

Road typology is associated with street-tree diversity, structure and composition in a rapidly urbanizing Indian city

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Abstract

Urban street trees are a key component of green infrastructure, yet how road typology influences their diversity, structure, and composition remains poorly understood in rapidly urbanizing Indian cities. We quantified street-tree composition, abundance, and health across four road categories in southern Guwahati, northeast India, using a spatially stratified survey of 143 roadside transects (200 m each). We tested whether street-tree composition and structure differed among road types, and whether contemporary planting and management practices were associated with compositional simplification. A total of 1,455 trees representing 80 species and 29 families were recorded. Species richness and Shannon diversity were highest along large roads and lowest along highways. Species composition differed significantly among road categories, although road type explained only a modest proportion of the variation. Five species collectively accounted for approximately 45% of all individuals, indicating strong compositional dominance. Mean diameter at breast height (DBH) was 21.9 ± 22.3 cm, and mean health scores indicated generally good tree condition. Tree diameter and health differed significantly among road categories, and native species comprised approximately 70% of all recorded individuals. Size-class distributions revealed a predominance of younger trees, indicating recent planting efforts and increasing reliance on smaller ornamental species. Our findings provide the first quantitative baseline of street-tree assemblages in Guwahati and demonstrate that road typology is associated with differences in urban forest composition and structure. Diversifying planting programmes, conserving mature canopy trees, and adopting road-specific greening strategies will be essential for enhancing ecological resilience in rapidly urbanizing cities.

1 Introduction

Rapid urbanization is transforming landscapes and reshaping the associated ecological processes worldwide. Cities, being the centers of economic and social activity, play a crucial role in shaping environmental quality and human well-being. Accelerated urbanization has intensified land-use change, habitat fragmentation, and biodiversity loss within urban ecosystems, especially in the context of the Global South [1]. At the global scale, urban greening patterns have been found to co-vary with human development and population density [2]. Within the context of urban ecosystems, street trees are a key yet often underexamined component, contributing substantially to urban ecological functioning while remaining among the understudied elements of urban biodiversity [3].

Street trees are those trees that are planted as well as naturally regenerated and are typically found along roadsides, medians, and sidewalks etc. They deliver a wide range of tangible and intangible benefits, both ecological and social. Street trees contribute to regulating microclimate, improving air quality and mitigating stormwater runoff; thus contributing to enhancing urban liveability [4–6]. Beyond these biophysical functions, street trees also support the psychological well-being of people, social interaction, and economic value; and also act as habitat and movement corridors for urban fauna [3]. Despite the importance of street trees, they are subject to multiple anthropogenic stressors limiting growth and survival. Some common constraints to street trees include compacted soils, restricted

rooting space, air pollution, heat stress, and water scarcity, which result in reduced canopy development and elevated mortality rates [6, 7]. These constraints are particularly pronounced in rapidly urbanizing cities, where infrastructure expansion often overpowers ecological planning [8].

Apart from the environmental stress, urban tree assemblages are also impacted by management decisions and associated species-selection practices. The widespread use of generalist, low-maintenance and often ornamental non-native species has contributed to biotic homogenization across urban landscapes, reducing taxonomic diversity as well as functional resilience [9]. Such practices weaken ecosystem service provision and diminish the benefits associated with structurally and compositionally diverse urban forests [3].

Road networks are one of the most extensive components of urban landscapes. In the context of urban greening, they are ecologically important too. Differences in road width, traffic intensity, surrounding land use, planting space availability, and maintenance regimes can strongly influence composition, diversity, structure, and condition of the street trees [10, 11]. Thus, road typology acts as an ecological determinant and filter, shaping urban forest assemblages. Understanding such patterns is particularly important in rapidly urbanizing cities, where infrastructure development and urban greening occur simultaneously to maximize ecological output.

Despite the expansion of research on urban forests, it remains geographically biased toward large metropolitan cities. In the Indian context, studies from metropolitan cities like Bengaluru and Delhi indicate that native species constitute less than one-quarter of urban flora [12]. This spatial concentration creates a knowledge gap in understanding regional variation in urban biodiversity patterns and management practices that influence them. This is particularly important in ecologically sensitive regions such as northeastern India, where rapid urban expansion intersects with high biodiversity and complex land-use histories.

Guwahati is the largest city in the northeastern state of Assam, India where the tension between rapid urban growth and ecological stewardship is very prominent. Guwahati is one of the earliest cities included under India's Smart Cities Mission (2015), and consequently, it has undergone extensive infrastructure development, often with limited integration of urban greening strategies. Despite its importance, baseline information on Guwahati's urban vegetation, particularly street trees, remains scarce, impacting evidence-based planning and management decisions aimed at enhancing ecological resilience.

