher education institutions, or with the academic environment.

According to Pans et al., (2023), mobility policies should take into account several factors such as gender, age, and socioeconomic level, among others, as these differences are fundamental in the development of active transportation programs for the population. According to Santos and Santos (2022), the high cost of tickets, the low turnover of public transport in peripheral areas, and the lack of infrastructure and policy for non-motorized transport, such as bicycles, mean that the low-income population is denied the right to have quality mobility in the city. Although the questionnaire was open, it may have been more comprehensive for this population. It was observed in Table 1 that the research reached the population with more years of study, that is, 54.3% of the people had postgraduate degrees. In Brazil, people with more years of study generally have higher income. According to Duarte et al. (2017), the increase in socio-spatial segregation is linked to the fact that people with lower incomes have worse housing conditions and a lower percentage of urban tree coverage.

Most respondents stated to have 1 and 2 bikes at home (23.50% and 28.90% respondents, respectively). The use of public transport has decreased in Latin America, while the preference for bicycles and walking has increased (O Estado de São Paulo, 2021). Brazil still faces several problems regarding urban mobility due to insufficient public transport, high fares, insufficient infrastructure for public transport, bicycle use and walking (Boareto, 2021).

Brazil is considered one of the 16 mega biodiverse countries in the world, presenting the greatest biodiversity on Earth, with the largest number of plants on the planet for landscaping, with 8,258 species of trees (Cardim, 2022). According to SOS Mata Atlântica (2025), the Atlantic Forest is present in 17 Brazilian states (Espírito Santo, Rio de Janeiro and Santa Catarina, and part of the territory of the states of Alagoas, Bahia, Goiás, Mato Grosso do Sul, Minas Gerais, Paraíba, Paraná, Pernambuco, Rio Grande do Norte, Rio Grande do Sul, São Paulo and Sergipe), with only 8.5% of its vegetation cover remaining, with an exuberant flora with 15,700 species of plants, 8 thousand of which are endemic; presenting 5% of the world's vertebrate species. The people who responded to the questionnaire lived predominantly in the Atlantic Forest biome, that is, 151 citizens from 10 Brazilian states (plus the Federal District) totaling 48 cities responded to the survey. This shows the importance of this study for the conservation and recovery of the green cover of this biome, as this study can serve as a basis for future decision-making.

The perception about urban greenery in the assessed cities was categorized by respondents as "reasonably green," "poorly green," or "very green." In total, 45.5% of respondents stated that their cities are "reasonably green," and this category was followed by "poorly green" (37.7%) and "very green" (16.6%). Greenery reflects social and environmental injustices in Brazil. Pinotti et al. (2024) also noted the difference in perception of urban afforestation according to levels of education, in the study it was observed that citizens with higher education had a greater perception of the degree of urban afforestation. According to Duarte et al. (2017) to reduce the difference in access to urban afforestation, it is necessary to reduce social inequality in access to urban infrastructure between social classes in Brazil. In this sense, the subdivision of urban land must provide conditions for afforestation, regardless of the social class for which it is intended.

In total, 53.7% of residents classified bike paths as having "few ornamental plants"; 31.5% classified them as "without any ornamental plants"; 11.4%, as having "reasonable number of ornamental plants"; and 3.4%, as having "many ornamental plants". This perception can be associated with the neighborhood where people live in and with the space where bike paths are located in. Regardless of the observed bike path, there seems to be low concern with using ornamental and functional plants in Brazilian bike paths' landscaping (Paiva et al., 2022), and this statement can be observed in people's perceptions about it. Residents also observed that 65.8% that the city has few trees along bike paths, 31.5% of them considered it reasonably tree-covered and only 2.7% perceived it as very tree-covered. Nascimento et al. (2023) mention that each individual reacts differently to the perception of urban greenery due to the ways in which people present cultural experiences and values when they relate to their environment. When residents were asked about the advantages of urban vegetation on the main cycle paths for a neighborhood, 40.6% mentioned as an advantage "heat reduction"; 27.9%, "shade"; 11.0%, "improved air quality"; 7.4%, "beauty of the streets", 1.5%, "production of flowers and fruits"; 1.5%, "noise reduction"; and 10.1%, "other advantages" (Fig. 4).

