The analytic hierarchy process for selection of suitable trees for Mexico City

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Urban foresters require methodologies that help to select tree species for urban environments, mainly in places where there is a large number of potential species such as the Valley of Mexico. We applied the Analytic Hierarchy Process (AHP) to select suitable native tree species that are under-represented or non-existent in Mexico City trees. Through bibliographic research, the selection criteria and the list of trees to be evaluated were selected; later, a group of specialists in urban forestry and arboriculture determined by pair-wise comparison matrices the specific weight of each selection criterion, while a set of taxonomists evaluated the rating of each attribute for each species. Finally, for practical purposes, the synthesis of both evaluations resulted in a ranking of 15 tree species according to their degree of aptitude suggested for Mexico City. According to results, *Buddleja cordata*, *Quercus glaucoides* and *Litsea glaucescens* obtained the highest degree of suitability as a large, medium and small-size species, respectively. The AHP proved to be an appropriate methodology to solve a complex problem through multiple criteria evaluation by diverse specialists in the subject. The implementation of the results contributes to the selection process of suitable tree species for urban environments.

Keywords: Multi-criteria Analysis, Native Species, Urban Environment, Urban Tree Diversity, Valley of Mexico.

Introduction

Selection of tree species for urban forests must be undertaken strategically to optimize the ecosystem benefits they provide (Morgenroth et al. 2016). Trees within urban environments are essential in the reduction of the heat island effect (Hardin & Jensen 2007), reduction in air pollution (Escobedo et al. 2011), infiltration of rainwater (Xiao & McPherson 2003), reduction of run-off, saving of electrical energy (Simpson &

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McPherson 1997), habitat, generation of feelings of well-being among people (Ulrich 1986), and biodiversity and carbon sequestration (Chiesura 2004, Wang et al. 2015). However, there is a need to select suitable tree species under the proposed "10-20-30 rule" which establishes not to exceed 10% of a single species, 20% of the same genus, and 30% of the same family in an urban forest to promote the tree benefits (Santamour 1990).

In many cities, one of the essential components of the urban structure is green areas, and different studies have been carried out to determine the most suitable tree species (Mizerit 2006, Benavides et al. 2011). For example, a great diversity of species has been recorded in Mexico city (50 botanical families, 94 genera and 181 different species – Mizerit 2006, Martínez 2008, Benavides et al. 2011); however, most species are represented by just a small number of individuals and predominating are those of exotic origin, particularly of the genera *Ficus, Jacaranda, Casuarina* and *Ligustrum* (Benavides et al. 2011). Benavides (1992) reported that about 70% to 72% of tree species in Mexico City are exotic, and about 28-30% are native species of the Valley of Mexico. Although many exotic species may have higher possibilities to tolerate changing climatic conditions compared to native species (Easterling et al. 2000); a most efficient provision of ecosystem services has been recorded when there is an adequate proportion of both native and exotic species (Nielsen et al.

2014) with higher resistance and resilience to adverse factors (Clark et al. 1997, Morgenroth et al. 2016).

An appropriate selection process that incorporates expert's opinions, the available scientific information, and the conditions of the plantation site is fundamental to avoid conflicts in the future, extend the tree life, and maximize tree benefits (Pauleit 2003, Li et al. 2011, Asgarzadeh et al. 2014). However, in many cities, the selection of tree species relies on the personnel in charge of reforestation and the availability of the plant material in the nearby nurseries, without taking into account the sizeable local tree diversity associated with the urban site conditions and technical recommendations (PAOT 2003, Chacalo et al. 1997). Similarly, the personnel usually lack a list of suitable tree species or a methodology that incorporates most of the essential criteria for species selection such as environmental resistance, stress tolerance, economic viability, functional quality, and aesthetical aspects, among others (Sjöman & Nielsen 2010, Asgarzadeh et al. 2014, Conway & Vander Vecht 2015).

The Analytical Hierarchical Process (AHP) is a multicriteria analysis technique that breakdown multiple datasets in a pair-wise comparison matrix, which is used to calculate the geometric mean and normalized weight of parameters parts to support complex decision making such as the selection of suitable trees in urban areas (Saaty 1987, Li et al. 2011, Asgarzadeh et al. 2014). This technique incorporates the expert's

Fig. 1 - Urban area of Mexico City.

experience with scientific information to make the final decision more robust. The AHP has been used in a wide variety of research to address different problems, including forestry, resource management and monitoring plants in national parks (González et al. 2016). Recently, the use of AHP has been suggested for urban tree selection because the process involves a combination of several factors (criteria), each with a different degree of importance on the final decision (Asgarzadeh et al. 2014). Previous research suggests implementing criteria such as tolerance to stress factors, aesthetics, maintenance, growth characteristics, and ecological effects, among others to guide species selection (Amir & Misgav 1990, Miller 1997, GDF 2000, Pauleit 2003, Sæbø et al. 2003) but the decision making can be complex. The AHP has been recommended as an inte-

grated assessment approach that considers the complexity of multiple criteria in tree selection for urban areas such as Hefei, China and Tehran, Iran (Li et al. 2011, Asgarzadeh et al. 2014). The tree selection process emphasizes when there is a large number of potential urban species to select. Therefore, this study adapts the Analytic Hierarchy Process (AHP) for the selection of suitable native tree species for Mexico City.

