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Article

Jardín botánico y *arboretum*: estrategias de conservación forestal en paisajes antropizados del trópico mexicano

Botanical garden and *arboretum*: forest conservation strategies in anthropized landscapes of the Mexican tropics

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Resumen

Los jardines botánicos y *arboreta* son considerados instrumentos de conservación relevantes a partir de las alarmantes tasas de deforestación que tienen las selvas y la consecuente afectación de su diversidad. En este trabajo se analizó la diversidad, el estatus de conservación y el uso potencial de las especies arbóreas en el jardín botánico (JB) y el *arboretum* (A) del Centro de Investigación y Transferencia de Tecnología Forestal El Tormento. En el primero, el muestreo se realizó en un área total de 9 375 m^2; mientras que, en el segundo el muestreo se hizo en 1.6 ha. Ambos espacios representan vegetación de selva mediana subperennifolia, con 11 871 individuos pertenecientes a 92 especies y 35 familias. El JB fue 1.6 veces más diverso que A. Se documentaron 15 usos potenciales en 98.9% de los taxones con al menos un uso registrado. Entre los taxa de ambas colecciones, se tienen siete clasificadas en la lista roja de la IUCN, dos en CITES y ocho en la NOM-059-SEMARNAT-2010. Estos resultados subrayan la importancia del jardín botánico y el *arboretum* como reservorios de especies forestales útiles desde muy diversas perspectivas y como espacios de conservación de taxa amenazados de las selvas medianas subperennifolias del sur de México.

Palabras clave: Centro de Investigación y Transferencia de Tecnología Forestal El Tormento, deforestación, especies arbóreas, estatus de conservación, manejo forestal, selva subperennifolia.

Abstract

Botanical gardens and *arboreta* are considered relevant conservation instruments based on the alarming deforestation rates that forests have and the consequent impact on their diversity. In this paper, the diversity, conservation status and potential use of tree species in the botanical garden (JB) and arboretum (A) of the *El Tormento* Forest Technology Research and Transfer Center were analyzed. In the first, the sampling was carried out in a total area of 9 375 m^2; while in the second the sampling was done in 1.6 ha. Both spaces represent vegetation of medium sub-evergreen forest, with 11 871 individuals which belong to 92 species and 35 families. JB was 1.6 times more diverse than A. 15 potential uses were documented in 98.9 % of the species with at least one registered use. Among the species in both collections, there are seven classified in the IUCN red list, two in CITES and eight in the NOM-059-SEMARNAT-2010. These results underscore the importance of the botanical garden and the arboretum as reservoirs of useful forest species from many different perspectives and as conservation spaces for threatened taxa from the medium-long sub-evergreen forests of southern Mexico.

Key words: *El Tormento* Forest Technology Research and Transfer Center, deforestation, tree species, conservation status, forest management, semi evergreen tropical forest.

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Introduction

Tropical forests keep more than half of the plant species of the plane and are considered important endemism centers (Dirzo *et al*., 2009). They regulate the water cycle and environmental temperature (Lawrence *et al*., 2004), and they provide several resources to the human communities such as food, wood, garments, medicines, recreation and some others (Balvanera, 2012). These ecosystems are among the most affected from antropogenic activities such as urbanization, agriculture and livestock, as well as from natural factors such as hurricanes and fires. All of these situations have favored the loss (deforestation), decline and fragmentation of a great part of the tropical forests (FAO, 2016), which has led to the loss of biodiversity and of a great amount of forest resources potentially useful for mankind (Sloan and Soyer, 2015).

In Mexico, it is accepted that deforestation has had a greater impact on tropical forests than on temperate forests, which is estimated to reduce their area by 80 % in the country (Challenger and Soberón, 2008). Deforestation and fragmentation processes have been very important in the tropical forests of the southern *Yucatán* Peninsula, which harbor a floristic richness around 161 families that group 2 329 species, of which 8.6 % are endemic to the region (Pérez- Sarabia *et al.,* 2017).

Botanical gardens and *arboreta*, as *ex-situ* or *in-situ* conservation centers, are a strategy for safeguarding forest resources, as they play a very important role in programs of environmental education, research and training in botanical knowledge at different levels (Arnet *et al.,* 2015; Dunn, 2017; Chen and Sun, 2018). They are particularly valuable when they preserve areas of forests or tropical forests immersed in agricultural or urban matrixes, since they constitute habitats or corridors that help in the conservation of flora and fauna (Dunn, 2017).

The botanical garden (JB) of the *El Tormento* Center for Research and of Forest Technology Transfer, located in the state of *Campeche*, Mexico, was founded in 1965 as a representative forest natural garden of the medium semi evergreen tropical forest, with the aim of preserving forest diversity of this ecosystem and introduce species from the Mexican tropics or from other parts of the world to make it richer (Salaya-Sánchez and Gómez-Gómez, 1981). The *arboretum* (A) was established in 1963 with the aim of representing a mixed commercial forest plantation of native and exotic species, as well as to preserve part of the genetic diversity of timber forest species, for research and educational purposes (Uzcanga-Pérez *et al*., 2018). Unfortunately both areas were abandoned for different reasons for more than twenty years. Currently, both, the JB and the A, are in the process of reactivation, in order to constitute a space for activities of environmental knowledge, scientific research, as well as a reserve of native and exotic species with multiple uses.

