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Socioeconomics explain tree diversity, abundance, and composition in the compact city of Barcelona, Spain

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HIGHLIGHTS

- In 2021, street trees represented 67% of the public trees in Barcelona.
- Tree richness and abundance was positively related to life expectancy.
- Wealthier neighborhoods had a lower tree species richness in public spaces.
- Tree composition responded to demographic and socioeconomic gradients.

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ABSTRACT

Trees are frequently unevenly distributed in urban areas, and their diversity, abundance, and composition vary spatially. Some studies have shown that the unequal distribution of urban trees can be associated with demographic and socioeconomic factors. However, most studies have been conducted in diffuse urban systems using remotely-sensed tree cover within single or aggregated land-use types. We examined if the relationship between tree diversity, abundance, composition, and socioeconomic factors varied across land-use types (parks, streets, zonal areas, and total) in the compact city of Barcelona, Spain. We calculated tree species richness and abundance across 73 neighborhoods using 229,962 geo-referenced records of individual trees sampled in 2021. Life expectancy positively explained tree richness and abundance across land-use types, reinforcing that access to urban green infrastructure promotes longer life spans. In contrast, income did not positively explain tree richness or abundance, indicating that tree distribution does not directly result in biodiversity and green space inequalities for disadvantaged groups in terms of income. Total tree composition across neighborhoods responded to socioeconomic gradients, evidencing that neighborhood appearances are socially stratified. Street tree abundance increased in densely populated neighborhoods, possibly because intense street tree plantings in these neighborhoods compensate for the lack of other green infrastructure. Urban tree planting, particularly in streets, can be an effective strategy to increase green spaces in compact cities to overcome the disparities resulting from the unequal distribution of urban vegetation. Long-term data on socioeconomic factors and urban tree distribution are necessary to determine how social stratification affects urban diversity.

1. Introduction

Urban trees are the main component of urban vegetation and deliver key ecosystem services, including several health, social, and economic benefits to urban residents (Roy et al., 2012; Morgenroth et al., 2016; Salmond et al., 2016). Trees in cities can also result in ecosystem disservices causing harm, nuisances, and costs to urbanites (Lyytimäki, 2017). However, urban vegetation is not equally distributed in cities (Kendal et al., 2012; Avolio et al., 2018), leading to inequality in the provision of tree-related ecosystem services and disservices. Government policies, such as those that mandate the planting and removal of trees in public open spaces and streetscapes, can determine the distribution of urban trees (Conway & Urbani, 2007). Therefore, disentangling the factors associated with urban tree distribution can support the creation and execution of appropriate strategies to promote the fair distribution of urban biodiversity and green space.

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Theories to explain spatial patterns of urban tree distribution within cities emphasize the relevance of socioeconomic and urban form factors. Among the first group, income has been proposed as a key factor related to urban tree diversity, with wealthier neighborhoods hosting landscapes with more species (Talarchek, 1990; Avolio et al., 2015; 2018), a phenomenon commonly known as the "luxury effect" (Hope et al., 2003; Leong et al., 2018). Similarly, affluent neighborhoods frequently have more tree canopy cover (Gerrish & Watkins, 2018) and a higher abundance of street trees (Anderson et al., 2023; Lin et al., 2021) than impoverished neighborhoods. Previous research has also found that tree cover is negatively associated with population density (Clarke et al., 2013; Pham et al., 2013) and the proportion of minority residents (Watkins & Gerrish, 2018), and positively associated with education (Luck et al., 2009; Kendal et al., 2012; Threlfall et al., 2022) and neighborhood age (Lowry et al., 2011). However, empirical studies have also demonstrated that the direction and strength of the associations between socioeconomic factors and tree cover vary amongst cities (Riley & Gardiner, 2020). It is also unclear if tree composition in neighborhoods with comparable socioeconomic characteristics remains similar (but see Avolio et al., 2018).

Among the second group of urban form factors, land-use type strongly determines urban tree distribution (Bourne & Conway, 2013; Avolio et al., 2018). City landscapes frequently consist of a mosaic of several public and private land-use types with contrasting vegetation, resulting in differences in plant diversity, abundance, and composition within urban areas (Aronson et al., 2017). These urban land-use types include streets, vacant lots, parks, or residential gardens. Because different land-use types provide various economic and social functions and typically respond to multiple landscaping goals, they can be used as research units to examine how socioeconomic factors and public decision-making affect urban tree distribution (Cheng et al., 2022). Moreover, environmental justice and political ecology research contend that policies that frequently generate socioeconomic inequality impact tree distribution. This inequality is more pronounced in public landscapes like streets or parks (Heynen et al., 2006; Landry & Chakraborty, 2009). At the neighborhood scale, the unique set of street and park tree drivers should translate into contrasting species compositions between these urban land-use types (Jim, 1993; Kirkpatrick et al., 2011).

