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Research article

Caracterización del arbolado y arbustos urbanos en Pampas, Huancavelica, Perú

Characterization of urban trees and shrubs in *Pampas*, *Huancavelica*, Peru

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Abstract

Urban trees are an important resource for the ecosystem services they provide. The objective of this study was to determine the structure, composition, richness, and diversity of urban trees and shrubs in the city of *Pampas*, *Huancavelica*, Peru. Trees and shrubs in two avenues, four *jirones* (green verges), the main square, and an ecological park were evaluated, and their normal diameter at a height of 1.30 m from the ground, crown diameter, and total height were measured. Abundance, dominance, frequency, area, and volume (Importance Value Index) were determined. Likewise, the Shannon diversity Index, the Margalef Index, and the number of key species were calculated. Thirteen species, distributed in 12 genera and 10 families, were recorded. 69 % accounted for introduced taxa, and 31 % for native taxa. The family with the most significant presence was Rosaceae, with three species. The analyses of diameter and height classes showed a higher proportion of individuals with high diameters (>5 cm and <40 cm) and intermediate heights (h>1 m and <7m). The urban areas reported low to moderate species richness and diversity. In conclusion, the need for improved management of urban trees and shrubs in the city of *Pampas* is highlighted. The use of species native to the region should be prioritized, and attention should be given to risk factors affecting the public infrastructure.

Keywords: Floristic composition, urban dasonomy, diversity, risk factors, public infrastructure, urban areas.

Resumen

El arbolado urbano es un recurso importante por los servicios ecosistémicos que aporta. El objetivo del presente trabajo fue conocer la estructura, composición, riqueza y diversidad de especies del arbolado y arbustos urbanos de la ciudad de Pampas, Huancavelica, Perú. Se evaluaron árboles y arbustos de dos alamedas, cuatro jirones (áreas verdes de alineación), la plaza principal y un parque ecológico, en donde se midieron el diámetro normal a 1.30 m de altura desde el suelo, el diámetro de copa y la altura total. Se determinó la abundancia, dominancia, frecuencia, área y volumen (Índice de Valor de Importancia). Asimismo, se calculó el Índice de diversidad de *Shannon*, el Índice de *Margalef* y la cantidad de especies clave. Se registraron 13 especies, distribuidas en 12 géneros y 10 familias. Los taxones introducidos representaron 69 % y 31 % fueron nativas. La familia con mayor presencia fue Rosaceae con tres especies. Los análisis de clases diamétricas y de alturas evidenciaron una proporción mayor de individuos con diámetros altos (>5 cm y <40 cm) y alturas intermedias (h>1 m y <7 m). En las áreas urbanas se obtuvieron datos bajos-intermedios de riqueza y diversidad de especies. En conclusión, se destaca la necesidad de gestionar mejor el arbolado y arbustos urbanos de la ciudad de Pampas, se debe priorizar el uso de especies nativas de la región y prestar atención a los factores de riesgos a la infraestructura pública.

Palabras clave: Composición florística, dasonomía urbana, diversidad, factores de riesgos, infraestructura pública, zonas urbanas.

Introduction

Cities play a crucial role in the advancement of society (Pashaei & An, 2024); thus, urbanization becomes a challenge for urban policymakers. It is advisable to plant trees and shrubs in green areas to promote benefits to people by improving their mental and physical health (Sharma et al., 2024). Thus, a better quality of life is generated by the ecosystem services that tree diversity provides, such as scenic beauty, improved air quality, and climate change mitigation (Ettinger et al., 2024; Kwon et al., 2021; Locosselli & Buckeridge, 2023; Sharma et al., 2024).

Several cities lack adequate management of the urban green areas, generating damages and risks for society (Koeser & Smiley, 2017; Koeser et al., 2016) —the product of structural instability, the inadequate height of the planted individuals, and their incorrect location in relation to physical assets (Matheny & Clark, 1993).

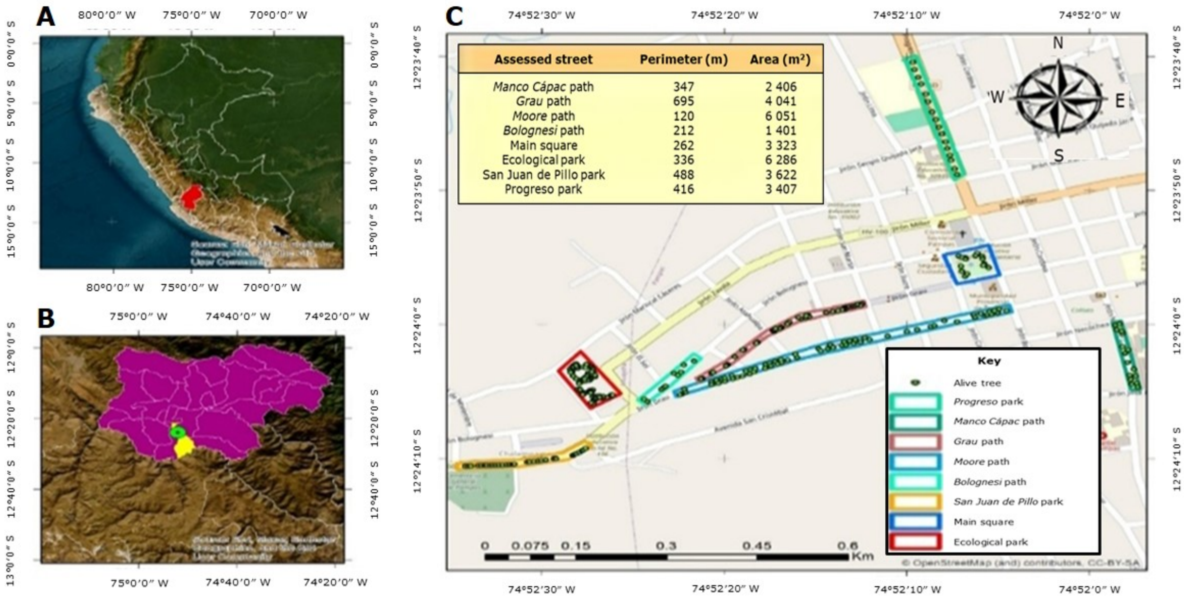
However, a large percentage of people still mistakenly believe that urban trees, regardless of their location, age, and health status, should remain intact for the goods and services they provide them (Saavedra-Romero et al., 2019); mainly because their cover effectively mitigates the consequences of heat island or urban heat stress (Li et al., 2024; Yang et al., 2024).