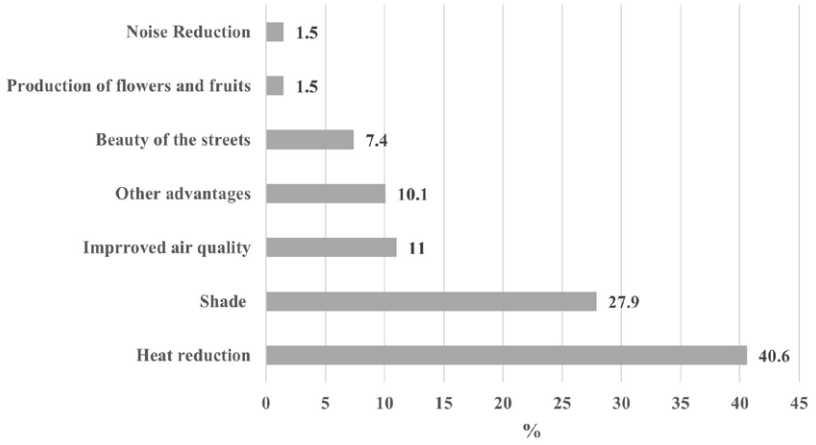

Fig. 4. Main bike paths' urban-greenery advantages observed by the citiziens.

This finding shows that heat is a significant current concern in urban centers, in different Brazilian cities. According to Peres and Schenk (2021) São Paulo State is the one that has been most affected by the effects of climate change, the authors mention that the city of São Paulo, over the last seven decades, has warmed the air temperature by 2.1 ºC, with a decrease in relative air humidity at 7%. In a study published by Barros and Roomero (2023) in the city of São Carlos-SP, it is concluded that there is an understanding on the part of the population of people about the importance of growth, as users in the scientific area sought to carry out similar activities in shaded areas, as the vegetation provided natural ventilation, leaving the environment pleasant. According to Meneses and Sales (2018), the shading provided by vegetation helps to mitigate the temperature of the asphalt used in the construction of cycle paths - a reduction of approximately 14°C in this temperature.

The present study also aimed at identifying the main disadvantages observed by the interviewees regarding urban greenery by the existing bike paths in their neighborhoods. In total, 31.6% of residents did not answer this question; 27.9% stated that "problems with the sidewalk" is the main disadvantage; 14.0% mentioned public "electrical lighting reduction" in the cities; 9.6% mentioned "dirt on streets and sidewalks"; 8.8% observed other disadvantages; 6.6% highlighted "problems with the electrical or telephone network"; and only 1.5% reported "dirt caused by birds", as bike path greenery disadvantages (Fig. 5).

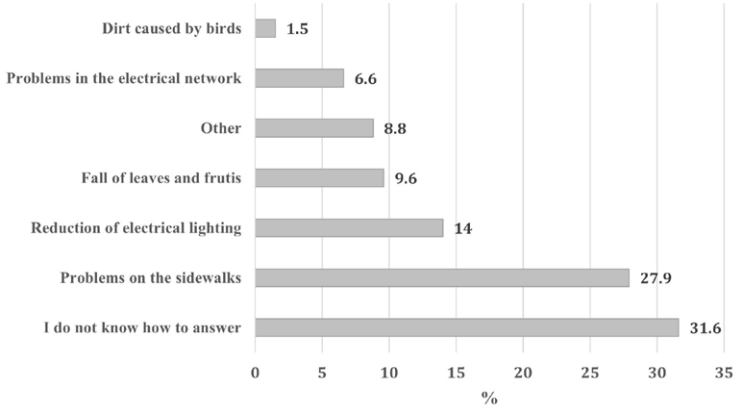

Fig. 5. Main disadvantages observed by the citizens regarding urban greenery on a cycle path.

