Street tree characterization and selection for urban environments: a case study in Matosinhos and Leça da Palmeira (Portugal)

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Abstract

Street trees play a critical role in urban environments, contributing to climate regulation, air quality improvement, stormwater management, and biodiversity support. They also enhance public space quality, pedestrian comfort, and help mitigate the urban heat island effect. However, their ability to deliver these benefits depends on their size, structure, and spatial arrangement.

This study characterizes the street tree population in Matosinhos and Leça da Palmeira (Portugal), analysing species diversity, attributes, and spatial distribution patterns based on a municipal tree inventory of 5,813 trees from 110 species. Results show a substantial proportion of small-sized species, which have limited capacity to provide essential ecosystem services compared to larger trees. While some streets feature larger, structurally robust trees, many rely on smaller ornamental species that offer aesthetic value but are less effective at providing shade, regulating temperatures, and sequestering carbon.

Species distribution patterns reflect both cultural and environmental factors, with coastal areas showing a higher prevalence of wind- and salinity-tolerant species such as Metrosideros excelsa. Species like Platanus × hispanica, Populus nigra, and Ulmus minor are more broadly distributed, demonstrating resilience in both coastal and inland areas.

To guide future urban forestry practices, the study proposes a framework for selecting trees based on the 'minimum street tree' concept, which balances ecological performance with the spatial constraints of urban streets. This research underscores the importance of aligning tree selection with site-specific conditions, advocating for increased tree size, species diversity, and resilience to enhance the long-term benefits of urban green infrastructure. By integrating ecological knowledge into street design, urban planners can foster more resilient, climate-adaptive, and liveable urban environments.

Keywords

Urban trees, minimum street tree, urban green infrastructure, climate adaptation, public space quality

Introduction

Street trees are vital components of urban infrastructure, offering a broad range of ecosystem services that enhance city resilience, environmental performance, and quality of life. Their integration into streetscapes contributes to the regulation of microclimates, interception of stormwater, improvement of air quality, and support for biodiversity and ecological connectivity (Nowak & Dwyer, 2007; Salmond et al., 2016; Tyrväinen et al., 2005). These benefits are particularly important in the face of climate change, as cities confront rising temperatures, more frequent heatwaves, and intense rainfall events.

As natural regulators of climate, street trees provide shade and release water vapor through evapotranspiration, helping to cool urban areas and mitigate the urban heat island effect. Their canopies intercept rainfall, reduce surface runoff, and promote infiltration, which is especially valuable in preventing localized flooding. Trees also play a role in carbon sequestration and can contribute indirectly to energy savings by shading buildings and moderating temperature extremes (Nowak & Dwyer, 2007; Salmond et al., 2016; Tyrväinen et al., 2005).

In addition to these environmental functions, street trees significantly enhance public health, well-being, and social cohesion. Exposure to green elements in the public realm has been shown to reduce stress levels, improve cognitive performance, and encourage physical activity and social interaction. Trees enhance the sensory quality of public space, improve walkability, and contribute to safer, more attractive, and more inclusive urban environments (Farinha-Marques et al., 2021; Nowak & Dwyer, 2007).

However, realizing these benefits requires overcoming spatial and functional constraints common to urban streets. As complex linear systems, streets host overlapping flows – pedestrians, vehicles, utilities – that often limit the space available for trees. The success of urban tree planting depends on selecting species that are, not only aesthetically pleasing, but also structurally compatible with streets' spatial configuration, environmentally resilient, and capable of providing significant ecosystem services over time with minimal conflict.

This paper examines these issues through a case study in Matosinhos and Leça da Palmeira, two coastal parishes in northern Portugal. By analysing the street tree population and street spatial configurations across a heterogeneous urban landscape, the study proposes a framework for enhancing the effectiveness of tree planting in urban streets. Central to the approach is the articulation between tree size, street width, environmental fit, and diversity. The aim is to move beyond ornamental or aesthetic criteria and toward a framework where street trees are seen as spatially integrated, structurally compatible, and ecologically functional components of the urban fabric.