In an attempt to address this gap, this study assessed street-tree assemblages across four road categories in the southern part of Guwahati city. Two hypotheses were tested: (1) street-tree composition and structure differ among road types, due to variation in planting space, management intensity, and urban form; and (2) urban planting and management practices promote compositional simplification, which results in dominance of fewer species across the streetscape. It was predicted that wider roads would support denser but less compositionally diverse tree assemblages, whereas smaller

roads would support more heterogeneous tree communities with greater representation of native species.

2 Study area

The study was conducted in the southern part of Guwahati (26°08'04" N, 91°46'05" E) (Fig. 1), the largest and most rapidly urbanizing city in Assam, India, located primarily on the southern bank of the Brahmaputra River. This part of the city forms Guwahati's principal urban core, encompassing major residential, commercial, institutional, and transportation corridors, and was therefore selected as the study area. The region is characterized by a humid subtropical climate, with a mean annual rainfall of approximately 1,600 mm [13]. Guwahati's rapid and unplanned urbanization has led to significant changes in land use and cover [14].

3 Methods

3.1 Sampling design and field survey

To capture variation in street-tree assemblages across different urban road types, a spatially stratified sampling design was employed. The study area (Fig. 1) was divided into grid cells of 1 km², and alternate diagonal grids were selected to ensure representation across varying intensities of land use. 63 grid cells were sampled in total, yielding 143 transects covering a total of 28.6 km of roadway.

Street-tree surveys were conducted within the selected grids, along 200 m transects across four different road categories: highways (≥ 20 m), large roads (10–19 m), medium roads (5–9m), and small roads (< 5 m). Adapting and modifying from Nagendra and Gopal [15], these categories were selected to represent the range of urban road types in Guwahati city and the associated differences in planting space, traffic intensity, and surrounding infrastructure. Transects were randomly located, taking road junctions as starting points following Nagendra and Gopal [15], with modifications to accommodate local accessibility constraints. A few areas were excluded due to inaccessibility, including defence establishments, industrial lands, water bodies, or inaccessible vegetation patches.

Field surveys were undertaken between the months of March 2022 and August 2022. Trees with circumference at breast height (CBH) ≥ 30 cm occurring along both sides of each transect were recorded. For each recorded tree, species identity, GPS coordinates, and circumference at breast height were documented. Scientific names and native/exotic status (relative to India) were confirmed using Plants of the World Online (POWO) [16]. Tree health was assessed using a standardized five-point ordinal scale that was adapted and modified from Kuruneru-Chitepo & Shackleton [17], where higher scores indicated poorer condition (Table 1). The objectivity of assigning scores was ensured by involving the same person throughout to minimize inter-observer variability.

Table 1

Criteria used to assess the health condition of street trees based on a five-point ordinal scale

Score	Description
1	The tree is in near-perfect health without any visible damage
2	The tree has minor damage, with one or two broken or damaged branches
3	The tree has few broken or damaged branches but retains an overall healthy structure
4	The tree has extensive branch damage and exhibits poor overall condition
5	The tree is severely damaged and/or dying

3.2 Data analysis

For each transect, we calculated the species richness, Shannon diversity (H'), mean DBH (calculated as CBH/π), and species dominance metrics. Shannon diversity was used because it accounts for both species richness and relative abundance and is widely applied in ecological studies to compare community diversity [18]. The five most abundant species in each road category were evaluated using relative abundance (RA), relative dominance (RD), and relative importance (RI) values following McPherson & Rowntree [19] and Welch [20]. Relative abundance was calculated as the percentage contribution of a species to the total number of individuals, while relative dominance was calculated as the percentage contribution of a species to the total basal area. Relative importance value was obtained as the sum of relative abundance and relative dominance:

$$RA = \left(\frac{N_i}{T} \right) \times 100$$

$$RD = \left(\frac{B_i}{BT} \right) \times 100$$

$$RI = RA + RD$$

Where N_i is the number of individuals of species i , T is the total number of individuals of all species, B_i is the basal area of species i , and BT is the total basal area of all species.

DBH size-class distributions of the six most abundant species were examined as proxies for planting history and population structure [15]. Since DBH and health score data did not satisfy assumptions of normality and homogeneity of variance, we tested differences among road categories using the Kruskal-Wallis test followed by Dunn's post hoc pairwise comparisons in the PAST (PAleontological STatistics) software, version 5.3 [21].

We used non-metric multidimensional scaling (NMDS; *metaMDS*) to determine how the species composition of street trees varies across road types, and we tested the statistical significance of these variations using permutational multivariate analysis of variance (PERMANOVA; *adonis2*, 999

permutations) based on Bray-Curtis dissimilarities in the *vegan* package of R statistical software [22]. The homogeneity of multivariate dispersion among road types was assessed using *betadisper*, followed by permutation tests (*permutest*) and Tukey's pairwise comparisons (*TukeyHSD*). To assess sample completeness and sampling adequacy among road types, we used the *iNEXT* package in R to generate sample-size-based rarefaction and extrapolation curves (*ggiNEXT*) based on species richness [23]. All these analyses were performed in R version 4.6.0 [24].

