Research Article

Trees and the City: Diversity and Composition along a Neotropical Gradient of Urbanization

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In this study we assessed tree species richness, density, and composition patterns along a gradient of urbanization of a megacity. Our results show that total, native, and exotic tree densities were highest in green areas where larger spaces are considered for greening purposes. Conversely, total, native, and exotic tree species richness were highest in land uses with intermediate levels of urban development (residential, residential-commercial areas). Not finding highest tree species richness in less developed urban areas suggests that cultural factors may shape the array of species that are planted within cities. Supporting this, tree composition analyses showed that green areas are comprised of different tree species when compared to the rest of the studied urban land uses. Thus, our results suggest that, to increase the ecological quality of cities, residents and managers should be encouraged to select a greater variety of trees to promote heterogeneous green areas.

1. Introduction

Natural habitats are transformed by urbanization processes to satisfy housing needs and support human activities [1–4]. Such man-made systems include physical, biological, and social processes and result in the development of urban infrastructure such as buildings and streets/roads, often leaving little space for vegetation [5]. Among urban green patches trees commonly comprise the main component, highly represented by exotic species that can become invasive in periurban areas [6]. Thus, urbanization implies not only the alteration of habitat structure, but also the modification of the diversity and composition of its vegetation component [7].

Urban vegetation, comprised of plants from parks, greenways, median strips, playgrounds, cemeteries, gardens, and sidewalks have important ecological and social implications [8–10]. In particular, trees are critical for the maintenance of some urban ecological processes [11] and have been identified as the most important habitat component known to affect wildlife diversity within urbanized systems [12–15]. Additionally, aggregated trees in recreational areas (e.g., parks, playgrounds) allow the interaction of people, although they have also been related to socioeconomic barriers [16, 17].

In this study we examined changes in tree species richness along a neotropical gradient of urbanization in the Metropolitan Area of Mexico City (hereafter Mexico City), assessing patterns of native and exotic species. We also evaluated tree density and composition patterns along this gradient to provide a context for our species richness results. We expected tree species richness to be similar between residential and residential-commercial areas. In contrast, we predicted low species richness and high tree density in urban

green areas. Finally, we expected to find a high number of exotic species in all the studied urban land uses (i.e., green areas, commercial areas, residential-commercial areas, commercial areas).

2. Study Area

We performed this study in Mexico City, one of the most populated urban areas in the world [18] (Figure 1). This city covers a current area of $>1000\, \text{km}^2$, houses a human population that surpasses 20 million inhabitants [19], and has an annual population growth of 0.8% [20]. Although the establishment and continuous growth of this megacity have negatively affected wildlife, it still holds considerable biodiversity values [21–23]. Similar to other Latin American cities, Mexico City is represented by four main urban land uses: (1) commercial, (2) residential, (3) industrial, and (4) green areas.

We focused our sampling effort in the central and southwestern section of the city, where industrial areas are practically absent. We established a gradient of urbanization considering the four major urban land uses, from green to commercial areas, including residential and residential-commercial areas. To discriminate among highly developed urban areas (i.e., residential, residential-commercial, commercial areas) and green areas, we followed the classification of urban development proposed by Marzluff et al. [24]. We used the presence of commercial lots to differentiate between commercial and residential urban land uses, and determined areas as residential-commercial where both residential and commercial components were present. As reported in a previous study [23], the four studied urban land uses represent a gradient that affects birds, from less developed (green areas) to highly developed urban sites (commercial areas).

3. Methods

3.1. Tree Surveys. We surveyed trees within 25 m radius circular plots at green, commercial, residential, and residential-commercial areas (modified from [25]) during June-July 2007. We sampled 30 plots within each urban land use, separated by a minimum distance of 250 m to represent independent sampling units, giving a total of 120 plots along the gradient of urbanization. We located survey plots along our study area to meet two main criteria: (1) that the land use was homogeneous in surrounding areas, and (2) that they were heterogeneously distributed along our study area. At each plot, we recorded the number of trees and identified each individual to species level or classified them as morphospecies.