The objective of the present study was to assess the current conservation *status* of the vegetation in the botanical garden and *arboretum* of the *El Tormento* Forest Technology Research and Transfer Center, by analyzing the representativeness of the tree species and the structure in both spaces with respect to the surrounding plant communities, the diversity of tree species in both spaces, and their potential use. This information will document the reactivation strategies in these living collections and will contribute to the forest conservation actions.

Materials and Methods

El Tormento Forest Technology Research and Transfer Center is located 7 km from *Escárcega* city, in the 292 km of the 186 highway, between 18°16´25” N and 90°43´55” W in *Escárcega* municipality, state of *Campeche* (Cedeño, 1981). The climate in the region is tropical, A (w) l'g, according to the Köppen classification, modified by García, with annual average temperatures between 23 and 25 °C, with maximums of 42 °C and minimums of 4.5 °C; with an average annual precipitation of 1145 mm (López-Torres and Tamarit-Urías, 2005).

JB is located in the southeast of the Research Center, next to the residential area; while A at the main entrance to the offices, both facing highway 186 (*Villahermosa*-

Escárcega). JB covers an area of 800 m long and 50 m wide (4 ha), while A has measures 1.6 ha, established as one collection of live trees (Figure 1); it is divided into two quadrants, separated by an access road to the offices. In both cases the predominant soils are Rendzina and Vertisol, according to the FAO classification system (Cuanalo, 1981).

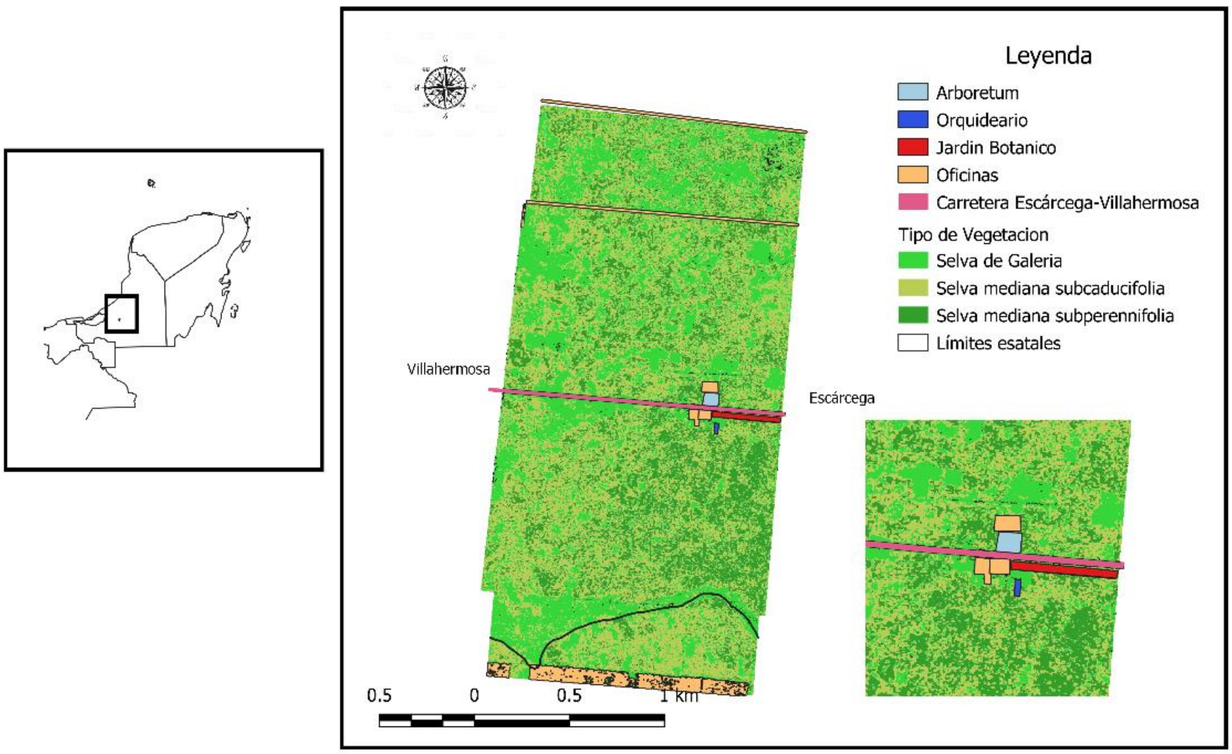

Figure 1. Location of the *El Tormento* Forest Technology Research and Transfer Center, the botanical garden (JB) and the *arboreetum* (A).

Sampling in the field was carried out in 15 square plots of 25 × 25 m (625 m^2), that is, in 9 375 m^2 in the JB. In A, it was carried out in the two quadrants of the total area and in the surrounding medium semi evergreen tropical forest (SM), five circular plots of 1 000 m^2 (17.84 m in diameter) were established. In these areas, the tree individuals present up to the species level were identified, whose diameter was measured at a height of 1.30 m from 2.5 cm, with a diameter tape model 283D / 5m Forestry Suppliers, and height, with a Vertex IV Hanglöf hypsometer.

Taxonomic identification was carried out with the support of parataxonomists (Demetrio Álvarez Montejo, Manuel Arana Cua y Antonio López Carrillo), specialized literature (Pennington and Sarukhán, 2005; Carnevali *et al*., 2010) and expert support from the herbarium of the *Universidad Autónoma de Campeche*. For their confirmation and, eventually, for the upgrading of the taxonomic data, The plant list (2013) was consulted.