4 Results

4.1 Street-tree abundance and composition

Across 143 transects, we recorded 1,455 street trees representing 80 species and 29 families. Fabaceae was found to be the most species-rich family, with 17 species. Sample-size-based rarefaction curves showed decreasing rates of species accumulation with increasing sampling effort but didn't reach complete sampling saturation, indicating that most species were sampled but future sampling would most likely reveal additional uncommon species (Fig. S1 of Supplementary). Five species together accounted for 45.3% of all individuals: *Pongamia pinnata*, *Monoon longifolium*, *Delonix regia*, *Neolamarckia cadamba*, and *Lagerstroemia speciosa*, with *P. pinnata* being the most abundant species (12.02%). Forty-one transects (8.2 km of roadway) did not have any street trees. Across all transects, mean diameter at breast height (DBH) was 21.9 cm, and mean health score was 1.5, indicating generally healthy populations of street trees. The largest individual recorded was *Samanea saman* with a DBH of 156 cm.

4.2 Variation across road categories

Density of street-trees varied strongly by road type, with highways supporting the highest densities (227 trees per km), and small roads the lowest (12 trees per km). Species richness was highest along large roads with 65 species, and lowest along small roads with 41 species. Shannon diversity (H') ranged from 2.82 on highways to 3.37 on large roads, while evenness increased progressively from highways (0.73) to small roads (0.88). Native species dominated across all road categories, comprising 65%–78% of individuals.

Mean DBH was highest on large roads (27.6 ± 24.5 cm) and lowest on highways (18.3 ± 12.5 cm) (Table 2). Mean DBH varied significantly among road categories (Kruskal-Wallis test: $H = 33.33$, $df = 3$, $p = 2.746 \times 10^{-7}$). Pairwise comparisons showed that large roads supported significantly larger trees than highways, medium roads, and small roads, while highways and small roads did not differ significantly in DBH.

Mean health scores ranged from 1.45 to 1.59 across road categories (Table 2). Tree health also differed significantly among road types (Kruskal-Wallis test: $H = 23.6$, $df = 3$, $p = 3.021 \times 10^{-5}$). Pairwise comparisons revealed significant differences between highways and both large and medium roads, as

well as between small roads and both large and medium roads. However, highways and small roads did not differ significantly, nor did large and medium roads.

Table 2

Summary of street-tree attributes across the four road categories in Guwahati. Different superscript letters indicate significant differences based on Dunn's post hoc pairwise comparisons ($p < 0.05$)

Street tree attributes	Highway	Large roads	Medium roads	Small roads
Range of tree density (per 200 m transect)	0–137	1–52	0–29	0–21
Mean DBH $\pm$ SD (cm)	18.26 $\pm$ 12.46 ^a	27.61 $\pm$ 24.47 ^c	24.60 $\pm$ 25.47 ^b	23.40 $\pm$ 18.72 ^a
Mean health score $\pm$ SD	1.45 $\pm$ 0.77 ^a	1.59 $\pm$ 0.79 ^b	1.57 $\pm$ 0.76 ^b	1.47 $\pm$ 0.84 ^a
Species richness	47	65	47	41
Number of native (N) vs exotic (E) trees	E: 31.36%, N: 68.64%	E: 26.98%, N: 73.02%	E: 34.95%, N: 65.04%	E: 22.22%, N: 77.77%
Total number of trees	727	367	226	135
Shannon diversity index (H')	2.82	3.37	3.17	3.33
Street tree attributes	Highway	Large roads	Medium roads	Small roads
Species evenness	0.73	0.81	0.83	0.88
Tree density (per km)	227.18	70.57	26.27	11.63

DBH class distributions showed clear differences among road categories (Fig. 2). Trees along highways were mostly represented by smaller diameter classes, while large roads supported a greater proportion of medium and large-sized trees. Medium and small roads were dominated mainly by trees in the lower and intermediate DBH classes, although a few very large individuals were also present on medium roads.

4.3 Species composition among road categories

Non-metric multidimensional scaling (NMDS) revealed partial separation of street-tree assemblages among road categories (Stress = 0.095; Fig. 3). Highways and large roads showed substantial overlap, whereas medium and small roads exhibited greater dispersion in species composition.

PERMANOVA detected significant differences in species composition among road categories ($F = 1.65$, $R^2 = 0.049$, $p = 0.001$). However, the road categories explained only a small fraction of the overall variation. Tests for multivariate dispersion revealed significant differences in within-group heterogeneity among road types ($F = 6.11$, $p = 0.002$). Pairwise comparisons showed that medium and small roads were compositionally more heterogeneous than highways and large roads, while the latter two did not differ significantly.