3.2. Data Analysis. To compare tree species richness among the studied urban land uses, we calculated average tree species richness and 95% confidence intervals using EstimateS [26]. This approach allows comparison among treatments using accumulated abundance, as average species richness is calculated by the repeated resampling of all
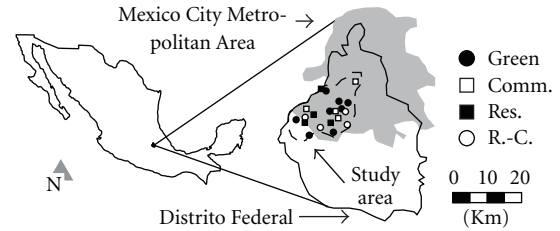

Figure 1: Map of study area. Green: green area, Comm.: commercial area, Res.: residential area, R.-C.: residential-commercial area.

pooled samples [27]. We calculated tree density per hectare by extrapolating the number of trees recorded at each plot (0.19 ha) to one hectare. To compare the calculated species richness and density values, we contrasted their 95% confidence intervals [28], assuming statistical differences with nonoverlapping intervals ($\alpha < 0.01$; M. E. Payton, pers. comm.). Finally, we used a Bray-Curtis multivariate cluster analysis to compare tree taxonomic composition of the studied land uses [29]. As community diversity patterns could be obscured by the origin of the recorded tree species, we also conducted species richness, density, and composition analyses for each land use distinguishing between native and exotic species. We considered all species that dwell within the southern region of the valley of Mexico, the area in which Mexico City is located, as native *sensu* [30], while we considered all others as exotic.

4. Results

We recorded a total of 89 tree species, with 48 in green areas, 64 in residential areas, 43 in residential-commercial areas, and 39 in commercial areas (Table 1). Of the total recorded species, 55 were exotic (61.8%), 30 were native (33.7%), and 4 morphospecies remained uncertain (4.5%). Total tree species richness differed among the studied land uses when compared at a constant calculated abundance (524 individuals based on the lowest abundance recorded in residential-commercial areas), with highest values in residential areas (49.0 ± 8.1 computed species), followed by residential-commercial areas (44.0 ± 7.3 species), commercial areas (32.3 ± 6.3 species), and green areas (20.2 ± 4.8 species; Figure 2). This pattern changed when we analyzed native and exotic species separately. On the one hand, native species richness was highest in residential areas (17.42 ± 4.69 species), followed by residential-commercial areas (13.0 ± 3.38 species), and lastly by green and commercial ones (8.8 ± 3.4 and 6.9 ± 3.0 species, resp.; Figure 2). On the other hand, exotic tree species richness was highest in residential, residential-commercial, and commercial areas (30.7 ± 6.0, 31.0 ± 6.4, and 23.9 ± 5.2 species, resp.) and lowest in green areas (11.3 ± 2.8 species; Figure 2).

Total tree density also differed among the studied urban land uses, with highest values recorded in green areas (499.5 ± 128.3 trees/ha), followed by residential areas (157.0 ± 32.0 trees/ha), commercial areas (135.0 ± 42.2 trees/ha), and residential-commercial areas (90.7 ± 22.7 trees/ha; Figure 3).

TABLE 1: Tree species recorded along the studied gradient of urbanization. Numbers represent the total number of individuals recorded in this study. Species are displayed alphabetically. (N): native species, (E): exotic species (see Section 3 for details). Green: green areas, Res: residential areas, Res-Com: residential-commercial areas, Com: commercial areas.

