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Article

Descripción del arbolado de alineación de la ciudad de Puebla por grado de marginación y vialidad

Description of the linear trees of *Puebla* City by degree of marginalization and street

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Resumen

El arbolado urbano forma parte fundamental del paisaje natural dentro de las ciudades, reduce los efectos negativos ocasionados por las actividades económicas y contribuye a mejorar la calidad de vida de los habitantes de todas las clases sociales. El objetivo del presente estudio fue realizar la caracterización de la estructura y la diversidad del arbolado en calles públicas de la ciudad de Puebla por áreas con diferente grado de marginación y orden vial. Se realizó un muestreo aleatorio estratificado en vialidades públicas de mayo a octubre de 2019; se determinó la especie, altura total, altura del fuste limpio, altura de copa viva y altura a copa viva, diámetro basal, diámetro normal, diámetro de la copa, así como condición y estado de desarrollo. Se registró un total de 2 188 árboles, de los cuales 2 068 estaban vivos; estos se agruparon en 31 familias, 56 géneros y 75 especies; 73.33 % son taxones introducidos y solo 26.67 % son nativos. Los resultados del estudio destacan la influencia de los aspectos socioeconómicos y urbanos en la composición y en la estructura del arbolado vial, por lo que deben de ser contemplados en la gestión y elaboración de planes de manejo.

Palabras clave: Arbolado de alineación, composición arbórea, dasonomía urbana, estructura arbórea, marginación económica, Puebla.

Abstract

Urban trees are a fundamental part of the natural landscape within cities, as they reduce the negative effects caused by economic activities and contribute to improve the quality of life for the inhabitants of all social classes. The aim of this study was to make a diagnosis of the urban trees in streets of *Puebla* City in areas with different degrees of marginalization and type of existing roads. A stratified random sampling was carried out in public roads from May to October 2019. The species, total height, height to the first branch and height to canopy, basal diameter, diameter to the breast height, canopy cover diameter, also health condition, status of development and conflicts with infrastructure were determined. A total of 2 188 trees were recorded, 2 068 of which were found alive, which belong to 31 families, 56 genera and 75 species; 73.33 % are introduced species and only 26.67 % are native. The results from this study highlight the influence that socio-economic aspects have on the composition and structure of urban trees, mainly in street trees, being important to recognize that in the development of management plans and management of public

urban trees it is necessary to integrate the different social and urban aspects that each urban center has.
Key words: Alignment trees, trees composition, urban forestry, tree structure, marginalization, *Puebla.*

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Introduction

The territorial and population growth of cities, coupled with poor urban design, make green spaces vulnerable to disappear (Szabó, 2010). Green areas regulate the effects of urbanization, such as heat islands, loss of biodiversity and pollution; these spaces protect the remaining vegetation (Gutiérrez-Pacheco *et al*., 2015). Urban trees are necessary for the environmental benefits they provide and for their role in the urban landscape and their interaction with all social classes, by improving their lives (Molina and Vargas, 2012).

Alignment trees are an integral element in cities, they connect with other green areas and help maintain biodiversity, which favors their environmental quality (León *et al.,* 2017). However, the elimination of trees due to urban growth is common. In *Puebla* there is unplanned growth that causes problems such as loss of biodiversity, pollution of water, air, soil and energy consumption (Ramírez *et al.,* 2019). Generating information about these trees is useful to help establish strategies that enrich the environmental conditions of the city (SDUS, 2015).