While previous studies have shown that urban tree distribution is associated with socioeconomic factors, the number of measures employed to analyze this distribution and the variety of locations analyzed have been constrained (Kendal et al., 2012; Avolio et al., 2015). Most studies have been conducted in diffuse cities in North American cities using remote sensing data on tree cover within single or aggregated land-use types (e.g., Riley & Gardiner, 2020; Locke et al., 2021). However, diversity metrics, such as the number of species, can be unrelated to tree cover or abundance. The number of species (or species richness) is a key characteristic of ecosystems that can increase their adaptability and resilience (Folke et al., 1996). Furthermore, neighborhoods with contrasting demographic and socioeconomic characteristics probably have contrasting tree compositions independently of the number of species. Studies comparing complementary metrics of tree diversity, abundance, and composition across land-use types and neighborhoods with different demographic and socioeconomic environments are necessary to determine whether generalizations can be made from the proposed theories to explain observed patterns, especially in highly compact cities.

In this study, we examined spatial patterns of tree diversity (tree species richness), abundance, and composition (tree species dissimilarities) in 73 neighborhoods in the municipality of Barcelona (Spain). We determined whether these patterns correlated with neighborhood demographic and socioeconomic factors. We selected Barcelona because of its highly compact urban matrix and because the city has ~ 230,000 georeferenced records of individual trees in parks, streets, and zonal areas publicly available. We complement previous studies in Barcelona that examined the regulating services of urban forests to reduce pollution (Baró et al., 2014) and showed that higher ecosystem service provision by street trees was linked to specific vulnerable groups, particularly elderly residents (Baró et al., 2019). We aim to answer three research questions: (1) Does urban tree diversity, abundance, and composition change between land-use types? (2) Are urban tree diversity, abundance, and composition related to neighborhood demographic and socioeconomic factors? (3) Do these relationships vary between land-use types?

2. Materials and methods

2.1. Study area

This study focuses on the municipality of Barcelona (Spain). The city is located in the north-eastern Iberian Peninsula along the Mediterranean Sea shore (41°23′3″N; 2°10′34″E; Fig. 1a). Barcelona is the second largest city by population in the country and one of the most densely populated cities in Europe (~16,000 hab/km^2). In recent decades, large-scale development demands have forced the conversion of a large fraction of green and agricultural land. The rapid urbanization period ended with the Olympic Games' urban development plans in 1992, which nearly completely depleted vacant open spaces (Huertas & Huertas, 2004). Barcelona has 73 neighborhoods distributed among ten districts (Fig. 1).

Urban green space in Barcelona is not uniformly distributed (Fig. 1b; Barcelona City Council, 2017). The city has about 7 m^2 of green space per resident (~1,100 ha). However, the high density of trees in the streets (~100 street trees per 1,000 residents) helps to offset this lack of green space (Baró et al., 2014). With a few notable exceptions, including the city's first urban park (Ciutadella Park, built in 1872), most of the green infrastructure dates back to the 1980s. Most trees in city parks are, therefore, relatively young.

Barcelona wants to expand the tree cover in the city by 5% before 2037 while maximizing ecosystem service provision (Barcelona City Council, 2017). Furthermore, the city intends to increase urban green space by 1 m^2 per resident and ensure that at least 40% of tree species will be climate-adapted through the climate action plan (Barcelona City Council, 2018). Tree and shrub plantings are programmed in parks and gardens to enrich the woody stratum, replace losses and increase biodiversity (Barcelona City Council, 2021).

2.2. Study units

We considered all administrative city neighborhoods as study units (Fig. 1). The administrative neighborhoods in Barcelona were established in 2006 by grouping several smaller historical neighborhoods. Barcelona has 73 neighborhoods ranging from 12 to 1,424 ha and a mean size of 139 ± 208 ha. In 2021, the average population in the neighborhoods was 22,744 ± 14,735 (~257 inhabitants/hectare). Neighborhoods differed in residential occupancy (Appendix S1: Figure S1.2). Although neighborhoods in Barcelona are subdivided into census tract units, some demographic and socioeconomic variables used in this study, such as household income, were only available at the neighborhood level.

