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The influence of environmental attitudes on urban afforestation in the most preserved state of the Brazilian Amazon

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Understanding how people perceive and interact with nature is essential to address the growing ecological challenges in rapidly urbanizing regions. In tropical cities, where biodiversity and urban infrastructure often coexist in tension, the role of human behavior in shaping urban green spaces remains understudied. Here we examine how environmental attitudes and sociodemographic factors influence urban tree distribution in Macapá, a capital city located in the Brazilian Amazon. Using a structured survey applied to 432 residents across 23 neighborhoods, we combined exploratory and confirmatory factor analyses to identify two latent dimensions of environmental attitudes: a pro-ecological factor supporting the value of urban trees, and an anti-anthropocentric factor rejecting human supremacy over nature. Although attitudes were largely positive, sidewalk tree presence was more likely in front of homes of older residents, individuals born outside the region, and those with more neutral attitudes, that is, closer to the midpoint between ecological and anthropocentric views. Education, income, and birthplace influenced attitudes, but these did not always translate into practical engagement with urban greening. This suggests that structural barriers such as regulatory limitations, social inequality, and conflicting perceptions about tree maintenance can constrain the effect of pro-environmental attitudes on behavior. Our results reveal a complex interplay between social values and ecological outcomes in the Global South, where informal urban growth and limited infrastructure intersect with cultural perceptions of nature. By integrating psychometric and ecological data, this study offers a novel contribution to understanding human–nature relationships in understudied tropical contexts, highlighting the need for inclusive urban forestry policies that bridge environmental awareness and structural opportunity.

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Introduction

In recent decades, environmental attitudes have been recognized as key components for biodiversity conservation and the promotion of sustainability, especially in urban areas. With over half of the global population now living in cities—a proportion expected to rise to two-thirds by 2050 (UNPD, 2019)—understanding how residents perceive and engage with the natural environment has become crucial for urban planning.

Pro-environmental attitudes can manifest in various ways, ranging from everyday practices such as recycling and resource conservation to engagement in public policies and social movements aimed at environmental protection (Stern, 2000; Schultz, 2000; Bamberg and Möser, 2007; Steg and Vlek, 2009; Faccioli et al., 2020; Sivonen, 2023a; 2023b; Jiang et al., 2025). In urban contexts, these attitudes are often reflected in people's perceptions of and care for trees, both in specific assessments (Balram and Dragicevic, 2005; Flannigan, 2005; Lohr et al., 2004; Schroeder et al., 2006; Zhang and Zheng, 2011; Conway and Bang, 2014; Saldarriaga et al., 2020; Olivero-Lora et al., 2020; Koeser et al., 2023; Moffat et al., 2024) and in broader measures of environmental attitudes (Balram and Dragicevic, 2005; Schroeder et al., 2006; Amaral et al., 2013; Castro and Dias, 2013; Conway and Bang, 2014; Cunha et al., 2019; Barradas and Ghilardi-Lopes, 2020; Souza et al., 2021).

Although environmental attitudes vary across regions (e.g., Flannigan, 2005; Zhang et al., 2007), they are influenced by sociodemographic factors. Younger individuals with higher education and income levels tend to display more positive environmental attitudes compared to older adults or those with lower income and education (Shen and Saijo, 2007; Franzen and Meyer, 2010; Cavalcanti Sá De Abreu and Lins, 2011; Bozoglu et al., 2016; Chase and Levine, 2018; Barradas and Ghilardi-Lopes, 2020; Wang et al., 2022; Moffat et al., 2024). Women also tend to express greater environmental concern than men (McStay and Dunlap, 1983; Lohr et al., 2004; Kirkpatrick et al., 2012; McCright and Xiao, 2014; Casaló and Escario, 2018; Echegaray and Hansstein, 2017; Li et al., 2022; Ho et al., 2022).

Urban tree abundance is also related to sociodemographic characteristics and personal preferences. Younger individuals with higher education levels tend to strongly support policies for tree planting and protection, which is often associated with increased tree density in their neighborhoods (Zhang and Zheng, 2011; Conway and Bang, 2014; Ibrahim et al., 2022). In contrast, older residents tend to prefer low-maintenance trees and are more likely to perceive them as safety hazards (Avolio et al., 2015). Households without elderly residents are also more likely to increase tree planting in their surroundings (Conway and Bang, 2014). Therefore, it is essential to understand how sociodemographic factors influence environmental attitudes and, consequently, urban tree planting and maintenance.

These relationships between attitudes, demographics, and urban vegetation cover are particularly relevant in tropical regions, where urban challenges are compounded by high climatic vulnerability. In recent decades, growing global concern about climate change and biodiversity loss has highlighted the strategic role of tropical ecosystems, such as the Amazon rainforest, in global climate stability (Laurance et al., 2010; Nepstad et al., 2014). At the same time, urbanization has rapidly expanded in the Brazilian Amazon, compromising ecological integrity and essential ecosystem services such as climate regulation and biodiversity conservation.

In this context, urban afforestation in the Amazon region plays a critical role by offering direct benefits (e.g., shade, thermal comfort, improved air quality) while also supporting the maintenance of green infrastructure, local biodiversity, and natural capital (Silva and Prasad, 2019; Herath et al., 2018; Priya and Senthil, 2024). Studies in tropical cities show that residents highly value these benefits—especially heat mitigation—and tend to display pro-environmental attitudes linked to urban vegetation (Olivero-Lora et al., 2020; Ngo et al., 2022; Priya and Senthil, 2024). Nevertheless, the Global South remains underrepresented in the scientific literature (see Winkler-Schor et al., 2024), despite facing the most severe impacts of urban warming.

Brazil, where 85% of the population lives in urban areas (IBGE, 2022), provides a critical setting for this discussion. The state of Amapá, located in the Brazilian Amazon, presents unique characteristics: high forest cover (with around 70% of its territory under legal protection—the most preserved state in the country), rapid urban population growth (31% between 2010 and 2021), and, paradoxically, a higher density of urban trees than larger, more populous Amazonian states (Soares et al., 2021). Its capital, Macapá, is home to two-thirds of the state's population and lies on the left bank of the Amazon River delta, surrounded by seasonally flooded tropical forests (várzeas). Despite its ecological and sociocultural context favorable to nature conservation (Souza et al., 2021), and the existence of studies on attitudes and urban afforestation in tropical cities, to the best of our knowledge, no prior research has jointly examined (1) sociodemographic factors, (2) specific environmental attitudes toward urban trees, and (3) actual tree occurrence in urban settings—especially in the Brazilian Amazon

Field observations suggest that Macapá residents interact actively with urban trees—planting, caring for, and at times removing them. These interactions underscore the importance of understanding how the population perceives and values urban afforestation, particularly in a city located in the most preserved state of the country. Despite increasing research efforts in the region, most studies focus on protected or rural areas, while urban spaces have received relatively little attention (with exceptions such as Vieira and Panagopoulos, 2020; Souza et al., 2021; Soares et al., 2021).