The item "problems with sidewalks" points out that inappropriate trees are still being used in Brazilian street greenery, because residents highlighted problems in sidewalks as one of the main disadvantages of street greenery of urban vegetation in cycle paths. The item “problems with the electrical or telephone network” suggests that many people believe that gray infrastructure, that is, cables and wires in the electrical and telephone network, should be prioritized to the detriment of green infrastructure (trees and bushes). The interviewees in many Brazilian cities think that trees hinder the gray infrastructure, since they require pruning, branch cutting or even plants’ removal by the competent authorities. The data in Fig. 5 show that intensive environmental awareness work needs to be done with citizens of Brazilian cities, as 31.6% were unable to answer the question. The use of urban vegetation in Brazilian cities is urgently needed to combat the effects of climate change. Marchioni et al. (2022) metioned that, in the climate change era, the adoption of strategies for building more resilient landscapes becomes more immediate, with the use of nature-based solutions to help urban afforestation to build more resilient cities.

The questionnaire also assessed whether cyclists saw advantages in using trees and ornamental plants by bike paths. The main advantage observed by them was "improvement in the quality of the air" (15.9%), which was followed by "beauty of the streets" (11.3%), "flowers and fruits’ production" (2.6%), "other advantages" (2.6%), and "wind reduction" and "protection from light rain" (0.7%, each).

Many studies conducted around the globe have presented the benefits of urban green areas, such as parks and urban greenery, for human health. Martelli and Delbim (2022) metion that a urban afforestation and reforested areas in cities prevent various pathologies, including cardiovascular diseases. According to Felappi et al. (2020) green infrastructure is associated with multiple benefits for physical and mental health, however, despite the importance of this issue, mental health and its relationship with the environment is still a neglected topic in urban planning. Mendes and Romero (2024), mention that the presence of urban trees in large centers provides noise reduction, carbon sequestration, socialization of individuals, reduction of temperature, reduction of the impact of rainwater, with potential for the creation of green areas to encourage environmental conservation, but with challenges for the sustainability of cities when it comes to the specific choice of species and their maintenance.

This research also sought to investigate to whom residents complain about problems with bike paths. In total, 96.0% of respondents reported the “municipal government”; 2.0% of them had no complaints, 1.3% complained about NGOs and 0.7% pointed to the “state government”.

The perception that municipalities are the entities to complain about is in compliance with the research by Almeida et al. (2019), who assessed the perception of residents in Iara District-CE about urban greenery and noticed that despite being unaware of the term “urban greenery”, residents understand the benefits provided by trees to the locality, besides pointing the municipal government as the main entity accountable for trees’ management in the city. Residents’ opinions about the responsibility for planting trees and ornamental plants in cities were also investigated. In total, 95.4% of residents marked the Municipal Government as the main entity responsible for tree planting, 2.6% of them marked the “State Government”, and only 2.0% stated that “residents themselves” are responsible for planting trees and plants. Knowing the entity responsible for implementing urban greenery helps in planning urban spaces’ greenery. Problems of accessibility, infrastructure, and maintenance of public roads can be aggravated when part of the population implements inadequate urban vegetation in unplanned public spaces. On the other hand, when planning occurs on the part of responsible bodies and public managers, the population can benefit from the use of certain species. Rodrigues and Aoki (2022), observing the increasing urbanization of municipalities, suggest to public managers of urban afforestation the use of species with food potential to assist in the population‘s food security. Aoki et al. (2024) mention that urban afforestation provides several ecosystem services and urban agroecology to the population because adequate planning and management, including the selection of species to be planted with the participation of the population, favors the production of quality food, the appreciation of culture local, the involvement of the population in the plantations.

Lack of knowledge on this subject is not a problem exclusive to Brazil but felt worldwide. Few studies address this issue in a broader way. Sartori et al. (2021) mention that the adequate implementation of urban afforestation is one of the ways to reduce the social-ecological impact of city growth and that in the city of Rio de Janeiro, there are many exotic species and there is a lack of more intensive use of native species, which impacts the city's natural ecosystems. According to Vargas-Maldonado

et al. (2023), bike paths' road structures were assessed but only a little information was found about their urban greenery and landscaping. A significant fraction of these projects does not distinguish urban greenery planted on sidewalks bike paths from that by bike paths, a fact that points out the relevance of the present study.

When asked how residents contribute to urban landscaping, 61.1% responded with "not damaging" the vegetation, 21.5% said it should be done by planting trees, 7.6% responded with "planting trees and ornamental plants", 5.6% mentioned performing "maintenance and pruning" and only 4.2% reported "planting only ornamental plants" (Fig. 6).