2.3. Tree data

We obtained tree occurrence data in public areas in Barcelona for the first trimester of 2021 from the City Council's official website (https://opendata-ajuntament.barcelona.cat/data/en/dataset?tags=Arbres). This database includes three datasets with tree occurrence data in three land-use types: parks, streets, and zonal areas. Zonal areas include squares, flower beds, gazebos, or small garden spaces. Therefore, zonal areas should be considered a heterogeneous land-use type. Individual tree occurrences in the datasets were originally geo-referenced and localized in the city neighborhoods (N = 73). As a highly compact city,

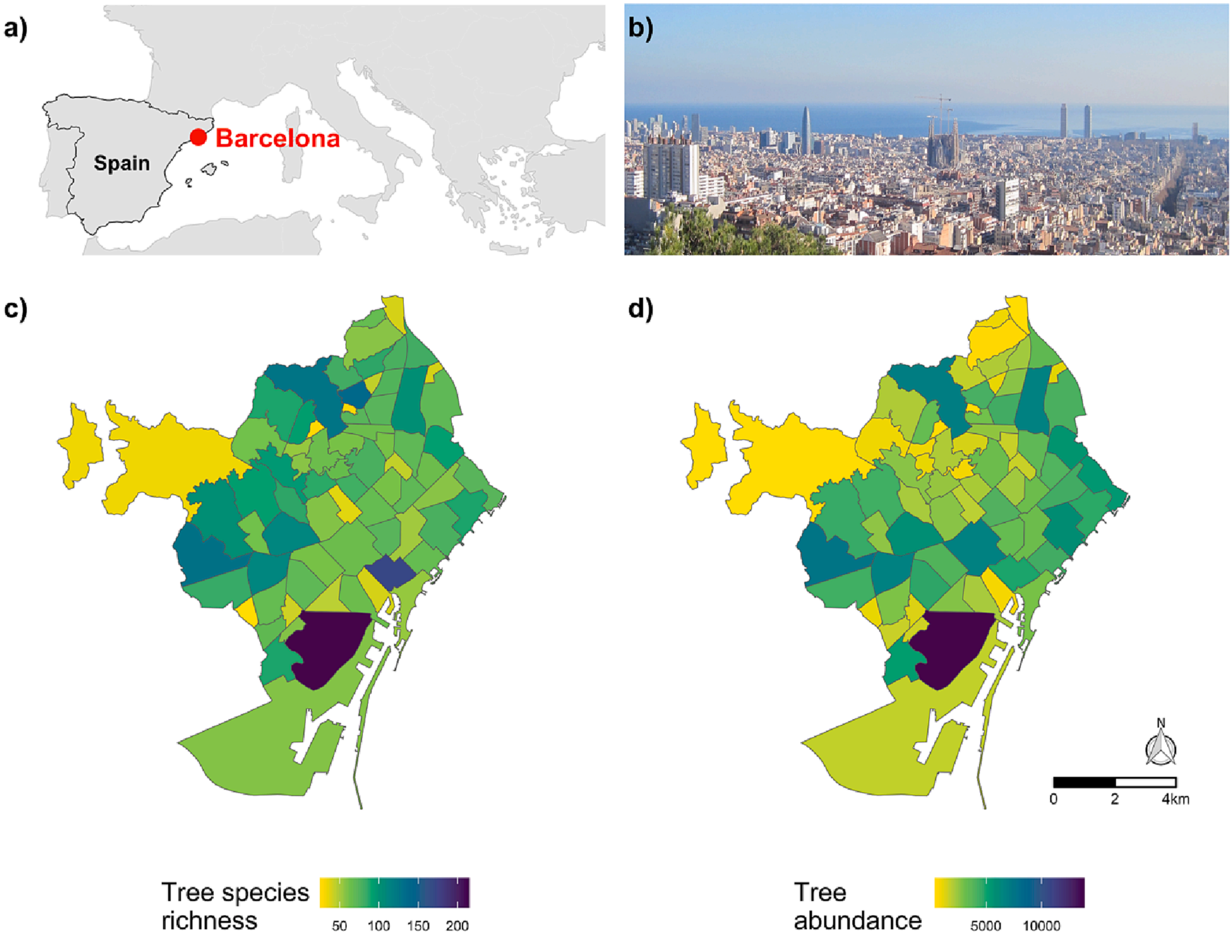

Fig. 1. Location of the study area (Barcelona) in Spain and the Mediterranean Basin (a). Aerial picture of the compact city of Barcelona (image by Patrick Gautier from Pixabay) (b). Total tree species richness (tree diversity) (c) and abundance (d) in the 73 neighborhoods in Barcelona.

most of the trees in the urbanized area of Barcelona occur in public spaces. Only 3% of the houses in the city were single-family in 2001, the last year with available data (INE, 2023).

We standardized species nomenclature at the species level, thus removing subspecies and cultivars. We assigned the epithet "hybrid" to the hybrid cultivars that we could not assign to the species level (5 taxa). We removed undetermined species from the study.

2.4. *Demographic and socioeconomic data*

We obtained demographic and socioeconomic data at the neighborhood level (N = 73) in Barcelona from the City Council's official website (https://ajuntament.barcelona.cat/estadistica/angles/Estadistiques_per_territori/Barris/index.htm). Specifically, we retrieved data for four demographic and socioeconomic variables: household disposable income per capita (HDIpc; €/person); population density (inhabitants/ha); mean population age (hereafter 'age'; years); and mean life expectancy (hereafter 'life expectancy'; years) (see further details in Appendix S1). All variables were recorded in 2021, except HDIpc, which was recorded in 2019.