With the field data, a floristic list of tree species was made, whose use was documented through specialized and published references, as well as their conservation status in NOM-059-SEMARNAT-2010 (Semarnat, 2010), the red list of the International Union for Conservation of Nature (IUCN, 2019) and the appendixes of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2017).

In order to examine the representativeness of species of JB and A with respect to SM, the listings were compared, the difference in the composition of species between JB and SM, as well as A and SM was analyzed by means of a similarity analysis (ANOSIM), using the distance from the Bray Curtis Index (Bray and Curtis, 1957). To estimate the proportion that each species contributes to the difference between the study areas, determined by the percentage of dissimilarity between them, the SIMPER subroutine was used (Clarke, 1993). These analyzes were made with the PAST 3.25 program (Hammer *et al.,* 2001).

The density (ind ha^{-1}), the basal area (m^2 ha^{-1}) and the value of relative importance of the species (VIR) were estimated. VIR was calculated as the sum of the relative abundance (number of individuals per species / total number of individuals of all species * 100); the relative frequency (frequency of one species / sum of the frequency of all species * 100); and relative basal area (basal area of each species / total basal area of all species * 100) (Magurran, 2004).

For the analysis of the horizontal structure, the DBH values were used, and for the vertical one, the data of total height; they were represented by class-grouped frequency distributions on histograms.

The richness of families (number of families) and the true diversity were estimated for the JB and A by the following expression:

$$qD = (\sum_{i}^{S} = 1\, p_i^q)^{1/(1-q)}$$

Where:

qD = True diversity

p_i = Relative abundance (proportional abundance) of the i^{eth} species

S = Number of species

q = Order of diversity

The expression defines the sensitivity of the index to the relative abundances of the species (Jost and González-Oreja, 2012). The measures of the true diversity estimated were those of order zero (0D), that is, the specific richness, and that of order 1 (1D) that considers all species in the value of diversity. In addition, estimating the expected richness for the study areas, the sampling efficiency or completeness of the inventory was calculated by comparing the observed and estimated species, using the non-parametric estimators Chao1, ACE (based on the incidence of the species) and Chao 2 (based on the abundance of individuals of the species) with the Estimates version 9.1 software (Colwell, 2017).

Results

A total of 11 871 individuals were registered, 10 723 in the JB (11 457 ind ha^{-1}) and 1 148 in the A (717.5 ind ha^{-1}). 92 species belonging to 35 families were documented, of which 86 were found in JB and 51 in A. The families with the highest number of species in JB and A were Fabaceae (19), Arecaceae (7), Sapotaceae (6) and Rubiaceae (5), which include 40% of those in both study areas (Table 1). The families with the largest number of individuals were Sapotaceae (1 369), Arecaceae, Anacardiaceae, Rubiaceae, Lauraceae and Fabaceae (Table 1).

Table 1. Abundance and use of the tree species recorded in the *El Tormento* Botanical Garden (JB) and the *Arboretum* (A).

Family/Species	**A**	**JB**	**Uses**
Anacardiaceae			
Astronium graveolens Jacq.	65	231	M
Metopium brownei (Jacq.) Urb.	26	672	Me, C
Spondias mombin L.	63	29	A, M, C, Md, CV, U, Pa
Annonaceae			
Annona reticulata L.	1	71	A, Me, Md
Mosannona depressa (Baill.) Chatrou		24	Me, M, Cr
Apocynaceae			
Thevetia ahouai (L.) A.DC.		4	M, Me, O
Araliaceae			
Dendropanax arboreus (L.) Decne. & Planch	4	167	Md, M, Ar, C, Me, Pa
Schefflera morototoni (Aubl.) Maguire, Steyerm. & Frodin	1	2	Md, M, I

Arecaceae			
Chamaedorea oblongata Mart.		130	O
Chamaedorea seifrizii Burret		560	O, Ar
Cryosophila stauracantha (Heynh.) R.J.Evans		1145	U, M, O
Desmoncus orthacanthos Mart.		1	Ar
Gaussia maya (O.F. Cook) H.J.Quero & Read		4	O
Sabal gretherae H. J. Quero	4		O
Sabal mexicana Mart.	3	131	O, Ar, Md
Asparagaceae			
Beaucarnea pliabilis (Baker) Rose		2	O
Bignoniaceae			
Handroanthus chrysanthus (Jacq.) S.O.Grose		3	Md, O, CV, U, Me, M, C
Tabebuia rosea (Bertol.) Bertero *ex* ADC.	18	1	A, C, M, Md, Me, U
Tecoma stans (L.) Juss. *ex* Kunth		87	C, Md, CV, M, O, E, F, I, Me
Boraginaceae			
Cordia dodecandra A. DC.	8		Md, A, U, M, Ar
Ehretia tinifolia L.		9	U, M, O, Md, Me, Ar
Burseraceae			
Bursera simaruba (L.) Sarg.	60	247	M, Md, P, CV, F, C, I, E, Ar, Me
Protium copal (Schltdl. & Cham.) Engl.		44	Md, CR, M
Cannabaceae			
Aphananthe monoica (Hemsl.) J.F.Leroy		17	Md, U
Clusiaceae			
Calophyllum brasiliense Cambess.		1	I, Ar, C, F, Md, M