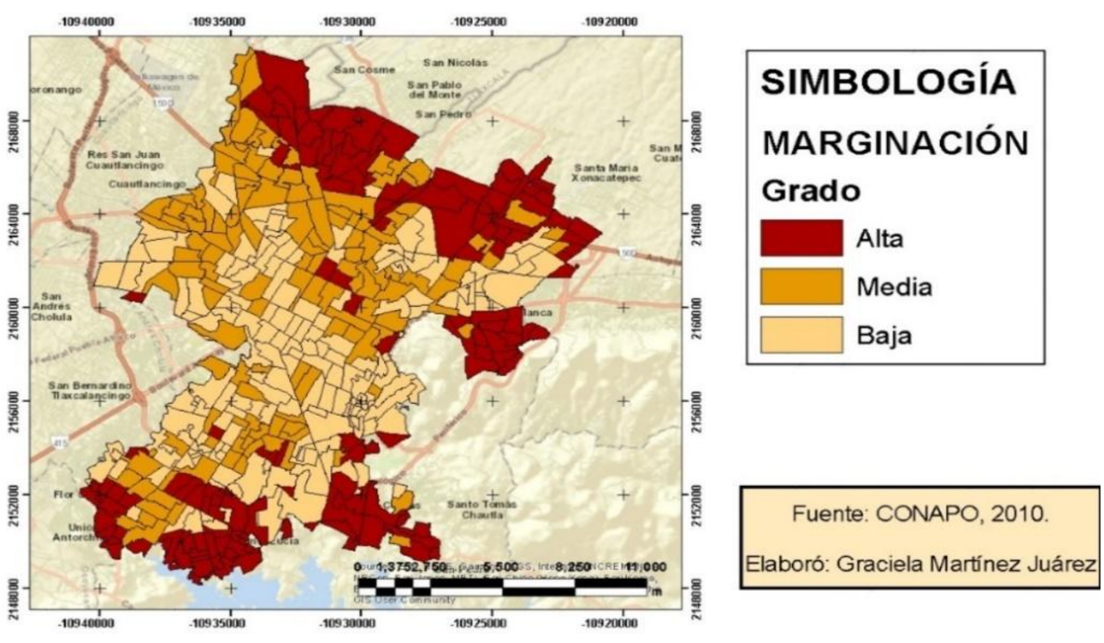
To understand the functioning of the urban environment, it is necessary to link aspects of the natural environment with social, economic and cultural ones (Carponi *et al*., 2016). Studying the situation of linear trees, with the influence of socioeconomic and urban factors, allows us to understand the factors that influence their characteristics (Rodríguez *et al.,* 2017).

Given this scenario, the objective of this study was to know the composition and some aspects of the structure of the public alignment trees of the city of *Puebla*, by degree of marginalization and type of roads present.

Materials and Methods

Study area

The city of *Puebla*, capital of the homonymous state, is located between 19°02'38.363" N and 098°11'18.452" W (Inegi, 2016) and covers 206.55 km^2. Its population is 1 434 062 inhabitants (Sedesol, 2010) and it is the fourth largest and most important city in Mexico (Figure 1).



Simbología = Symbology; *Marginación* = Marginalization; *Alta* = High; *Media* = Medium; *Baja* = Low; *Fuente* = Source.

Figure 1. Zoning of the study area: city of *Puebla.*

Sampling technique

A stratified random sampling was carried out, with the information generated by Conapo (2010); Geostatistically urban areas (AGEB) were grouped into three marginalization strata: high (AMA), medium (AMM) and low (AMB), which were considered as sampling units. The order of roads present was also determined; those of the first order (VPO) are made up of avenues, boulevards, roads, circuits, ring roads, road axes, peripheral or viaduct; as second order roads (VSO) the extensions, continuations, corridors, diagonals or extensions were taken; third order thoroughfares (VTO) included streets, alleys and turns; and the private and closed ones integrate those of fourth order (VCO) (INEGI, 2010).

With the Create Random Points tool of ArcGis (2012) software, v. 10.1, from the distribution of the 460 available AGEB's, 33 of them were randomly selected, which presented at least three road orders. Of these, 12 correspond to AMB, 11 to AMA and 10 to AMM. The sampling intensity was equal to 7 %. On each road order, 200 m routes were carried out, in which trees and shrubs were recorded (Nagendra and Gopal, 2010). 118 transects were made: 32 in VPO, 23 in VSO, 33 in VTO and 30 in VCO. Sampling was carried out from May to October 2019.

Vegetation analysis

The following characteristics were recorded for each tree: species (verified in the MEXU National Herbarium database), diameter at 1.30 m (normal diameter, *DN*), and at 20 cm (basimetric diameter, *DB*) from the base of the tree, which were calculated by taking the measurements of the circumferences with a JESOCUP B087NTH86P tape measure and dividing them by the value of *pi*; height, height of the clean stem and height of the live crown, measured with a Haga gun; live crown diameter, with a Truper 12639 tape measure. Likewise, its condition (alive, dead felled or standing dead) and the state of development were pointed out: juvenile for trees with less than 20 cm of DN or individuals of early species with reproductive structures, mature for trees with more than 20 cm of DN or individuals that present reproductive structures, and senile for individuals with decreased vigor caused by biotic or abiotic factors. Such signs of reduced vigor were crowns with partial or almost total foliage absence, dead branches in the upper part or trunks with no bark or rot and stump (Gobierno del Estado de México, 2018; Cervantes *et al.,* 2019).

Data analysis

With the field data, the following were calculated: crown cover, species richness (*S*), Margalef diversity index (D_{Mg}), Simpson index (*D*) and equity index (*H'*) (Moreno, 2001), to obtain parameters that would allow determining the alpha diversity and giving an overview of the effects caused by environmental disturbances. These indices were obtained by degree of marginalization and road order.