Methodology

In the context of climate change and increasing urban complexity, understanding the structure, size, and diversity of street tree populations is critical for planning resilient and adaptive urban environments. The capacity of street trees to provide ecosystem services depends heavily on their dimensions and other characteristics. Likewise, the overall resilience of the urban forest is closely tied to its biological diversity and its capacity to withstand environmental stressors, pests, and diseases. Species selection for street planting must also consider a range of site-specific factors, like sun exposure, shade, street orientation, wind or proximity to the sea. However the common factor for discussion should be tree size, as a minimum dimension is fundamental and should apply across all species selected for street planting.

This study adopts the concept of the 'minimum street tree' (Figure 1) as a benchmark for assessing the potential of street trees to contribute meaningfully to ecosystem service provision within the spatial and functional constraints of urban streets. The 'minimum street tree' is defined, by Farinha-Marques et al., 2021, as the smallest tree that, once mature, can deliver relevant ecological benefits without compromising pedestrian movement and emergency access. For the specific context of Northwestern Portugal, based on the literature and the recent developments of narrow tree varieties in nurseries, the 'minimum street tree' is based on the following spatial characteristics:

- Minimum expected height of 12 m (after 20-30 years), capable of forming a clean bole of at least 4 m, to avoid interfering with circulation, and corresponding 8 m canopy (ratio of ⅓ bole to ⅔ canopy) to optimize ecological performance.
- Narrow and/or columnar canopy, with potential growth up to 4 m wide, to reduce competition for space.

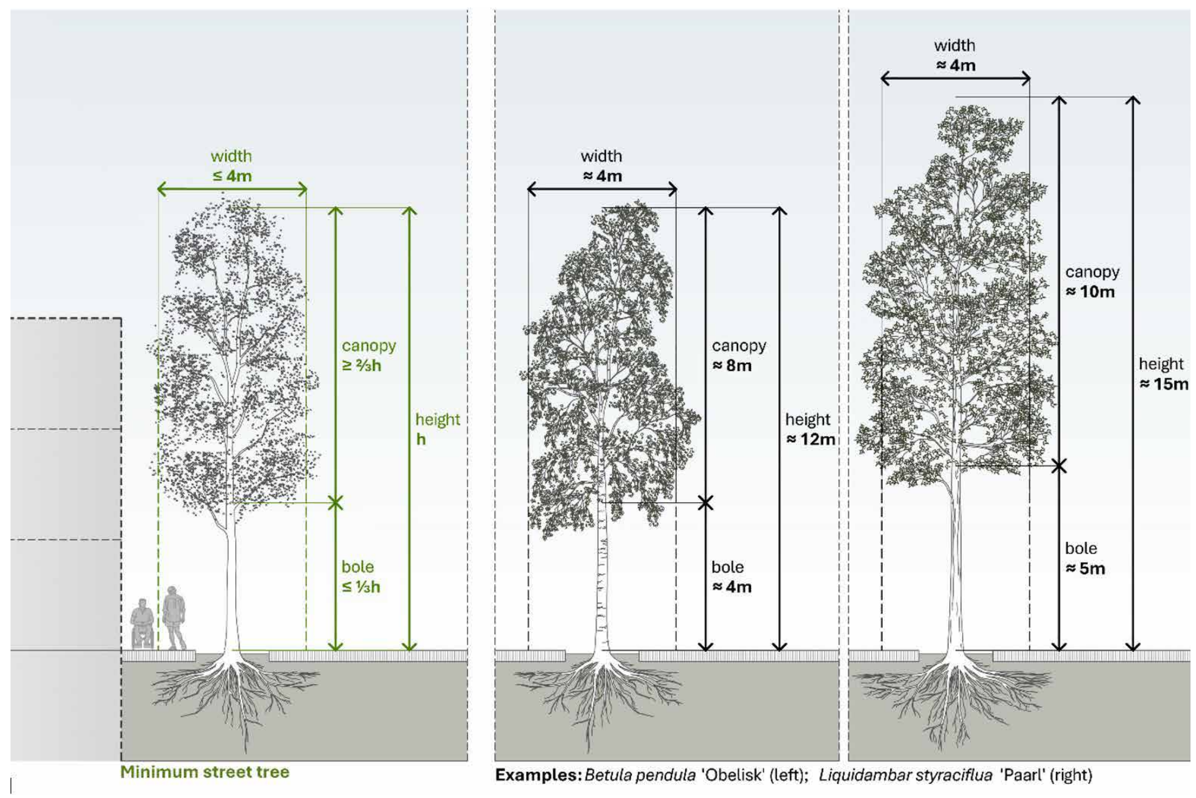

Figure 1. Representation of the 'minimum street tree' and its spatial features (adapted from Farinha Marques et al., 2021).