Combretaceae			
Bucida buceras L.	7	26	Md, C
Erythroxylaceae			
Erythroxylum confusum Britton		20	Md, M
Euphorbiaceae			
Alchornea latifolia Sw.		2	I, Md, E
Gymnanthes lucida Sw.		272	Md
Hippomane mancinella L.	1	13	M
Fabaceae			
Acacia cornígera (L.) Willd		24	M, C, Me
Acosmium panamense (Benth.) Yakovlev	27	16	Md, U, Ar, C, M
Albizia niopoides (Benth.) Burkart	1	12	Md, O, F, M
Bauhinia divaricata L.		5	Md, M, CR, F, C
Delonix regia (Hook.) Raf.	7		O, C, Me
Enterolobium cyclocarpum (Jacq.) Griseb.	33	1	C, Md, CV, F, M, A, P, Ar, U, Me, E
Gliricidia maculata ("Humb., Bonpl. & Kunth") Steud.		1	CV, Md, M, Ar, A, C, F, U, I, Me
Lonchocarpus castilloi Standl.	89	138	Md, C, I, Me, F
Lonchocarpus guatemalensis Benth.	1	88	M, Md, I, C, Me
Lonchocarpus longistylus Pittier		2	CR, O, M
Lotus berthelotii Masf.		8	O
Lysiloma latisiliquum (L.) Benth.	131	177	Md, Me, C, Cn, F, M, U
Mariosousa dolichostachya (S.F. Blake) Seigler & Ebinger	31	259	Md, Me
Myroxylon balsamum (L.) Harms	2	3	I, Md, M, Me, E
Piscidia piscipula (L.) Sarg.	176	26	M, Md, Me, C, CV, F

Platymiscium yucatanum Standl.		1	Md, U, Ar
Schizolobium parahyba (Vell.) S.F. Blake		4	Ar, C, Md, Pa
Swartzia cubensis (Britton & Wilson) Standl.	1	17	Me, C, M, Md
Vatairea lundellii (Standl.) Record		5	Md
Lamiaceae			
Gmelina arborea Roxb.	1		Md, C, M
Tectona grandis L. f.	2		Md
Vitex gaumeri Greenm.	77	120	C, M, CV, Me, Ar, U
Lauraceae			
Licaria peckii (I.M.Johnst.) Kosterm.	5	78	Md
Nectandra salicifolia (Kunth) Nees.	4	1107	C, CV, Me
Malvaceae			
Guazuma ulmifolia Lam.	3	11	Md, C, MCM F, Me, Ar, A, E, I, CR
Hampea trilobata Standl.		85	Md, U, M, Me, C
Pseudobombax ellipticum (Kunth) Dugand	12	35	F, O, Me, E, CR
Meliaceae			
Cedrela odorata L.	77	24	Md, M, E, Ar, C, U, Me
Swietenia macrophylla King	31	49	Md, Ar, E, U, M, Me
Moraceae			
Brosimum alicastrum Sw.	3	125	Ar, A, U, Pa, Md, F, M
Pseudolmedia glabrata (Liebm.) C.C.Berg	5	127	Md, A
Trophis racemosa (L.) Urb.	2	307	CV, Md, U, Me
Myrtaceae			
Eucalyptus sp	3		I, Md, M, E

Pimenta dioica (L.) Merrill	34	161	A, E, M, C, Md, U, I
Psidium sartorianum (O.Berg) Nied.		3	Md, M, A
Phyllanthaceae			
Margaritaria nobilis L.f.		8	C, Md
Picramniaceae			
Alvaradoa amorphoides Liebm.	7	20	M, Md, U, C
Piperaceae			
Piper aduncum L.		89	M
Polygonaceae			
Coccoloba barbadensis Jacq.		2	Md, U
Coccoloba cozumelensis Hemsl.	2	196	Md, Me,
Putranjivaceae			
Drypetes lateriflora (Sw.) Krug & Urb	2	153	Md, CR
Rhamnaceae			
Krugiodendron ferreum (Vahl) Urb	1	11	Md
Rosaceae			
Crataegus rhipidophylla Gand.		34	O
Rubiaceae			
Alseis yucatanensis Standl.	23	479	Md, Me
Blepharidium guatemalense Standl.	20	72	
Exostema mexicanum A. Gray	5	225	Md, C, Me
Guettarda combsii Urb	2	287	Md
Simira salvadorensis (Standl.) Steyerm	1	34	U, Md
Rutaceae			

Zanthoxylum caribaeum Lam.		1	M
Salicaceae			
Laetia thamnia L.		116	M, CR, Md
Zuelania guidonia (Sw.) Britton & Millsp.	3	105	M, Md, C
Sapindaceae			
Cupania glabra Sw.		430	Md
Matayba oppositifolia (A.Rich.) Britton & Millsp.		9	Md
Melicoccus oliviformis subsp. intermedius (Radkl.) Acev. Rodr		13	A, C, Md
Sapotaceae			
Chrysophyllum mexicanum Brandegee		24	A, Md, M
Manilkara zapota L(L.) P.Royen	3	163	A, Md, M, I, Ar, F, U
Pouteria campechiana (Kunth) Baehni	1	130	Md, A, M, Me
Pouteria reticulata (Engl.) Eyma		946	Md, A
Sideroxylon foetidissimum Jacq.		5	Md, F, M, Me, I
Sideroxylon salicifolium (L.) Lam.		96	M, Md, Me, A
Simaroubaceae			
Simarouba amara Aubl.	33	134	M, Md, Pa, U, A, Ar, Me, E
Urticaceae			
Cecropia peltata L.		2	M, Ar, A, I, F, U, Pa, Md

Uses: A = Food; M = Traditional medicine; C = Fuel; Md = Timber; O = Ornament; Ar = Handcrafts; U = Tools; P = Glue; CV = Live fences; F = Forage; CR = Cultural, religious; E = Escences, cosmetics, soaps; Me = Melliferous, I = Ethanol, insecticide, other secondary metabolites used in industry; Pa = Paper.