In Peru, there are no specific studies that comprehensively consider the potential of vegetation in urban areas. Despite not having very large areas with urban vegetation, there are green areas in the cities; for example, in *Pampas*, *Huancavelica*, there are two avenues, the main square, and an ecological park. For this reason, the objective of this study was to evaluate the structure, composition, richness, and diversity of its urban trees and shrubs, as well as the green verges of four streets.

Materials and Methods

Study area

The work was carried out in the *Pampas* district, *Tayacaja*, *Huancavelica*, located in the South-Central part of Peru (12°23′58.34″ S and 74°52′07.69″ W, Figure 1), at an altitude of 3 261 masl. The district is predominantly cold, with rainfall from October to March. The average annual temperature ranges between 13 and 22 °C, with an average rainfall of 512 mm (Servicio Nacional de Meteorología e Hidrología del Perú [Senamhi], 2022).



A = Map of Peru highlighting *Huancavelica*; B = Map of *Huancavelica* highlighting *Pampas*; C = Location of green areas in the city of *Pampas*.

Figure 1. Study area in the city of *Pampas*, *Huancavelica*, Peru.

A total of eight green urban areas were identified in the city of *Pampas* (Table 1), in which a census of all trees and shrubs was carried out.

Table 1. Urban green areas evaluated in *Pampas*, *Huancavelica*, Peru.

ID	Name	Perimeter (m)	Surface area (m²)
A	*San Juan de Pillo* park	488.0	3 622.0
B	*Progreso* park	416.0	3 407.0
C	*Bolognesi* path	212.0	1 401.0
D	*Grau* path	695.0	4 041.0
E	*Moore* path	120.0	6 051.0
F	*Manco Cápac* path	347.0	2 406.0
G	Ecological park	336.0	6 286.0
H	Main square	262.0	3 323.0
Total		2 876.0	30 537.0

Trees and shrubs with normal diameters greater than or equal to 5 cm were considered in the evaluation (Dangulla et al., 2020; Saavedra-Romero et al., 2019). The total height (*h*) was measured using a model PM-5/360PC Suunto® clinometer, the normal diameter with a model 283D/5m Forestry Suppliers Inc.® diameter tape, and the crown radius with a Major® 30 m tape measure with handle; in addition, the tree density was determined.

Species were identified by common and scientific names (Martínez-Trinidad et al. 2021; Sikuzani et al., 2019). Finally, the scientific name was corroborated through The WFO Plant List system (World Flora Online [WFO], 2025).

Structure and composition

Table 2 shows the equations to calculate the absolute and proportional abundance of each taxon according to the number of individuals recorded; the absolute and proportional dominance of each species according to the basal area of the individuals; the absolute and proportional frequency, according to the presence in the eight green urban areas; the crown area, the most active area that assimilates the light radiation, which included the lateral area of the crown and the area of the crown reflection was eliminated (Rodríguez-Laguna et al., 2009); for crown volume, we considered the shape of the crowns (elliptical, conical or cylindrical), which serve as a reference for the production of living matter and ecosystem functions, such as air pollution reduction and carbon sequestration (Fernández-Sarría et al., 2013; Hecht et al., 2008; Korhonen et al., 2013; McPherson & Rowntree, 1988; Meng et al., 2007; Mõttus et al., 2006; Zhu et al., 2021). The contextualized variables were used to obtain the Importance Value Index (percentage ranging from 0 to 100; *IVI*); the importance of each species was ranked based on abundance, frequency, dominance, area and crown volume (Saavedra-Romero et al., 2019).

Table 2. Equations used to calculate the structure and composition of vegetation in urban areas of the city of *Pampas*, *Huancavelica*, Peru.

