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Research article

Servicios ambientales de la vegetación arbórea de los parques de Texcoco de Mora, Estado de México

Environmental services of tree vegetation of the parks of *Texcoco de Mora*, State of Mexico

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Abstract

Urban trees play an important role within cities due to the environmental services they provide and their contribution to mitigating the current climate crisis. In this context, the objective of this study was to evaluate the tree vegetation of five public parks in the *Texcoco de Mora* municipality in order to estimate the environmental services they provide. A census was carried out per park and the data were processed through the i-Tree® Eco v6 software. 1 325 individuals from 23 families and 37 genera were recorded with a richness of 55 species in the five parks, an average density of 157 trees ha^{-1} and a total of 242.6 megagrams of carbon storage with a carbon capture of 10.5 Mg year^{-1}. The avoided rain runoff was 481 m^{3} year^{-1} and the value represented by these environmental services is MXN $894 514.93 for carbon storage, MXN $38 650 annually for carbon capture, and MXN $481.93 for runoff. The replacement value of the trees reaches MXN $24 408 534. A tree cover of 30 485 m^{2} was estimated, which represents a factor of 0.86 m^{2} inhabitant^{-1}. It is concluded that *Texcoco* is below the recommended factor of trees per inhabitant proposed by the UN. It is necessary to study the green areas, medians, alignment trees and community parks, to achieve a more complete panorama of the municipality.

Key words: Urban trees, quality of life, climate change, carbon sequestration, green infrastructure, i-Tree®.

Resumen

El arbolado urbano desempeña un papel importante dentro de las ciudades por los servicios ambientales que provee y por su contribución a la mitigación de la actual crisis climática. En ese contexto, el objetivo del presente estudio consistió en evaluar la vegetación arbórea de cinco parques públicos del municipio Texcoco de Mora a fin de estimar los servicios ambientales que proporcionan. Se realizó un censo por parque y se procesaron los datos a través del *software i-Tree® Eco* V6. Se registraron 1 325 individuos de 23 familias y 37 géneros con una riqueza de 55 especies en los cinco parques, una densidad promedio de 157 árboles ha^{-1} y un total de 242.6 megagramos de almacenamiento de carbono con una captura de 10.5 Mg año^{-1}. El escurrimiento de lluvia evitado fue de 481 m^{3} año^{-1} y el valor que representan estos servicios ambientales en pesos es de MXN $894 514.93 para el almacenamiento de carbono, MXN $38 650 anuales para la captura del mismo y MXN $481.93 para el escurrimiento. El valor de sustitución del arbolado es de MXN $24 408 534.00. Se estimó una cobertura arbórea de 30 485 m^{2}, lo cual representa un factor de 0.86 m^{2} habitante^{-1}. Se concluye que Texcoco está por

debajo del factor recomendado de arbolado por habitante propuesto por la ONU. Es necesario estudiar las áreas verdes, camellones, árboles de alineamiento y parques comunitarios para tener un panorama del municipio más completo.
Palabras clave: Árboles urbanos, calidad de vida, cambio climático, captura de carbono, infraestructura verde, *i-Tree*®.

Introduction

In the current context of climate change and the growing human population, trees in cities play a crucial role in providing vital environmental services for society and the planet (IPCC, 2022); they improve air quality, help mitigate the effects of the heat island, capture rainwater that helps recharge aquifers, serve as social gathering centers, are references for neighborhoods and communities and, in addition, contribute positively to the mental health of visitors (Martínez-Soto *et al.*, 2016; Herrera and Romo, 2021).

Climate change, largely caused by greenhouse gas emissions, has led to an increase in global temperature, mainly within cities, as well as changes in precipitation patterns (Bárcena *et al.*, 2020). In this scenario, trees serve as carbon reservoirs, absorbing carbon dioxide from the atmosphere and by storing it in their biomass and soils. In addition, they act as regulators of the local climate through shade, reducing room temperature and reducing energy demand for cooling in densely populated urban areas (FAO, 2022).