Regarding the species, the most abundant in the JB were *Cryosophila stauracantha* (Heynh.) R.J.Evans (1 145), *Nectandra salicifolia* (Kunth) Nees. (1 111), *Pouteria reticulata* (Engl.) Eyma (946), *Metopium brownei* (Jacq.) Urb. (672), and *Chamaedorea seifrizii* Burret (560); while in A they were *Piscidia piscipula* (L.) Sarg. (176), *Lysiloma latisiliquum* (L.) Benth. (131), *Lonchocarpus castilloi* Standl. (89), *Vitex gaumeri* Greenm. and *Cedrela odorata* L. (77) (Table 1).

Among the species in JB and A there were seven endemic species; two in both study areas: *Mariosousa dolichostachya* (S.F. Blake) Seigler & Ebinger and *Alseis yucatanensis* Standl., and five present only in JB: *C. stauracantha*, *Gaussia maya* (O.F. Cook) H.J. Quero & Read, *Lonchocarpus longistylus* Pittier, *Platymiscium yucatanum* Standl. and *Hampea trilobata* Standl. In addition, five introduced species were registered, one shared in both areas: *Myroxylon balsamum* (L.) Harms (native to Central America), one in the JB *Lotus berthelotii* Masf. (endemic to Tenerife) and three in the A; *Delonix regia* (Hook.) Raf. (endemic to Madagascar), *Gmelina arborea* Roxb. (native to Southeast Asia and India) and *Eucalyptus* sp. (originally from Australia and New Guinea).

In regard to the conservation status of the species recorded in the JB and A, seven are on the IUCN red list in the endangered categories (EN: *Blepharidium guatemalense* Standl.), Vulnerable (VU: *C. odorata* and *Swietenia macrophylla* King), almost threatened (NT: *Mariosousa dolichostachya*) and least concern (LC: *Tabebuia rosea* (Bertol.) Bertero ex ADC., *Lonchocarpus guatemalensis* Benth. and *Pouteria campechiana* (Kunth) Baehni). In CITES two species were found in appendixes II (*S. macrophylla*) and III (*C. odorata*); while for NOM-059-SEMARNAT-2010 eight species are in the endangered categories (P: *Vatairea lundellii* (Standl.) Record), threatened (*A: Astronium graveolens* Jacq., *G. maya*, *Beaucarnea pliabilis* (Baker) Rose, *Handroanthus chrysanthus* (Jacq.) SO Grose, *Calophyllum brasiliense* Cambess. and *Acosmium panamense* (Benth.) Yakovlev) and subject to special protection (Pr: *C. odorata*).

On the other hand, regarding the representation in the JB and the A of the utility potential of tropical forest species, 15 potential uses were identified. Only one of the species has no reported use (*B. guatemalense*); while 77.6 % are multipurpose species (Table 1). Among the uses include timber species (wood for construction, carpentry or joinery - 74.5 %), medicinal use (52.1 %), the provision of nectar and pollen (melliferous, 36.2 %) and fuels (firewood and coal, 34 %).

Hundred three species were identified in the SM, of which 54 (52.43 %) were present in the JB and 38 in the A (36.89 %). ANOSIM analysis showed that the species composition in both cases was statistically different ($R = 0.769$, $p = 0.0086$). The SIMPER analysis allowed to identify that this concept between the SM and the JB, the average dissimilarity was 83.96 %, and 89.91 % between the SM and the A. The species that mostly contributed to these differences are in Table 2.

Table 2. Species that contribute with the highest percentages to the dissimilarity found among the species composition between SM and JB, SM and A in *El Tormento*. Results obtained with the SIMPER analysis.

JB *vs* SM			
Especie	Pd	% Contr.	% Contr. A
Thouinia paucidentata Radlk.	20.06	23.89	23.89
Cryosophila stauracantha (Heynh.) R. J.Evans	5.892	7.018	30.91
Nectandra salicifolia (Kunth) Nees	5.222	6.219	37.13
Pouteria reticulata (Engl.) Eyma	4.74	5.646	42.78
Metopium brownei (Jacq.) Urb.	3.545	4.222	47
Guettarda combsii Urb	2.247	2.676	49.67
Cupania glabra Sw.	2.162	2.575	52.25
Alseis yucatanensis Standl.	2.119	2.524	54.77

Chamaedorea seifrizii Burret	2.1	2.501	57.27
A *vs* SM			
Especie	Pd	% Contr.	% Contr. A
Thouinia paucidentata Radlk.	20.06	22.31	22.31
Piscidia piscipula (L.) Sarg.	10.04	11.17	33.48
Lysiloma latisiliquum (L.) Benth.	6.857	7.626	41.1
Lonchocarpus castilloi Standl.	5.08	5.65	46.75
Vitex gaumeri Greenm.	4.292	4.773	51.52
Cedrela odorata L.	3.797	4.223	55.75
Spondias mombin L.	3.625	4.032	59.78
Astronium graveolens Jacq.	3.535	3.932	63.71
Bursera simaruba (L.) Sarg.	3.044	3.385	67.1

Pd = Dissimilitude average; % Contr. = Percentage of contribution; % Contr. A = Accumulated percentage of contribution.