Recent research on environmental attitudes and behaviors has advanced considerably, incorporating psychometrically validated instruments (e.g., DeVille et al., 2021), exploratory and confirmatory factor analyses (e.g., Aiman et al., 2022; Jiang et al., 2025), and robust statistical models capable of handling latent variables and complex causal relationships (e.g., Muñoz-Pacheco et al., 2025; Cilek et al., 2024). These methodological advances have been accompanied by more diverse sampling strategies, with increased attention to sociodemographic diversity, spatial representativeness, and integration between attitudinal data and built environment variables (e.g., Tumi Quispe, 2024; Jiang et al., 2025).

Despite this progress, few studies have explicitly linked environmental attitudes with empirical data on urban green infrastructure. Most research remains focused on perceptual or educational dimensions, without examining whether pro-environmental attitudes translate into observable actions in urban spaces—particularly in cities characterized by spatial inequalities and structural constraints (Cilek et al., 2024; Jiang et al., 2025). Moreover, studies that combine micro-spatial scales with actual tree cover data are still scarce, limiting our understanding of the objective conditions that shape or constrain environmental behavior.

This study aims to address this gap by integrating environmental attitude data with empirical data on the presence of street trees, analyzing the extent to which pro-environmental values are expressed in socio-spatially unequal urban contexts. This approach allows for a critical and realistic analysis of the relationship between attitude and action, considering the territorial and structural disparities that influence urban afforestation in tropical cities.

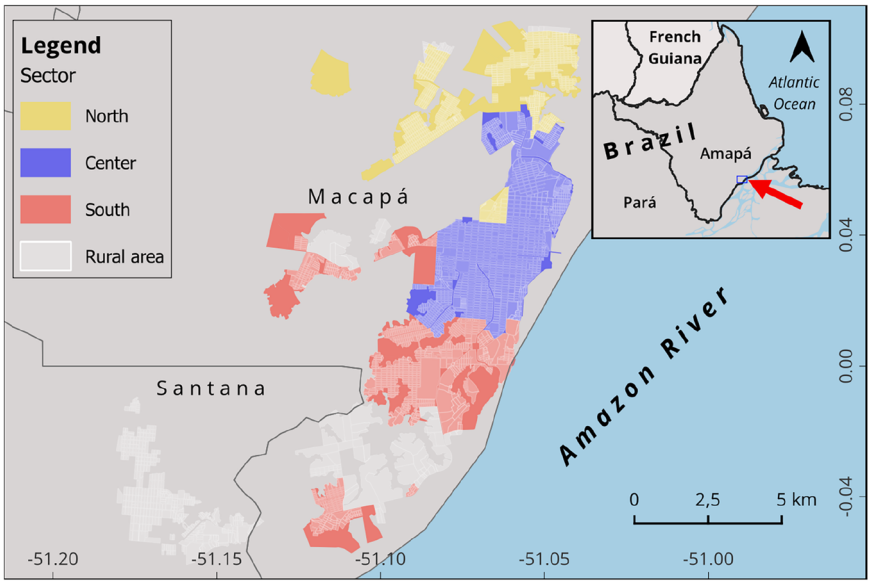

Fig. 1 Location of the urban area of Macapá and its city zones (center, north, south, rural area) in the state of Amapá, Brazil.

By applying this framework in an Amazonian city characterized by recent and uneven urbanization, this study contributes to the literature by offering original empirical evidence on the intersection between environmental attitudes, green infrastructure, and territorial justice. Furthermore, by adopting an integrated perspective—encompassing ecological, social, and spatial dimensions—the study aligns with contemporary approaches to urban sustainability (Muñoz-Pacheco et al., 2025; Maleknia, 2025; DeVille et al., 2021).

Based on this approach, the article analyzes the environmental attitude patterns of Macapá's population and investigates: (1) how sociodemographic factors influence these attitudes, (2) how these factors affect the presence of street trees, and (3) how residents' attitudes shape urban afforestation.

Methods

Study area. The study was conducted in the urban area of Macapá, located in the northeasternmost region of the Brazilian Amazon (Fig. 1). Macapá covers a territorial area of 6563.85 km^2 and has a population of 442,933 inhabitants, with a population density of 67.48 inhabitants/km^2 (IBGE, 2022).

The regional climate is equatorial, with an annual precipitation of approximately 2600 mm, a rainy season peaking from February to May, and a dry season from August to November. The average minimum and maximum temperatures are 22.9 °C and 32.6 °C, respectively, with an annual mean of 27 °C. The original vegetation consisted of species-rich várzea forest, patches of semideciduous forest, and Amazonian savanna (Tavares, 2004). The five most abundant tree species in the urban area of Macapá are *Carpentaria acuminata* (native to Australia), *Mangifera indica* (Asia), *Syzygium malaccense* (Asia), *Moquilea tomentosa* (Brazilian Atlantic Forest), and *Andira inermis* (Amazon), accounting for 60% of all trees. The vast majority of species (approximately 70%) are exotic.

Data collection

Measurement instrument. A structured questionnaire (Supplementary Material 1) was used to collect data on urban residents' attitudes toward city trees. The survey was conducted in accordance with the ethical principles established by Resolution 466/12 of the Brazilian National Health Council (CNS) of the Ministry of Health. The questionnaire and its administration protocol were approved by the Research Ethics Committee of the Federal University of Amapá (Certificate of Presentation for Ethical Consideration–CAAE: 40791720.0.0000.0003/Approval No.: 5.053.336). Only individuals aged 18 or older were interviewed, and all participants signed an informed consent form after being informed about the study's objectives.

The questionnaire included 16 statements regarding the urban environment and street trees, of which 13 were developed specifically for this study and three were adapted from the New Ecological Paradigm (NEP) scale (Dunlap, 2008). The items were selected to assess different dimensions of environmental attitudes toward urban afforestation. These dimensions were based on the specialized literature and on exploratory conversations with residents conducted prior to the instrument's development.

A total of 45 pilot interviews were conducted randomly to evaluate the efficiency of the questionnaire (e.g., item clarity, average completion time, and level of difficulty) and its ability to capture public attitudes. Based on these results, the questionnaire was refined for clarity and conciseness. However, since no new items were added, the pilot interviews were retained in the final dataset.

Of the 16 statements, eight were phrased positively (e.g., "Tree-lined streets are very important for human health") and eight negatively (e.g., "Maintaining trees in the city is a waste of public money"). Respondents rated their level of agreement using a five-point Likert scale, ranging from 1 (strongly agree) to 5 (strongly disagree), with 3 as the neutral option (neither agree nor disagree / don't know).

In addition, sociodemographic data were collected for each respondent, including: self-declared gender, age, place of birth (state level), self-declared political orientation, educational attainment (highest level completed), and average per capita income (in R$/neighborhood/year), obtained from the Brazilian Institute of Geography and Statistics (IBGE). Finally, the presence of a tree on the sidewalk in front of the respondent's home was recorded, including information on species identity, origin (exotic or native), and whether the tree bore edible fruit.

Sampling procedure. The selection of blocks was based on the official cartographic base of the city (scale 1:25,000), which contains georeferenced information on urban zones, neighborhoods, and blocks (SEMA, 2014). We considered the 32

neighborhoods officially established by decree, as these neighborhoods have systematized sociodemographic data (e.g., foundation date, resident population, average income), allowing integrated analyses with secondary databases.