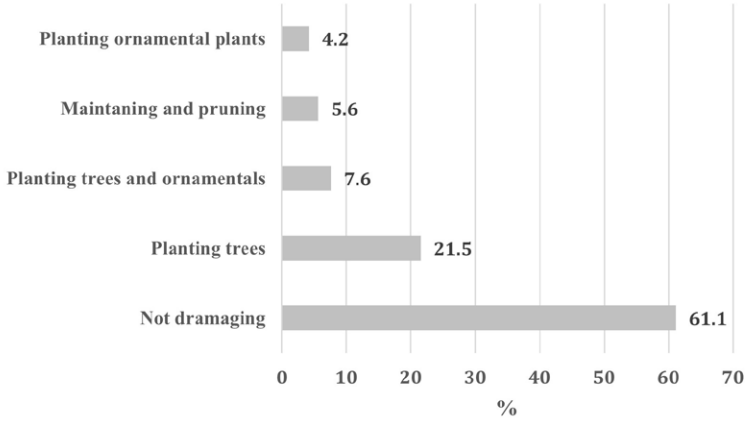

Fig. 6. Ways residents contribute to city landscaping.

This research proved that residents help to preserve urban vegetation, since a large part of the interviewees collaborate by planting trees and ornamental plants, with the majority not damaging the plants.

When asked about what could be done to improve and encourage the use of vegetation and ornamental plants on cycle paths, residents responded with the items "demand from authorities" (35.1%), "plant more trees and ornamental species" (33.1%), "perform adequate maintenance and pruning" (16.6%) and "carry out environmental education and landscaping work" (15.2%) (Fig. 7).

When asked about the origin of the species that residents would like to see planted on the bike paths, 33.9% responded by saying "native" species, 35.1% chose any species, and 31.0% did not know how to answer (Fig. 8).

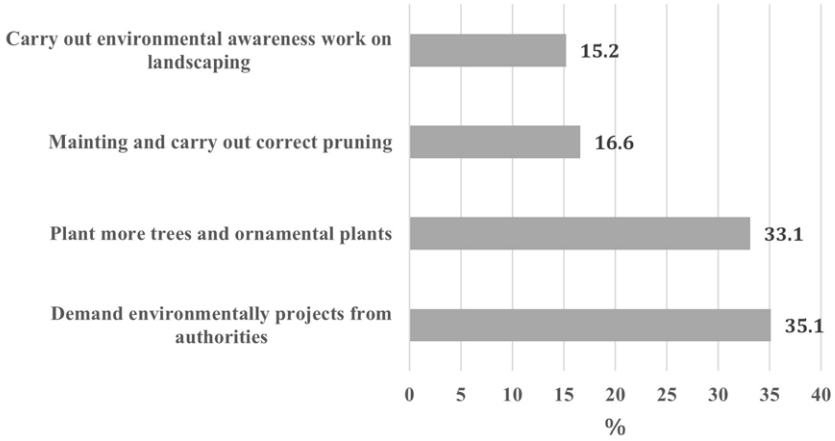

Fig. 7. Residents' opinions on what could be done to improve urban greenery and the use of ornamental plants on a cycle path.

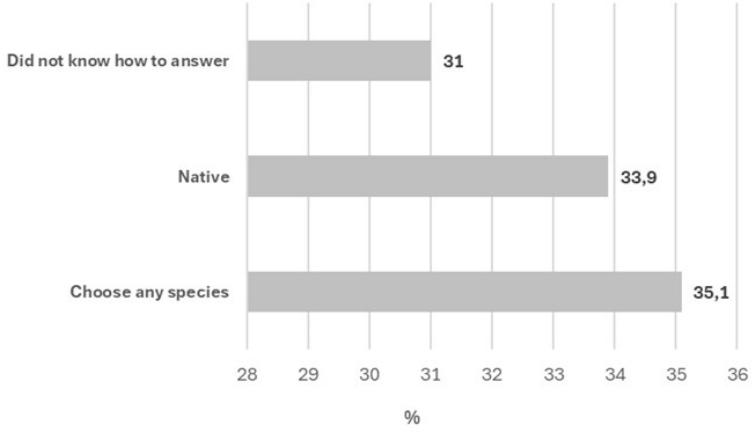

Fig. 8. Suggestions of species according to origin for planting on cycle paths.