Equations	Where
$A = \frac{n}{PA}$ (1)	A = Total abundance
	PA = Proportional abundance
$PA = \left[\frac{A}{\Sigma_{i=1}^{n} A}\right] \times 100$ (2)	n = Number of individuals per species
	SA = Sampling area (ha)
$D = \frac{BA}{SA}$ (3)	D = Total dominance
$PD = \left[\frac{D}{\Sigma_{i=1}^{n} D}\right] \times 100$ (4)	PD = Proportional dominance
	BA = Basal area per species
$F = \frac{Pi}{TNS}$ (5)	F = Absolute frequency
	RF = Relative frequency
$RF = \left[\frac{F}{\Sigma_{i=1}^{n} F}\right] \times 100$ (6)	Pi = Number of sites where the species are found
	TNS = Total number of sites
$CA = \frac{\pi \times CR}{6CL^2}[(4CL^2 + CR^2)^{1.5} - CR^3]$ (7)	CA = Crown area
	CR = Crown radius
	CL = Crown length
$Ellipsoid\ CV = \left[\left(\frac{4}{3} \times \pi \times CD^3 \times CL\right) \times \frac{1}{8}\right]$ (8)	CV = Crown volume
$Conic\ CV = \left(\frac{1}{3} \times \pi \times CD^3 \times CL\right)$ (9)	CD = Crown diameter
$Cylindrical\ CV = (\pi \times CD^3 \times CL)$ (10)	CL = Crown length
$IVI = \frac{\Sigma_{i=1}^{n}(PA,PD,RF,CA,CV)}{5}$ (11)	IVI = Importance Value Index

Richness and diversity of species

Table 3 presents the equations for calculating species richness and diversity using the Shannon diversity Index, the Margalef Index, and the number of keystone species (Cultid-Medina & Escobar, 2019; Jost, 2006; Leal Elizondo et al., 2018).

Table 3. Equations used to calculate vegetation richness and diversity in urban areas of the city of *Pampas*, *Huancavelica*, Peru.

Equations	Where
$H' = -\Sigma_{i=1}^{S} \frac{n}{N} \times nl\frac{n}{N}$ (12)	H' = Shannon Index
	S = Number of species present
	N = Total number of individuals
	n = Number of individuals per species
	nl = Natural logarithm
$D_{Mg} = \frac{S-1}{nl\,(N)}$ (13)	D_{Mg} = Margalef Index
${}^{1}D = exp\,(H')$ (14)	${}^{1}D$ = Number of key species
	exp = Exponential

Three types of urban green areas (verge, sports area, and park) were compared in relation to three variables: the diversity and richness indices. For this purpose, a one-way analysis of variance (ANOVA) was applied and, subsequently, a *post hoc* test was performed using Tukey's method to identify any significant differences between groups.

Results

The total evaluated area of green urban areas was 30 537 m^2, where 322 individuals were recorded, with a tree density of 105 individuals ha^{-1}. The most diverse families are shown in Table 4, with three species of Rosaceae and two species of Oleaceae. 13 species were identified, distributed in 12 genera and 10 families; 46 % presented a shrubby growth habit, while 54 % were of arboreal habit. Total absolute dominance was 11.32 m^2, with a total crown area of 8 813.8 m^2 and a total crown volume of 97 341.4 m^3 (Table 4).

Table 4. Structure and composition of vegetation in urban green areas in the city of *Pampas*, *Huancavelica*, Peru.

Species	Family	*Pa*	*Pd*	*Pf*	*PCA*	*PCV*	*IVI*
Populus nigra L.	Salicaceae	22.7	65.1	12.0	46.0	79.3	45.0
Ligustrum lucidum W. T. Aiton	Oleaceae	37.9	6.1	4.0	20.2	2.6	14.2
Sambucus nigra L.	Viburnaceae	12.4	14.2	24.0	10.4	3.2	12.8
Pinus patula Schiede *ex* Schltdl. & Cham.	Pinaceae	4.3	1.9	8.0	7.4	5.8	5.5
Araucaria columnaris (G. Forst.) Hook.	Araucariaceae	3.7	3.1	8.0	4.4	7.3	5.3
Fraxinus americana L.	Oleaceae	9.9	2.6	8.0	5.3	0.6	5.3
Buddleja coriacea J. Rémy	Scrophulariaceae	2.2	2.0	8.0	0.9	0.1	2.6
Schinus molle L.	Anacardiaceae	1.9	2.4	4.0	1.4	0.2	2.0
Prunus lusitanica L.	Rosaceae	0.6	0.3	8.0	0.6	0.1	1.9
Genipa americana L.	Rubiaceae	2.2	0.2	4.0	1.5	0.2	1.6
Cryptomeria japonica (Thunb. *ex* L.) D. Don	Cupressaceae	1.2	0.2	4.0	1.0	0.3	1.4
Polylepis incana Kunth	Rosaceae	0.6	0.9	4.0	0.6	0.2	1.3
Prunus cerasus L.	Rosaceae	0.3	0.1	4.0	0.2	0.0	0.9
Total		100	100	100	100	100	100

Pa = Proportional abundance; *Pd* = Proportional dominance; *Pf* = Proportional frequency; *PCA* = Proportional crown area; *PCV* = Proportional crown volume; *IVI* = Importance Value Index.

Ligustrum lucidum W. T. Aiton had the highest relative abundance (37.9 %); *Populus nigra* L. had the highest relative dominance (65.1 %), relative crown area (46.0 %), and relative crown volume (79.3 %); and *Sambucus nigra* L. had the highest relative frequency (24 %). In terms of the Importance Value Index (*IVI*), the first place was occupied by *P. nigra* (45 %), followed by *L. lucidum* (14.2 %) and *S. nigra* (12.8 %) (Table 4).