Species	Green	Com	Res	Res-Com
Abies religiosa (Kunth) Schltdl. and Cham. (N)	288		36	
Acacia melanoxylon R. Br. (E)	1	3		
Acacia retinodes Schltdl. (E)	17			
Acer negundo L. (N)		1	1	
Alnus acuminata Kunth (N)	34	2	1	2
Alnus jorullensis Kunth (N)			3	9
Anacardiaceae	5			
Araucaria heterophylla (Salisb.) Franco (E)		1	15	7
Bauhinia sp. (E)		1		
Buddleia cordata Kunth (N)	222	38	22	11
Buddleia parviflora Kunth (N)			15	
Casuarina equisetifolia L. (E)	75	14	10	17
Celtis occidentalis L. (E)	1			
Citrus limon (L.) Osbeck (E)		2	5	1
Citrus sinensis (L.) Osbeck (E)			2	
Citrus sp. (E)				1
Crataegus mexicana Moc. & Sessé ex DC. (N)	3		1	9
Cupressus lusitanica Mill. (N)	337	51	186	72
Cupressus macrocarpa Hartw. ex Gordon (E)		27	13	4
Cupressus sempervirens L. (E)	6	31	80	47
Cupressus sp. (E)			1	1
Dombeya wallichii (Lindl.) K. Schum. (E)		1		
Eriobotrya japonica (Thunb.) Lindl. (E)	13		29	6
Erythrina coralloides DC. (N)	1	9	30	14
Eucalyptus spp.[1] (E)	771	48	44	43
Euphorbiaceae sp. (E)			1	
Ficus benjamina L. (E)	6	123	74	61
Ficus carica L. (E)			1	1
Ficus elastica Roxb. (E)		2	5	8
Ficus microcarpa L. f. (E)		1	3	
Ficus sp. (E)			4	1
Fraxinus uhdei (Wenz.) Lingelsh. (N)	684	233	42	69
Furcraea bedinghausii K. Koch (N)			4	
Garrya laurifolia K. Koch (N)	37		10	
Grevillea robusta A. Cunn. ex R. Br. (E)	10	16		
Jacaranda mimosifolia D. Don (E)	11	33	24	30
Juglans regia L. (E)			3	1
Laurus sp. (E)	2			
Liquidambar styraciflua L. (E)	9	34	22	2
Magnolia grandiflora L. (E)	2	28	1	2
Morus alba L. (E)	6			
Morus rubra L. (E)				2
Persea americana Mill. (E)		1	1	
Phoenix canariensis Chabaud (E)	2	20	3	1
Phoenix dactylifera L. (E)		2		
Picea sp. (E)		1		
Pinus ayacahuite C. Ehrenb. ex Schltdl. (N)			5	1

TABLE 1: Continued.

Species	Green	Com	Res	Res-Com
Pinus leiophylla Schiede ex Schltdl. & Cham. (N)			1	
Pinus maximartinezii Rzed. (E)		4	2	
Pinus montezumae Lamb. (N)			1	
Pinus patula Schltdl. & Cham. (E)	25		1	1
Pinus pseudostrobus Lindl. (N)			4	1
Pinus radiata D. Don (E)		6		
Pinus sp. 1	3			
Pinus sp. 2			1	
Pinus sp. 3			1	
Pinus sp. 4 (E)			2	
Pinus sp. 5 (E)			1	
Pinus sp. 6 (E)			1	
Pinus sp. 7 (E)			10	
Pinus teocote Schltdl. & Cham. (N)		15	1	5
Pithecellobium dulce (Roxb.) Benth. (E)		1		
Pittosporum undulatum Vent. (E)			3	
Populus alba L. (E)	81		1	2
Populus tremuloides Michx. (E)	3	11		1
Prunus domestica L. (E)	23	4	14	15
Prunus persica (L.) Batsch (E)	3	2	17	3
Prunus serotina Ehrh. (N)	48	1	57	44
Pyrus communis L. (E)			5	7
Pyrus malus L. (E)	1		1	5
Quercus castanea Née (N)	12			
Quercus crassipes Humb. & Bonpl. (N)	19		4	
Quercus deserticola Trel. (N)	15		3	
Quercus laeta Liebm. (N)	32			
Quercus laurina Bonpl. (N)	17		9	
Quercus obtusata Bonpl. (N)			5	
Quercus robusta C.H. Mull. (E)	8			
Quercus rugosa Née (N)	4			2
Quercus sp. (N)			15	
Salix bonplandiana Kunth (N)	3		2	
Salix paradoxa Kunth (N)	44			
Sambucus nigra L. (N)	72		5	4
Schinus molle L. (E)	9	24	23	5
Taxodium mucronatum Ten. (N)	3			
Thuja sp. (E)	1	3	29	1
Trema sp. (E)	8			
Ulmus sp.	6	14		3
Washingtonia robusta H. Wendl. (E)		16	7	
Yucca elephantipes Regel ex Trel. (E)	5	1	21	2