Of these 32 neighborhoods, 23 were selected using stratified sampling, with equal distribution across the four zones of the city. All blocks in these neighborhoods were numbered ($n = 1620$ blocks), and 10% were randomly selected in each neighborhood, proportionally to its size. Blocks that were exclusively commercial, institutional, or unoccupied were excluded. The interviews were conducted in the remaining 100 blocks. The random selection was performed using the sample function in R software, version 3.5 (R Core Team, 2018).

The interviews took place between October 2021 and February 2022, conducted by two interviewers (L.A.J. and T.B.L.). The approach began at the corner residence. In cases of refusal or absence after five minutes, the interviewers proceeded to the next house. After each interview, they moved on to the fourth house, repeating this pattern until the entire block was covered. Interviews were conducted only with the informed consent of the resident. The number of respondents per block varied depending on acceptance, totaling 432 residents (mean of 4.32 ± 2.98 per block).

Data analysis. Validation of the environmental attitude measurement instrument was initially performed using the Kaiser–Meyer–Olkin (KMO) and Bartlett's tests to assess data adequacy before proceeding with exploratory factor analysis (EFA). The maximum likelihood estimator with orthogonal rotation (Varimax) was used for factor extraction. To test the model with the factors resulting from the EFA, a confirmatory factor analysis (CFA) was conducted using the unweighted least squares (ULS) estimator (Xia and Yang, 2019). Additionally, Cronbach's alpha was calculated to assess the internal consistency of the questionnaire. Two latent attitude factors were derived from these analyses and are described in the Results section. A comprehensive explanation of factor analysis can be found in Legendre and Legendre (1998).

Each respondent's overall attitude score was calculated as the sum of the questionnaire item scores, with scores of positive statements reversed (i.e., 1 = strongly disagree and 5 = strongly agree) before calculation. Thus, each respondent's total score ranged from 16 (entirely negative profile) to 80 (entirely positive profile), with neutrality at 48.

Respondents' overall attitude scores, as well as the scores for latent attitude Factors 1 and 2, were analyzed in relation to sociodemographic variables using generalized linear models (GLMs), with a Gamma error distribution and logarithmic link function, since the attitude data were not normally distributed (Shapiro–Wilk test: $W < 1$, $P < 0.001$). The model used was as follows:

$$A = a + b_1\, political\ preference + b_2\, age + b_3\, gender + b_4\, education\ level + b_5\, income + b_6\, birthplace \quad (1)$$

where A represents environmental attitude and the respondents' Attitude Factors 1 and 2. We chose the Gamma distribution because the response variables (environmental attitude scores) were continuous, strictly positive, and right-skewed. We did not apply any data transformation to force normality, as using a distribution that naturally fits the characteristics of the data allows for direct modeling of the observed skewness. This approach yields more interpretable and intuitive results while preserving the original scale and the meaning of the parameter estimates. See Zuur et al (2009) for a comprehensive explanation of GLM with Gamma distribution errors.

To estimate the probability of tree occurrence, we related tree presence–absence data to sociodemographic variables and attitude scores using logistic regression models with a maximum likelihood estimator. Two generalized linear models (using the *glm* function) assuming a binomial distribution were fitted according to the following equations:

$$\ln\left[\frac{P(t)}{1-P(t)}\right] = a + b_1\, political\ preference + b_2\, age + b_3\, gender + b_4\, education\ level + b_5\, income + b_6\, birthplace \quad (2)$$

$$\ln\left[\frac{P(t)}{1-P(t)}\right] = a + b_1\, attitude\ Factor1 + b_2\, attitude\ Factor2 \quad (3)$$

where the left-hand side of both equations represents the odds ratio of the probability (P) of tree (t) occurrence. These equations can be rearranged into a logistic function as follows:

$$P(t) = \frac{\exp(a + b_1\, political\ preference + b_2\, age + b_3\, gender + b_4\, education\ level + b_5\, income + b_6\, birthplace)}{1 + \exp(aa + b_1\, political\ preference + b_2\, age + b_3\, gender + b_4\, education\ level + b_5\, income + b_6\, birthplace)} \quad (4)$$

$$P(t) = \frac{\exp(a + b_1\, attitude\ factor1 + b_2\, attitude\ factor2)}{1 + \exp(a + b_1\, attitude\ factor1 + b_2\, attitude\ factor2)} \quad (5)$$

where *exp* is the base (~2.72) of the natural logarithm (see Zuur et al., 2009).

Multicollinearity in the regression models was tested using the Variance Inflation Factor (VIF), which remained controlled (<2), following Johnston et al. (2018).

For the regression analyses, birthplace was grouped into three categories (Amapá, Pará, and other states), considering that fewer than 10% of respondents were born outside Amapá and Pará. Pará is the only Brazilian state bordering Amapá and was, therefore, the second most common birthplace in the sample after Amapá.

Educational attainment was converted into the number of years of schooling typically required to reach the reported level in the Brazilian education system, using the following equivalencies: illiterate = 0 years; incomplete elementary = 4 years; complete elementary = 8 years; incomplete high school = 9.5 years; complete high school = 11 years; incomplete college = 13 years; complete college or postgraduate education = 15 years. For individuals who reported incomplete levels, we assigned half the duration normally required to complete that level. We assigned four years to undergraduate degrees, as this is the most common duration in Brazilian universities.

All analyses were performed using R, version 4.1.3 (R Core Team, 2022). KMO, Bartlett's, and Cronbach's tests, as well as the factor analyses (EFA and CFA), were conducted using the lavaan package (Rosseel, 2012), version 0.5–22. The Shapiro–Wilk test

Table 1 Loadings (Pearson correlations) of 16 items of environmental attitude on the bifactorial structure resulting from the Exploratory Factor Analysis.

Items	Factors	
	Pro-ecological	Anti-anthropocentric
1. Trees contribute to the reduction of heat in cities because they provide shade and help reduce the air temperature.	0.98	
2. Trees excessively increase the humidity on sidewalks and in residences.	0.69	
3. The trees contribute to noise softening, reducing noise pollution.	0.72	
4. Trees contribute to increased insecurity regarding robberies and assaults.		0.70
5. Trees make the streets more beautiful because of their colors, flowers, and shapes.	0.98	
6. A tree, when damaging the sidewalk structure or electrical wiring, should be cut down.		0.67
7. Trees contribute to the conservation of fauna, because they serve as shelter and food for various animals, such as birds and butterflies.	0.99	
8. Trees make a mess due to falling leaves and fruit in the streets.	0.53	
9. Streets with trees are very important for human health.	0.97	
10. Tree maintenance in the city is a waste of public money.		0.96
11. The population and those in positions of public power should plant trees in the streets to improve the life of the population.	0.96	
12. The presence of trees in the urban environment hinders people's daily life.		0.95
13. Most of the time that human beings interfere in nature, and the consequences are disastrous[a].	0.91	
14. Plants and animals have as much right to exist as human beings[a].	0.98	
15. The human being was made to rule over nature[a].		0.66
16. Planting and caring for trees contribute to the conservation of the planet.	0.99	

The correlation between the Pro-ecological and Anti-anthropocentric factors is 0.79.
[a]Items were taken from the NEP scale.

and logistic regression analyses were performed using base R (stats package), while the GLM with a negative binomial distribution was run using the MASS package (Venables and Ripley, 2002), version 7.3–55. Multicollinearity was assessed with the car package (Fox and Weisberg, 2019), version 3.0–12.