The data reflects the low level of knowledge among those interviewed about the importance of the origin of the species when it comes to planting trees, as the high number of people who responded that they would plant any species plus those who did not know was much higher than those who responded by saying native species.

The Brazilian population in cities is quite aware of urban greenery, and most of it suggested native and tree species to be planted by bike paths, only a small minority of the population would avoid planting by these paths. The herein gathered data are following results reported by Roppa et al. (2007), who assessed the Camobi neighborhood, in Santa Maria-RS, and concluded that residents had an excellent understanding of greenery relevance and its benefits to quality of life.

The main needs pointed out by interviewees for them to use bike paths more often were also assessed. Most of them chose the item "greater and better suitable infrastructure" 54.0%, which was followed by "more safety and respect in traffic" (27.3%), "more greenery and shading" (8.7), "more public security" (7.3%) and "other factors" (2.7%) (Fig. 9).

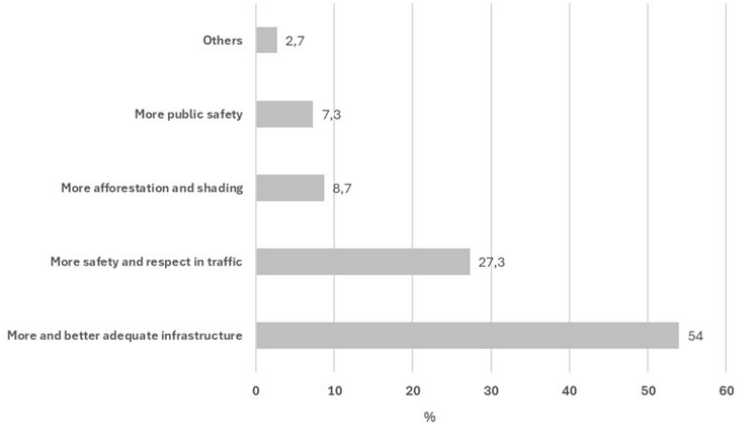

Fig. 9. Needs pointed out by interviewees to use their cycle paths more frequently.

Greater and better cycling infrastructure, greater safety, and respect for traffic were the most relevant factors for cyclists to consider cycling in Brazil. In general, Brazilian cycle paths lack vertical and horizontal signage. Simply opening a lane between cars does not mean building a cycle path, as many claim. Another serious issue concerns public safety and respect for traffic. To resolve this situation, it would be necessary to create traffic education programs, create tax incentives for bicycle users, and improve the cycling infrastructure of cycle paths. With these improvements, we could reduce the number of cyclist deaths in Brazilian cities.

Survey on afforestation by bike paths in Rio de Janeiro City

In total, 212 trees were found along a 4-km route, and it resulted in a ratio of one tree every 19 meters of bike lane (Table 2). Thirty (30) species belonging to 14 botanical families were identified. The most frequently recorded species were *Terminalia catappa* 22.6 of the totals, *Pachira aquatica* (21.2%) *Libidibia ferrea* (7.5%), *Taliparitiliaceum* (7.1%), and *Couroupita guianensis* (5.7%). These five species accounted for 64.0% of the total number of trees. Botanical families presenting the largest number of representatives were Malvaceae with 29.3% of the total, Combretaceae (22.6%), and Fabaceae (13.2%). Families with the highest species richness were Fabaceae represented by seven species, Arecaceae (4), Moraceae (3), and Malvaceae (3), respectively (Table 2).