2.5. *Statistical analyses*

We conducted statistical analyses in R v. 4.2.0 (<https://www.r-project.org>) and established significance at $\alpha < 0.05$ throughout all tests. The core code for the analyses is available at: https://github.com/padullesj/bcn_trees.

2.5.1. *Tree diversity and abundance*

We conducted all analyses separately for parks, streets, and zonal areas and then aggregated individual tree occurrences across all land-use types (total). In each neighborhood, we calculated tree diversity as the total number of tree species (hereafter tree species richness) and tree abundance as the total number of trees. Furthermore, we also calculated the Shannon diversity index in each neighborhood. Due to its partial overlap with species richness and the fact that it could only be calculated for a subset of neighborhoods with treed parks, we moved the methods and results for Shannon diversity to Appendix S2. Therefore, we used Shannon diversity results to supplement the main findings from tree species richness and abundance.

2.5.2. *Models for tree diversity and abundance*

Poisson regression is frequently used to model discrete data such as tree species richness and abundance (Agresti, 2015). This type of generalized linear model (GLM) assumes a Poisson error distribution and includes the natural logarithm as the link function. However, two attributes of discrete variables induce problems for Poisson regressions: overdispersion (i.e., variance largely exceeding the mean); and a large proportion of zero values (Agresti, 2015). Although only a small proportion of neighborhoods had zeros for tree species richness and abundance (32%), most response variables exhibited overdispersion. Therefore, we used quasi-Poisson regressions. In this extension of the Poisson model, the dispersion parameter is not fixed but estimated from the data. This method generates the same coefficient estimates as the standard Poisson regression, but the inference is adjusted for overdispersion (Agresti, 2015).

We created several GLMs with tree species richness and abundance in each land-use type as response variables and the four demographic and socioeconomic variables (i.e., HDIpc [$\log_e$-transformed]; population density; mean age; and life expectancy) as predictors. We included neighborhood area ($\log_e$-transformed) in the GLMs as a covariate. We interpreted the neighborhood area as the potential area that could be used for planting trees in each neighborhood. We also included the proportion of residential land in the neighborhoods as a covariate. However, this variable showed no significant effects on tree species richness and abundance and was finally discarded.

We centered and standardized predictors before introducing them to the models to make their coefficients comparable (Zuur et al., 2007). We used diagnostic plots to check model assumptions (i.e., normally distributed errors with a constant variance; homogeneity of variance; and independence of residuals) (Zuur et al., 2007). We also tested for spatial autocorrelation in the models' residuals with Moran's *I* in the "ape" R package (Paradis & Schliep, 2019). These tests revealed no significant spatial autocorrelation in the models' residuals. For each GLM, we report McFadden's pseudo R^2 as a metric of the goodness of fit (McFadden, 1977).

2.5.3. *Tree composition and demographic and socioeconomic correlates*

To examine tree composition across neighborhoods, we created a site-by-site pairwise dissimilarity matrix using Bray Curtis distances and tree abundance data (i.e., the number of tree occurrences per species divided by the total number of tree occurrences) within each neighborhood in the "vegan" R package (Oksanen et al., 2022). Then, we performed an ordination on the site-by-site pairwise dissimilarity matrix with principal coordinates analysis (PCoA). We fitted demographic and socioeconomic vectors to the ordination with the *envfit* function in the "vegan" R package.

2.5.4. *Differences in tree diversity, abundance, and composition between land-use types*

To examine differences in diversity, abundance, and composition in the neighborhoods between land-use types, we used non-parametric Kruskal-Wallis tests. When the result was significant, we performed post hoc paired comparisons following Dunn (1964). We adjusted *P*-values with the Holm method (Holm, 1979).

3. Results

3.1. *Urban tree diversity and abundance across land-use types*

The datasets collectively included 229,962 tree occurrences from 371 species. The majority of trees occurred in streets (67%), followed by zonal areas (18%) and parks (15%). Parks consistently had more tree species (319) than zonal areas (243) or streets (208). On average, streets and zonal areas had a higher tree species richness than parks across neighborhoods (Fig. 2a). Streets also had a higher tree abundance than zonal areas and parks across neighborhoods (Fig. 2b). Shannon diversity was higher in zonal areas than in parks or streets (Appendix S2). Spatial patterns in tree diversity across land-use types can be found in Appendix S3.

3.2. *Demographic and socioeconomic factors related to urban tree diversity and abundance*

GLMs explained tree abundance better than tree species richness (Fig. 3). Tree species richness and abundance in parks, streets, zonal areas, and across all land-use types were significantly positively related to life expectancy in the neighborhoods. Furthermore, tree species richness and abundance in zonal areas were significantly positively related to mean population age. Tree abundance in streets also responded positively to population density. In contrast, tree species richness and abundance were significantly negatively related to population density and household disposable income per capita (HDIpc) in zonal areas and across all land-use types. Tree species richness and abundance were significantly negatively related to population density and HDIpc across all land use types, respectively.