In the analysis of the structure, the average basal area of the A was 39.08 m^2 ± 0.71, that of the JB was 14.12 m^2 ± 2.98 and that of the SM was 38.93 m^2 ± 9.37. The species with the highest VIR for each of the areas are shown in Table 3; it can be seen that in JB and A the value of VIR is associated with high figures of relative abundance or of the relative basal area; while in SM there are species in which the relative frequency is responsible for the high value of VIR.

Table 3. List of species with the highest relative importance value (VIR) in the *El Tormento* Arboretum (A), Botanical Garden (JB) and tropical forest.

Species	**Frec rel**	**Ab rel**	**AB rel**	**VIR**
A				
Lysiloma latisiliquum (L.) Benth.	0.00	11.84	21.31	11.05
Piscidia piscipula (L.) Sarg.	2.67	15.66	11.30	9.88
Enterolobium cyclocarpum (Jacq.) Griseb.	2.67	3.01	14.99	6.89
Lonchocarpus castilloi Standl.	2.67	8.01	9.60	6.76
Vitex gaumeri Greenm.	2.67	7.01	8.60	6.09
Spondias mombin L.	2.67	5.74	4.54	4.31
Bursera simaruba (L.) Sarg.	2.67	5.46	4.59	4.24
Cedrela odorata L.	2.67	6.10	3.88	4.22
Astronium graveolens Jacq.	2.67	5.92	2.59	3.72
JB				
Lysiloma latisiliquum (L.) Benth.	2.08	1.65	14.43	6.05
Cryosophila stauracantha (Heynh.) R.J.Evans	2.08	10.68	1.83	4.86
Pouteria reticulata (Engl.) Eyma	2.08	8.83	3.48	4.79
Nectandra salicifolia (Kunth) Nees.	2.08	10.33	1.86	4.75
Metopium brownei (Jacq.) Urb.	2.08	6.27	5.50	4.62
Alseis yucatanensis Standl.	2.08	4.47	4.31	3.62
Bursera simaruba (L.) Sarg.	2.08	2.30	5.28	3.22
Vitex gaumeri Greenm.	2.08	1.12	6.11	3.10
Manilkara zapota L (L.) P.Royen	2.08	1.52	5.53	3.04
SM				
Piscidia piscipula (L.) Sarg.	15.09	2.78	12.67	10.18
Pimenta dioica (L.) Merrill	2.26	0.93	19.12	7.44

Lysiloma latisiliquum (L.) Benth.	2.64	3.70	9.85	5.40
Vitex gaumeri Greenm.	2.45	1.85	9.81	4.70
Guettarda combsii Urb	7.55	3.70	1.63	4.29
Bursera simaruba (L.) Sarg.	3.40	3.70	3.97	3.69
Metopium brownei (Jacq.) Urb.	2.83	3.70	2.94	3.16
Lonchocarpus castilloi Standl.	3.21	2.78	3.40	3.13
Blepharidium guatemalense Standl.	3.77	2.78	2.61	3.05

The vertical and horizontal structures in the JB are characterized by an "inverted J" distribution, with more than 70 % of individuals in the first two categories. In A and SM, the distribution is bell shaped, in which the intermediate categories (2 to 4) concentrate around 75 % of the individuals (figures 2 and 3).