4.4 Dominant species and importance values

Table 3 shows the five most abundant species across road categories. *Pongamia pinnata* was the most abundant species in three of the four road types however *Samanea saman* had high relative importance values for large, medium and small roads. Highways were dominated by *Monoon longifolium*, while *Neolamarckia cadamba* had a disproportionate contribution to relative dominance because of its large basal area. Across broader road categories, *Samanea saman* consistently attained high values of dominance, indicating its structural significance in the urban streetscape. Other dominant species, such as *Pongamia pinnata*, *Delonix regia*, and *Lagerstroemia speciosa*, were all flowering ornamental trees, indicating that aesthetics play a role in species selection. Three of the five most dominant species on medium roads were exotic.

Table 3

Five most frequently encountered species in each road category with corresponding relative abundance, dominance, and importance values

Road category	Abundance rank	Species name	Relative abundance (RA)	Relative dominance (RD)	Relative importance (RI)
Highway	1	<i>Monoon longifolium</i>	0.18	0.04	0.23
	2	<i>Neolamarckia cadamba</i>	0.12	0.27	0.40
	3	<i>Delonix regia</i>	0.09	0.16	0.25
	4	<i>Pongamia pinnata</i>	0.07	0.03	0.11
	5	<i>Lagerstroemia speciosa</i>	0.07	0.06	0.14
Large Roads	1	<i>Pongamia pinnata</i>	0.18	0.07	0.26
Road category	Abundance rank	Species name	Relative abundance (RA)	Relative dominance (RD)	Relative importance (RI)
	2	<i>Samanea saman</i>	0.08	0.36	0.45
	3	<i>Delonix regia</i>	0.08	0.08	0.16
	4	<i>Ficus religiosa</i>	0.05	0.10	0.16
	5	<i>Monoon longifolium</i>	0.04	0.03	0.08
Medium Roads	1	<i>Pongamia pinnata</i>	0.15	0.03	0.19
	2	<i>Samanea saman</i>	0.09	0.50	0.59
	3	<i>Thevetia peruviana</i>	0.08	0.01	0.09
	4	<i>Delonix regia</i>	0.07	0.02	0.10
	5	<i>Mimusops elengi</i>	0.06	0.01	0.07
Small Roads	1	<i>Pongamia pinnata</i>	0.10	0.02	0.13
	2	<i>Samanea saman</i>	0.09	0.09	0.19
	3	<i>Areca catechu</i>	0.08	0.01	0.09

Road category	Abundance rank	Species name	Relative abundance (RA)	Relative dominance (RD)	Relative importance (RI)
	4	<i>Neolamarckia cadamba</i>	0.05	0.04	0.09
	5	<i>Lagerstroemia speciosa</i>	0.05	0.01	0.07

Along the Highways, *Monoon longifolium* was the most abundant species (RA = 0.18, RI = 0.23), while *Neolamarckia cadamba* was the second most abundant species (RA = 0.12), and it exhibited the highest relative dominance (RD = 0.27), owing to its large basal area. It also had the greatest relative importance value (RI = 0.40). Other commonly encountered species contributing to the composition and canopy structure along highways included *Delonix regia*, *Pongamia pinnata*, and *Lagerstroemia speciosa*.

Along large roads, *Pongamia pinnata* showed the highest relative abundance value (RA = 0.18). However, *Samanea saman* showed the most relative dominance (RD = 0.36) due to its substantial basal area, and also showed the highest relative importance value of 0.45. Apart from these two, *Delonix regia*, *Ficus religiosa*, and *Monoon longifolium* were some other species that were frequently observed on large roads.

Pongamia pinnata was found to be the most abundant species along medium roads (RA = 0.15). *Samanea saman* exhibited the highest relative dominance (RD = 0.5), which can be attributed to its large canopy and basal area. As a result, it also emerged as the most ecologically important species, showing a relative importance value of 0.59. Other commonly observed species along the medium road category included *Thevetia peruviana*, *Delonix regia*, and *Mimusops elengi*, reflecting a mix of ornamental and shade-providing species.

Along small roads, *Pongamia pinnata* (RA = 0.1) and *Samanea saman* (RA = 0.09) again remained the most abundant species. However, their dominance values were lower compared to wider road types, indicating smaller tree sizes or less structural influence. Other frequently encountered species in this category were *Areca catechu*, *Neolamarckia cadamba*, *Lagerstroemia speciosa*, and *Ficus hispida*. It reflects a tendency toward smaller ornamental species better suited to the spatial constraints of narrow bylanes.

4.5 Size-class distribution of dominant species

DBH class distributions revealed contrasting population structures among the six dominant species (Table 4). *P. pinnata* and *M. longifolium* showed strongly skewed distributions toward smaller size classes, with most individuals under 20 cm DBH. In contrast, *D. regia* and *N. cadamba* exhibited more even size-class distributions, with greater representation in intermediate DBH classes. *S. saman* dominated the > 50 cm class (33.33%), contributing substantially to total basal area, whereas *L. speciosa* was primarily represented by small-stemmed individuals. These patterns indicate a predominance of younger cohorts among several commonly planted street-tree species.