Results

A total of 2 188 trees and shrubs were recorded; 2 068 were alive. 75 species of 56 genera and 31 families were found (Table 1). 73.33 % (55) are introduced species and 26.67 % (20), native to Mexico; 69.33 % (52) correspond to trees of evergreen species and 30.67 % (23) to deciduous. Of the total species, 48 were represented by less than 10 individuals. *Ficus benjamina* L. and *Cupressus sempervirens* L. are the species with the highest number of individuals, covering 17.26 and 15.96 % of the total, respectively. Of the 75 species, the Rosaceae family was the most representative (8 species), followed by Fabaceae and Myrtaceae (6), and Cupressaceae, Moraceae and Rutaceae (5). The most common genera were *Prunus* (6 species), *Ficus* (5) and *Citrus* (4).

Table 1. Identified species in the study area in the city of *Puebla*.

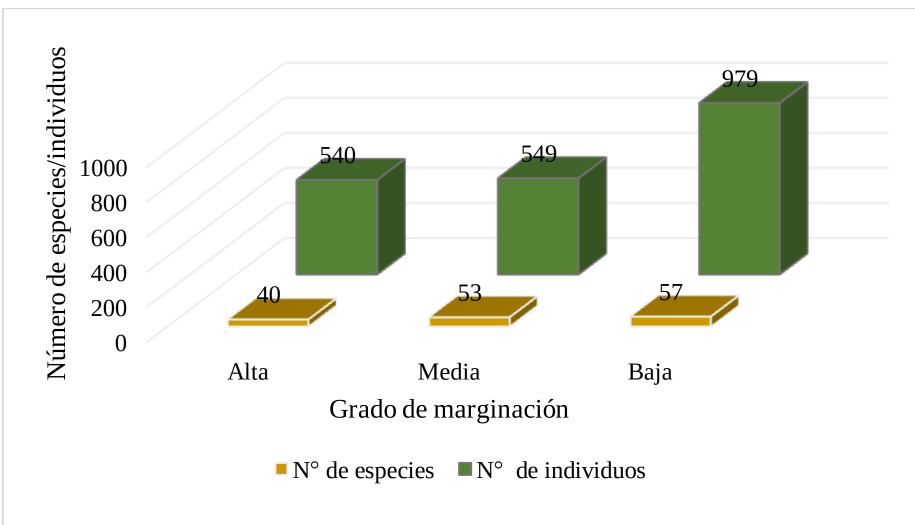
Species	Species	Species
Araucaria heterophylla (Salisb.) Franco	*F. elastica* Roxb. ex Hornem.	*Phoenix canariensis* Chabaud
Acacia farnesiana (L.) Willd.*	*F. retusa* var. *nitida*(Thunb.) Miq.	*Pinus patula* ssp. *patula**
A. retinodes Schltdl.	*Fraxinus uhdei* (Wenz.) Lingelsh. *	*P. teocote* Schied. ex Schltdl. & Cham. *
Bauhinia variegata L. *	*Grevillea robusta* A.Cunn. ex R.Br.	*Platycladus orientalis* (L.) Franco
Callistemon citrinus (Curtis) Skeels	*Hibiscus rosa-sinensis* var. *rosa-sinensis*	*Populus alba* L.
Carissa macrocarpa (Eckl.) A.DC.	*Ipomoea arborescens* (Humb. & Bonpl. ex Willd.) G. Don*	*P. deltoides* ssp. *deltoides*
Casimiroa edulis Llave*	*I. murucoides* Roem. & Schult.	*P. tremuloides* Michx. *
Casuarina equisetifolia L.	*Jacaranda mimosifolia* D.Don	*Prunus armeniaca* L.
Citrus aurantiifolia (Christm.) Swingle	*Juglans regia* L.	*P. domestica* L.
C. reticulata Blanco	*Laurus nobilis* L.	*P. persica* (L.) Batsch
C. sinensis (L.) Osbeck	*Leucaena esculenta* ssp. *esculenta* Benth. *	*P. salicina* Lindl.
Crataegus mexicana Moc. & Sessé ex DC. *	*Ligustrum lucidum* W.T.Aiton	*P. serotina* ssp. *serotina**
Cupressus lindleyi Klotzsch ex Endl. *	*Liquidambar styraciflua* L. *	*Punica granatum* L.
C. macrocarpa Hartw. ex Gordon	*Lycianthes rantonnetii* (Carrière ex Lesc.) Bitter	*Psidium guajava* L. *
C. sempervirens L.	*Macadamia integrifolia* Maiden & Betche	*Roystonea regia* (Kunth) O.F.Cook
Delonix regia (Hook.) Raf.	*Magnolia grandiflora* L.	*Salix babylonica* L.
Duranta erecta L. *	*Malus pumila* Mill.	*Schinus terebinthifolius* Raddi
Eriobotrya japonica (Thunb.) Lindl.	*Mangifera indica* L.	*Schefflera actinophylla* (Endl.) Harms
Erythrina coralloides DC. *	*Melia azedarach* L.	*Senecio salignus* DC.
Eucalyptus camaldulensis Dehnh.	*Musa paradisiaca* L.	*Spathodea campanulata* P.Beauv.
E. globulus Labill.	*Myrtus communis* L.	*Syzygium paniculatum* Gaertn
Euphorbia cotinifolia L.	*Nerium oleander* L.	*Thuja occidentalis* L.