Results

Validation of the measurement instrument. Both the Kaiser–Meyer–Olkin test (KMO = 0.96) and Bartlett's test of sphericity ($\chi^2 = 13{,}581.12$, df = 120, $P < 0.001$) indicated that the data were suitable for exploratory factor analysis (EFA). Parallel analysis suggested the extraction of two factors, each with eigenvalues greater than 1. The factors extracted via EFA using maximum likelihood estimation were named the *Pro-ecological* (Factor 1) and *Anti-anthropocentric* (Factor 2) factors, based on the thematic content of the items grouped within each factor.

Factor 1 consisted of 11 items with ecologically oriented statements, generally emphasizing the importance of afforestation. Factor 2 included five items reflecting a stronger emphasis on human dominance over nature, thereby expressing an anthropocentric perspective (Table 1). We labeled Factor 2 "Anti-anthropocentric" to standardize score direction, ensuring that higher values on both factors represent more pro-environmental attitudes. This convention facilitates the interpretation of results in subsequent analyses.

In this study, anthropocentrism is understood as a perspective that places human beings at the center of concern, attributing to them a higher value compared to other forms of life. Within this view, human interests are considered to prevail over those of nature and other species.

The factor loadings ranged from 0.14 to 0.99 and together explained 81% of the total variance, with the first factor accounting for 57% and the second for 24% (Table 1). All items retained in each final factor had loadings above 0.50, indicating a strong association with their respective latent constructs. The model demonstrated a good fit to the data (Tucker–Lewis Index [TLI] = 0.99; Root Mean Square Error of Approximation [RMSEA] = 0.05; 90% CI = 0.038–0.059), meeting the recommended thresholds (TLI > 0.95 and RMSEA < 0.06) established in the literature (Hu and Bentler, 1999).

Cronbach's alpha indicated a high level of consistency (0.75). Given the high factor loadings and the fact that excluding any of the 16 items would lower the alpha, the full set was considered a reliable measurement instrument.

In the CFA, the model showed a good fit (Fig. 2). The Comparative Fit Index (CFI = 0.98), the Tucker–Lewis Index (TLI = 0.98), and the Root Mean Square Error of Approximation (RMSEA = 0.09) were all within acceptable ranges (≥0.90 for CFI and TLI, and ≤0.10 for RMSEA). These results confirmed the factor structure suggested by the EFA and indicated satisfactory convergent validity for the scale measuring environmental attitudes toward urban afforestation.

Profile of the interviewees. Most of the interviewees (58.57%) were women, and the majority were between 31 and 60 years old (Table 2). The predominant place of birth was the state of Amapá, followed by Pará, together accounting for 91% of the sample. Only 25% of participants reported having a political preference. The average level of education was 11.6 years, equivalent to "complete high school." The average monthly income per capita (R$1614.95, approximately US$317.00) was 33% higher than the national minimum wage (R$1212.00, approximately US$238.00), placing it in income category 2 according to the IBGE classification.

Approximately one-quarter of the respondents ($n = 104$) had trees on the sidewalk in front of their homes (Table 2), and 31% of these ($n = 32$) had more than one tree. Among the sampled trees, 80% ($n = 86$) were exotic to the Amazon biome, and more than half (~58%, $n = 60$) were fruit-bearing species.

Attitude toward Urban Forestry. The overall mean score on the NEP scale was 67.74 ± 6.17 (mean ± standard deviation), ranging from 44 to 80 (Fig. 3a). Considering that the possible range for this metric is 16 (negative attitude) to 80 (positive attitude), with neutrality at 48.5 points, the results indicate that the population

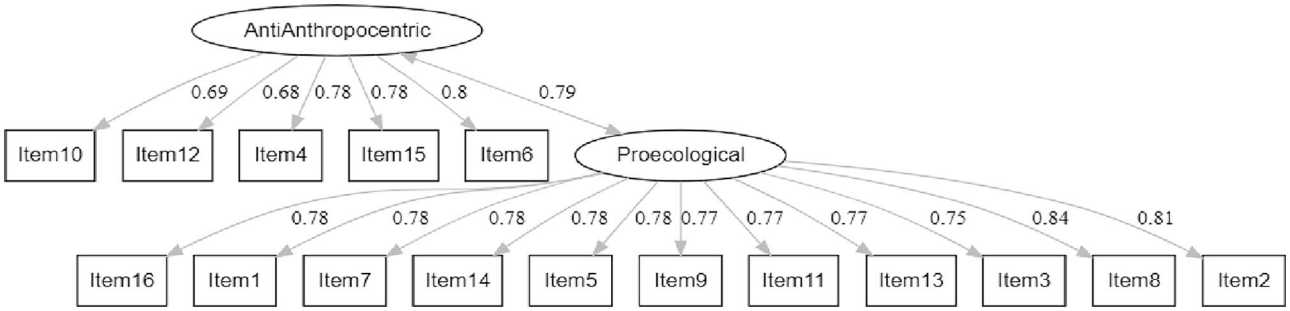

Fig. 2 Bifactor structure resulting from the confirmatory factor analysis of the 16 environmental attitude items. The values next to the lines represent the estimated loadings (i.e., correlations between the items and the latent factors, labeled Anti-Anthropocentric and Pro-Ecological). The numbers inside the boxes correspond to the item numbers on the environmental attitude scale.

Table 2 Sociodemographic characteristics of the sample population ($n = 432$) in Macapá.

Variable	Categories	(%)	(*n*)
Gênero	Female	58.57	253
	Male	41.43	179
Age	Young (18–30 years old)	25.90	112
	Adult (31–60 years)	54.60	236
	Elderly (>60 years)	19.40	84
Birthplace	Amapá	62.73	271
	Pará	27.78	120
	Other States	9.49	41
Political Preference	None	74.00	320
	Right	12.50	54
	Left	12.00	52
	Center	1.30	6
Education (years of study)	0 (Illiterate)	1.10	5
	4 (Incomplete Elementary)	9.70	42
	8 (Complete Elementary)	3.90	17
	9.5 (Incomplete High School)	5.50	24
	11 (Complete High School)	33.70	146
	13 (Incomplete college)	9.70	42
	15 (Complete college)	36.10	156
***Per capita* income (R $/inhabitant/month)**	1 (600–1.200)	22.70	98
	2 (1.200–2.400)	73.60	318
	3 (2.400–4.800)	3.70	16
Presence of a tree in front of the residence	No (0)	75.90	328
	Yes (1)	24.10	104

Age was categorized as young, adult, and elderly to improve result interpretation; place of birth was grouped into Amapá, Pará, and other states (individuals from any other Brazilian state); education level was converted into expected years of schooling; and average per capita income by neighborhood (exchange rate: US$1.00 = R$5.10) was classified into three categories according to the standards of the Brazilian Institute of Geography and Statistics (IBGE).

of Macapá demonstrates a highly positive attitude toward urban afforestation.