Table 5 shows the origin of the inventoried species, among which the introduced taxa stand out (9), compared to the native taxa (4). The species with the highest number of individuals was *L. lucidum* (122); *P. nigra* had the largest mean diameter (31.7 cm) and the largest basal area (0.101 m^2); and *Pinus patula* Schiede *ex* Schltdl. & Cham. had the greatest average height (11.5 m). The largest number of species (6) and individuals (205) were recorded in the ecological park.

Table 5. Urban vegetation and mean dasometric variables by species in the city of *Pampas*, *Huancavelica*, Peru.

Species	Origin	Number of individuals	Diameter (cm)	Height (m)	Basal area (m^2)
Araucaria columnaris (G. Forst.) Hook.	Introduced	12	18.1	5.1	0.029
Buddleja coriacea J. Rémy	Native	7	20.0	4.6	0.033
Cryptomeria japonica (Thunb. *ex* L.) D. Don	Introduced	4	7.9	5.3	0.005
Fraxinus americana L.	Introduced	32	10.2	5.6	0.009
Genipa americana L.	Native	7	6.0	5.3	0.003

Ligustrum lucidum W. T. Aiton	Introduced	122	8.1	4.5	0.006
Pinus patula Schiede *ex* Schltdl. & Cham.	Introduced	14	13.9	11.5	0.015
Polylepis incana Kunth	Native	2	24.7	4.5	0.048
Populus nigra L.	Introduced	73	31.7	10.9	0.101
Prunus cerasus L.	Introduced	1	11.0	4.5	0.009
Prunus lusitanica L.	Introduced	2	14.4	2.4	0.017
Sambucus nigra L.	Introduced	40	20.8	4.8	0.040
Schinus molle L.	Native	6	22.7	5.1	0.064

The diameter class graph shows a logarithmic trend (Figure 2), where the number of individuals decreases as the diameter increases (Figure 2). We observed 307 individuals with normal diameters of less than 40 cm. Given that the diameter indicates the stage of development of trees and urban shrubs, most of them are likely to be young specimens.

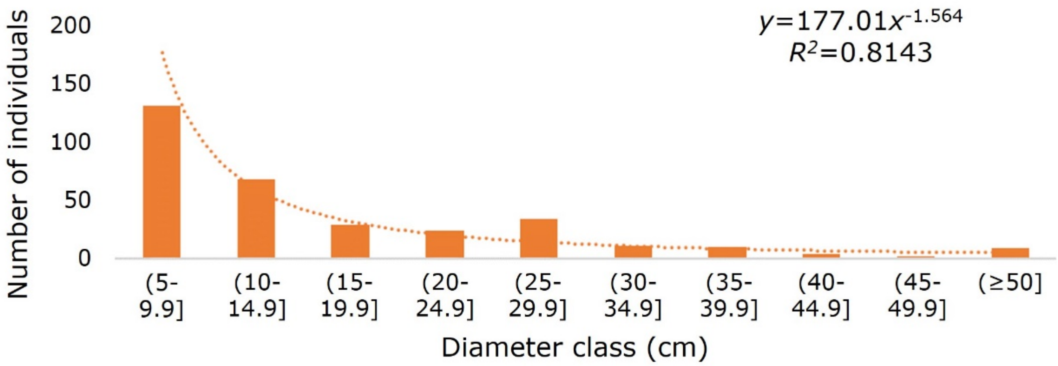


Figure 2. Number of individuals according to diameter (cm).

The distribution of the bars in the height class graph (Figure 3) did not show a tendency; there were a large number of individuals in the 4-6.9 m category and a small number in the rest of the categories. There was a deceleration in the growth of the evaluated individuals, which reflects a non-constant growth rate. There were 248 individuals with heights of less than 7 m.