Ficus benjamina L.	*Olea europaea* L.	*Thymophylla tenuifolia* (Cass.) Rydb.
F. benjamina L.cv. *variegata*	*Olyra latifolia* L.	*Washingtonia robusta* H.Wendl. *
F. carica L.	*Persea americana* Mill. *	*Yucca elephantipes* Regel*

*Native species of Mexico.

Distribution of alignment trees by degree of marginalization

Both the number of species and trees show an inverse trend with respect to the level of marginalization (Figure 2).

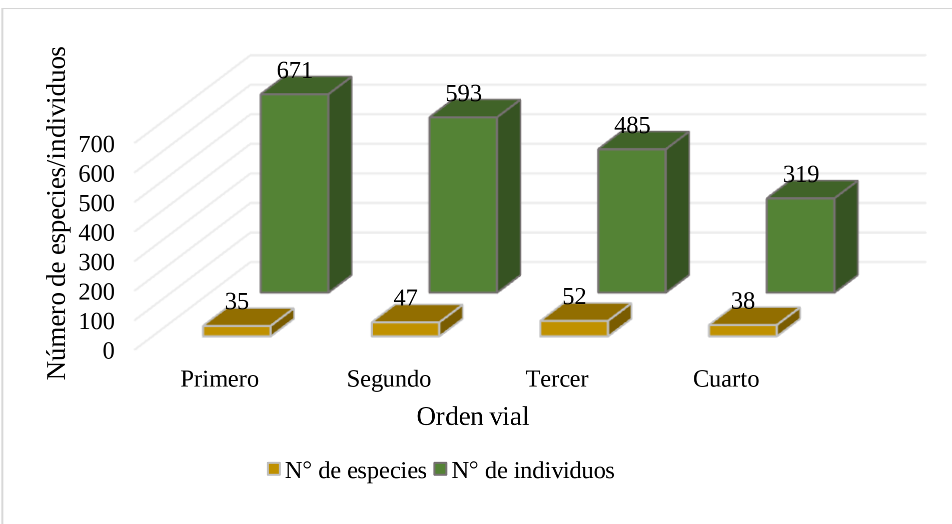


Número de especies/individuos = Species and number of individuals; *Grado de marginación* = Degree of marginalization; *Alta* = High; *Media* = Medium; *Baja* = Low.

Figure 2. Distribution of the number of species and number of individuals by degree of marginalization.

Distribution of alignment trees by road order

The number of trees decreases from VPO, with 671, to VCO, with 319. Despite this, only 35 species were found in VPO, among which *Fraxinus uhdei* (Wenz.) Lingelsh (107), *Ligustrum lucidum* W.T.Aiton (80), *F. benjamina* (78), *F. retussa* var. *nitida* (Thunb.) Mig. (74) and *Populus tremuloides* Michx. (62) stand out. They are followed by VCO, with 38 species, among which *C. sempervirens* and *F. benjamina* (89 each), *C. lindleyi* Klotzsch *ex* Endl*.* (26), *F. retussa* var. *nitida* (21) and *F. uhdei* (12), are the most frequent. VSO had 47 species, where *C. sempervirens* (106), *F. benjamina* (98), *L. lucidum* (47), *C. lindleyi* (43), *F. retussa* var. *nitida* and *F. uhdei* (30) were dominant. In VTO 52 species being the most abundant: *F. benjamina* (92), *C. sempervirens* (86), *F. retusa* var. *nitida* (43), *L. lucidum* (37) and *C. macrocarpa* (Eckl.) A.DC. (25) (Figure 3).



Número de especies/individuos = Species and number of individuals; *Orden vial* = Road order; *Primero* = First; *Segundo* = Second; *Tercero* = Third; *Cuarto* = Fourth.

Figure 3. Distribution of the number of species and number of individuals by road order.

Low Marginalization

Tree distribution

A total of 1 034 individuals were located in the AMBs, 979 alive. In VPO and VSO the highest number of trees were located, with 37.43 and 32.40 %, respectively. VPO showed a higher percentage of dead individuals compared to the three remaining road orders (Table 2).

Table 2. Distribution of road trees in areas of low marginalization, by road order.