The mean score for the Pro-ecological factor was 48.08 ± 3.37, ranging from 33 to 55 (Fig. 3b). The minimum possible score (11) indicates an anti-ecological attitude, while the maximum score (55) reflects a strong pro-ecological attitude, with neutrality at 33.5 points. The mean score for the Anti-anthropocentric factor was 19.66 ± 4.16, ranging from 6 to 25 (Fig. 3c). In this case, the minimum score (5) indicates a strongly anthropocentric attitude, neutrality is set at 15.5, and the maximum score (25) indicates low anthropocentrism.

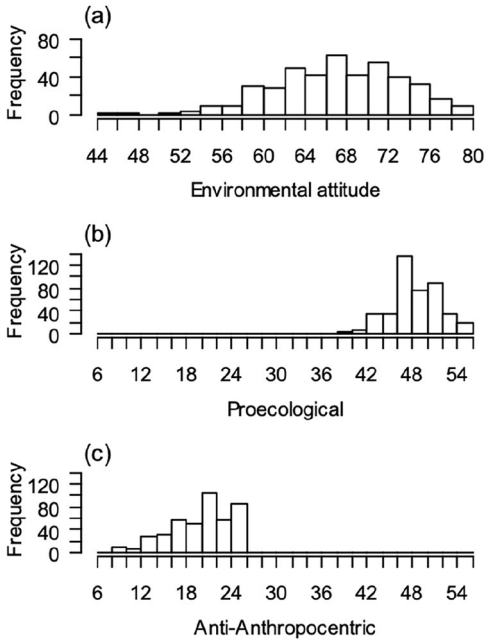

Fig. 3 Frequency distribution of environmental attitude scores among respondents in Macapá, Brazil (432). a Overall environmental attitude score, **b** Pro-ecological factor, and **c** Anti-anthropocentric. Results are presented for: **a** overall attitude, calculated as the sum of scores for all items (1–16); **b** the Pro-ecological factor (sum of scores for items 1–3, 5, 7–9, 11, 13, 14, and 16); and **c** the anti-anthropocentric factor (sum of scores for items 4, 6, 10, 12, and 15).

Relationship between attitude and sociodemographic characteristics. Respondents' income and education levels were positively associated with overall environmental attitude (GLM: $t = -2.238$, $P = 0.025$; $t = 4.901$, $P < 0.001$, respectively) and with the Anti-anthropocentric factor ($t = 2.833$, $P < 0.005$; $t = 4.685$, $P = 0.032$, respectively) (Table 3). Education level was also positively associated with the Pro-ecological factor ($t = 3.152$, $P < 0.01$). These findings indicate that individuals with higher education and income levels tend to hold more positive attitudes —i.e., more pro-ecological and less anthropocentric—toward urban afforestation.

The age of the participants showed a negative relationship with the anti-anthropocentric factor ($z = 3.096$, $P < 0.01$), indicating that older individuals tended to hold more anthropocentric attitudes (Table 3).

The birthplace categories "Pará" and "other states" showed a positive relationship with overall attitude ($z = 3.504$, $P < 0.001$

and $z = 2.700$, $P < 0.01$, respectively) and with the anti-anthropocentric factor ($z = 3.803$, $P < 0.001$ and $z = 2.031$, $P < 0.05$, respectively) (Table 3). This indicates that residents of Amapá have less positive and more anthropocentric attitudes compared to people from other states.

Political preference and gender showed no significant relationships with overall attitude or with the Pro-ecological and Anti-anthropocentric factors (Table 3).

Table 3 Results of the generalized linear models relating attitudes toward urban trees with political preference (center, right, left, or none), age, gender (male or female), education level (years of study), per capita income, and birthplace (Amapá, Pará, or other states) of residents in Macapá, Amapá.

	Coefficient of determination		
Predictors	**Attitude**	**Pro-ecological**	**Anti-anthropocentric**
Intercept	4.150***	3.819***	2.871***
Political preference:			
Center	−0.002	−0.410	0.071
Right wing	−0.042	−0.001	−0.137
Left wing	0.014	0.030	−0.020
None	−0.039	−0.009	−0.106
Age	−0.0003	0.0002	**−0.002****
Gender	0.004	−0.006	0.032
Education level	**0.006*****	**0.003****	**0.014*****
Per capita income	**0.00001***	0.000003	**0.00005****
Birthplace:			
Other states	0.050***	0.018	0.012***
Pará	0.026**	0.017	0.050*

The coefficient of determination for each predictor is shown in bold when statistically significant. The overall attitude score refers to the sum of all item scores, while the Pro-ecological and Anti-anthropocentric scores correspond to the sum of specific items identified through factor analysis (see Fig. 2).
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Probability of tree occurrence. No significant relationship was found between the overall attitude and the probability of tree occurrence (logistic regression: $z = 0.446$, $P = 0.656$). However, the Pro-ecological factor was negatively associated with the probability of tree occurrence ($z = -2.165$, $P = 0.03$), while the Anti-anthropocentric factor was positively associated ($z = 2.409$, $P = 0.016$). Therefore, the higher the Pro-ecological factor score, the lower the probability of tree occurrence in front of houses (Fig. 4a); conversely, the more anti-anthropocentric the attitude, the higher the probability of tree occurrence (Fig. 4b).

Among the sociodemographic variables, age ($z = 2.20$, $P < 0.05$) and being born in "other states" ($z = 2.87$, $P < 0.01$) (Table 4) showed a positive relationship with the probability of tree occurrence. That is, the likelihood of trees being present is higher among older individuals (Fig. 3c) and those born in states other than Amapá or Pará.

Discussion

Attitude toward urban forestry. The respondents' attitude toward urban afforestation was positive, indicating that the population of Macapá recognizes the importance of trees in the urban environment. We identified two distinct attitude factors: the Pro-ecological factor, which emphasizes the benefits of urban afforestation, and the Anti-anthropocentric factor, which reflects views concerning human dominance over nature. Although these factors were correlated ($r = 0.79$), their conceptual foundations and indicator items were distinct. The Pro-ecological factor included items addressing the benefits of urban trees, such as climate regulation, biodiversity, and human health (e.g., items 1, 3, 5, 7, 9, 11, and 16), with high loadings and no overlap with the Anti-anthropocentric factor. The latter included items related to anthropocentric concerns, such as conflicts with infrastructure, public safety, and human priorities (items 4, 6, 10, 12, and 15). Despite the correlation, the two factors represent separate dimensions of environmental attitudes, with minimal conceptual overlap.