The explanatory power of demographic and socioeconomic variables was consistently lower for Shannon diversity than for species richness (Appendix S2). The Shannon diversity across all land use types was positively related to life expectancy in the neighborhoods but negatively related to HDIpc and population density.

3.3. *Demographic and socioeconomic factors related to urban tree composition*

Tree composition was more homogeneous (i.e., had lower mean Bray Curtis distances) in streets than in zonal areas and, especially, parks (Fig. 4). Tree composition also varied widely across land-use types (Fig. 5). Variation in tree composition amongst neighborhoods was significantly related to HDIpc and life expectancy in streets and to

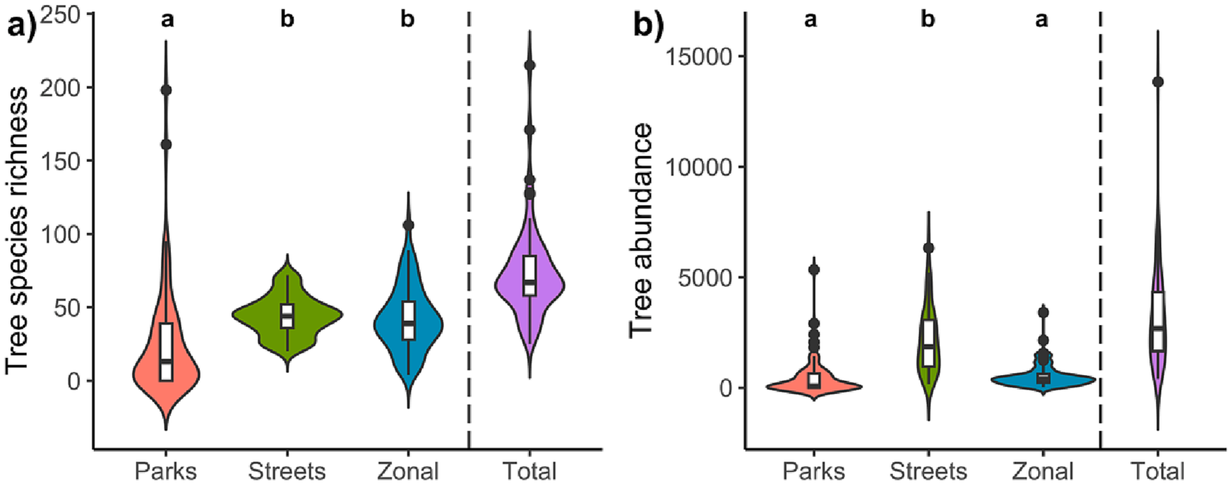

Fig. 2. Patterns of tree species richness (a) and abundance (b) in parks, streets, zonal areas, and across all land-use types (total) in neighborhoods in Barcelona. The black line and the boxes within each violin plot show the median values and the 95% confidence intervals, and the whiskers in each violin plot represent the range. Different lower-case letters on top of the violin plots show a significant difference ($P < 0.05$) among other groups based on Kruskal-Wallis multiple comparisons.