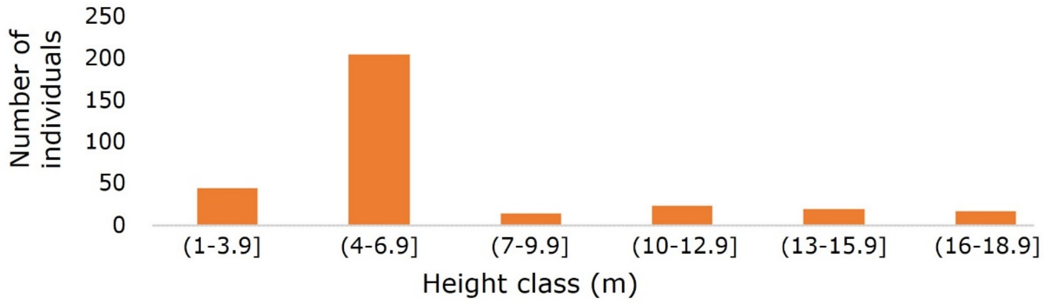
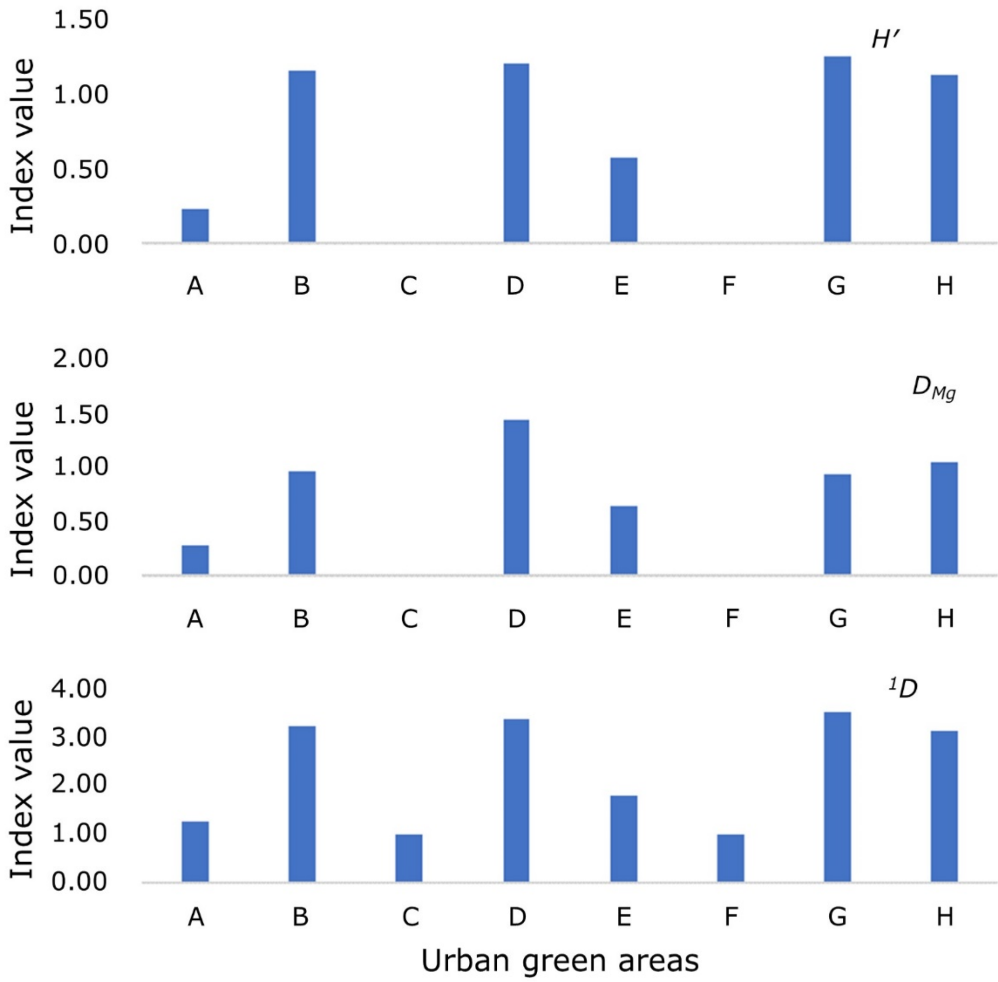


Figure 3. Number of individuals by total height (m).

The eight urban green zones showed diverse areas and functions; however, the diversity was similar (*P*>0.05) among the evaluated zones, which were classified as verge (two avenues), sports area (four streets with facilities for various sports or physical activities) and park (ecological park and main square with fountains and monuments) (Figure 4). There were no significant differences (*P*>0.05) in richness and diversity between the different types of urban green areas (Table 6). The park type stood out as the one with the highest richness and diversity (H'=1.39, D_{Mg}=1.21), unlike the sports area type, which exhibited the lowest values (H'=0.54, D_{Mg}=0.56).



H′ = Shannon-Wiener Index; D_{Mg} = Margalef Index; ^{1}D = Number of key species.

Figure 4. Richness and diversity indices evaluated in eight green urban areas of the city of *Pampas*, *Huancavelica*, Peru.

Table 6. Richness and diversity indices estimated by type of urban green area in the city of *Pampas*, *Huancavelica*, Peru.

Type of urban green area	Shannon (*H′*)	Margalef (D_{Mg})	Number of key species (^{1}D)
Verge	0.70±0.66a	0.63±0.48a	2.24±1.39a
Sport area	0.54±0.63a	0.56±0.70a	1.99±1.19a
Park	1.39±0.04a	1.21±0.12a	4.02±0.16a

Equal letters do not indicate significant differences (*P*>0.05). ± = Standard error.

Discussion

The density of individuals was 105 ha^{-1}, which is lower than that determined in the *Chapultepec* Forest in Mexico City, where the density of individuals is 295 ha^{-1} (Benavides Meza & Fernández Grandizo, 2012), and in the city of *Montemorelos*, Mexico, where it is 195 ha^{-1} (Canizales Velázquez et al., 2020). Values indicate a non-uniform distribution of urban trees and shrubs in the inventoried sites. Areas with higher densities may be associated with microclimate conditions that influence plant survival, as well as with anthropogenic intervention factors that can cause disturbances, water supply issues, and poor soil quality, among others.

13 species were recorded in the city of *Pampas* within a surface area of 30 537 m^2, estimating 4.3 species per ha^{-1}, which is higher than the value estimated for the city of *Montemorelos*, Mexico (2.8 species ha^{-1}) (Canizales Velázquez et al., 2020), for the city of *Linares*, Mexico (1.5 species ha^{-1}) (Leal Elizondo et al., 2018), and for the city of *Sancti Spíritus*, Cuba (2.3 species ha^{-1}) (Delgado Fernández et al., 2021).