Overpopulation, on the other hand, generates a series of challenges in terms of limited resources, increased demand for food, energy and living space (Zamora, 2015). Trees help mitigate these problems by providing key ecosystem services. For example, fruit and forest trees can help meet the demand for food and timber resources, while improving the quality of life of communities by providing green and recreational spaces (Sader, 2020).

In this perspective, understanding and valuing trees and the environmental services they provide becomes essential to address the challenges of climate change and overpopulation. This involves the conservation and restoration of green areas in the city, as well as the implementation of reforestation and agroforestry strategies in urban and rural areas (ONUAA, 2021). In addition, it is necessary to promote sustainable management of forest resources and the adoption of policies that encourage the protection and expansion of urban tree ecosystems (Bárcena *et al.*, 2020). Implementing these actions will prepare cities to face future environmental challenges, social disparities and food security (Giannotti *et al.*, 2020).

To quantify the services that trees provide, there are several methods, however, one of the tools that has recently been used for its usefulness and efficiency is the i-Tree® Eco software (De la Concha, 2018). This instrument allows a more efficient evaluation of urban areas, whether small or large, that have trees. The results obtained through this evaluation help to manage and improve decision-making in these areas effectively (i-Tree, 2021).

In this work, the benefits of the environmental services provided by the trees of different parks in *Texcoco*, State of Mexico, were quantified and evaluated due to the importance of their conservation and maintenance to maximize the benefits and thus the quality of life of the inhabitants. Additionally, the performance of the i-Tree® Eco V6 software is evaluated for data collection and analysis of the current investigation.

Materials and Methods

Study area

The study was carried out in the *Texcoco de Mora* municipality, State of Mexico, whose surface area is 6 212.17 km^2 and has 35 491 inhabitants according to Inegi (2021). The trees were analyzed in the five most visited parks in the municipality that have 14.41 ha: (a) *Niños Héroes* Park with 1 600 m^2 (19°30'32.53" N, 98°52'32.57" W), (b) Municipal Garden Park with 9 000 m^2 (19°30'51.56" N, 98°52'56.04" W), (c) Elderly Age Park with 9 100 m^2 (19°30'37.55" N, 98°53'6.67" W); (d) *Alameda de Texcoco* Park with 42 950 m^2 (19°31'8.56" N, 98°52'31.99" W), and (e) *Silverio Pérez* Sports Park with 81 500 m^2 (19°31'16.80" N, 98°53'4.37" W) (Figure 1).

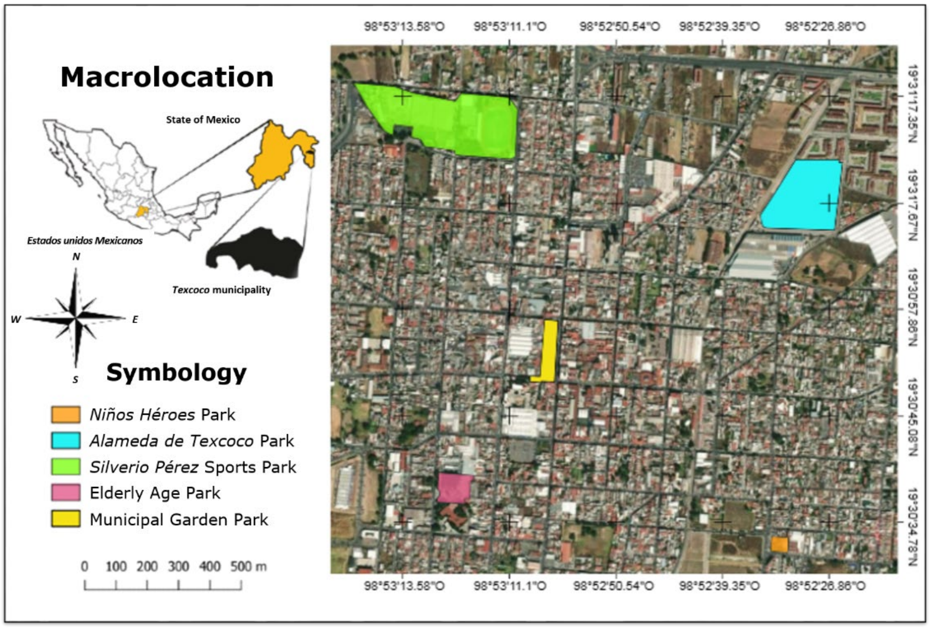


Figure 1. Location map of the five censused parks in *Texcoco de Mora*, State of Mexico, Mexico.