Tree status	Road order				
	1st (%)	2nd (%)	3rd (%)	4th (%)	Total (%)
Alive	34.82	30.56	17.41	11.90	94.68
Stump	1.06	1.45	0.39	0.29	3.19
Standing dead	1.45	0.39	0.19	0.00	2.03
Felled dead	0.10	0.00	0.00	0.00	0.10
Total	37.43	32.40	17.99	12.19	100.00

Development Status

In the AMB, 979 living individuals were recorded, of which 60.4 % had a mature developmental stage, 34.2 % were juveniles and 5.4 % senile. In the VPO, 387 trees were found, 360 alive and 74.44 % mature, 17.50 % juvenile and 8.06 % senile. In the VSO, 335 individuals were recorded, 316 alive; 50.95 % mature, 44.94 % juvenile and 4.11 % senile. The VTO covered 186 trees, 180 live and, of the latter, 59.44 % mature, 35 % juvenile and 5.56 % senile. In VCO there were

126 individuals, 123 alive; of these, 44.72 % were mature, 54.47 % juvenile, and 0.811 % senile.

Structure

The average dimensions of the living trees in these AMBs were: height (5.92 ± 3.59 m), height of the clean stem (1.50 ± 1.21 m), height of the living crown (3.54 ± 2.52 m), height of the living crown (2.38 ± 1.73 m), normal diameter (25.50 ± 18.64 cm), basimetric diameter (30.26 ± 21.37 cm) and crown cover (21.67 ± 29.76m^2). The structure of the individuals in AMB is presented by road order in Table 3.

Table 3. Mensuration variables of alignment trees in the city of *Puebla*, by road order, for low marginalization areas.

Variable	Road order			
	1st	**2nd**	**3rd**	**4th**
Height (m)	6.83±3.20	5.90±3.89	4.67±2.44	5.14±4.47
AltFL (m)	1.87±1.03	1.43±1.40	1.15±0.90	1.11±1.30
AtlCopV (m)	4.02±2.54	3.51±2.36	2.76±1.85	3.37±3.30
AltACopV (m)	2.80±1.34	2.40±2.17	1.91±1.24	1.76±1.80
DN (cm)	28.83±18.56	24.89±22.16	22.21±11.49	19.96±13.06
DB (cm)	35.28±21.64	29.54±24.42	26.07±114.42	23.59±17.08
CobC (m^2)	32.66±16.62	19.58±28.38	10.71±14.65	10.87±21.28

AltFL = Height of the clean stem; AltCopV = Height of the live crown; AltACopV = Height up to the live crown; DN = Normal diameter; DB = Basimetric diameter; CobC = Crown cover.

Frequency and composition

In AMB 57 species were determined. *F. benjamina* with 218 individuals, *L. lucidum* (122), *F. retusa* var. *nitida* (Thunb.) (119), *C. sempervirens* L. (102) and *F. uhdei* (67) were the most representative. In VPO there were 24 species, from which *L. lucidum* (78 trees), *F. retusa* (68)*, F. uhdei* (44) and *F. benjamina L.* (43) the most frequent. Within the VSO, the largest number of trees and species was found, 36 of these, the most abundant: *F. benjamina* (69 individuals), *C. sempervirens* (33), *C. lindleyi* (28) and *F. retusa* var*. nitida* (22). The trees in VTO consisted on 28 species, with *F. benjamina* (55), *F. retusa* var. *nitida* (22), *L. lucidum* (22) and *C. sempervirens* (17) as the most frequent. In VCO there were less individuals; from 19 species, *F. benjamina* (51), *C. sempervirens* (29), *F. uhdei* (10) and *C. lindleyi* (7) the most frequent.

Diversity

Within the AMB, a Shannon-Wiener index of 2.84, a Simpson index of 0.90 and a Margalef index of 8.13 were determined. The values calculated by road order for these areas are presented in Table 4.

Table 4. Diversity indexes by road order for low marginalization areas.

Road order	Number of Individuals	Number of species	Diversity indexes		
			Shannon-Wiener	Simpson	Margalef
First	360	24	2.37	0.87	3.91
Second	316	36	2.86	0.91	6.08
Third	180	28	2.51	0.86	5.20
Fourth	123	19	1.92	0.75	3.74

Medium Marginalization

Tree distribution

In the MMA, 593 individuals were found (27.10 % of the total), and 549 were alive. The AMM VSO had the highest number of trees (Table 5).

Table 5. Distribution of street trees in areas of medium marginalization by road order.