In the city of *Pampas* there is a low to medium diversity of species; however, 91 % of the total number of inventoried individuals belong to six species, a characteristic that makes them susceptible to diseases and pest attacks (Velasco Bautista et al., 2013). Likewise, the predominance of exotic species was recorded, possibly because they are less aesthetically attractive and due to the scarcity of native plants in nurseries (Hardberger et al., 2025). This agrees with reports from other urban areas such as Mexico (*Monterrey* Metropolitan Area, *Montemorelos* and three parks in

Mexico City) and Cuba (*Sancti Spíritus*), where introduced species showed predominance, with 53, 54, 61, and 50.84 %, respectively (Alanís Flores, 2005; Canizales Velázquez et al., 2020; Delgado Fernández et al., 2021; Martínez-Trinidad et al., 2021). This pattern of reporting a larger number of introduced species occurs worldwide because nurseries are dedicated to producing small numbers of native ornamental plants (Pagès i Clavaguera, 2005).

Populus nigra reported the highest Importance Value Index (48.58 %) in urban areas. Some locations in Mexico report *Fraxinus uhdei* (Wenz.) Lingelsh. as the most important introduced species in urban green areas (Alanís et al., 2014; Canizales Velázquez et al., 2020; Leal Elizondo et al., 2018; Rocha Estrada et al., 1998). *P. nigra* is well-adapted to the specific conditions of the city of *Pampas*, demonstrating its capacity to thrive in the local environment.

The diameter classes chart confirms that most of the urban trees and shrubs in the city of *Pampas* are juvenile, agreeing with the data reported in four parks in Mexico City (Martínez-Trinidad et al., 2021), which can be associated with planting activities in cities in recent years (Alanís Flores, 2005); however, in many cities, vegetation and green areas have been lost (Shirazi & Kazmi, 2016).

The height classes ranged from 0 to 2.99 m, which could be attributed to their age (Alanís Flores, 2005). It is essential to observe the development of individuals, since growth in height increases the demand for resources for tasks such as pruning. In this sense, Skovsgaard et al. (2018) developed a work efficiency model for pruning, especially high pruning, demonstrating that the time required increases with pruning height, the number of branches, and the thickness of the largest branch.

The Margalef Index (D_{Mg}=1.76) indicates moderate species richness, suggesting that the city of *Pampas*, despite having a reasonable number of species, has some represented by few individuals, while others dominate with a larger number of specimens. This value is lower than that recorded by Leal Elizondo et al. (2018), who estimated an index of 5.24 in the city of *Linares*, Mexico, but higher than the 1.19 reported by Canizales Velázquez et al. (2020) for the city of *Montemorelos*, Mexico.

The Shannon Index (*H′*=1.64) corresponds to a moderate species diversity, which is why the city of *Pampas* exhibits an uneven distribution of individuals among species. This value meets the minimum criterion for urban areas, *H′*=1.50; it is higher than the 1.17 cited for *Montemorelos*, Mexico (Canizales Velázquez et al., 2020), but lower than the 1.99 registered in *Linares*, Mexico (Leal Elizondo et al., 2018), and in the green areas of *Texcoco*, Mexico (Martínez-Trinidad et al., 2021).

Conclusions

In the green areas of the city of *Pampas*, the families with the highest number of taxa were Rosaceae and Oleaceae. The best-represented species are *Ligustrum lucidum* and *Populus nigra*; introduced taxa and individuals are predominant. Urban trees and shrubs are relatively young (diameters <40 cm and heights <7 m), with moderate richness and diversity, and an uneven distribution of individuals per species. In addition, they exhibit management and planning issues.

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Conflict of interest

The authors declare that they have no conflicts of interest.

Contribution by author

Jairo Edson Gutiérrez-Collao: drafting of the manuscript and statistical analysis; Pabel Mariano Meza Mitma: interpretation of results; Karen Deysi Ramos Huaman: data analysis; Liz Roxana Ospina Castro: review of the manuscript; Sheyla Zarain Pariona Duran: statistical analysis; Jakelin Janeth Chancha Inga: data analysis and manuscript review; Christian Edinson Murga-Tirado: statistical analysis; Anais Gabriela Vasquez Salazar: data analysis.

References

Alanís Flores, G. J. (2005). El arbolado urbano en el área metropolitana de Monterrey. *Ciencia UANL*, *8*(1), 20-32. https://www.redalyc.org/pdf/402/40280104.pdf

Alanís, E., Jiménez, J., Mora-Olivo, A., Canizales, P., y Rocha, L. (2014, diciembre). Estructura y composición del arbolado urbano de un campus universitario del noreste de México. *Revista Iberoamericana de Ciencias*, *1*(7), 93-101. https://www.reibci.org/publicados/2014/diciembre/0700111.pdf

Benavides Meza, H. M., y Fernández Grandizo, D. Y. (2012). Estructura del arbolado y caracterización dasométrica de la segunda sección del Bosque de Chapultepec. *Madera y Bosques*, *18*(2), 51-71. https://doi.org/10.21829/myb.2012.182352

Canizales Velázquez, P. A., Alanís Rodríguez, E., Holguín Estrada, V. A., García García, S., & Collantes Chávez Costa, A. (2020). Description of the urban trees of

Montemorelos city, *Nuevo León*. *Revista Mexicana de Ciencias Forestales*, *11*(62), 111-135. https://doi.org/10.29298/rmcf.v11i62.768