Table 2. Species found on the bike paths of Rio de Janeiro, containing data on the percentage of individuals found, origin, and issues related to roots, large fruits, leaf dehiscence, or invasiveness, where: E-Exotic and N-Native

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Botany Family	Specie	%	Origen	Root Damage	Fruit	Llaves	Invasive Specie
Combretaceae	*Terminalia catappa*	22.6	E	1	1	1	1
Malvaceae	*Pachira aquatica*	21.2	E	1	1	0	0
Fabaceae	*Libidibia ferrea*	7.5	N	1	0	0	0
Malvaceae	*Talipariti tiliaceum*	7.1	E	1	0	0	1
Lecythidaceae	*Couroupita guianensis*	5.7	E	1	1	1	0
Moraceae	*Ficus religiosa*	4.7	E	1	0	1	0
Bignoniaceae	*Handroanthus heptaphyllus*	3.8	N	0	0	0	0
Arecaceae	*Syagrus romanzoffiana*	3.3	N	0	0	0	0
Polygonaceae	*Coccoloba uvifera*	3.3	E	0	0	0	0
Arecaceae	*Cocus nucifera*	2.4	N	0	1	0	0
Lythraceae	*Lagerstroemia speciosa*	2.4	E	0	0	1	0
Fabaceae	*Senna siamea*	2.4	E	1	0	1	0
Chrysobalanaceae	*Moquilea tomentosa*	1.9	E	1	1	0	0
Bignoniaceae	*Tabebuia rosea*	1.9	E	0	0	1	0
Myrtaceae	*Psidium guajava*	1.4	N	0	0	1	0
Fabaceae	*Cenostigma pluviosum*	0.9	N	0	0	0	0
Fabaceae	*Leucaena leucocephala*	0.9	E	0	0	0	1
Malvaceae	*Palmeira Fenix*	0.9	E	0	0	0	0
Myrtaceae	*Eugenia uniflora*	0.5	N	0	0	0	0
Sapindaceae	*Sapindus saponaria*	0.5	N	0	0	0	0
Moraceae	*Artocarpus heterophyllus*	0.5	E	0	1	0	1
Arecaceae	*Bismarckia nobilis*	0.5	E	0	0	0	0
Fabaceae	*Clitoria fairchildiana*	0.5	E	0	0	1	1
Fabaceae	*Delonix regia*	0.5	E	1	0	1	0
Moraceae	*Ficus benjamina*	0.5	E	1	0	0	0
Anacardiaceae	*Mangifera indica*	0.5	E	1	1	0	0
Fabaceae	*Paubrasilia echinata*	0.5	E	0	0	0	0
Lauraceae	*Persea americana*	0.5	E	0	1	0	0
Arecaceae	*Roystonea oleracea*	0.5	E	0	0	0	0
Polygonaceae	*Triplaris americana*	0.5	E	0	0	0	0

The existing trees shaded 11,334 m^2. However, only 14.0% of this coverage was over bike paths; therefore, they did not fulfill their shading function with high efficiency in bike paths. These values were obtained from the calculation of the tree coverage area along the bike path, considering the entire length of the bike path. This made it possible to determine the percentage of coverage. Approximately 50.0% of them had undergone inappropriate pruning, had sparse crowns, were leaning out of the bike path, or presented some disease that was causing leaves to fall. Only 1,600 meters of the 6,000 m^2 of surveyed bike path were covered by trees, and this number represents 27.0% of the total.

Species, such as *Ficus religiosa, Terminalia catappa, Couroupita guianensis, F. benjamina,* and *Moquilea tomentosa* accounted for the largest trees; they reached up to 15 m in height and 140 cm in diameter at breast height (1.3 m), besides having dense canopies (up to 18 m in diameter). However, these large trees can damage the infrastructure when they are planted close to the pavement (Fig. 10).