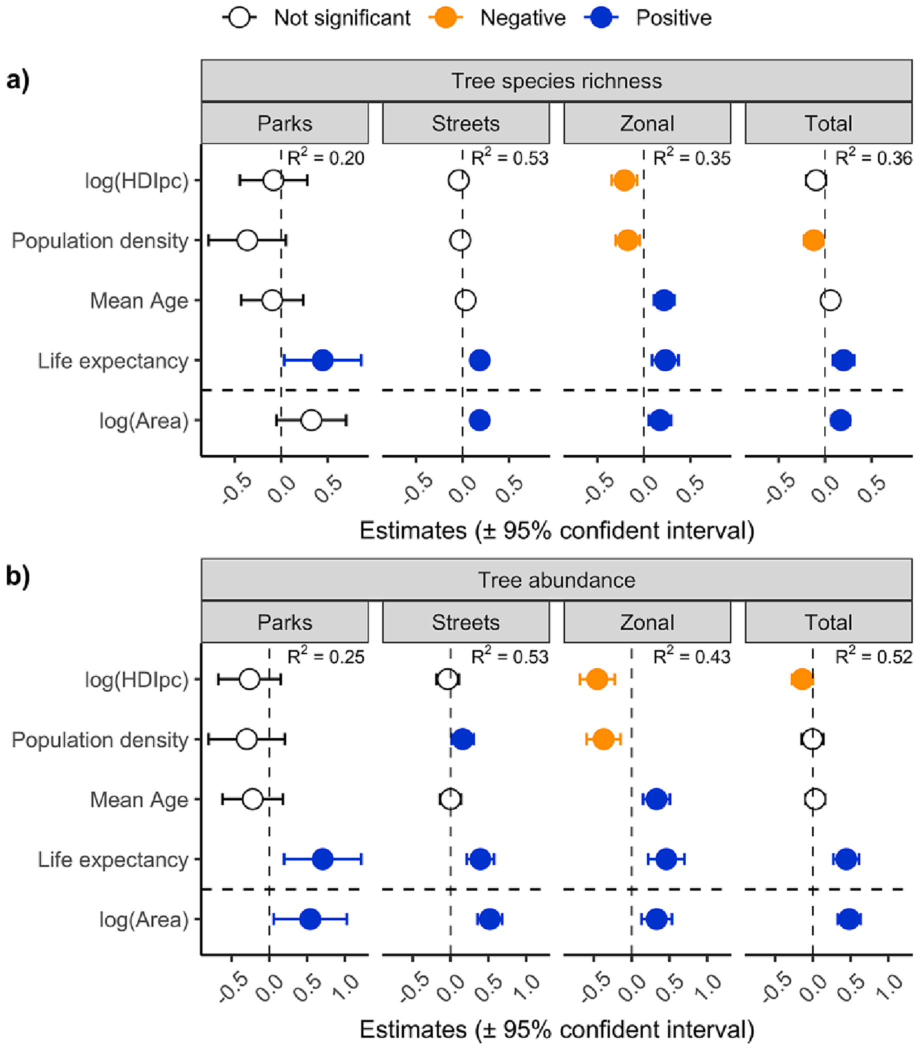

Fig. 3. Estimated coefficients (±95% confidence intervals) for all variables included in GLMs of tree species richness (a) and abundance (b) in parks, streets, zonal areas, and across all land-use types (total) in neighborhoods in Barcelona. Confidence intervals that do not overlap zero indicate significance. The dashed horizontal line separates focal predictors (demographic and socioeconomic variables) from the covariate (neighborhood area). For each model, McFadden's pseudo R^2 is also shown.

population density in zonal areas and across all land-use types.

4. Discussion

This study shows that the demographic and socioeconomic factors related to tree diversity, abundance, and composition vary between land-use types within a compact city. The direction and magnitude of these relationships do not always coincide with those reported in other cities, indicating that distinct factors may be at work in other locations. In the highly compact city of Barcelona, tree abundance responded more strongly to the variation in the social environment than tree diversity. Taken together, our findings support the notion that urban tree distribution varies across social strata (Riley & Gardiner, 2020).

Given that a significant fraction of urban trees are planted, particularly in compact cities, it seems plausible to assume that demographic and socioeconomic factors should relate to tree diversity and abundance and that tree composition should reflect the management considerations of the actors who choose trees (Aronson et al., 2017; Avolio et al., 2015). Accordingly, we found that tree diversity and abundance increased with life expectancy across all land-use types when controlling for neighborhood area and other socio-demographic variables. A growing body of research shows that access to green spaces can have numerous benefits for mental and physical health, social cohesion, and overall quality of life (Takano et al., 2002; Jonker et al., 2014). These benefits are usually related to the fact that urban green spaces lower stress levels, promote physical activity, enhance local climates, and lower ambient air pollution (Tzoulas et al., 2007; Correia et al., 2013; Heaviside et al., 2016). However, we are cautious when interpreting our results as causal effects. It is possible that socioeconomic variables do not adequately capture other confounders and selection effects. For instance, the lasting impacts of historical or past events on the present urban ecosystem, such as changes in land use, past human activities, or species introduction, can shape tree species distribution in cities (Clarke et al., 2013; Larson et al., 2017). Recognizing the combined influence of legacy effects and socioeconomic factors on the current tree diversity patterns can help urban planners develop more effective strategies for promoting and sustaining plant diversity in cities.

In contrast to life expectancy, income was negatively related to tree diversity in zonal areas and unrelated to tree diversity in the other land-use types. Therefore, this finding contradicts the idea that affluent residents live in more diverse neighborhoods (i.e., luxury effect; Hope et al., 2003; Leong et al., 2018), a pattern commonly reported in more diffuse cities (Schwarz et al., 2015; Avolio et al., 2015; 2018). Nonetheless, luxury effects may become more evident in private landscapes where owners' preferences and choices have greater effects on tree distribution (Martin et al., 2004). Our study also did not account for *peri*-urban vegetation. Private landscapes and *peri*-urban areas make up a significant portion of the urban matrix and play an essential role in the distribution of trees. Combining the existing data with information on tree occurrences in private landscapes and residents' access to *peri*-urban areas would enable us to further support our conclusions. This would provide a more comprehensive and accurate representation of the state