Table 4

Diameter-at-breast-height (DBH) class distribution of six dominant street-tree species in the study area

Species	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	> 50 cm	No. of individuals
<i>Pongamia pinnata</i>	29.19	47.57	16.76	3.24	1.62	1.62	185
<i>Monoon longifolium</i>	50.31	44.03	1.89	3.14	0.62	0	159
<i>Delonix regia</i>	10.57	23.58	25.20	25.20	6.50	8.94	123
<i>Neolamarckia cadamba</i>	2.78	10.19	35.17	34.26	11.11	6.48	108
Species	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	> 50 cm	No. of individuals
<i>Samanea saman</i>	8.08	20.20	14.14	16.16	8.08	33.33	99
<i>Lagerstroemia speciosa</i>	5.71	54.29	32.86	5.71	1.43	0	70

5 Discussion

In Guwahati, road typology contributes to shaping the composition and structure of street-tree assemblages, although it represents only one of the several factors influencing community composition. The significant differences detected by NMDS and PERMANOVA support our first hypothesis that road typology influences urban tree assemblages. However, the relatively small proportion of the explained variation suggests that local planting decisions and characteristics of different road environments also contribute substantially to species composition.

Differences in compositional variability among road categories were further established by the multivariate dispersion analysis. The categories of highways and large roads exhibited lower within-group variation, whereas the categories of medium and small roads showed significantly greater compositional heterogeneity. One possible explanation for this pattern is the standardized planting schemes, most commonly associated with major transportation corridors. In contrast, residential and secondary roads show characteristics of heterogeneous planting decisions and site conditions.

The contrasting diversity patterns among road categories may reflect differences in planting objectives. Although highways supported the highest tree density, they showed the lowest diversity and evenness, indicating a reliance on a limited number of species in roadside planting schemes. In contrast, large roads supported the highest species richness and structural maturity, likely indicating longer planting histories and greater availability of planting space, although historical planting records were unavailable to verify this interpretation. Though the small residential roads contained fewer trees overall, they exhibited greater species evenness and a higher proportion of native species, and further displayed higher compositional heterogeneity than other categories.

Both mean DBH and tree health differed significantly among road categories, likely reflecting that road type influences not only species composition but also the structural development and condition of trees. The comparatively larger average DBH observed along large roads suggests that these roads may retain older trees established during earlier phases of urban development. In contrast, highways and smaller roads were dominated by smaller diameter classes, consistent with more recent planting or higher rates of tree replacement. These findings are consistent with studies from Bengaluru, New York, and other urban centers exhibiting strong associations between urban form, development history, and street-tree diversity and structure [10, 11, 15].

This study also finds that native species constituted between 65% and 78% of individuals across all road categories in Guwahati, unlike many urban centers where exotic species dominate roadside plantings. This relatively high representation of native species suggests that there are opportunities to strengthen biodiversity-sensitive urban forestry through the retention and expansion of native plantings. Such strategies may enhance habitat quality for native fauna in the urban landscapes while improving ecological connectivity within urban landscapes. However, species selection should not rely solely on native status. Site suitability, projected climate resilience, functional traits, and the capacity of species to provide long-term ecosystem services should also be considered when designing urban planting programmes.

Although species composition differed significantly among road categories, road type explained only a small proportion of total compositional variation. This indicates substantial overlap among street-tree assemblages. Nevertheless, the recurrent dominance of a limited number of species across all the road categories suggests that urban planting and management practices may be contributing to compositional simplification. The five most abundant species accounted for more than 45% of all recorded individuals, while *P. pinnata*, *M. longifolium*, and *S. saman* were consistently dominant across multiple road categories. In urban forestry, such patterns are frequently reported, where a small number of species are repeatedly selected because of their ornamental value, ease of maintenance, or tolerance to urban stressors [1, 9]. While these species do provide important ecosystem services, excessive reliance on a narrow species pool may reduce long-term ecological resilience by increasing vulnerability to pests, diseases, and climate-related disturbances. Studies from Bengaluru have reported lower dominance by individual species, suggesting that Guwahati's street-tree assemblages may be comparatively less diverse and potentially less resilient to future disturbances [15].

The tendency toward compositional simplification may also reflect contemporary urban planting practices that prioritize planting species with ease of maintenance, rapid establishment, and aesthetic appeal. Although such criteria are understandable from a management perspective, they may inadvertently reduce functional diversity and increase the ecological vulnerability of the urban forests in the long term. Collectively, these findings support our second hypothesis that contemporary urban planting practices promote compositional simplification through repeated use of a relatively narrow species pool.