[1] *Eucalyptus globulus* and *E. camaldulensis* are both referred as *Eucalyptus* spp. due to difficulties in identifying individuals of each species at the time of the year when we carried out our surveys.

The same pattern was observed for exotic tree density, with highest values recorded in green areas (183.3 ± 76.9 trees/ha), followed by residential areas (79.8 ± 18.3 trees/ha), commercial areas (79.0 ± 24.2 trees/ha), and residential-commercial areas (46.7 ± 14.5 trees/ha; Figure 3). The density of native species showed highest values in green areas (301.7 ± 97.2 trees/ha), while no differences existed among the rest of the studied land uses (residential: 77.2 ± 33.3 trees/ha,
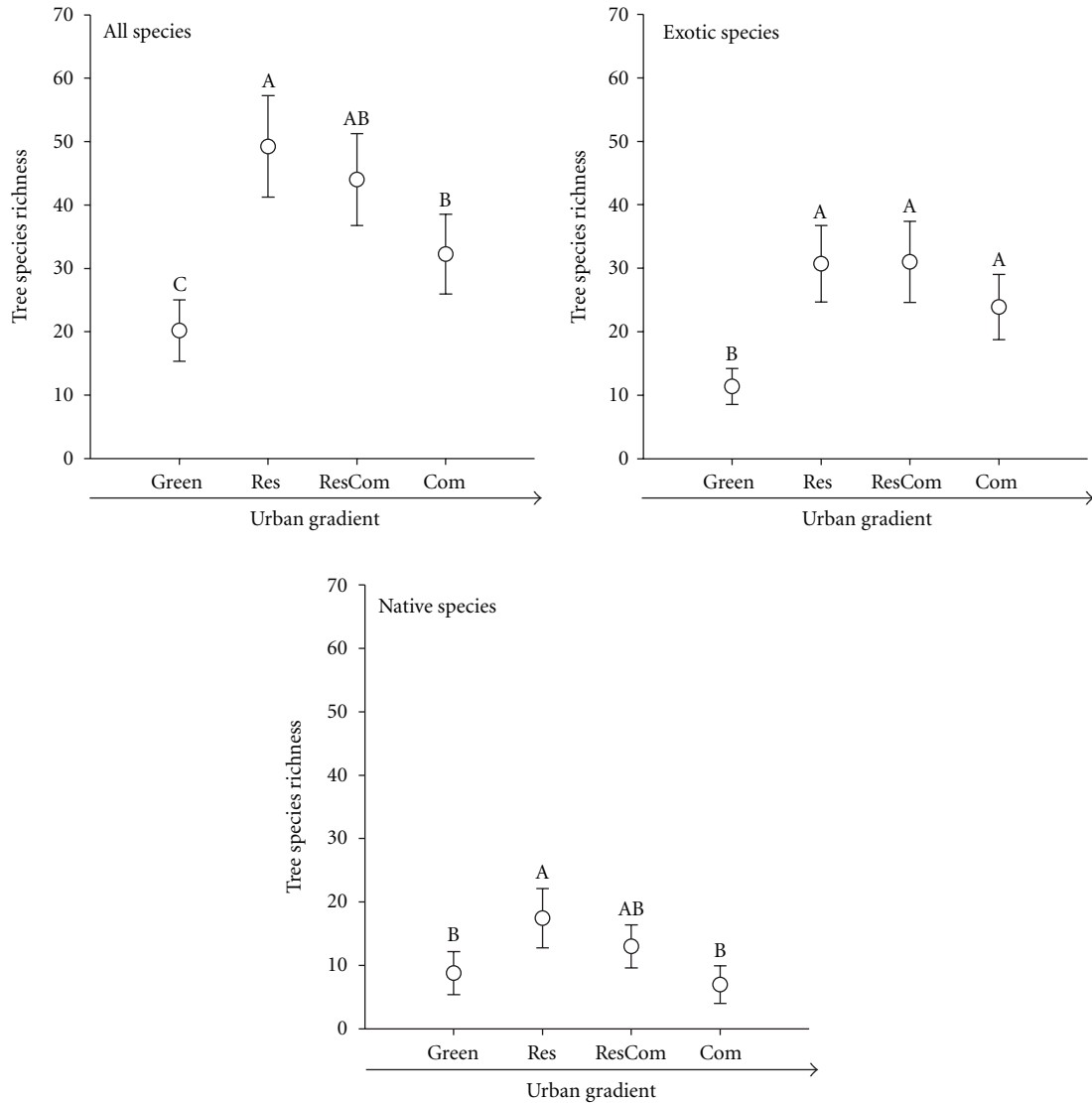
Figure 2: Computed tree species richness for the studied urban land uses. Values represent average values (±95% confidence intervals) computed at 524, 281, and 243 individuals for total, exotic, and native species, respectively. Letters represent statistical differences. Green: green areas, Res: residential areas, ResCom: residential-commercial areas, Com: Commercial areas.