Cultid-Medina, C. A., y Escobar, F. (2019). Pautas para la estimación y comparación estadística de la diversidad biológica (^{q}D). En C. E. Moreno (Ed.), *La biodiversidad en un mundo cambiante: Fundamentos teóricos y metodológicos para su estudio* (pp. 175-202). Universidad Autónoma del Estado de Hidalgo. https://www.researchgate.net/publication/340104672_Pautas_para_la_estimacion_y_comparacion_estadistica_de_la_diversidad_biologica_qD

Dangulla, M., Manaf, L. A., Ramli, M. F., & Yacob, M. R. (2020). Urban tree composition, diversity and structural characteristics in North-Western Nigeria. *Urban Forestry & Urban Greening*, *48*, Article 126512. https://doi.org/10.1016/j.ufug.2019.126512

Delgado Fernández, L. A., Rabassa Pérez, A., Trocones Boggiano, A. G., & Orrantia Cárdenas, I. (2021, mayo-agosto). Diagnóstico del arbolado urbano en una sección de la ciudad de Sancti Spíritus. *Revista Cubana de Ciencias Forestales*, *9*(2), 285-301. https://cfores.upr.edu.cu/index.php/cfores/article/view/703

Ettinger, A. K., Bratman, G. N., Carey, M., Hebert, R., Hill, O., Kett, H., Levin, P., Murphy-Williams, M., & Wyse, L. (2024). Street trees provide an opportunity to mitigate urban heat and reduce risk of high heat exposure. *Scientific Reports*, *14*, Article 3266. https://doi.org/10.1038/s41598-024-51921-y

Fernández-Sarría, A., Velázquez-Martí, B., Sajdak, M., Martínez, L., & Estornell, J. (2013). Residual biomass calculation from individual tree architecture using terrestrial laser scanner and ground-level measurements. *Computers and Electronics in Agriculture*, *93*, 90-97. https://doi.org/10.1016/j.compag.2013.01.012

Hardberger, A., Craig, D., Simpson, C., Cox, R. D., & Perry, G. (2025). Greening up the city with native species: challenges and solutions. *Diversity*, *17*(1), 56. https://doi.org/10.3390/d17010056

Hecht, R., Meinel, G., & Buchroithner, M. F. (2008). Estimation of urban green volume based on single-pulse LiDAR data. *IEEE Transactions on Geoscience and Remote Sensing*, *46*(11), 3832-3840. https://doi.org/10.1109/TGRS.2008.2001771

Jost, L. (2006). Entropy and diversity. *Oikos*, *113*(2), 363-375. https://doi.org/10.1111/j.2006.0030-1299.14714.x

Koeser, A. K., & Smiley, E. T. (2017). Impact of assessor on tree risk assessment ratings and prescribed mitigation measures. *Urban Forestry & Urban Greening*, *24*, 109-115. https://doi.org/10.1016/j.ufug.2017.03.027

Koeser, A. K., Hauer, R. J., Miesbauer, J. W., & Peterson, W. (2016). Municipal tree risk assessment in the United States: Findings from a comprehensive survey of urban forest management. *Arboriculture Journal*, *38*(4), 218-229. https://doi.org/10.1080/03071375.2016.1221178

Korhonen, L., Vauhkonen, J., Virolainen, A., Hovi, A., & Korpela, I. (2013). Estimation of tree crown volume from airborne lidar data using computational geometry. *International Journal of Remote Sensing*, *34*(20), 7236-7248. https://doi.org/10.1080/01431161.2013.817715

Kwon, O.-H., Hong, I., Yang, J., Wohn, D. Y., Jung, W.-S., & Cha, M. (2021). Urban green space and happiness in developed countries. *EPJ Data Science*, *10*, Article 28. https://doi.org/10.1140/epjds/s13688-021-00278-7

Leal Elizondo, C. E., Leal Elizondo, N., Alanís Rodríguez, E., Pequeño Ledezma, M. Á., Mora-Olivo, A., & Buendía Rodríguez, E. (2018). Estructura, composición y diversidad del arbolado urbano de Linares, Nuevo León. *Revista Mexicana de Ciencias Forestales*, *9*(48), 252-270. https://doi.org/10.29298/rmcf.v8i48.129

Li, H., Zhao, Y., Wang, C., Ürge-Vorsatz, D., Carmeliet, J., & Bardhan, R. (2024). Cooling efficacy of trees across cities is determined by background climate, urban morphology, and tree trait. *Communications Earth & Environment*, *5*, Article 754. https://doi.org/10.1038/s43247-024-01908-4

Locosselli, G. M., & Buckeridge, M. S. (2023). The science of urban trees to promote well-being. *Trees*, *37*, 1-7. https://doi.org/10.1007/s00468-023-02389-2

Martínez-Trinidad, T., Hernández López, P., López-López, S. F., & Mohedano Caballero, L. (2021). Diversidad, estructura y servicios ecosistémicos del arbolado en cuatro parques de Texcoco mediante *i-Tree Eco*. *Revista Mexicana de Ciencias Forestales*, *12*(67), 202-223. https://doi.org/10.29298/rmcf.v12i67.880

Matheny, N., & Clark, J. (1993). *A photographic guide to the evaluation of hazard trees in urban areas* (2nd ed.). International Society of Arboriculture. https://urbanforestrysouth.org/resources/library/ttresources/a-photographic-guide-to-the-evaluation-of-hazard-trees-in-urban-areas