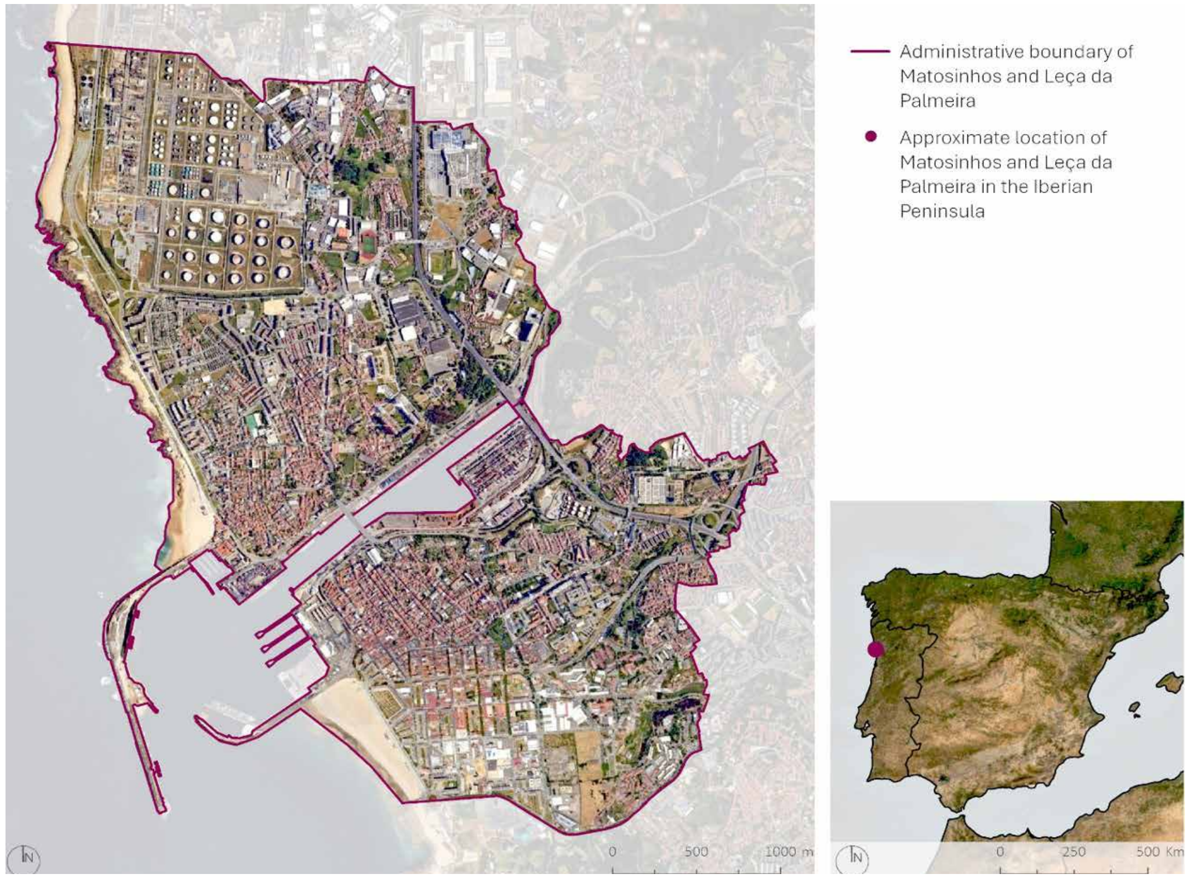

Figure 2. Study area.

This concept provides a pragmatic reference for evaluating existing tree populations and guiding future species selection and planting strategies.