residential-commercial: 39.5 ± 11.9 trees/ha, commercial: 58.3 ± 29.4 trees/ha; Figure 3).

Finally, total tree species composition was more similar among residential, residential-commercial, and commercial areas (>50% similarity), than green areas, which in turn showed an average dissimilarity of 75% with the rest of the studied land uses (Figure 4). Composition among land uses showed a similar pattern for both native and exotic tree species, with residential and residential-commercial areas exhibiting the highest similarity value among all land uses, followed by commercial areas, and finally by green areas (Figure 4).

5. Discussion

Along the studied neotropical gradient of urbanization of Mexico City, total, native, and exotic tree species richness were highest in residential and residential-commercial areas, which represent intermediate levels of urban development. Thus, the species richness pattern recorded in this study was consistent with the intermediate disturbance hypothesis [31]. This pattern is different from that observed for other wildlife groups (e.g., birds, mammals, reptiles), which exhibit higher species richness in less developed sites, such as green areas [23, 32]. Our results show that higher species richness of both native and exotic trees in Mexico City is related to the residential component of land uses, suggesting that residents promote tree species richness by choosing diverse tree species for their gardens and homesteads. Thus, tree species richness seems to be molded by cultural forces, as well as by landscaping, horticultural, and recreational practices [33]. Lower tree species richness in land uses with commercial components was not surprising, as the space available for planting trees is often reduced. In the case of green areas,
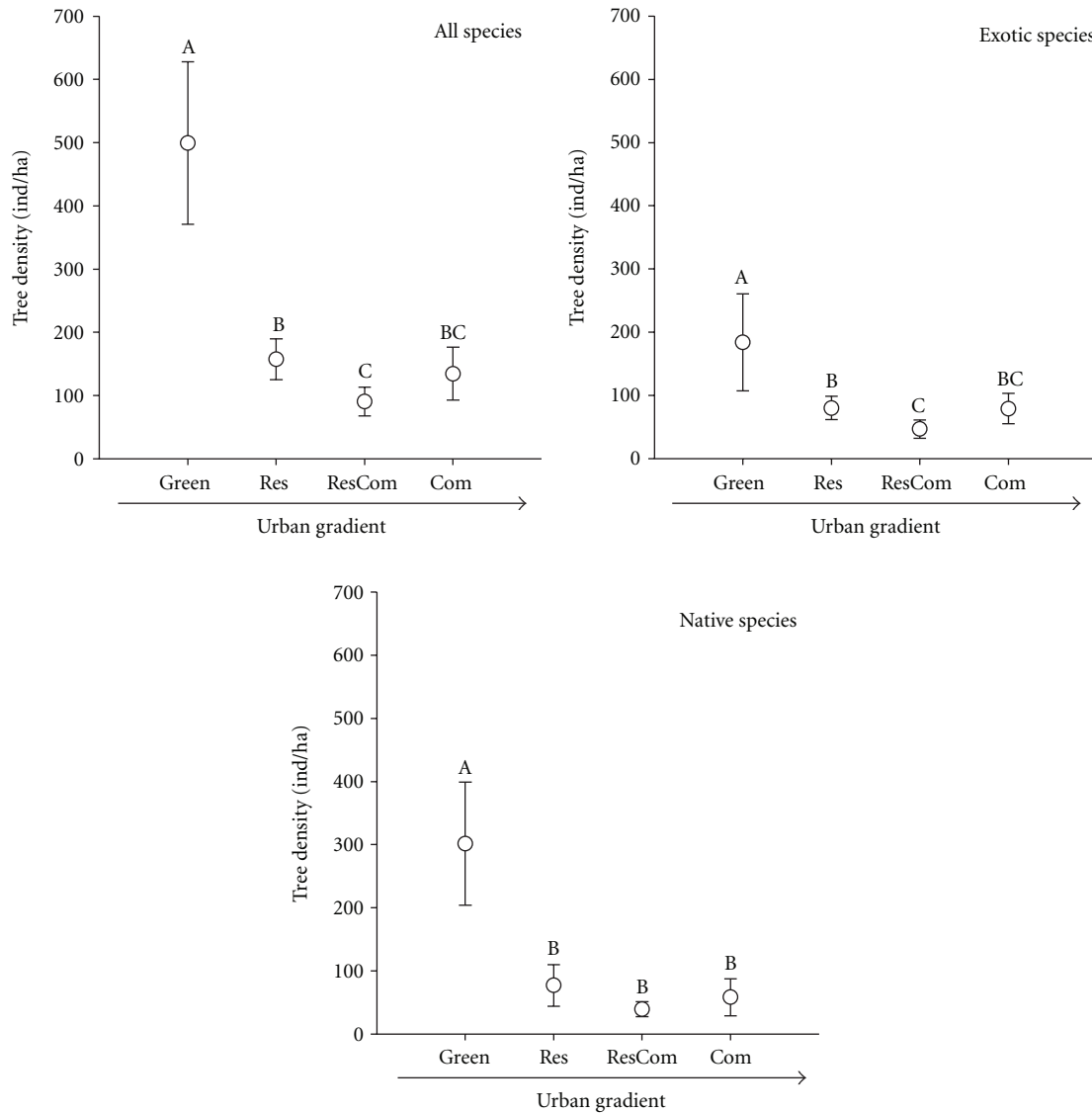
FIGURE 3: Total, exotic, and native tree species density (ind/ha) average values (±95% confidence intervals) for the studied urban land uses. Letters represent statistical differences. Green: green areas, Res: residential areas, ResCom: residential-commercial areas, Com: commercial areas.

trees are usually used to achieve greening purposes, which could lead to the creation of stands comprised by few tree species. Thus, native and exotic tree species richness were low within such urban land uses. Moreover, some green areas have original vegetation patches (e.g., shrublands, fir forests; [34]) which are characterized by the presence of a limited number of tree species.