McPherson, E. G., & Rowntree, R. A. (1988). Geometric solids for simulation of tree crowns. *Landscape and Urban Planning*, *15*(1-2), 79-83. https://doi.org/10.1016/0169-2046(88)90017-5

Meng, S. X., Lieffers, V. J., & Huang, S. (2007). Modeling crown volume of lodgepole pine based upon the uniform stress theory. *Forest Ecology and Management*, *251*(3), 174-181. https://doi.org/10.1016/j.foreco.2007.06.008

Mõttus, M., Sulev, M., & Lang, M. (2006). Estimation of crown volume for a geometric radiation model from detailed measurements of tree structure. *Ecological Modelling*, *198*(3-4), 506-514. https://doi.org/10.1016/j.ecolmodel.2006.05.033

Pagès i Clavaguera, J. M. (2005). Viveros ornamentales en España. *Horticultura Internacional*, *1*, 30-35. https://dialnet.unirioja.es/servlet/articulo?codigo=1089452

Pashaei, S, & An, C. (2024). Assessment of urban greenhouse gas emissions towards reduction planning and low-carbon city: a case study of Montreal, Canada. *Environmental Systems Research*, *13*, Article 12. https://doi.org/10.1186/s40068-024-00341-y

Rocha Estrada, A., Torres Cepeda, T. E., González de la Rosa, M. del C., Martínez Lozano, S. J., & Alvarado Vázquez, M. A. (1998, diciembre). Flora ornamental en plazas y jardines públicos del área metropolitana de Monterrey, México. *SIDA, Contributions to Botany*, *18*(2), 579-586. https://www.jstor.org/stable/41967647

Rodríguez-Laguna, R., Meza-Rangel, J., Vargas-Hernández, J., y Jiménez-Pérez, J. (2009). Variación en la cobertura de suelo en un ensayo de procedencias de *Pinus greggii* Engelm. en el cerro El Potosí, Galeana, Nuevo León. *Madera y Bosques*, *15*(1), 47-59. https://doi.org/10.21829/myb.2009.1511196

Saavedra-Romero, L. de L., Hernández-de la Rosa, P., Alvarado-Rosales, D., Martínez-Trinidad, T., y Villa-Castillo, J. (2019). Diversidad, estructura arbórea e índice de valor de importancia en un bosque urbano de la Ciudad de México. *Polibotánica*, *47*, 25-37. https://doi.org/10.18387/polibotanica.47.3

Servicio Nacional de Meteorología e Hidrología del Perú. (2022). *Datos/Datos hidrometeorológicos a nivel nacional* [Conjunto de datos]. Ministerio del Ambiente de Perú. https://www.senamhi.gob.pe/?&p=estaciones

Sharma, S., Hussain, S., Kumar, P., & Singh, A. N. (2024). Urban trees' potential for regulatory services in the urban environment: an exploration of carbon sequestration. *Environmental Monitoring and Assessment*, *196*, Article 504. https://doi.org/10.1007/s10661-024-12634-x

Shirazi, S. A., & Kazmi, J. H. (2016). Analysis of socio-environmental impacts of the loss of urban trees and vegetation in Lahore, Pakistan: a review of public perception. *Ecological Processes*, *5*, Article 5. https://doi.org/10.1186/s13717-016-0050-8

Sikuzani, Y. U., Malaisse, F., Kaleba, S. C., Mwanke, A. K., Yamba, A. M., Khonde, C. N., Bogaert, J., & Kankumbi, F. M. (2019). Tree diversity and structure on green space of urban and peri-urban zones: The case of Lubumbashi City in the Democratic Republic of Congo. *Urban Forestry & Urban Greening*, *41*, 67-74. https://doi.org/10.1016/j.ufug.2019.03.008

Skovsgaard, J. P., Ols, C., & Mc Carthy, R. (2018). High-pruning of silver birch (*Betula pendula* Roth): work efficiency as a function of pruning method, pole saw type, slash removal, operator, pruning height and branch characteristics. *International Journal of*

Forest Engineering, *29*(2), 117-127. https://doi.org/10.1080/14942119.2018.1462593

Velasco Bautista, E., Cortés Barrera, E. N., González Hernández, A., Moreno Sánchez, F., & Benavides Meza, H. M. (2013). Diagnóstico y caracterización del arbolado del bosque de San Juan de Aragón. *Revista Mexicana de Ciencias Forestales*, *4*(19), 102-111. https://doi.org/10.29298/rmcf.v4i19.382

World Flora Online. (2025). *The WFO Plant List. Browse the WFO Plant List* [Data set]. Royal Botanic Gardens and the Missouri Botanical Garden. https://wfoplantlist.org/

Yang, L., Ge, J., Cao, Y., Liu, Y., Luo, X., Wang, S., & Guo, W. (2024). Enhanced cooling efficiency of urban trees on hotter summer days in 70 cities of China. *Advances in Atmospheric Sciences*, *41*, 2259-2275. https://doi.org/10.1007/s00376-024-3269-9

Zhu, Z., Kleinn, C., & Nölke, N. (2021). Assessing tree crown volume—a review. *Forestry: An International Journal of Forest Research*, *94*(1), 18-35. https://doi.org/10.1093/forestry/cpaa037