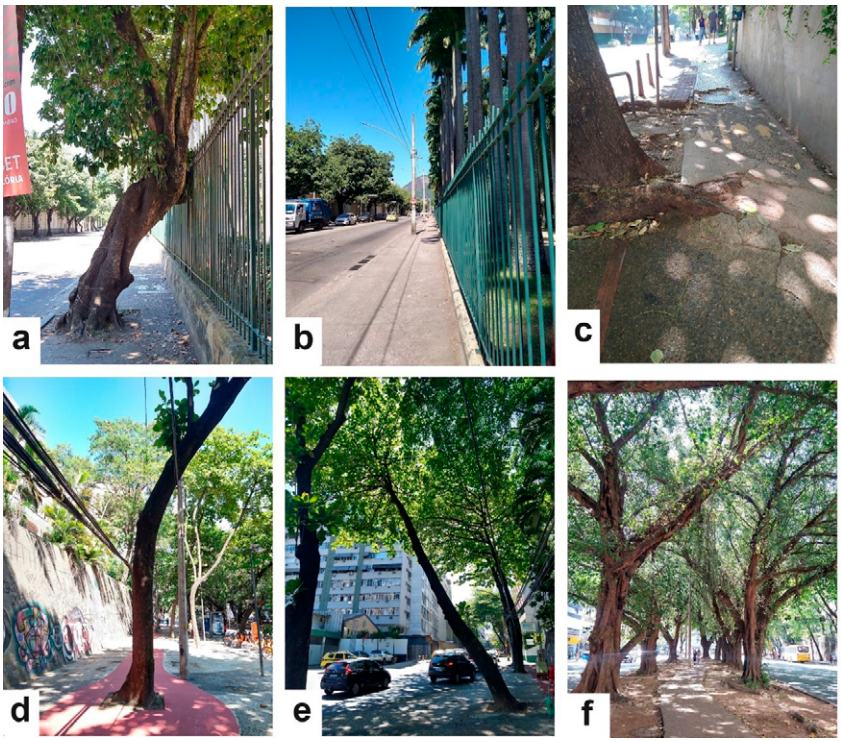

Fig. 10. Images taken on bike paths in Rio de Janeiro.

The mean distance calculated between the trees and the starting edge of the bike path was 0.75 m: 30% of the trees were at the edge of the bike path and 53% of them were within 2 meters from it. Only 8.5% of this total was over the bike path and hindering the path to the bike. Only 4.7% of trees were farther than two meters from the bike path.

Regarding plant origin, 80% of trees and 73% of species are exotic, and the use of native species is limited. These results are consistent with other vegetation surveys conducted in the urban forestry of Rio de Janeiro, as well as by Sartori et al. (2021). Using exotic species is a standard landscaping and urban afforestation procedure (Vidal-Couto et al., 2023), a fact also observed by Alves et al. (2023) who noted that Brazilian cities have many exotic species in their tree parks.

A total of 24 species, representing 80% of the total species and 76% of the plant individuals surveyed, exhibited at least one characteristic that may impair their suitability for bike paths. Among them, 11 species (37%) frequently cause pavement damage, accounting for 67% of the plant individuals in this study. Eight species (27%) produce large fruits, representing 55% of the individuals assessed. Dehiscent species were represented by nine species (30%), comprising 42% of plant individuals. Thirteen species (43%) had sparse crowns, corresponding to 23% of plant individuals. Additionally, five species (17%) are listed as invasive by the municipality, making up 32% of the plant individuals. Data is presented in Table 2.

One of the main issues with using inappropriate species is public rejection, as they can cause damage to streets. *Terminalia catappa* was the species with the highest potential for causing problems. This species was the most often recorded in the present study and it represented 22.6% of the total number of individuals. Yet, it is one of the most used plants in urban afforestation, as also presented in (Miranda et al., 2015).

Species ranked after *Terminalia catappa* were *Couroupita guianensis, Clitoria fairchildiana, Delonix regia,* and *Senna siamea*. *Couroupita guianensis*, which accounted for approximately 6% of the total. This species produces large fruits that weigh up to 5 kg besides having dehiscent leaves and tabular roots (Lorenzi, 2020).

Senna siamea has small but dehiscent leaves, presents sparse canopies (Athokpam et al., 2013) and has invasive potential (Bergallo Filho et al., 2021). *Delonix regia*, despite being widely used in urban afforestation, has large fruits that can cause accidents with cyclists and its roots can damage the pavement. Overall, this species can have leafy canopy, but its specimens showed sparse canopies.

Species with invasive potential are often used in urban afforestation projects; however, they become ecologically harmful and can lead to the emergence of new plant individuals along bike paths. These individuals proliferate fast and block the passage, just as observed with *Leucaena leucocephala* and *Taliparitiliaceum* (Narciso et al., 2023).

Two species of the *Ficus* genus were found: *Ficus religiosa* L. and *Ficus benjamina* L. Together, they account for 5.2% of the total. These species are considered highly problematic in many urban forestry studies worldwide. However, when planted in larger spaces, they can provide shade without damaging the pavement (Rocha et al., 2004; Sampaio, 2008). *Mangifera indica, Pachira aquatica,* and *Moquilea tomentosa* are other species that can be harmful to pavement and that, consequently, can make bike paths unviable. These three species are frequently used in urban afforestation in Rio de Janeiro City and are among the main species causing damage to streets' wiring and pavement (Fig. 10).