These findings reinforce previous studies showing that people generally appreciate and express positive attitudes toward trees (Lohr et al., 2004; Schroeder et al., 2006; Zhang et al., 2007; Zhang

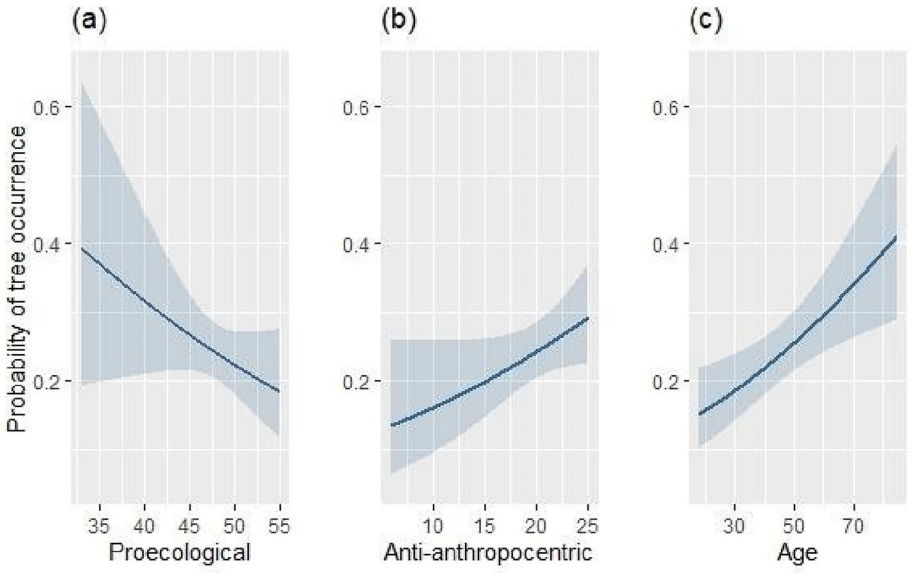

Fig. 4 Results showing the relationship between environmental attitudes, age and the probability of tree occurrence. Probability of tree occurrence in relation to (**a**) the Pro-ecological factor, (**b**) the Anti-anthropocentric factor, and (**c**) age. Solid blue lines indicate logistic regression fits, and shaded areas represent 95% confidence intervals.

Table 4 Results of the generalized linear models relating the probability of tree occurrence to: overall attitude toward urban trees (first model); the Pro-Ecological and Anti-Anthropocentric factors (second model); and political preference (center, right, left, or none), age, gender (male or female), education level (in years of study), per capita income, and birthplace (Amapá, Pará, or other states) (third model) among residents of Macapá, Amapá.

Predictors	Coefficient of determination
Model with overall attitude as predictor	
Intercept	−1.703
Attitude	0.008
Model with attitude factors as predictors	
Intercept	−1.064
Proecological factor	**−0.076***
Anti-anthropocentric factor	**0.073***
Model with sociodemographic factors as predictors	
Intercept	−1.769**
Political preference:	
Center	−0.339
Right wing	−0.859
Left wing	−1.613
None	−1.131
Age	**0.016***
Gender	0.147
Education level	0.018
Per capita income	0.0003
Birthplace:	
Other states	**1.055****
Pará	0.153

Statistically significant predictors are highlighted in bold. The overall attitude score refers to the sum of all item scores, while the Pro-Ecological and Anti-Anthropocentric scores correspond to the sum of specific items identified through factor analysis (see Fig. 2).
*$P < 0.05$; **$P < 0.01$.

and Zheng, 2011; Conway and Bang, 2014; Saldarriaga et al., 2020; Koeser et al., 2023; Moffat et al., 2024). Additionally, our results are consistent with those reported by Souza et al. (2021), who observed pro-environmental attitudes among residents of Amapá, and by Cunha et al. (2019), who highlighted biodiversity conservation as the main motivation for supporting protected areas. In the present study, one of the questionnaire items associated trees with wildlife conservation, with 99% of respondents strongly agreeing with the statement—an indication that pro-conservation attitudes are also expressed in anthropogenic environments.

Similar results have been observed in other tropical cities, such as Puerto Rico (Olivera-Lora et al., 2020), Singapore (Ngo et al., 2022), and India (Priya and Senthil, 2024), where residents also demonstrate favorable attitudes toward urban vegetation, often associated with thermal comfort and biodiversity benefits. These findings suggest that, in tropical regions, the value attributed to trees may be intensified by factors such as excessive heat and direct exposure to nature.

Despite positive attitudes, Macapá exhibits a significant deficit in urban tree cover, with approximately one tree per 100 meters and less than one-tenth of a tree per capita (0.03) (Jimenez et al., 2024)—a substantially lower value than those reported by Álvarez et al. (2015) for Campinas, Brazil (0.17–0.6 trees per capita), and by McPherson et al. (2016) for California (0.26 trees per capita). Additionally, the city has experienced a significant loss (29%) of urban trees over the past 10 years (*L.A.J., unpublished data*), indicating that tree removal—whether by residents or public authorities—has outpaced planting efforts. These findings suggest that, although there is an association between pro-environmental attitudes and behaviors, such attitudes do not always translate into concrete conservation actions (Kirkpatrick et al., 2012; Meijer et al., 2015; Liu et al., 2020). This contradiction may stem from contextual factors, such as the absence of effective policies, socioeconomic barriers, and a limited sense of individual responsibility for the maintenance of urban greenery.

The consolidation of environmental policies in Amapá—the most protected state in Brazil—contributes to this scenario. The state has preserved approximately 95% of its original vegetation (Drummond et al., 2008), and over 70% of its territory lies within protected areas, including twenty conservation units and five Indigenous lands (CI-BRASIL, 2009; SEMA, 2014). Amapá also leads national rankings in environmental protection, planning, and the implementation of conservation policies, which include the Urban Afforestation Plan of Macapá (Souza et al., 2021). This institutional and ecological context may have influenced the high level of environmental awareness and the favorable attitudes observed among residents. Nevertheless, the effectiveness of these policies in promoting concrete conservation actions depends on the continuity of investment, community engagement, and the effective implementation of legal guidelines.

Despite ongoing conservation efforts, the state has experienced a significant expansion of large-scale agriculture in recent years, accompanied by a gradual weakening of environmental policies (Mustin et al., 2017; Hilário et al., 2017). In addition, there has been a substantial increase in deforestation and the number of forest fires in the region (MPAP, 2020). This erosion of environmental governance may also be extending into the urban context, as evidenced by the recent intensification of tree removal in the city of Macapá. This trend highlights the complexity of environmental attitudes, which are shaped not only by individual convictions but also by the structural and political conditions specific to each territory.

Influence of sociodemographic factors on environmental attitudes. Our results indicate that birthplace, education level, income, and age influence the environmental attitudes of Macapá residents. Individuals born in Amapá exhibited more anthropocentric and less ecological attitudes compared to those from other Brazilian states. However, these attitudes remained positive (i.e., above the neutrality threshold). Although previous research did not identify differences between the pro-environmental attitudes of Amazonian and non-Amazonian individuals (Souza et al., 2021), it is plausible that natives of the Amazon, due to their proximity to preserved natural areas, may have greater exposure to and connection with nature. This relationship has been consistently associated with stronger environmental perceptions and values (Barradas and Ghilardi-Lopes, 2020; Cameron et al., 2020; DeVille et al., 2021; Maleknia, 2025).

More broadly, Brazilians exhibit a well-documented tendency to support environmental protection (Aklin et al., 2013) and to maintain pro-environmental attitudes (Bechtel et al., 1999; Amaral et al., 2013; Echegaray and Hansstein, 2017; Barradas and Ghilardi-Lopes, 2020; Souza et al., 2021; Rosa et al., 2021). However, translating these attitudes into concrete behaviors may be constrained by contextual factors. For instance, a study with Brazilian migrants in Canada found that although participants already held positive attitudes before migration, they only began to adopt environmentally responsible behaviors once embedded in a context with well-established and fully operational environmental policies and infrastructure (Romero et al., 2018). These findings highlight the role of normative systems and institutional support in turning attitudes into practice. Moreover, evidence suggests that non-punitive mechanisms—such as financial incentives for tree planting and conservation—can also serve as

effective tools to promote pro-ecological behaviors (Ordóñez-Barona et al., 2021; Koeser et al., 2023).