Tree status	Road order				
	1st (%)	2nd (%)	3rd (%)	4th (%)	Total (%)
Alive	19.90	30.35	19.90	22.43	92.58
Srump	0.34	3.20	0.51	0.34	4.38
Standing dead	1.35	1.52	0.17	0.00	3.04
Total	21.59	35.08	20.57	22.77	100.00

Development status

There were 549 living individuals; in the MMA 65.6 % juvenile, 31.9 % mature and 2.6 % senile. In VPO, 128 trees were found, 118 alive. 38.98 % were mature, 56.78 % juvenile and 4.24 % senile. There were 208 trees in the VSOs, 180 alive; 37.22 % mature, 60 % juvenile and 2.78 % senile. The VTOs had 122 individuals, 118 alive. 30.5 % of these were mature, 66.95 % had a juvenile developmental stage and the rest (2.54 %) were senile. The VCOs included 135 trees, of which 133 were alive. In turn, of the latter, 19.55

% had a mature developmental stage, 79.70 % were juveniles and 0.75 % were senile.

Structure

The average height to the total living individuals in the MMA was 4.75 ±3.38 m, the height of the clean stem, 0.94 ± 0.90 m, the height of the live crown, 3.47 ± 2.74 m, the height of the live crown, 1.29 ± 1.18 m, the mean normal diameter was 18.40 ± 17.01 cm, basimetric diameter reached 19.70 ± 18.60 cm and crown coverage 11.22 ± 23.52m^2. The structure of the trees in the low marginalization areas, by road order, is shown in Table 6.

Table 6. Mensuration variables of alignment trees in the city of *Puebla*, by road order, for medium marginalization areas.

Variable	**Road order**			
	1st	**2nd**	**3rd**	**4th**
Height (m)	5.12±2.82	5.25±3.72	4.67±3.75	3.82±2.77
AltFL (m)	1.20±0.83	0.95±1.08	0.90±0.88	0.75±0.60
AtlCopV (m)	3.53±2.05	4.01±2.97	3.43±3.11	2.73±2.46
AltACopV (m)	1.60±1.09	1.26±1.42	1.24±1.11	1.09±0.89
DN (cm)	118.63±13.49	20.12±19.61	20.02±19.52	13.74±11.35
DB (cm)	19.96±116.38	22.22±21.36	20.99±22.31	14.92±10.26
CobC (m^2)	16.14±24.43	12.23±20.74	13.60±34.63	3.38±5.65

Frequency and composition

In MMA, 53 species were recorded; Of these, the most common were: *C. sempervirens* (154), *F. uhdei* (47), *C. lindleyi* (46), *P. tremuloides* Michx. (34) and *F. benjamina* (36). Among the 19 species of trees in VPO, the most important were: *F. uhdei* (35), *C. sempervirens* (19), *C. lindleyi* (14) and *P. tremuloides* (13). In VSO, 20 species were identified, among which the following stood out: *C. sempervirens* (67), P. *tremuloides* (21), *Erythrina coralloides* DC. (13) and *C. lindleyi* (11). In VTO there were 31 species, of which the following outstand: *C. sempervirens* (28), *F. retusa* var. *nitida* (17), *C. macrocarpa* (7) and *C. lindleyi* (6). VCOs are represented by 26 species, the most abundant of which were: *C. sempervirens* (40), *F. benjamina* (25), *C. lindleyi* (15) and *F. retusa* var. *nitida* (7).

Diversity

In these areas, Shannon-Wiener (2.90), Simpson (0.89) and Margalef (8.24) indexes were calculated. Here, the species richness and equity index was higher than in AMB and AMA. The indexes, by road order are in Table 7.

Table 7. Diversity indexes by road order for areas of medium marginalization.

Road order	Number of Individuals	Number of Species	Diversity index		
			Shannon-Wiener	Simpson	Margalef
First	118	19	2.27	0.85	3.77
Second	180	20	2.29	0.83	3.66
Third	118	31	2.87	0.9	6.29
Fourth	133	26	2.43	0.85	5.11

High marginalization

Tree distribution

These areas gathered 561 individuals, 25.63 % of the great total, with 540 alive. Here, the VPO concentrated the largest number of trees; their distribution by road order is shown in Table 8.

Table 8. Distribution of road trees in highly marginalized areas, by road order.

Tree status	**Road order**				
	1st (%)	**2nd (%)**	**3rd (%)**	**4th (%)**	**Total (%)**
Alive	34.40	17.29	33.33	11.23	96.26
Srump	0.71	0.00	0.18	0.00	0.89
Standing dead	1.43	0.36	0.53	0.53	2.85
Total	36.54	17.65	34.05	11.76	100.00

Development status

MMA gathered 540 live trees, 56.3 % juvenile, 38.5 % mature and 5.4 % senile. In VPO there were 205 individuals, 193 alive. 38.86 % of them were mature, 49.74 % juvenile and 11.40 % senile. For VSO there were 99 individuals, 97 alive, 54.64 % mature, 43.30 % juvenile and 2.06 % senile. In VTO, 191 trees were found, 187 alive; 66.84 % mature, 32.62 % juvenile and 0.53 % senile. In VCO there were 66, 63 alive; 30.16 % mature, 65.08 % juvenile and 4.76 % senile.