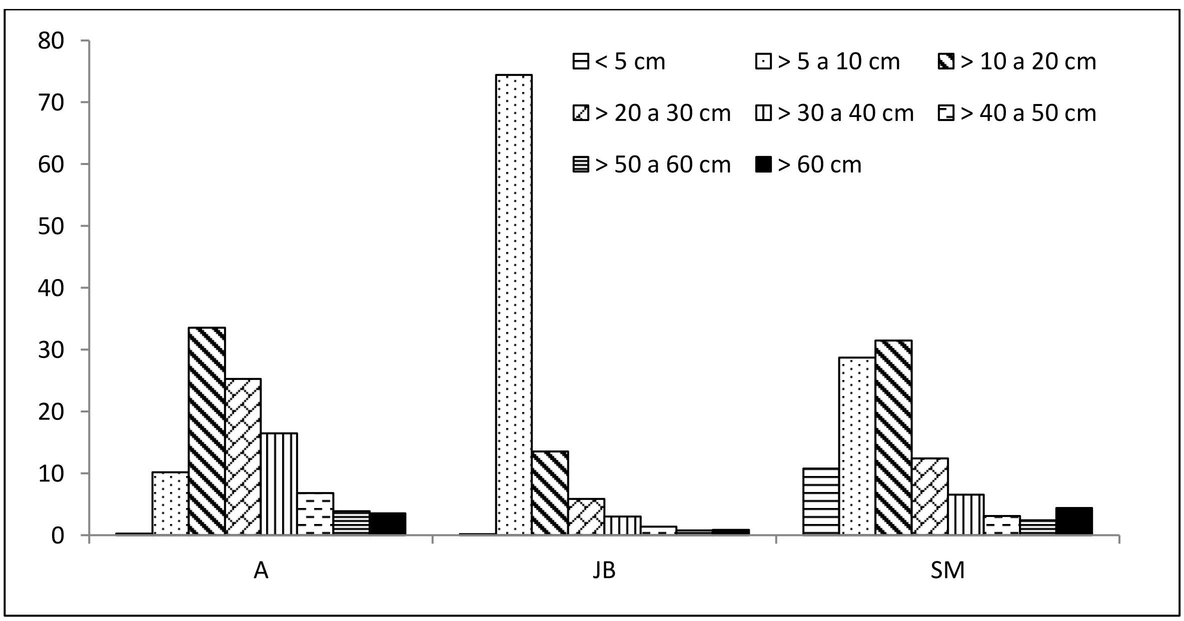

Figure 2. Horizontal structure (diameters) in the *arboretum* (A), botanical garden (JB) and tropical forests (SM) of *El Tormento.*

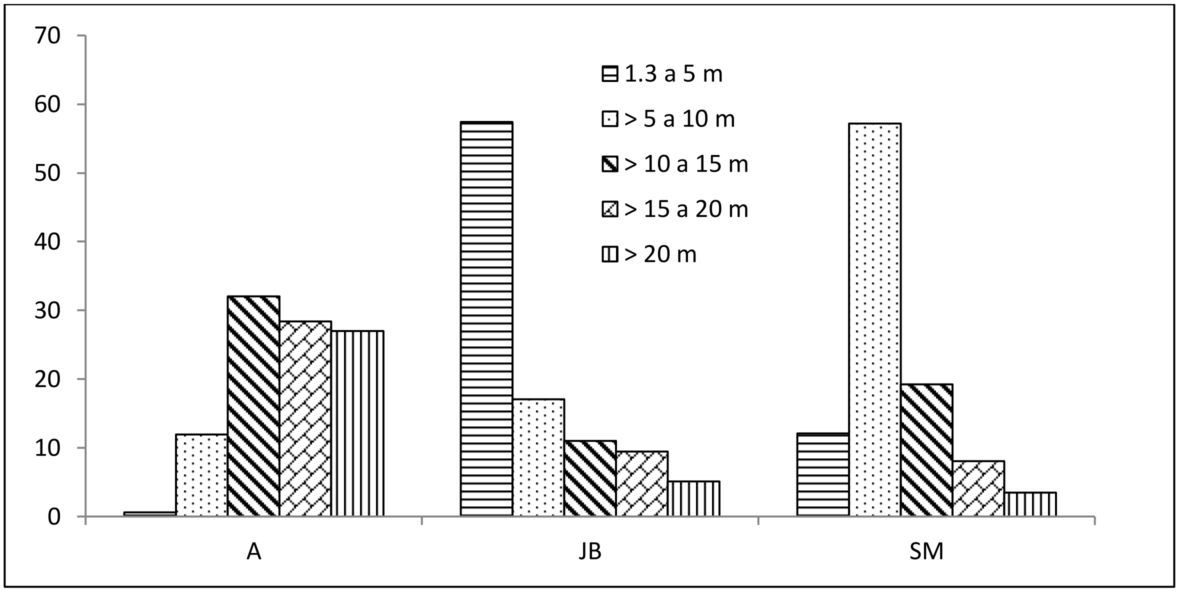

Figure 3. Vertical structure (height) in the areas of the *arboretum* (A), botanical garden (JB) and tropical forests (SM) of *El Tormento.*

The number of effective species shows that the JB (1D = 32.82) is 1.6 times more diverse than the A (1D = 20.8). Regarding the completeness of the inventory, both sites showed high values in the JB, the estimated numbers were distributed between 80.69 % (Chao 2: 109.05), 92.09 % (ACE: 95.56) and 94.48 % (Chao 1: 93.14); while for A the estimates varied from 79.27 % (ACE: 64.33), 88.81 % (Chao 1: 57.42) to 92.12 % (Chao 2: 55.36). All estimators predict a higher richness in JB (five to 21 new species) compared to A (four to 13 new species).

Discussion

The number of species and families recorded in this study for JB and A, agree with the 10 most frequent families and with the highest number of species recognized for the *Yucatán* Peninsula (Carnevali *et al.,* 2010), and, partially with the results of the work of Salaya-Sánchez and Gómez-Gómez (1981), who mentioned that in the *El Tormento* JB the families with the highest number of species were Fabaceae (14), Euphorbiaceae (6), Rubiaceae, Moraceae and Sapotaceae (5). While the most abundant were Rubiaceae (839), Fabaceae (582), Lauraceae (500) and Anacardiaceae (437). All the species in both areas have been collected in medium semi evergreen tropical forest and some of them, such as *Pouteria reticulata*, are considered characteristic of mature forests, while others such as *Nectandra salicifolia* can appear from early stages of succession.

The results indicate the importance of JB and A as reservoirs of representative forest species of medium semi evergreen tropical forests useful from many different perspectives and as conservation spaces for threatened species. This coincides with that reported by Chen *et al*. (2009), Oldfield (2009), Miller *et al*. (2016), Gaio-Oliveira *et al.* (2017), Volis (2017), and Chen and Sun (2018) who highlight the value of these spaces as centers of diversity, design of conservation strategies, management and research of forest resources, as well as for safeguarding the biodiversity associated with different ecosystems represented.