The effect of education level on attitudes toward urban trees observed in this study is consistent with the literature, which indicates that individuals with higher educational attainment tend to exhibit more positive attitudes toward urban trees and assign greater importance to the presence of trees in their properties, neighborhoods, or cities (Zhang and Zheng, 2011; Conway and Bang, 2014; Avolio et al., 2015; Moffat et al., 2024). Similar findings are also common in the broader field of environmental attitudes (McMillan et al., 1997; Cavalcanti Sá De Abreu and Lins, 2011; Bozoglu et al., 2016; Barradas and Ghilardi-Lopes, 2020; Wang et al., 2022). However, education may be correlated with other variables—such as access to information, cultural capital, political engagement, or geographic location within the city—that influence both environmental attitudes and the distribution of urban greenery.

Moreover, although the type of content accessed during formal education also influences environmental attitudes (Wysor, 1983; Ogunbode, 2013; Janmaimool and Khajohnmanee, 2019; Kurokawa et al., 2023), studies indicate that this relationship varies according to sociocultural context and the quality of education (Al-Rabaani and Al-Mekhlafi, 2009). This reinforces the notion that structural factors—such as school curricula, institutional environment, and pedagogical engagement—play a crucial role in the development of pro-environmental values.

The positive relationship between income and environmental attitudes observed among respondents is also consistent with previous studies, both on urban trees (Kirkpatrick et al., 2012; Saldarriaga et al., 2020; Olivero-Lora et al., 2020) and broader environmental attitudes (Shen and Saijo, 2007; Franzen and Meyer, 2010). Income and education reflect systemic inequalities that shape access to environmental resources and engagement in conservation practices. The theory of intergenerational value change (Inglehart, 1997) suggests that individuals in contexts of economic security tend to prioritize post-materialist values, such as environmental protection. Nevertheless, this pattern depends on the presence of institutional opportunities and public policies that enable the translation of these values into concrete behaviors.

Regarding age, our data indicate a tendency toward increased anthropocentrism among older individuals—a pattern previously identified in Macapá (see Souza et al., 2021). In general, younger people tend to show greater concern for environmental issues and a higher willingness to adjust their attitudes in response to contemporary challenges (Shen and Saijo, 2007; Conway and Bang, 2014; Chase and Levine, 2018). However, contrasting evidence shows that older individuals may express greater support for urban trees, while younger individuals often display lower awareness of the ecological and social benefits provided by trees (Moffat et al., 2024). We suggest that age-related differences in environmental attitudes should be interpreted in light of multiple influences, including generational values, accumulated experiences with nature, and specific institutional contexts.

Influence of attitude on tree occurrence. We observed that the probability of tree occurrence on sidewalks in Macapá is higher in front of the homes of older individuals, people who are not originally from Amapá or Pará, and those with more neutral environmental attitudes (i.e., at the threshold between ecological and anthropocentric orientations). The negative relationship between tree occurrence and the Pro-ecological factor was an unexpected result. However, the maximum observed score (33 points) did not fall below the neutrality threshold. In other words, even among those classified as less pro-ecological, there was no evidence of anti-ecological attitudes.

The negative correlation between pro-ecological attitudes and the presence of trees on sidewalks, although counterintuitive, may be explained by multiple contextual and structural factors. A limitation of the present study is that tree presence was recorded exclusively on public sidewalks in front of residences—a scope that may not fully capture the complex relationship between individual attitudes and urban vegetation cover. Public space afforestation is subject to institutional, legal, and infrastructural constraints that go beyond residents' personal preferences or values. In Puerto Rico, for example, despite positive attitudes toward trees, urban tree abundance was more closely related to property ownership and tree location (Olivero-Lora et al., 2020).

In Macapá, although planting trees on sidewalks does not require prior authorization, pruning and removal are subject to regulations involving costs and bureaucratic procedures. As a result, residents who already live with trees may be more aware of these burdens and limitations, which can reduce their willingness to plant, even when they hold conservation-friendly attitudes. Conversely, residents without trees may overestimate the benefits of urban afforestation due to a lack of awareness about the associated challenges. Moreover, factors not measured in this study—such as length of residence and housing status (tenant or owner)—may also influence individuals' ability to intervene in urban space. These findings reinforce that while pro-environmental attitudes are important, they do not guarantee the adoption of pro-ecological behaviors, especially in urban contexts shaped by structural and institutional barriers.

The positive correlation between anti-anthropocentric attitudes and the probability of tree occurrence aligns with the expectation that values less centered on human dominance promote environmentally responsible behaviors. Beliefs in human superiority over nature are associated with a greater propensity for destructive actions toward trees, even when the environmental consequences are well known (Ho et al., 2022). Thus, more anthropocentric attitudes may reduce engagement with urban afforestation, especially when the perceived costs outweigh the benefits.

On the other hand, recent research suggests that anthropocentric attitudes are not necessarily incompatible with conservation practices. Lou et al. (2025), for example, show that individuals may value nature for its direct benefits—such as thermal comfort or aesthetics—and thus adopt pro-environmental actions. Saavedra et al. (2024), in their analysis of attitudes toward marine pollution in Chile and Peru, observed that anthropocentric values related to recreational and economic use of the sea also motivated environmentally protective behaviors. In the Amazonian context, the association between anti-anthropocentric attitudes and the probability of tree occurrence may reflect not only a rejection of human dominance but also a practical and affective relationship with nature. Direct interaction with natural environments and traditional ecological knowledge may reinforce a non-utilitarian appreciation of trees, which helps explain the higher probability of tree presence among residents with this profile in Macapá.

The results indicated a higher probability of tree occurrence in front of the residences of older individuals. Studies conducted in other countries have already identified a positive relationship between age and willingness to participate in urban greening initiatives, as well as a greater appreciation of trees among older adults (Lohr et al., 2004). In the United Kingdom, for example, age was the main sociodemographic factor associated with support for urban trees, with younger people showing less enthusiasm for newly planted trees compared to older individuals (Moffat et al., 2024). However, this relationship is not universal. Studies conducted in different population contexts suggest that

younger people may demonstrate greater motivation for tree planting than older individuals (Ibrahim et al., 2022; Gwedla et al., 2022).

Age may also influence both environmental attitudes and how individuals translate them into concrete actions. In a study on motivations for tree planting, older individuals showed greater willingness to engage in activities such as watering and caring for already established trees, whereas younger people preferred physically demanding tasks like digging and planting (Gwedla et al., 2022). However, the effects of age on environmental attitudes are strongly shaped by contextual factors. Local ecological characteristics and the degree of connection with the natural environment directly influence people's perceptions and relationships with urban trees (Avolio et al., 2015). In the Amazonian context, for instance, a direct bond with nature is common, reflected in daily interactions with the world's most biodiverse tropical forest. In this setting, older individuals—having accumulated greater exposure to these environments over their lifetimes—may develop a more refined sensitivity to the ecological and symbolic value of trees.