This study is based on the analysis of the municipal street tree inventory (Câmara Municipal de Matosinhos, 2024) of Matosinhos and Leça da Palmeira (Figure 2), which includes 5,813 recorded trees occurring in the public street network (123.9 km). The inventory, provided by the Municipality of Matosinhos, was examined to assess species diversity, species attributes and spatial patterns. The study area exhibits a complex urban fabric, combining historic cores with narrow streets, modern residential zones, industrial areas, and coastal avenues. This diversity makes them a particularly rich context for analysing how different spatial and environmental conditions influence tree selection, performance, and distribution across an urban street network.

Results

According to the most recent municipal inventory, a total of 5,813 trees are planted within the public street network of Matosinhos and Leça da Palmeira. This figure represents 52% of the inventoried urban tree population for the area, indicating the significant role of street trees in the region's urban green infrastructure.

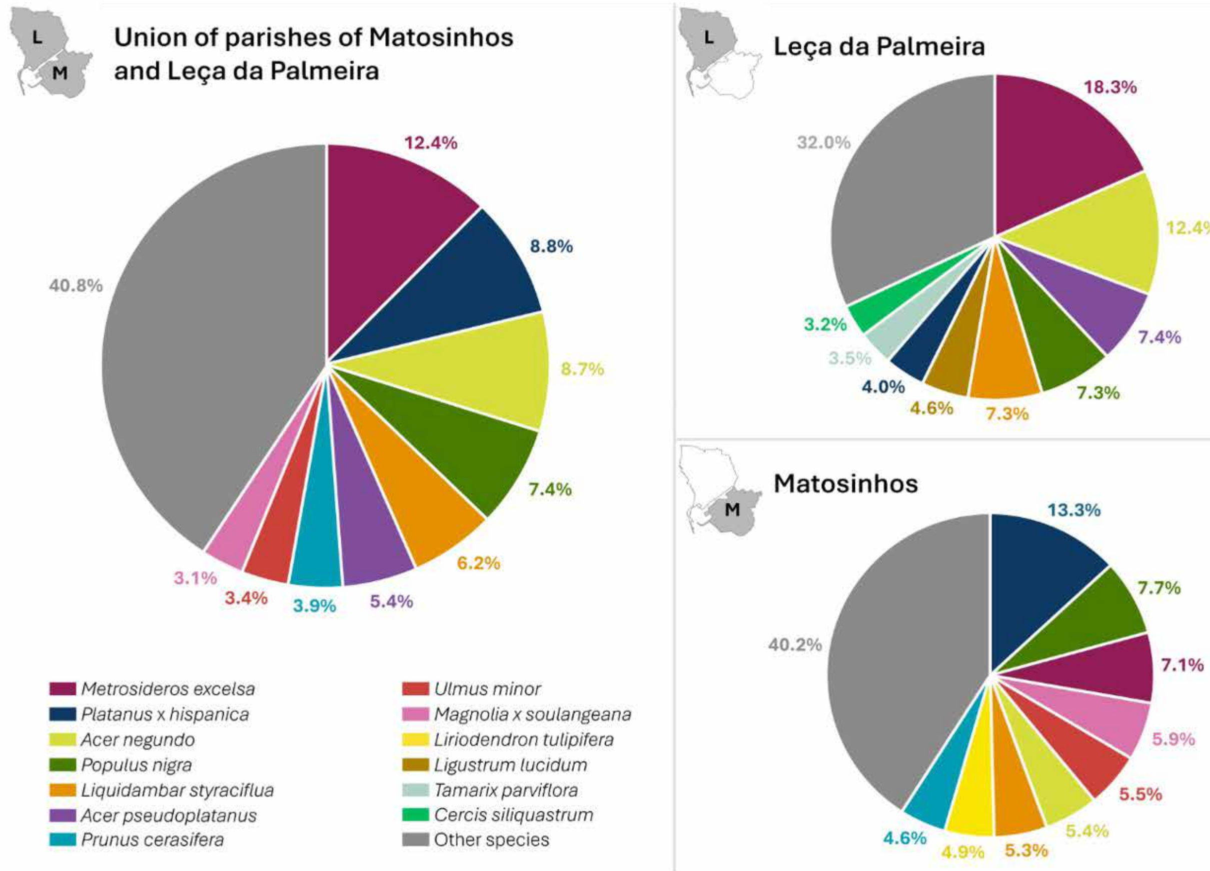

Figure 3. Proportion of species in the street tree population, in the total study area and in each parish.