Urban tree census

An urban tree census was carried out based on the VTA (Visual Tree Assessment) method proposed by the ISA (International Society of Arboriculture) (Calaza and Iglesias, 2016). To record the data, the i-Tree® manual (i-Tree, 2021) was followed based on the location, identifier number and species of each individual counted in each of the parks.

To estimate the height of the trees, a software for high-end mobile devices called Arboreal®-Height of tree was used, which works with augmented reality (AR) technology to measure the distance from the tree to the device and subsequently take the angles and distance to the top (apex of the crown) and bottom of the tree (base of the trunk) and with these data estimate the total height of the tree. In the same way, the height of the clean stem and the height of the clean crown were obtained (Arboreal, 2023).

For the diameter, a flexible synthetic fabric diameter 320 cm/10m 283D Forestry Supplier® diameter tape was used. For the crown diameter, a long flexible 50 m TP50ME Trupper® tape was used. For each individual, the diameter of the crown was taken in the North-South direction and East-West, information that was subsequently averaged.

For the health condition of the crown, the proportion in healthy or present percentage of the crown was recorded, based on the i-Tree® manual (i-Tree, 2021).

Population density

The relationship between the number of people living in the *Texcoco de Mora* city (35 491 inhabitants) and the extent of the space they live in (6 212.17 km^2) was determined to obtain the population density per square kilometer within the urban area (Inegi, 2022).

Green space factor per inhabitant

The relationship between the area (km^2) of the tree cover of the five parks evaluated and the extension (km^2) of the City of *Texcoco de Mora* was calculated, to obtain the green space factor per inhabitant (ONU, 2015).

Data analysis

Data were captured in i-Tree® Eco V6 software (i-Tree, 2021) through the use of a mobile device and were finally processed into one project per park, based on the reference data.

They are mentioned below, since they are mandatory so that each project can be executed and analyzed within the i-Tree® Eco V6 software (i-Tree, 2021). Information from the mobile weather station *Lic. Benito Juárez* Intl. with ID: 766793-99999 was used, with weather data from 2020 (most recent year in the software). For the economic valuation, the price of the ton of carbon stored and captured that was used was MXN $3 687.66 ton^{-1}, according to market values (i-Tree, 2021). The value of the avoided runoff used was $44.90 MXN/m^3; because there is no runoff evaluation for Mexico, the national average value for the United States was used and converted to local currency (i-Tree, 2021).

Only trees greater than 2 m in height and diameter >3 cm were taken into account; and specimens whose crown height was less than their clean stem height were excluded before performing the analysis in the i-Tree® Eco software, since the program does not recognize individuals with these characteristics. The tree census was carried out from August 2022 to February 2023.

Results

In the five parks evaluated, 1 477 trees were censused, however, after excluding those that cannot be processed by the i-Tree® Eco software, 1 325 individuals were analyzed. 55 tree species belonging to 23 families and 37 genera were recorded (Table 1).

Table 1. Composition of tree species in the five censused parks in *Texcoco de Mora*, State of Mexico, Mexico.