Structure

The average height of live trees in AMA was 5.67± 4.62 m, the height of the stem reached 1.18 ± 1.02 m, the live crown 3.90 ± 3.77 m, height to live crown equal to 1.79 ± 1.45 m; the average of the normal diameter was 19.88 ± 14.1 cm, while the basimetric diameter reached 21.4 ± 16.7 cm and the average crown cover, 16.12 ± 29.17m^2. The structure of the trees in the AMB, by road order, is presented in Table 9.

Table 9. Mensuration variables of linear trees in the city of *Puebla*, by road order, for highly marginalized areas.

Variable	Road order			
	1st	2nd	3rd	4th
Height (m)	6.54±5.51	5.22±2.75	5.17±4.32	5.19±4.46
AltFL (m)	1.35±1.17	1.08±0.73	1.14±1.00	0.97±0.89
AtlCopV (m)	4.63±4.58	3.36±2.19	3.51±3.55	3.63±3.33
AltACopV (m)	1.93±1.57	1.88±1.04	1.66±1.34	1.56±1.87
DN (cm)	20.83±13.71	21.26±12.79	18.82±14.83	17.53±15.25
DB (cm)	21.53±15.87	26.33±17.37	19.27±16.33	19.66±17.94
CobC (m^2)	21.88±33.40	17.90±21.07	10.82±25.93	11.49±31.99

Frequency and composition

Within AMAs, 40 species were detected; the most common were: *F. benjamina* (103 trees), *C. sempervirens* (74), *F. uhdei* (48), *C. lindleyi* (30) and *P. tremuloides* (32). VPO concentrated most of the trees, 193, of 19 species, the most abundant of which were: *P. tremuloides* (32), *Grevillea robusta* A.Cunn. ex R.Br. (31), *F. benjamina* (31) and *F. uhdei* (28). There were 97 trees of 19 species in VSO; *F. benjamina* (26), *L. lucidum* (19), *F. uhdei* (9), *F. retusa* var. *nitida* (8) and *Washingtonia robusta* H.Wendl. (8) the most common. For VTO, 187 trees of 32 species were recorded, highlighting *C. sempervirens* (41), *F. benjamina* (33), *Eucalyptus camaldulensis* (14) and *C. macrocarpa* (13). In VCO only 63 individuals were found, of 32 species, being *C. sempervirens* (20), *F. benjamina* (13), *F. retusa* var. *nitida* (7), *C. lindleyi* (4) and *E. camaldulensis* (4) the most abundant.

Diversity

In these areas, the Shannon-Wiener indexes equal to 2.85, Simpson equal to 0.91 and Margalef equal to 6.20 were estimated. The calculated values, by road order, for the AMAs are shown in Table 10.

Table 10. Diversity indexes by road order for highly marginalized areas.

			Diversity indexes		
Road order	**Number of Individuals**	**Number of species**	**Shannon-Wiener**	**Simpson**	**Margalef**
First	193	19	2.44	0.89	3.42
Second	97	19	2.33	0.86	3.93
Third	187	16	2.73	0.9	2.87
Fourth	63	32	2.17	0.85	7.48

Discussion

There are few characterizations of alignment trees in Mexican cities, in which socioeconomic and urban factors are included. These conditions influence the composition and diversity (Nagendra and Gopal, 2010).

Distribution

The degree of marginalization and the road order have effects on the distribution of road trees in *Puebla*. The largest roads (VPO and VSO) concentrated the largest number of trees in AMB and AMM; Similarly, Nagendra and Gopal (2010) noted that there are more trees on wide streets than on narrow ones. In AMA, more trees were recorded on VPO and VTO.

Development Status

In AMB and AMA, almost all road orders had more mature trees; but in roads of the AMM the young trees dominated. By having these data, it is feasible to replace the senile specimens (Saavedra-Romero *et al*., 2019).

Structure

Among the most used measurements for urban trees, height and normal diameter stand out; This study showed that in AMB there were larger trees in all types of roads, with an average height of 5.92 ± 3.59 m, *DN* of 25.50 ± 18.54 cm and *DB* of 30.26 ± 211.37 cm. Roman *et al.* (2019) in *Tuxtla Gutiérrez,* state of *Chiapas*, Mexico, managed a height of 5.75 m, *DN* 37.94 cm and *DB* 29.96 cm, which are close values to the ones in the present study. Saavedra-Romero *et al.* (2019), limited a height of 8.6 m and *DN* of 17.5 cm, for an urban forest in *Ciudad de México*. IMPLAN (2018) refers to a height of 10.3 m and a *DN* of 33.4 cm.