The street tree population of these two parishes comprises 110 distinct species, spanning 65 genera and 38 botanical families. Among these, a few species dominate the landscape (Figure 3). The most abundant species is the New Zealand Christmas tree (Metrosideros excelsa, 719 individuals), followed by the London plane (Platanus × hispanica, 513 individuals), the box elder (Acer negundo, 504 individuals), the black poplar (Populus nigra, 433 individuals), and the sweet gum (Liquidambar styraciflua, 360 individuals). Other notable species include the sycamore (Acer pseudoplatanus, 312 individuals), the cherry plum (Prunus cerasifera, 229 individuals), the field elm (Ulmus minor, 195 individuals), and the saucer magnolia (Magnolia × soulangeana, 179 individuals).

Regarding their distribution in the different parishes, Matosinhos hosts 3,069 trees across 89 species, demonstrating greater species richness than Leça da Palmeira, which counts 2,744 individuals across 68 species (Figure 3). In Matosinhos, dominant species include the London plane (403), the black poplar (233), the New Zealand Christmas tree (216), and the saucer magnolia (178). Other frequent species in Matosinhos include the field elm, box elder, sweet gum, tulip tree (Liriodendron tulipifera), and cherry plum. In Leça da Palmeira, the most numerous species are the New Zealand Christmas tree (503), box elder (340), sycamore (202), black poplar (200), and sweet gum (199). Additionally, species like the Chinese privet (Ligustrum lucidum), the small-flowered tamarisk (Tamarix parviflora), and