In both sites, the high percentage of species with multiple uses stands out, which suggests the enormous richness of biotic components and, consequently, of environmental services offered by forest tree species. In this context, the supply of wood, medicines, food, fodder and live fences can be mentioned, for example, but also the presence of melliferous species that favor pollination and those with a high cultural and religious value. In this sense, Hardwick *et al.* (2011) emphasize the role of botanical gardens in functioning as custodians of important taxa for local communities from the ecosystem services they provide.

Chen *et al.* (2009) underscore the importance of documenting the uses of native species and developing management strategies in tropical botanical gardens, and disseminating both among the different users of the forest to promote its conservation. Other authors focus on threatened or endemic species with utility and relevance to meet the needs of communities in relation to health, nutrition, forestry, fuels and agriculture, particularly in the context of climate change Hardwick *et al*., 2011; Heywood, 2011; Chen and Sun, 2018). Cannon and Kua (2017) and Dunn (2017) emphasize the need to incorporate socio-economic perspectives in botanical garden conservation plans, including the integration of local, traditional uses and cultural value, that is, with a biocultural context.

Both the *arboretum* and the botanical garden fulfill the function of protecting species with some degree of threat and constitute reservoirs and potential sources of germplasm for the conservation of species. In this sense, Oldfield (2009) highlights the importance of botanical gardens in the conservation of tree species and emphasizes the need for spaces that represent the natural habitat. While Chen *et al.* (2009) point out the relevance of having in-situ tropical botanical gardens that promote initiatives, not only for the conservation of native tree species and their reintroduction, but also for the great biodiversity that they can harbor and conserve. Other authors (Heywood, 2017; Volis, 2017) document the importance of these spaces to prioritize the conservation of species at the regional level, based on their vulnerability to the effects of climate change and the possibility of verifying their impacts on flowering processes, hybridization, pollination, colonization of invasive species or in the plasticity that some of them can show.

On the other hand, Miller *et al.* (2016) consider that the living collections studied here can have a great impact on the generation and monitoring of restoration strategies, since they are areas that gather information related to succession, the composition of reference ecosystem species, the correct propagation of forest species; at the same time that they are spaces that contribute to disseminating the importance of caring for and sustainable management of forest resources.

Despite the high value in the percentage of dissimilarity between the composition of the SM *vs* the JB and the A, it is undeniable that the JB can harbor more species present in the SM, particularly those with some threat status or a high potential for use.

The values of the AB of the SM and the A are similar to those reported by various authors for medium semi evergreen tropical forest of southern Mexico such as Reed and Lawrence (2003), García-Licona *et al*. (2014) and Esparza-Olguín and Martínez-Romero (2018), while in JB, the AB are comparable with those of secondary vegetation (Reed and Lawrence, 2003; Van Breugel *et al*., 2006; Vester *et al.,* 2007 ; García-Licona *et al.* 2014; Esparza-Olguín *et al*., 2019). Both in the JB and in the A, species registered for medium evergreen tropical forests and secondary vegetation derived from these forests with high VIR values stand out (Díaz *et al*., 2002; Read and Lawrence, 2003; Pennington and Sarukhán, 2005; Vester *et al.,* 2007; Zamora-Crescencio *et al.,* 2012; Garcia-Licona *et al*., 2014; Esparza-Olguín and Martínez-Romero, 2018).

In regard to the behavior of horizontal and vertical structures, both the JB (inverted J) and the A, and SM (bell-shaped), coincide with the argument that both patterns indicate that the areas maintain recovery processes through of the successional process, and thus guarantee the replacement of trees eliminated for various causes (Díaz *et al*., 2002; Zamora-Crescencio *et al*., 2012; García-Licona *et al.,* 2014; Báez-Vargas *et al.,* 2017; Chiquini-Heredia *et al.,* 2017).

The differences in diversity between the JB and the A are probably associated with the fact that the JB is a space that did not receive management or maintenance for more than 35 years, so that its vegetation underwent the process of ecological succession, with the consequent change of species, leading to greater diversity (Poorter, 2007; Norden *et al.,* 2009; Chazdon *et al*., 2010; Lebrija *et al.,* 2010). In the A, sporadic maintenance actions were maintained that contributed to its preservation as a collection of live trees with the arrangement of a plantation. On the other hand, the species richness estimators used indicate a sufficient sampling effort that allows a good representation of the species composition for both JB and A, given the relatively high completeness values (Álvarez-Zúñiga *et al.* , 2012; Vite *et al.,* 2014).

Conclusions

The results of the present study as a whole confirm the importance of the Botanical Garden and the *Arboretum* as reservoirs of the arboreal diversity associated with medium semi evergreen tropical forest and their potential use. They constitute spaces for the formulation of conservation strategies, management and knowledge of forest resources. By being part of a center for research and technology transfer, the information provided in this work will contribute to the generation and development of lines of research and propagation of tree species and biodiversity associated with forests at local and regional levels. Likewise, the data gathered here may inform the design of education and outreach plans related to the different themes that are worked on in both living collections.

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Conflict of e interests

The authors declare no conflict of interests.

Contribution by author

Ligia Guadalupe Esparza Olguín: data analysis and writing of the whole manuscript; Aixchel Maya Martínez: field work, and writing of some sections of the manuscript and general review of it; Gonzalo Hernández García: field work and general review of the manuscript; Eduardo Martínez Romero: writing of some sections of the manuscript and general review of it.

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