Although total tree density also varied among urban land uses, the pattern was contrastingly different to that found for tree species richness. In fact, highest total, native, and exotic tree densities were recorded in green areas. This result was expected, as larger spaces within these areas are used for greening purposes [35] and are generally managed by the city council. Residential areas showed less total, native, and exotic tree densities than green areas, but exhibited higher values than residential-commercial and commercial areas. This

could result from socioeconomic considerations, reflecting the preponderance of gardens in high-income residential areas [36, 37], as people who live in these sites tend to appreciate and afford greener neighborhoods. Similar to our tree species richness results, land uses with commercial components (i.e., residential-commercial, commercial areas) had the lowest total, native, and exotic tree density values, mainly because a major proportion of the land is occupied by urban infrastructure components.

Our cluster analyses reinforce the point that residents can shape the diversity and density of total, native, and exotic trees in residential areas, even within those that contain commercial components [38, 39]. Higher taxonomic similarity of urban land uses that include residential components could result from a similar incorporation of both exotic and native species by residents. Differences among
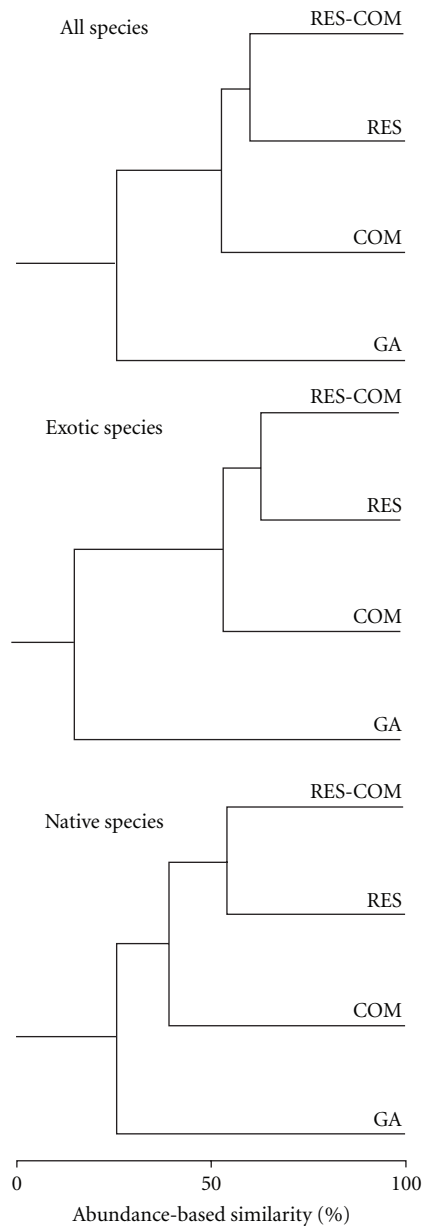
FIGURE 4: Abundance-based Bray-Curtis multivariate cluster analysis depicting tree composition similarity among the studied urban land uses. GA: green areas, RES: residential areas, RES-COM: residential-commercial areas, COM: commercial areas.

the latter land uses and commercial areas could emerge as local managers tend to prefer exotic over native species for aesthetic purposes in commercial sites. Finally, green areas were highly different from the rest of the studied land uses, likely due to higher densities of few species (e.g., Gum Trees—*Eucalyptus* spp., Mexican Cypress—*Cupressus lusitanica*, Mexican Ash—*Fraxinus uhdei*).

Although few studies have analyzed the variation of tree species richness along gradients of urbanization, our results agree with them, indicating that tree species richness, native or exotic, does not decrease with urbanization intensity [32]. Particularly, higher values of plant species richness

have been reported within moderately urbanized areas, likely enhanced by different plant cultivation choices [32, 40]. Thus, resident preferences and decisions play a fundamental role in determining the vegetation component of urban systems. To increase the potential benefits of human activities on the ecological quality of cities, residents and green area managers should be encouraged to select for a greater variety of tree species to avoid monospecific stands, promote heterogeneous green areas that benefit different wildlife groups, and maintain several ecological processes within urban ecosystems [41]. Moreover, further efforts are needed to enhance higher densities of trees outside green areas (e.g., residential areas, residential-commercial areas), which could derive in benefits for urban wildlife and local residents.

Acknowledgments

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