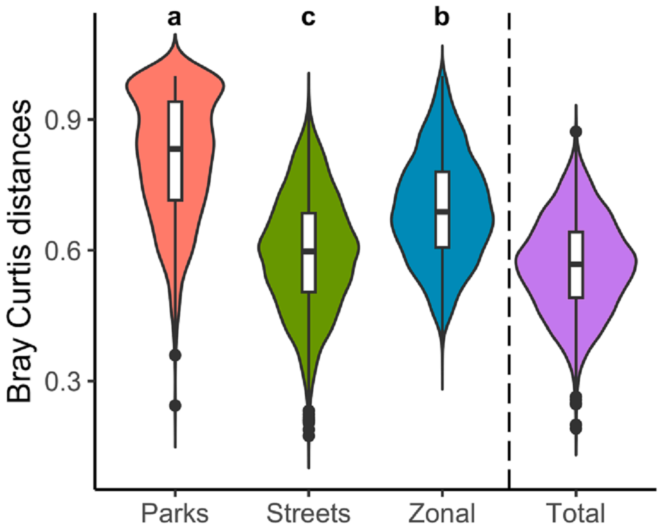

Fig. 4. Bray Curtis distances between neighborhoods considering tree species composition in parks, streets, zonal areas, and across all land-use types (total) in Barcelona. The black line and the boxes within each violin plot show the median values and the 95% confidence intervals, and the whiskers in each violin plot represent the range. Different lower-case letters on top of the violin plots indicate a significant difference ($P < 0.05$) among other groups based on Kruskal-Wallis multiple comparisons.

of tree populations in the study region.

Total tree abundance in Barcelona also decreased with income across neighborhoods, further demonstrating the positive relationship between wealth and urban tree canopy cover (Gerrish & Watkins, 2018) and street tree abundance (Anderson et al., 2023; Lin et al., 2021) may not hold in highly compact cities. Accordingly, Anguelovski et al. (2018) found that urban green areas in Barcelona were not associated with gentrification processes in historically impoverished neighborhoods. This has important social implications because it suggests that urban planners and policymakers should not assume that increasing income levels alone will lead to an increase in tree cover or green spaces. Instead, they need to take a more targeted approach that focuses on identifying and addressing the barriers that prevent particular social groups from accessing trees and green spaces.

Street tree composition across neighborhoods responded to income and life expectancy. This finding is in line with the theory of the ecology of prestige, which posits that urban vegetation gives locals a way to flaunt their socioeconomic status and support neighborhood identity through unique neighborhood appearance (Grove et al., 2014). These landscape identities probably play a part in how trees shape people's sense of place (Dwyer et al., 1991; Pearce et al., 2015), wherein residents develop a connection to particular trees and the qualities of an area that trees contribute to. Although the ecology of prestige is often more prominent in private urban landscapes, it can still be present in public urban landscapes. While people may have limited decision-making power regarding the trees planted in public areas, the competition for status and recognition within a social context can still influence the development of public urban areas, leading to the gentrification of certain neighborhoods or the implementation of policies that prioritize the landscaping interests of powerful or influential groups (Molotch, 1996; Bryson, 2013). Future research should assess how residents' connections to specific vegetation and locations in cities affect public decisions on tree plantings and removals.

We found street tree abundance in Barcelona was positively related to population density, in contrast to similar studies conducted in diffuse cities in Australia and the US (Grove et al., 2006; Iverson & Cook, 2000; Kendal et al., 2012). This finding, combined with a higher tree abundance in streets than in parks or zonal areas, indicates that more intense street tree plantings in densely populated areas likely compensate for the lack of other green infrastructure. Accordingly, tree abundance in zonal areas, representing a variety of land cover, such as squares, flower beds, gazebos, or small garden spaces, decreased with population density. Furthermore, street trees were more diverse and compositionally homogenous than in parks. Because street trees are usually exposed to high-stress levels, their lifespan is generally lower than that of park trees (Sæbø et al., 2003), and street trees are more frequently replanted with similar sets diverse species throughout the city than those in parks. In contrast, large, old trees are keystone structures in urban parks (Stagoll et al., 2012), likely reinforcing parks' distinctive landscape designs. Because many ecosystem services depend on urban tree abundance (Morgenroth et al., 2016), street trees may provide a broader range of ecosystem services than trees in other land-use types.

Our findings highlight the importance of discriminating between trees in parks, streets, and zonal areas and identifying rules for removing and planting trees when evaluating urban tree diversity. For instance, while tree monocultures have traditionally been planted for aesthetic reasons, more diverse tree assemblages are encouraged to provide a broader range of ecosystem services (McPherson et al., 2016) and greater stability and resilience to global change drivers (Morgenroth et al., 2016). Local authorities can use online resources like Citree (Vogt et al., 2017) to support multicriteria tree selection. Our study also emphasizes that street trees significantly contribute to tree abundance in densely populated cities such as Barcelona. Streets are at the interface of private and public landscapes and reflect political influences more strongly than parks or zonal areas as they are more directly tied to individual dwellings. Street tree planting schemes can help urban planners handle mismatches between social groups and plant diversity caused by the generally uneven distribution of urban green spaces like private gardens, parks, or urban forests (Nielsen et al., 2017). Even though the expansion of street trees may be physically limited in highly compact cities, transforming the street network, for example, by reducing the number of private traffic lanes, may open up new opportunities for increased tree planting.