The DBH distributions of dominant species reflect the recent changes in urban planting practices. The concentration of *P. pinnata* and *M. longifolium* within smaller DBH classes suggests extensive recent planting. This is likely associated with urban greening initiatives and roadside beautification programs. These species are frequently selected because of their rapid growth, ornamental value, and tolerance to urban conditions. In contrast, large-canopied species such as *S. saman* were predominantly seen in larger DBH classes. They also contributed substantially to the overall basal area of the street-tree population. These mature trees contribute disproportionately to ecosystem services, including shade provision, carbon storage, stormwater interception, and mitigation of urban heat island effects [25]. The high relative dominance values of large-canopied trees across multiple road categories further highlight their structural and ecological importance.

However, many of these mature trees occur along older and wider roads which are increasingly being targeted for infrastructure expansion. Recent infrastructure expansion in Guwahati has involved the removal of mature roadside trees along several transportation corridors. Although the extent of these losses was not quantified in this study, such interventions are likely to alter the structural composition of the city's street-tree population. While replacement planting efforts may maintain numerical tree cover, they are unlikely to instantly compensate for the ecological services offered by mature canopy trees. The distinction between tree abundance and ecological function is particularly important in rapidly urbanizing cities. Ecological benefits such as canopy cooling, carbon storage, habitat provision, and stormwater interception are strongly dependent on tree size. As a result, if a single mature canopy tree is lost, it may require decades of growth by multiple replacement trees before comparable ecological benefits are restored.

The predominance of younger individuals across several commonly planted tree species suggests that the structure of Guwahati's street-tree population is also changing. If these observed patterns persist, Guwahati's street-tree population may become increasingly numerically abundant but structurally simplified, potentially reducing its capacity to deliver ecosystem services associated with large-canopy trees.

Street trees are an essential part of urban biodiversity. Beyond their biophysical contributions to thermal comfort, air quality improvement, and stormwater regulation, they also provide habitat and connectivity within increasingly fragmented urban landscapes [3, 26]. The relatively higher proportion of native species observed on small roads highlights the potential for locally adapted and ecologically appropriate planting strategies within urban environments.

The observed differences in species composition among different road types, although modest, suggest that a blanket city-wide planting approach may be insufficient. Our findings suggest that road-specific planting strategies may better accommodate the ecological and spatial constraints associated with different urban environments than uniform city-wide planting approaches.

Our findings indicate that urban forestry programmes should move beyond simple tree-count targets and instead incorporate species diversity, structural complexity, and long-term ecosystem functioning into

planting and management decisions. The conservation of mature canopy trees is particularly important in urban forestry because of their disproportionate contribution to ecological services and urban biodiversity. Equally important is the diversification of the planting pool through the inclusion of a wider range of native and functionally complementary species, which will be capable of enhancing resilience to environmental change.

Thus, integrating biodiversity considerations into street-tree planting, protecting large-canopy mature trees, and adopting road-specific, ecologically resilient planting strategies are therefore critical. More broadly, systematic street-tree inventories and long-term monitoring programs are essential for supporting ecologically resilient and livable cities across the Global South, where urban expansion continues to transform landscapes at an unprecedented rate.

This study provides a baseline for understanding street-tree assemblages in northeastern India, a region that remains underrepresented in urban forestry research. Nevertheless, restricted access to certain areas as well as reliance on a single season of data collection may have limited the spatial and temporal scope of the analysis of this study. Furthermore, while DBH distributions provide useful insights into the structure and planting history of the street-trees, direct information on tree age and historical planting records was unavailable.

Future studies should incorporate long-term monitoring of tree growth, mortality, and ecosystem service provision, while also examining tree-infrastructure interactions, plantation policies and public perceptions of street-trees as well as urban greening practices. Quantifying functional diversity, ecosystem services, and patterns of beta diversity would further improve understanding of how urbanization influences street-tree assemblages and would allow more direct assessment of ecological homogenization processes. Comparative studies across various other rapidly urbanizing cities in northeastern India would also help establish whether the patterns observed in Guwahati are representative of broader regional trends.

6 Conclusion

This study provides the first quantitative assessment of street-tree diversity, structure, and condition in Guwahati, which is also a first in the northeastern part of India. It demonstrates that road typology significantly influences street-tree assemblages across the city. Differences in tree density, diversity, species composition, and structural attributes across road categories show that urban road environments contribute to variation in street-tree assemblages, although substantial compositional overlap persists across the urban landscape. While highways supported dense but compositionally simplified tree populations, large roads retained structurally mature and species-rich tree communities, whereas medium and small road categories, which mostly include residential lanes supported lower-density yet more even and predominantly native assemblages.