Species	Common name	Origin	Abundance

Acacia baileyana F. Muell.	*Acacia azul*	New south Wales	5
Acacia melanoxylon R. Br.	*Acacia negra*	Australia	35
Acacia retinodes Schtldl.	*Acacia*	Australia	4
Alnus acuminata Kunth	*Aile*	South America	4
Araucaria columnaris (J. R. Forst.) Hook.	*Araucaria*	New Caledonia	6
Bauhinia divaricata L.	*Pata de vaca*	American continent	14
Casuarina equisetifolia L.	*Casuarina*	Australia	100
Citrus sinensis (L.) Osbeck	*Naranjo*	Asia	1
Cupressus arizonica Greene	*Cedro*	Mexico	37
Cupressus lusitanica Mill.	*Cedro blanco*	Mexico	29
Cupressus macrocarpa Hartw. *ex* Gordon	*Cedro limón*	United States of America	95
Cupressus sempervirens L.	*Ciprés panteonero*	Mediterranean region	77
Eriobotrya japonica (Thunb.) Lindl.	*Níspero*	Asia	2
Erythrina coralloides DC.	*Colorín*	Mexico	1
Eucalyptus camaldulensis Dehnh.	*Eucalipto*	Australia	194
Eucalyptus cinerea F. Muell. *ex* Benth.	*Eucalipto dólar*	Australia	1
Euphorbia cotinifolia L.	*Sangre de Líbano*	South America	3
Ficus benjamina L.	*Ficus*	India	103
Ficus microcarpa L. f.	*Laurel de la india*	Asia	78
Fraxinus uhdei (Wenz.) Lingelsh.	*Fresno*	Mexico	133
Grevillea robusta A. Cunn. *ex* R. Br.	*Grevillea*	Australia	12
Hibiscus tiliaceus L.	*Tulipán*	Hawai	18
Jacaranda mimosifolia D. Don	*Jacaranda*	South America	97
Larix spp.	*Alerce*	North America	5
Leucaena esculenta (DC.) Benth.	*Guaje rojo*	Mexico	3
Ligustrum lucidum W. T. Aiton	*Trueno*	Asia	58
Liquidambar styraciflua L.	*Liquidambar*	Mexico	7
Magnolia mexicana DC.	*Magnolia*	Mexico	6
Malus domestica (Suckow) Borkh.	*Manzano*	Asia	2
Olea europaea L.	*Olivo*	Europa	6
Persea americana Mill.	*Aguacate*	Mesoamerica	1
Phoenix canariensis Wildpret	*Palma canaria*	Africa	25
Pinus cembroides Zucc.	*Pino piñonero*	Mexico	3
Pinus greggii Engelm. *ex* Parl.	*Pino greggi*	Mexico	2

Pinus leiophylla Schiede *ex* Schltdl. & Cham.	*Pino leiophylla*	Mexico	1
Pinus patula Schiede ex Schltdl. & Cham.	*Pino patula*	Mexico	2
Pinus pinceana Gordon & Glend.	*Pino piñonero llorón*	Mexico	1
Pinus pseudostrobus Lindl.	*Ocote blanco*	Mexico	1
Pinus radiata D. Don.	*Pino radiata*	California	3
Pinus spp.	*Pino*	Mexico	8
Pinus teocote Schltdl. & Cham.	*Pino teocote*	Mexico	1
Platanus mexicana Moric.	*Platanus*	Mexico	2
Populus alba L.	*Álamo blanco*	Asia	103
Populus nigra L.	*Álamo negro*	Europa	1
*Prunus domestic*a L.	*Ciruelo*	Asia	1
Prunus persica (L.) Batsch	*Durazno*	Asia	19
Prunus serotina Ehrh.	*Capulín*	Mexico	2
Quercus virginiana Mill.	*Encino blanco*	North America	3
Roystonea regia (Kunth) O. F. Cook	*Palma real*	Asia	32
Salix bonplandiana Kunth	*Ahuejote*	Mexico	1
Schinus molle L.	*Pirul*	Peru	85
Senna multiglandulosa (Jacq.) H. S. Irwin & Barneby	*Retama*	Mexico	14
Spathodea campanulata P. Beauv.	*Tulipán africano*	Africa	4
Taxodium mucronatum Ten.	*Ahuehuete*	Mexico	16
Washingtonia filifera (Gloner *ex* Kerch., Burv., Pynaert, Rodigas & Hull) de Bary	*Palma washingtonia*	California	9