Methods

Study area

Mexico City's territory is divided into urban land (UL) with an area of 60,867.9 ha and conservation land (CL) with 87,294.4 ha (Fig. 1) and is part of the Valley of Mexico. This study comprises only the urban area of Mexico City.
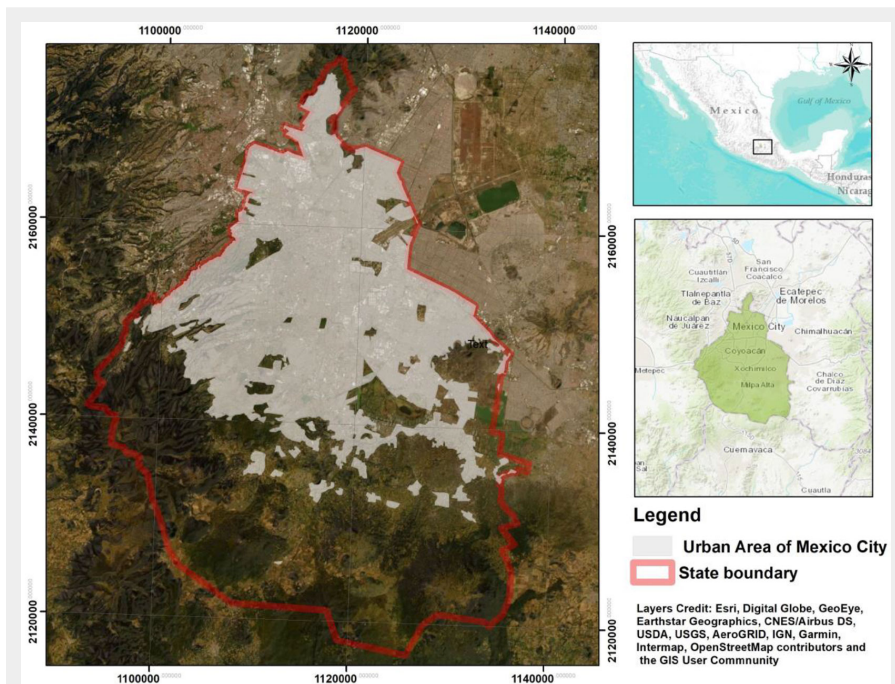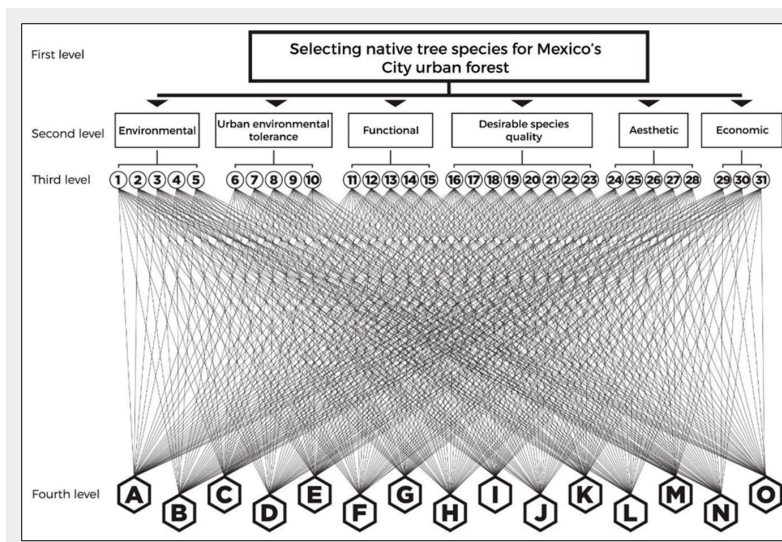
Analytic Hierarchy Process (AHP)

A conventional four-level hierarchy model was constructed to integrate all the AHP stages properly. In the first level, the overall objective of the process was established. In the next level, the selection of the most critical criteria to solve the main problem were selected. In the third level, each criterion was broken down into a series of subordinate criteria or subcriteria to provide further specificity to the resolution of the problem. Finally, the last level identified the alternatives (tree species) to be evaluated for planting purposes in an urban environment. The purpose of breaking down the problem into four stages is to analyze in an isolated manner all the elements that contribute to its resolution (Fig. 2).

First level: determination of the overall objective

The first level of the decision-making process was the selection of small, medium and large native trees suitable for urban conditions of Mexico City. This level was determined based on the configuration of the urban landscape with a small dominating number of species, the large number of native species growing in natural conditions of the Valley of Mexico, and the recommendation of increasing native species on the urban plant selection (Mizerit 2006, Martínez 2008, Benavides et al. 2011).