The dominance of a limited number of species across multiple road categories, together with the predominance of younger trees, is consistent with contemporary planting practices promoting

compositional simplification, although direct evidence on planting decisions was beyond the scope of this study. At the same time, mature canopy trees were found to be concentrated along older roads and contributed disproportionately to structural complexity. Their continued removal during infrastructure expansion may reduce ecological functioning despite compensatory planting efforts.

These findings together highlight the need to move beyond tree-count-based greening targets, which frequently guide urban greening policies and compensatory plantation programs. We also suggest that urban forestry planning should prioritize species diversity, structural complexity, and long-term ecosystem functioning. Integrating biodiversity considerations into street-tree planting, protecting mature large-canopy trees, and adopting road-specific, climate-adaptive greening strategies are therefore critical for sustaining urban ecological resilience in the long-term. More broadly, systematic street-tree inventories and long-term monitoring of street-trees are also essential to support evidence-based urban planning, to ensure that rapidly urbanizing cities like Guwahati can retain both the biodiversity and ecosystem services upon which urban sustainability depends.

Declarations

Ethics approval and consent to participate

Not applicable

Ethics and guidelines statement

This study did not involve human participants, human subjects, or personal data and therefore did not require ethical approval. The study involved field-based observations and measurements of street trees in public urban spaces. All data were collected for scientific research purposes in accordance with applicable institutional and fieldwork guidelines.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Author Contribution

B.K.: Conceptualization, Study Design, Methodology, Field Investigation, Data Analysis and Original Draft Writing. H.K.: Conceptualization, Visualization, Interpretation of Results, Original Draft Writing, Review and Editing. N.M.: Data Analysis, Original Draft Writing, Review and Editing. K.D.: Field Investigation and Tree Species Identification. N.S.: Conceptualization, Study Design, Supervision, Review and Editing.

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Data Availability

All data collected or analyzed during this study are included in this manuscript and its supplementary file.