Species belonging to family Arecaceae, commonly known as palm trees, are often used for squares and roads' landscaping. They do not have canopies and are often expensive; therefore, they are not interesting species to be used by bike paths. They should be replaced by cheaper species, with more extensive canopies. Fig. 10a shows *Pachira aquatica* falling onto the bike path and obstructing part of the way. Fig. 10b also shows large part of the bike paths lacking trees, and it can be related to poor bike–path planning. These paths share the same space with pedestrian paths due to lack of urban-afforestation planning. Fig. 10c depicts *Moquilea tomentosa* breaking the sidewalk, which is a common issue seen in bike paths; they break the pavement and put cyclists at risk. This section, although like a pedestrian sidewalk, is designated as a bike path and is included in the city's official bike path network, shared with pedestrian sidewalks. Fig. 10d clearly presents a lack of afforestation planning, given the tree standing in the middle of the bike path. Often, since bike paths are adapted in areas with older trees, the bike path must be adjusted to these spaces, allowing the trees to provide shade without obstructing the path. Figure 10e shows some *T. catappa* individuals leaning outward from the path due to canopy competition for sunlight exposure. Figure 10f shows a bike path surrounded by *Ficus religiosa* trees, providing shade without damaging the pavement. This image demonstrates the possibility of using large trees with tabular roots, if they are planted at a suitable distance from the path. We can see an example of space adaptation for the use of trees that are usually considered harmful. However, many *Ficus* species are native and could be tested in areas like this, avoiding the use of exotic and invasive species.

Species herein recommended to be planted by bike paths are introduced in Table 3. They were basically chosen based on the present survey and in observations from other areas of the municipality where they are being used, with positive points. Species that do not have large fleshy fruits, that are native, have dense canopy, reach a minimum height of three meters and that do not damage the pavement were considered (Table 3).

Table 3. Recommended species for planting on bike paths in the Atlantic Forest area.

Botanical Family	Species	Local Common Name
Anacardiaceae	*Schinus terebinthifolius*	Aroeira
Cordiaceae	*Cordia superba*	Babosa-branca
Bignoniaceae	*Handroanthus heptaphyllus*	Ipê-rosa
Bignoniaceae	*Tabebuia roseoalba*	Ipê-branco
Fabaceae	*Pterocarpus violaceus*	Aldragon
Fabaceae	*Cenostigma pluviosum*	Sibipiruna
Fabaceae	*Inga laurina*	Ingá
Lythraceae	*Lafoensia glyptocarpa*	Mirindiba
Melastomataceae	*Pleroma granulosum*	Quaresmeira
Myrtaceae	*Eugenia uniflora*	Pitangueira
Myrtaceae	*Eugenia involucrata*	Cerejeira

Conclusion

Brazilians, especially bicycle users, know their bike paths are poorly tree-lined and have a small number of ornamental plants. They highlight that afforestation issues are visible and point out negative assessment items. However, they also observed some positive aspects of it, such as heat reduction, shading, and improved quality of the air, which were the main advantages pointed out by interviewees when there are trees and ornamental plants by bike paths. However, it is important to highlight the fact that bike paths' green infrastructure, whenever there is, needs improvement because citizens pointed out issues, such as reduced public lighting, which impairs visibility on bike paths at night, lack of sidewalk maintenance, and dirt on the streets, caused on bike paths.

The main needs of Brazilian citizens, in the context of the addressed topic, include improvements in bike path infrastructure, with lanes and signage, increased traffic safety, and more afforestation and shading. Accordingly, it would be possible to encourage cycling, mainly on days of intense heat, in cities like Rio de Janeiro.

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Author contribution

MVF: Conceptualization, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review & Editing. **FJCL:** Supervision, Writing – Review & Editing. **HR:** Data Curation. **JPAP:** Data Curation, Investigation, Writing – Original Draft. **RAS:** Supervision, Writing – Original Draft, Writing – Review & Editing.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available upon request to the authors.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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