The abundance of the species in each park was estimated and it turned out that only six species of the 55 recorded amount for 49.25 % of the total number of individuals in the parks, which means that even with a high species richness, there is no equity in the abundance. *Eucalyptus camaldulensis* Dehnh. (13.13 % of the total abundance) tops the list of the most abundant species, followed by *Fraxinus uhdei* (Wenz.) Lingelsh. (9 %), *Populus alba* L. (6.97 %), *Ficus benjamina* L. (6.97 %), *Casuarina equisetifolia* L. (6.7 %) and *Jacaranda mimosifolia* D. Don. (6.56 %). Only those six species make up almost 50 % of the total number of recorded individuals. It was estimated that 82.89 % of the individuals are exotic.

The *Niños Héroes* Park, despite being the park with the smallest surface area (1 600 m^2), has the highest tree density compared to the others (256.3 individuals ha^{-1}). Due to the average diameter and height of its trees, the *Silverio Pérez* Sports Park has the highest values for storage (242.6 Mg) and carbon capture (10.5 Mg year^{-1}), as well as for avoided runoff (481.9 m^3 year^{-1}) (Table 2).

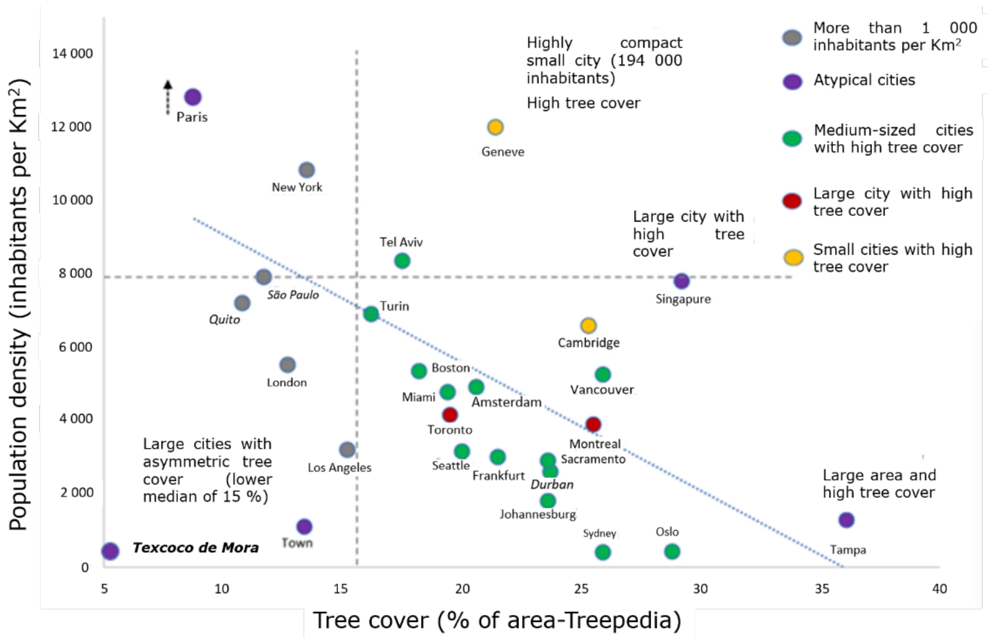
Table 2. Area, tree density, tree cover and environmental services provided by the five studied parks in *Texcoco de Mora*, State of Mexico, Mexico.