Finally, the higher probability of tree occurrence in front of homes of people from other regions may be related to cultural and contextual factors. The states of Amapá and Pará, located in northern Brazil, have some of the lowest Human Development Index (HDI) scores in the country (IFDM, 2018). In such contexts, allocating resources for the maintenance of urban trees may not be considered a priority, especially in light of significant structural deficits, such as the low proportion of paved streets (8.8%) and access to adequate sanitation services (26.8%) (IBGE, 2018). Moreover, individual beliefs about trees influence attitudes toward urban afforestation (Heberlein, 2012). In the present study, approximately 36% of respondents agreed with the item associating the presence of trees with public insecurity. This perception may be partially explained by the broader context of public safety concerns in the region. According to the Brazilian Yearbook of Public Security (FBSP, 2022), the North region contains a significant share (30%) of the most violent cities in the country. Thus, in areas marked by socioeconomic limitations and high crime rates, urban afforestation may be deprioritized by residents, who may perceive trees more as obstacles to safety than as beneficial elements.

During the Bolsonaro administration (2019–2022), Brazil experienced a significant weakening of its environmental policies (Ferrante and Fearnside, 2019; Vilani and Fearnside, 2022; Dutra et al., 2022). Budget cuts and operational restrictions undermined the functioning of key environmental agencies, such as the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and the Chico Mendes Institute for Biodiversity Conservation (ICMBio), reducing their capacity for monitoring and enforcement. These setbacks led to increased deforestation and other illegal activities, particularly in the Amazon region. National environmental policy—or its absence—had direct repercussions at the local level, contributing to the rise in wildfires and the predatory exploitation of natural resources. The Bolsonaro government also promoted agribusiness expansion and relaxed regulations on mining and logging, including in protected areas and Indigenous lands. Furthermore, there was a clear disregard for international commitments related to biodiversity conservation and climate change, which weakened Brazil's engagement in multilateral sustainability forums.

Despite encompassing extensive protected areas and Indigenous lands, the state of Amapá faces shortcomings in basic infrastructure and lacks public policies focused on sustainable development. The inadequate enforcement of environmental laws undermines efforts to control illegal deforestation, perpetuating a perception of impunity and, consequently, encouraging predatory practices. This is compounded by the absence of environmental education initiatives—an essential component for fostering public understanding of the importance of local ecosystems and individual responsibility in conservation. Moreover, limited civil society participation in the formulation of environmental policies constrains the scope and effectiveness of preservation efforts. A clear reflection of this scenario is the fact that Macapá's Urban Afforestation Plan was only established in 2016, highlighting delays in the formulation of environmental guidelines and priorities in the urban context.

In recent years, the weakening of national environmental policies may have negatively influenced the environmental perceptions of Macapá's residents. The belief that environmental protection hinders economic development appears to have gained traction, at the expense of recognizing conservation as essential to sustaining human life. Although many residents express favorable attitudes toward urban trees, the absence of trees in front of their homes suggests a mismatch between attitude and practice. Contributing factors include the ineffective enforcement of regulations governing tree removal, the financial costs of maintenance, and inconveniences associated with urban vegetation, such as damage to sidewalks and sewage infrastructure (Riedman et al., 2022). Furthermore, the lack of adequate public policies and incentives (Ordóñez-Barona et al., 2021; Koeser et al., 2023), urban form (Lin and Guneralp, 2024), and sociocultural factors (Kirkpatrick et al., 2012; Heberlein, 2012; Avolio et al., 2015) may also contribute to this scenario.

We assumed a causal relationship between environmental attitudes and sociodemographic factors and the occurrence of trees. However, we acknowledge that tree presence may also influence attitudes, particularly in older neighborhoods where large trees are more common and residents may have developed stronger emotional connections to urban greenery. These areas also tend to have older populations, which complicates causal interpretation. Our assumption is supported by recent evidence indicating that most trees in Macapá are small to medium-sized (1–30 cm diameter), reflecting recent planting efforts following the removal of larger trees (Jimenez et al., 2024). This suggests that current tree presence may reflect recent decisions shaped by residents' attitudes. Another known confounding factor in afforestation decisions is conflict with urban infrastructure (Fernandes et al., 2019). Although this variable was not explicitly included in our models, it was addressed in item 6 of the questionnaire, which loaded onto the Anti-anthropocentric factor—a factor that was significantly associated with tree occurrence. This suggests that concerns related to infrastructure may have been indirectly captured through attitudinal variables.

Conclusions

This study demonstrated that attitudes toward urban trees vary according to sociodemographic characteristics and directly influence urban afforestation in Macapá, particularly the occurrence of trees along sidewalks. Individuals with higher education and income tend to hold less anthropocentric attitudes, and this factor increases the probability of tree occurrence.

Income and education are strongly correlated in urban environments, reflecting historical inequalities. The literature shows a consistent positive relationship between vegetation cover and income, with wealthier neighborhoods typically exhibiting greater tree cover (Iverson and Cook, 2000; Schwarz et al., 2015; Gerrish and Watkins, 2018; Arantes et al., 2021; McDonald et al., 2021; Jimenez et al., 2024). This pattern highlights how urban afforestation also reflects and perpetuates social inequalities and environmental injustices, as it directly affects quality of life.

The presence of trees in cities depends not only on individual decisions but also on effective public policies that promote tree planting and maintenance. Pro-ecological attitudes can be strengthened through governmental actions in the fields of environmental management, education, and urban planning. In the case of Macapá, although the population demonstrates conservation-oriented tendencies, the sociopolitical context appears to constrain the translation of these attitudes into action. In more favorable governance scenarios, this potential is expected to result in greater practical support for urban afforestation (see Romero et al., 2018; Koeser et al., 2023; Ordóñez-Barona et al., 2023).

Thus, the findings reinforce the importance of integrating sociodemographic factors and environmental attitudes into urban planning policies, particularly in contexts marked by structural inequalities. Advancing environmental justice requires recognizing urban afforestation as a vector of equity and collective well-being.

Data availability

Data is provided within the manuscript or supplementary information files.

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Author contributions

LAJ, SS, TC, and LF wrote the main manuscript text and JJT prepared figures and tables. LAJ and JJT conducted the statistical analyses. All authors reviewed the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Ethical approval

Our research was conducted in accordance with the ethical standards established by Resolution 466/12 of the National Health Council (CNS) of the Brazilian Ministry of Health, as well as with the 1964 Declaration of Helsinki and its later amendments. The questionnaire and its application procedures were approved by the Research Ethics Committee of the Federal University of Amapá (Certificate of Presentation for Ethical Review – CAAE: 40791720.0.0000.0003 / Approval number: 5.053.336, approved on October 21, 2021). The approval covered the use of structured questionnaires for collecting sociodemographic and environmental attitude data from adult residents of the city of Macapá.

Informed consent

Written informed consent was obtained from all participants prior to their inclusion in the study. Consent was collected between October 2021 and February 2022, before the interviews took place. Only individuals aged 18 years or older who signed the informed consent form—acknowledging their awareness of the study objectives, confidentiality, voluntary participation, and the right to withdraw at any time—were included. Individuals who declined or expressed uncertainty about participation were not included, in accordance with the ethical standards.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-025-05994-3.

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