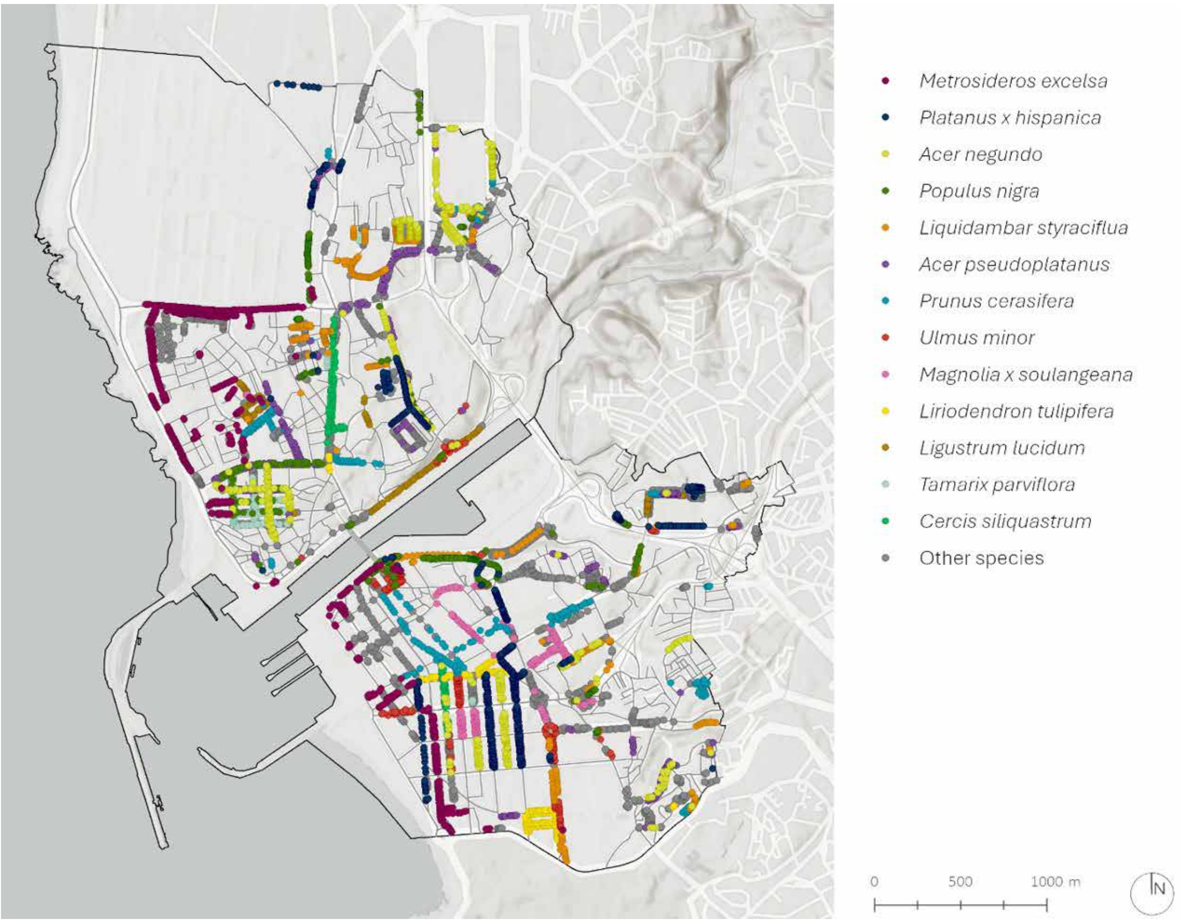

Figure 4.
Spatial distribution of the street tree species in the study area.

the Judas tree (Cercis siliquastrum) appear more frequently in Leça's streets.

Spatial analysis reveals distinct environmental and planning influences on species distribution (Figure 4). Coastal streets (within approximately 500 meters of the shoreline) are characterized by the dominance of the New Zealand Christmas tree (Metrosideros excelsa), owing to its high tolerance to wind and salinity. Other species also seem adapted to the coastal influence, including the field elm (Ulmus minor) and London plane (Platanus × hispanica) in Matosinhos, and the small-flowered tamarisk (Tamarix parviflora), spineless yucca (Yucca elephantipes), cabbage palm (Cordyline australis), Persian lilac (Melia azedarach), and black poplar (Populus nigra), particularly in Leça da Palmeira.

In contrast, some species are more frequently used in the more interior streets (Figure 4), such as the sweet gum (Liquidambar styraciflua), the tulip tree (Liriodendron tulipifera), the small-leaved lime (Tilia cordata), the silver lime (Tilia tomentosa), the Japanese cherry (Prunus serrulate), the common beech (Fagus sylvatica), the common oak (Quercus robur), and the red oak (Quercus rubra). Although susceptible to harsh environmental conditions, these larger, deciduous species are often associated with higher levels of ecosystem service provision, due to their canopy size and seasonal dynamics.

Together, these findings suggest a relatively high level of species diversity across the study area, which is promising in terms of ecological resilience. However, the spatial distribution of this diversity is uneven. While some zones feature a broader mix of species, others, particularly in coastal or more recently developed areas, are dominated by just a few taxa. In some cases, these dominant species have spatial and functional features that limit their capacity to deliver the desired ecosystem services. These results underscore the need for more balanced, site-sensitive planting strategies that consider both diversity and functional performance in future planning efforts.

Discussion

The analysis of the street tree population in Matosinhos and Leça da Palmeira highlights both progress and persistent limitations in how urban trees are integrated into the public realm. On the one hand, the relatively high species richness (110 species across 65 genera) suggests a diversified planting strategy with potential for ecological resilience. On the other hand, the structure, size, and spatial distribution of these trees reveal several critical weaknesses that limit their capacity to provide ecosystem services at scale.

In fact, a substantial proportion of the street tree population consists of small-statured ornamental species, such as the cherry plum (Prunus cerasifera), saucer magnolia (Magnolia × soulangeana) or Judas tree (Cercis siliquastrum). While these species may fulfil aesthetic expectations, they typically lack the structural dimensions and canopy volume necessary to provide significant environmental benefits, falling short of the criteria defined for the 'minimum street tree'. Notably, their use is widespread even along streets that offer ample space for larger, more ecologically functional trees. This pattern reveals a disconnect between species selection and the spatial characteristics of the street network, reflecting missed opportunities to maximize ecosystem service provision.

Moreover, while some species choices reflect a commendable alignment with local environmental conditions, particularly the use of the New Zealand Christmas tree (Metrosideros excelsa) in coastal areas, greater diversity is still needed. The New Zealand Christmas tree is highly tolerant of wind and salinity, making it an appropriate choice, but its dominance suggests an over-reliance on a single species. Other resilient options, including larger deciduous trees like the London plane (Platanus × hispanica) and the field elm (Ulmus minor), could offer seasonal benefits and improved microclimatic performance, especially in wider streets. Even in harsh environments, diversity should be pursued to enhance ecological function and reduce vulnerability to pests, diseases, and climate stress.