Location	Area (m^2)	Density (trees ha^{-1})	Number of trees	Tree cover (m^2)	Carbon storage (Mg)	Gross carbon capture (Mg yr^{-1})	Avoided runoff (m^3 yr^{-1})
Niños Héroes Park	1 600	256.3	41	938	8.26	0.35	13.84
Municipal Garden Park	9 000	168.9	152	4 692	29.21	1.00	40.15
Elderly Age Park	9 100	194.5	177	4 304.5	22.41	0.56	71.76
Alameda de Texcoco Park	42 950	111.3	478	4 173.7	22.65	2.10	33.50
Silverio Pérez Sports Park	81 500	58.5	477	16 377	160.05	6.47	322.68
Total	144 150	157.9	1 325	30 485.2	242.6	10.5	481.9

The tree cover was estimated in m^2 for each park, obtaining that the *Niños Héroes* Park has 58.6 % of its surface covered by canopy, 47.3 % of its surface for the Elderly Age Park, 52 % for the Municipal Garden Park, 20.1 % for the *Silverio Pérez* Sports Park, and finally 9.7 % for the *Alameda de Texcoco* Park. Like the density of trees, the *Niños Héroes* Park is the assessed area that has the greatest vegetation cover in relation to its extension.

With the value of the tree cover of the five censused parks (30.48 km^2) and the surface area that includes *Texcoco de Mora* city (6 212.17 km^2), the green space factor per inhabitant was estimated, which resulted in the contribution of these areas for the population of *Texcoco* is 0.86 m^2 per inhabitant.

Li *et al.* (2015), Seiferling *et al.* (2017) and Lüttge and Buckeridge (2020), took as reference a computational analysis based on the Google® Street view to calculate a green view index for each city, which yields the percentage of vegetation cover with respect to the total population per km². When comparing data from 27 cities around the world, it can be seen that the trend is that tree cover increases as population density decreases. If the software does not have data from *Texcoco* and if there are few published works on tree cover (Martínez-Trinidad *et al.*, 2021; Hernández-López *et al.*, 2023), the data generated for this work are the closest to what is locally known about its green areas; therefore, contrasting it with other cities around the world offers a perspective of the reality of such data in the municipality (Figure 2).



Source: Own modification, taken from Lüttge and Buckeridge (2020).

Figure 2. Comparison between the percentage of tree cover and population density per km² in 27 cities.

As can be seen, *Texcoco de Mora* city turns out to be positioned in a place not close to the trend line, so it could be considered an atypical city. Because only the tree cover of the five parks was considered, the relationship in terms of the surface of the city is 0.49 % of green cover, and the population density was estimated at 5.7 inhabitants per Km^2.

The values in Mexican pesos that the services provided by urban trees in the parks of *Texcoco* would have annually were estimated, in order to justify better management and maintenance. Regarding the value of carbon storage, *Silverio Pérez* Sports Park obtained the best value with MXN $590 204.05 because its trees are mature and have the highest average diameters and heights recorded (34.6 cm and 11 m). In the same way, it records the highest carbon capture estimated at MXN $23 862.06 annually, and also the avoided runoff with MXN $322.68 (Table 3).

Table 3. Value in Mexican pesos that represents the environmental services provided by the five studied parks.

Location	Value in Mexican pesos of carbon storage (Mg)	Value in Mexican pesos of carbon capture (Mg year^{-1})	Value in Mexican pesos of avoided runoff (m^3 year^{-1})	Replacement value (MXN)
Niños Héroes Park	83 509.08	7 728.95	33.5	4 603 802.51
Municipal Garden Park	30 454.54	1 285.44	13.84	961 314.47
Elderly Age Park	107 713.61	3 697.71	40.15	3 679 594.48
Silverio Pérez Sports Park	590 204.05	23 862.06	322.68	11 836 976.69
Alameda de Texcoco Park	82 633.65	2 076.57	71.76	3 326 845.86
Total	894 514.93	38 650.73	481.93	24 408 534.01

A total value of 242.6 Mg was obtained for carbon storage estimated at MXN $894 514.93 and a value of 10.5 Mg per year for carbon capture estimated at MXN $38 650.73 per year. The runoff avoided by the trees in the five parks was 481.9 m^3 annually, estimated at MXN $481.93. According to the estimated values of the annual services and the replacement value, or the value that the parks have with the conditions of the current trees, they add up to MXN $24 408 534.01.