5. Conclusions

Our research shows that while total tree diversity and abundance were positively related to life expectancy, it was neither positively related to income nor population age. Therefore, as reported for tree-related ecosystem services (Baró et al., 2019), tree distribution in Barcelona does not directly result in biodiversity inequalities for low-income or elderly groups. Furthermore, our study demonstrates that the relationship between socioeconomic factors and urban biodiversity varies across land-use types. Specifically, tree diversity and abundance responded more strongly to residents' demographic and socioeconomic characteristics in streets and zonal areas than in parks. We conclude that tree planting, particularly in streets, can be an effective greening strategy for compact cities to overcome the disparities resulting from the typically unequal distribution of urban vegetation. Long-term data on alternative socioeconomic factors and urban tree change are required to reveal social stratification's impact on urban diversity.

Declaration of Competing Interest

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

Data availability

All datasets are publicly available and referenced in the Materials and methods.

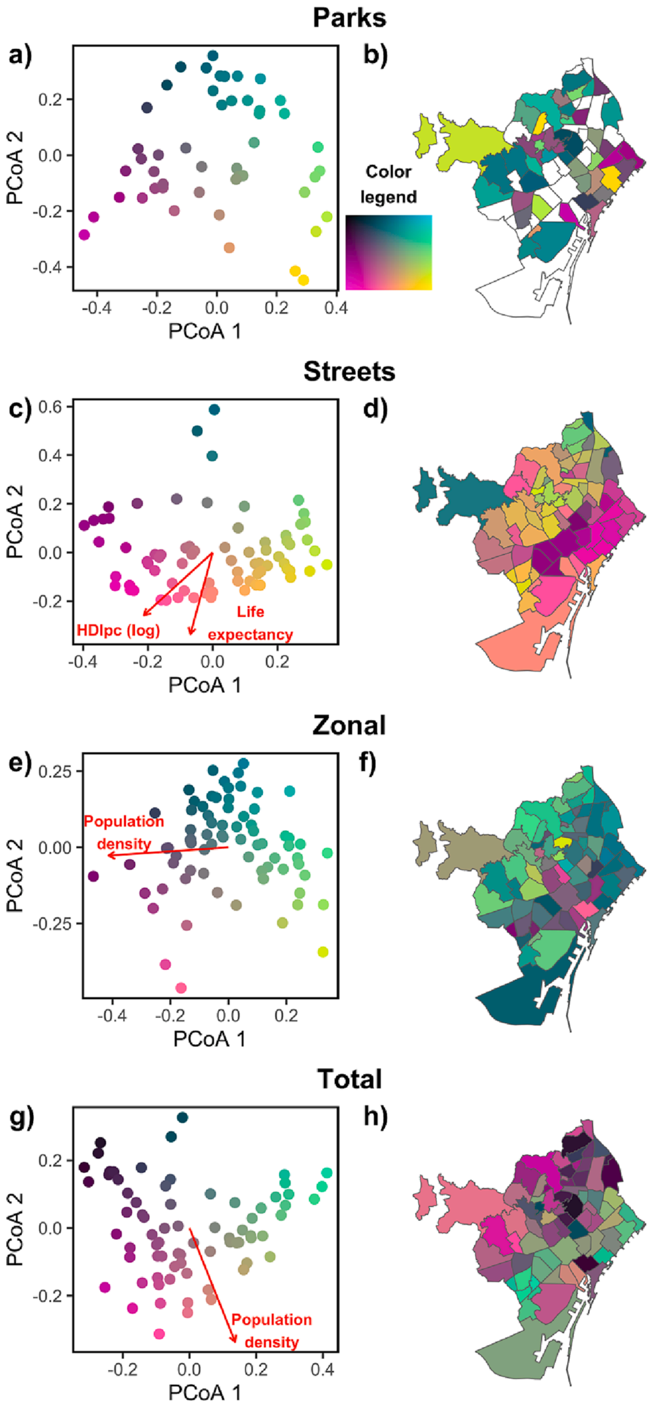

Fig. 5. Results from principal coordinates analyses (PCoA) showing tree composition in parks, streets, zonal areas, and across all land-use types (total). Red arrows indicate demographic and socioeconomic gradients significantly ($P < 0.05$) related to tree composition. The length of the arrow is positively related to the strength of the gradient. The colors are only for visualization purposes to connect points in the ordinations (left column) to their respective neighborhoods in the city (right column).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2023.104778.

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