A further concern is the prevalence of potentially invasive species, such as Acer negundo and Ligustrum lucidum, which poses risks to local biodiversity and undermines the integrity of urban green networks. Avoiding such species and favouring a varied selection of site-adapted trees is essential to building a resilient and sustainable urban forest.

To address these challenges, we propose the following principles to guide future tree planting strategies:

Use the largest tree possible for the available space. Tree size directly influences the magnitude of ecosystem services provided. Larger trees deliver greater shade, reduce air and surface temperatures more effectively, intercept more rainfall, and sequester more carbon. Therefore, street tree selection should prioritize species capable of reaching meaningful dimensions, at least those of the 'minimum street tree', particularly in wide streets and those with central medians, where physical space is not a limiting factor. Tree positioning and underground conditions must be coordinated to support healthy, long-term growth with minimal need for pruning or replacement.

Articulate tree selection and positioning with street width and uses. Street trees must coexist with essential urban functions, including pedestrian flows, emergency access, and multiple infrastructures. However, thoughtful spatial design can accommodate trees even in relatively constrained streets. Good spatial planning allows trees to be included in streets, without compromising accessibility, by placing them thoughtfully in areas where they complement street function and maximize ecological impact. This articulation requires collaborative planning between arborists, street designers, and infrastructure managers.

Match tree species to local environmental conditions. Species selection must consider the specific environmental conditions of each street segment, such as salinity, soil compaction, water availability, heat exposure, and air pollution. For example, salt-tolerant species are essential in coastal areas, while drought-resistant species are critical in unwatered zones. In streets with limited space or strong shading requirements, deciduous species are particularly appropriate, as they allow sunlight to reach façades during winter while providing cooling shade in summer. Matching species to site-specific conditions enhances resilience, reduces maintenance demands, and extends tree lifespans.

Optimize diversity and avoid invasive species. Promoting diversity in the street tree population is essential to ensure long-term resilience against climate variability, pests, and diseases. A varied selection of species, across different genera, growth forms, and ecological functions, enhances the capacity of the urban forest to adapt to changing conditions and reduces the risk of widespread failure. While species choice must always respond to local constraints and environmental conditions, diversity should remain a central goal in any planting strategy. At the same time, the use of invasive or ecologically aggressive species should be avoided, in line with national guidelines and ecological best practices.

Conclusion

This study highlights the critical role that street tree planning and species selection play in shaping resilient, climate-adaptive, and liveable urban environments. In the case of Matosinhos and Leça da Palmeira, the existing street tree population demonstrates encouraging species richness and a clear awareness of environmental constraints in certain areas, particularly along the coast. However, significant gaps remain between the ecological potential of urban trees and their actual performance in the street network.

The widespread use of small-statured ornamental species and the underutilization of larger trees, particularly where space would allow for them, indicate a missed opportunity to enhance urban ecosystem services. Likewise, a limited selection of species in environmentally challenging areas, coupled with the use of potentially invasive trees, underscores the need for more strategic and ecologically grounded planning practices.

To address these issues, this paper proposes four guiding principles: 1) use the largest tree possible for the available space, 2) articulate species selection with street width and urban functions, 3) match species to site-specific environmental conditions, and 4) optimize diversity while avoiding invasive species. These principles provide a practical framework to support urban forestry decisions and help align tree planting strategies with broader urban design and climate adaptation goals. Municipalities should incorporate these principles at the urban scale, embedding them in street tree planning and overall urban green infrastructure strategies. The spatial allocation for street trees should be planned together with all other street functions and infrastructures, with equal importance, from the earliest stages of street design. This integrated approach ensures that trees are conceived as fundamental components of the street rather than secondary additions.

Moving forward, cities must approach street tree planning not simply as a decorative element but as a central component of sustainable infrastructure. By integrating ecological knowledge with spatial design and long-term management considerations, planners and urban tree managers can work together to build more robust, adaptable, and inclusive green street networks.

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