Differences in height and diameter may be due to age, size by species, genetics, environment (soil, water, growing space), etc. In general, in the AMA and the AMB, the mensuration values decrease from VPO to VCO. The roads in AMB have larger dimensions, which allows establishing more trees, but in these AMB and in AMM there are more dead trees and stumps. This can be explained by the urbanization process, since the trees are affected or eliminated due to the increase in construction and urban infrastructure (Ramírez *et al.,* 2019). It is important to consider the establishment of large trees, as they have a greater capacity to reduce problems related to air pollution and those caused by heat islands, compared to small trees (Nagendra and Gopal, 2010).

Although the basimetric diameter (*DB*) has been little considered, it turns out to be a more accurate measure in urban trees, because due to the management given to these trees, such as pruning or mutilation, many times the normal diameter loses accuracy in its real measurements. Real measurements, so it is more advisable to measure only the basimetric diameter (Magarik *et al.,* 2020).

Frequency and composition

In urban areas, introduced species are usually more abundant than the native ones. This is the case of the study area, with more than 70 % of them; Jiménez *et al.* (2015) for streets in *Habana, Cuba*, and Leal *et al.* (2018) in an urban forest in *Linares*, state of *Nuevo León,* Mexico. In contrast, Román *et al*. (2019) point out 70 % of native species in roads of *Tuxtla Gutiérrez*, state of *Chiapas*.

The present work includes 75 species, a figure greater than that of: Benavides and Fernández (2012), with 38 of them in an urban forest of *Ciudad de México*; Leal *et al*. (2018), who limit 41 for an urban forest in *Linares* state of *Nuevo León*; and IMPLAN (2018), where 54 refer to 11 main roads in the municipality of *Puebla*; the most abundant were *L. lucidum, F. uhdei* and *F. benjamina*. However, the 75 species are less than those given by Nagendra and Gopal (2010), 108, in roads of Greater Bangalore, India (sampling intensity, 0.9 %) or the 117 that Román *et al*. (2019) note for roads in *Tuxtla Gutiérrez* state of *Chiapas* (sampling intensity, 5 %).

In AMB the most frequent species were introduced, with the exception of *F. uhdei* (with one of the highest frequencies in VPO and VCO). while in AMM native species were found more frequently, such as *P. tremuloides, F. uhdei* and *E. coralloides*; the latter was recorded in VSO.

On the other hand, in AMA, some of the most common species were *G. robusta* and *E. camaldulensis*, both introduced and not frequently found in the other two degrees of marginalization. It is worth mentioning that *E. camaldulensis* had a higher frequency in VTO and VCO.

Diversity

In all roads and degrees of marginalization, the Simpson index (*S*) was ≥ 0.75. The Shannon-Wiener (*H'*) ranged between 1.92, in VCO of WBA, and 2.87, for VTO in MMA. For the Margalef index (D_{Mg}), the highest value reached 7.48. The latter was higher than the 5.24 obtained for *Linares* state of *Nuevo Léon* (Leal *et al.,* 2018). Likewise, the Simpson index (0.85) reported by Saavedra *et al.* (2019) for a forest in CDMX. The latter denotes species richness and diversity for the linear trees of *Puebla*.

The VCOs, in AMA, had greater distribution of species and richness, but with moderate equity, since few species dominate. This is also observed in the rest of the areas. It is necessary to increase diversity, with native species, to provide greater resilience to various threats from urban environments, such as pests and diseases (Saavedra *et al.,* 2019).

Conclusions

The former study demonstrates that the characteristics of the *Puebla* alignment trees vary according to their location in areas with different degrees of marginalization and, within these, in the different types of roads.

There is richness and diversity of species in the study area, but most are not native to the country and few are abundant. The trees have the right conditions for their survival, since mortality is minimal.

The greatest afforestation efforts seem to occur in areas of low marginalization, with more trees, especially on main roads. However, the high margination areas show the higest tree survival. The areas of medium marginalization have young trees, on all types of roads, as well as the areas of low marginalization in important roads, perhaps because tree growth is less or more recent in all of them, or because they could have a higher rate of affectation to mature trees due to the establishment of new constructions.

In the management of alignment trees, the establishment and handling must be carried out considering the environmental, social characteristics and urban aspects of each city for its proper development and function.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Graciela Martínez Juárez: methods, field work, data analysis, writing of the manuscript; Dante A. Rodríguez Trejo: methods, study supervision and review of

the manuscript; Diódoro Granados Sánchez, Leopoldo Mohedano Caballero and Antonio Villanueva Morales: identification of species, study supervision and general review of the manuscript.

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