Discussion

The loss of biological diversity constitutes a global environmental problem that humanity must solve (Almaguer, 2006), and one of the main problems it faces is the presence of introduced species (Badii *et al.*, 2015). In *Texcoco*, 82.89 % of the tree species present in the evaluated parks are of this type, which warrants immediate measures for their management. The most worrying problems of ignoring this bioindicator are the damage to human health and economic well-being, the functioning of ecosystems and the survival of native species (Rodríguez, 2001).

Regarding environmental services, there is a precedent with the work of Martínez-Trinidad *et al.* (2021), who evaluated what the urban trees of the city of *Texcoco de Mora* provide, but it was only carried out for four parks and 391 individuals were registered compared to 1 325 for five parks in this work. Values above those mentioned by said authors were obtained for carbon capture in the *Niños Héroes* Park, where 3.35 Mg were recorded compared to 8.26 Mg, for the Elderly Age Park, 17.13 Mg compared to the current record of 22.41 Mg, and finally where there was the greatest difference due to the number of trees censused was in the *Silverio Pérez* Sports Park, where they calculated 16.76 Mg against 160.05 Mg in the present work. These differences are due to the number of trees counted and the time elapsed until 2023.

Based on the recognized relevance of the environmental services provided by green spaces to improve the quality of life of the population in urban environments, the World Health Organization (WHO) recommends a minimum threshold of 9 m^2 of green space per inhabitant (ONU, 2015). According to this work, the city of *Texcoco de Mora* requires 8.14 m^2 of tree cover per inhabitant to meet this condition, or in other words, 10.46 times the current estimated tree area in the five parks of *Texcoco* is required, from the data of these green areas.

Based on the work of Lüttge and Buckeridge (2020), due to the low population density, *Texcoco* has the potential to grow as a city characterized by its green infrastructure, which Quiroz (2018) defines as a natural environment with great importance in the mitigation and adaptation to climate change. However, if the authority does not provide the necessary support for the creation of green areas, as well as for the investigation of the current condition of other areas with urban vegetation such as medians, road trees and small dispersed parks, *Texcoco* will continue to be a case atypical outside of an ideal average with very little area of tree cover.

A city that has abundant trees projects a positive image to its visitors and this has effects on the local economy such as the creation of employment opportunities thanks to municipal policies focused on the generation of activities that involve green areas and maintenance of said spaces (Figueroa and Díaz-Galiano, 2018). In *Texcoco*, the lack of specialized maintenance is one of the main reasons that generates problems in urban trees. These problems turn into economic and environmental losses. That said, it is very valuable to establish new wooded areas in areas where there are none, so that little by little the city is filled with green areas, taking into account a functional design, as well as a correct selection of species and distribution to maximize the benefits they can provide.

Conclusions

The objective of this work was to make visible the environmental part offered by urban trees, and focused on five parks in the city of *Texcoco de Mora*.

i-Tree® Eco V6 software is a tool that, when used correctly, provides reliable data that can be used for making decisions about the administration and management of urban trees. However, user feedback is necessary to improve the software, because it has certain limitations, among which are that the program does not allow the registration and analysis of individuals whose crown height is less than the height of clean stem, as well as the lack of meteorological stations and updated years of pollutant registration.

A total value of 242.6 Mg was obtained for carbon stored in standing trees, 10.5 Mg annually for carbon capture and avoided runoff of 481.9 m^3 annually for the five parks. 82 % of the censused trees correspond to exotic species. The green area factor per inhabitant is 0.86 m^2 of green space per inhabitant for the city.

The data provided by this study brings forth key alternatives, such as the economic value, so that authorities can focus their attention on the real problems of the parks and thus they can become common spaces in excellent condition and thus contribute to a better quality of life for their residents.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Miguel Mancilla Morales: planning, data collection and analysis, writing of the manuscript; Leopoldo Mohedano Caballero: direction, planning and monitoring of the project, data analysis and review of the manuscript; Ro Linx Granados Victorino: project monitoring and manuscript review; Diódoro Granados Sánchez: direction, project monitoring and manuscript review; Alejandro Corona Ambriz: review of data and manuscript.

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