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Figures

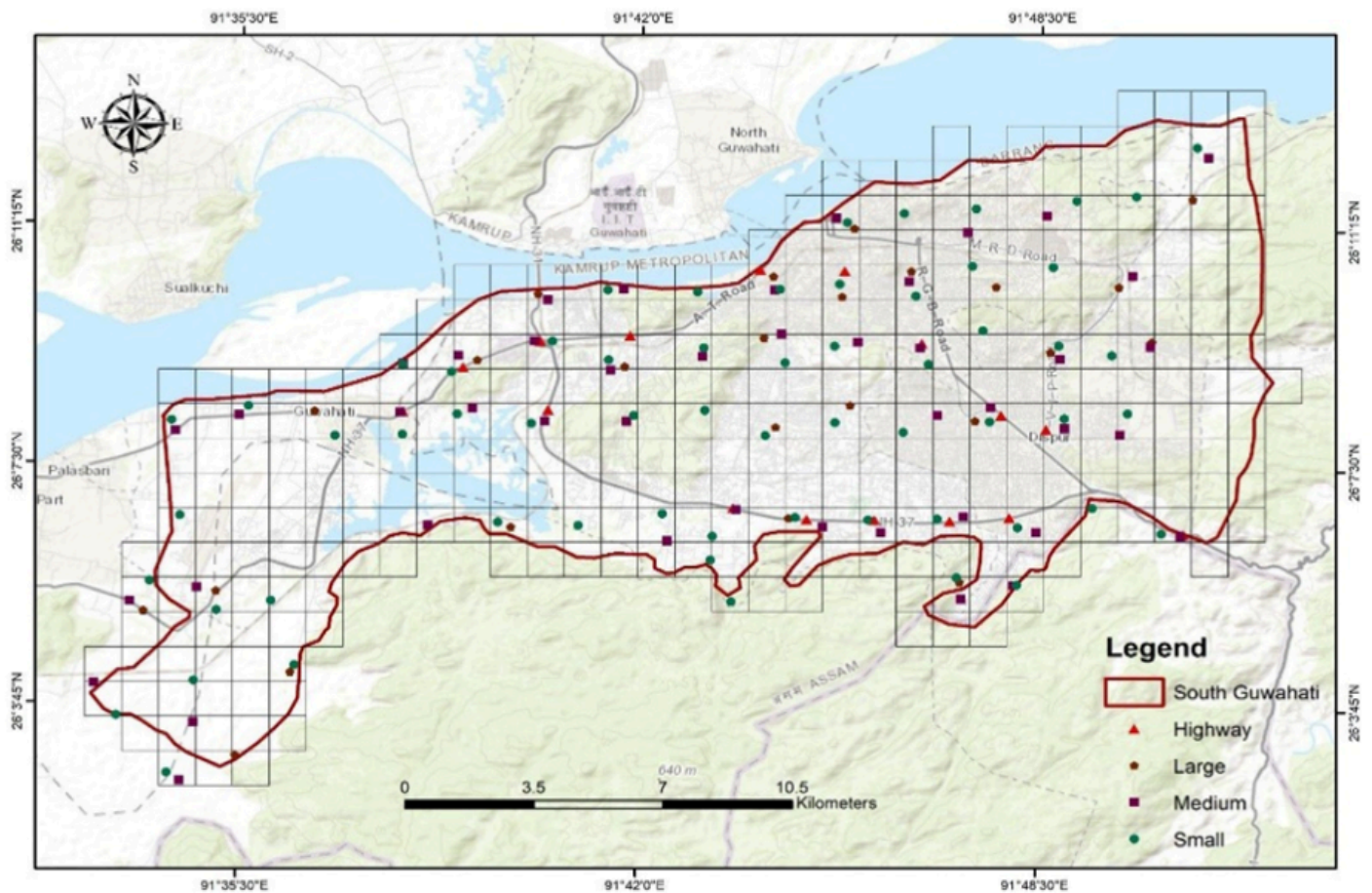


Figure 1

Study area map showing sampled grids and transects in South Guwahati, Assam, India

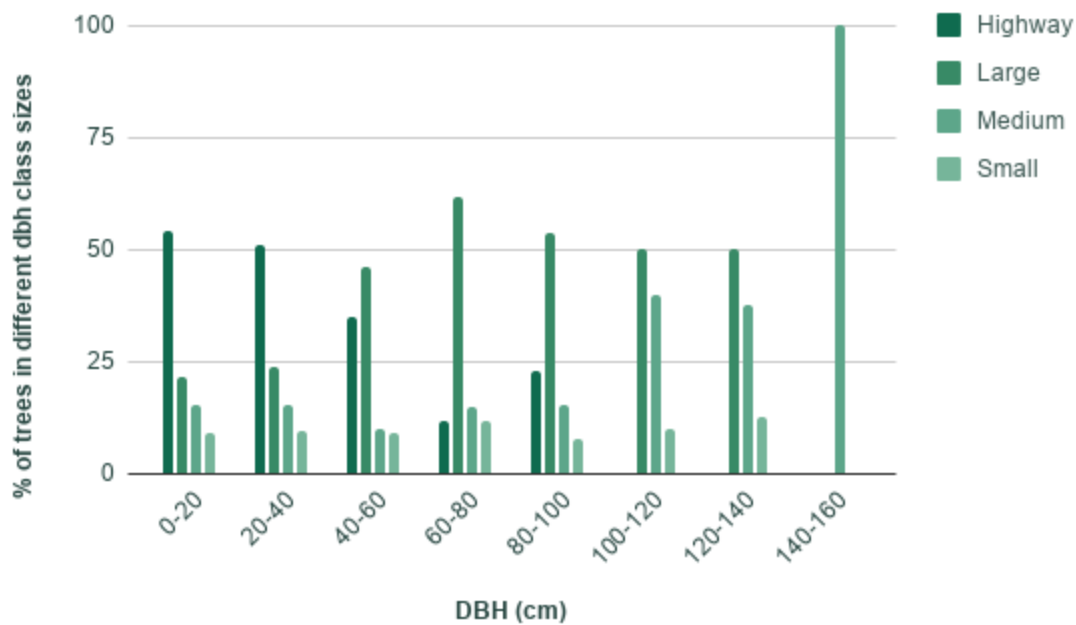


Figure 2

DBH size-class distribution of street trees across highway, large, medium and small road categories

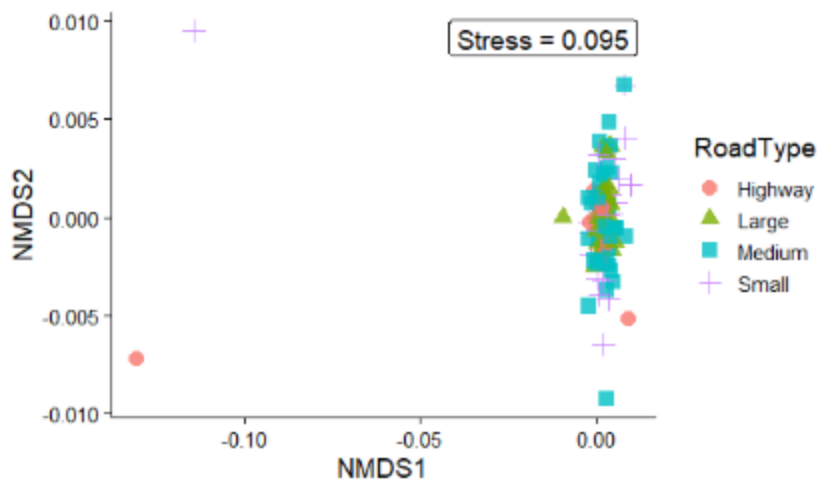


Figure 3

NMDS ordination of street-tree assemblages across four road categories based on Bray-Curtis dissimilarities

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