Second and third levels: determination of selection criteria and subcriteria

Criteria and subcriteria were based on previous research on the selection of trees for urban environments (Amir & Misgav 1990, Miller 1997, GDF 2000, Pauleit 2003, Sæbø et al. 2003, Li et al. 2011, Asgarzadeh et al. 2014). The most recommended subcriteria were selected giving a total of 31 subcriteria, three of which were incorporated for particular characteristics relevant to Mexico City: (i) retention of suspended particles; (ii) low volatile organic compound (VOC) emissions; and (iii) reduced soil volume tolerance. Then, the 31 subcri-

Fig. 2 - Structure of the hierarchy for Mexico City tree species selection. (1): Drought resistance; (2): High-temperature resistance; (3): Low-temperature resistance; (4): Pest and disease resistance; (5): Salinity resistance; (6): Air pollution tolerance; (7): Wind tolerance; (8): Soil compaction tolerance; (9): Shade tolerance; (10): Poor soil tolerance; (11): Ability to retain suspended particles; (12): Noise absorption; (13): Plant palette diversification; (14): Microclimate regulation; (15): Visual beauty; (16): Lifespan; (17): Plasticity; (18): Growth rate; (19): Suitability for restrictive soil volumes; (20): Non-aggressive rooting systems; (21): Species with low VOC emissions; (22): Phenology (Deciduous/Perennial); (23): Resistance to limb breakage; (24): Flowering and fruiting; (25): Fragrance; (26): Foliage color; (27): Crown shape; (28): Bark texture; (29): Establishment costs; (30): Maintenance costs; (31): Disposal costs. (A to O): Species evaluated for Mexico City's green areas.

teria were grouped into six criteria (Tab. 1).

Weighting of criteria and subcriteria

The relative weights of both criteria and subcriteria were estimated by assigning them numerical values of the so-called fundamental scale of absolute numbers (1-9), based on the degree of importance they have on the decision (Saaty 1990). For the above, the opinion, preferences, or judgments of 17 out of 20 professionals were considered. They were selected based on their expertise in urban forestry and arboriculture. The opinions were collected by a survey design following the format described by Malczewski (1999) and Olivas-Gallegos et al. (2007), consisting of seven questionnaires. The participants indicated their level of preference for one criterion or sub-criterion over another through independent comparisons between pairs of elements of level two and similar for level three of the hierarchy, choosing a value between one and nine on the fundamental scale proposed by Saaty (1987). The use of this scale is one of the central points of the methodology. It allows to transform qualitative aspects into quantitative, eliminates ambiguities generated when comparing very close elements, is based on the natural tendency to compare only two elements at the same time, and provides an adequate interval that allows a clear distinction to be made between the different levels of intensity of the preference of one judgment over another (Malczewski 1999, Saaty 1987).

In the case of the criteria, each one was compared against the remaining criteria and for the subcriteria, the comparisons were made only between the elements within each criterion, *i.e.*, subcriteria of different criteria were not compared (Li et al. 2011). To analyze the questionnaires, they were transformed into comparison matrices that were entered in the GIS Analysis/Decision Support/Weight module of the IDRISI® Selva software (López-Upton et al. 2015, González et al. 2016). The respective weights were obtained for the criteria and subcriteria from each participant (Tab. 2) answering the seven questionnaires.

From the previous procedure, the consistency index was calculated to determine the strength of the comparisons made by the participants and to validate that the judgments do not have errors, nor contradictions among them. Based on the result of this index for each questionnaire, only those whose result was equal to or less than 0.10 were considered as recommended by Saaty (1987). Finally, to obtain the definitive weight of the criteria and subcriteria, the arithmetic mean of the values from all the questionnaires was taken (Asgarzadeh et al. 2014, González et al. 2016).

Fourth level: species determination

A total of 13 bibliographic sources were reviewed to identify the taxonomic tree diversity near Mexico City (Valley of Mexico),

Tab. 1 - Criteria and subcriteria used to guide Mexico City tree species selection. (1): Asgarzadeh et al. 2014; (2): Li et al. 2011; (3): Amir & Misgav 1990; (4): Miller 1997; (5): Sæbø et al. 2003; (6): Pauleit 2003; (7): GDF 2000.

Criteria	Subcriteria	Source
Environmental	1. Drought tolerance	1, 2, 6, 7
	2. High temperature resistance	1, 2, 6, 7
	3. Low temperature resistance	1, 2, 6, 7
	4. Pest and disease resistance	2, 5, 6, 7
	5. Salinity resistance	1, 6, 7
Urban environment tolerance	6. Air pollution tolerance	1, 4, 5, 7
	7. Wind tolerance	1, 5, 6
	8. Soil compaction tolerance	6
	9. Shade tolerance	1, 6
	10. Poor soil tolerance	1, 2
Functional	11. Ability to retain suspended particles	(new)
	12. Noise absorption	3
	13. Diversification of plant palette	3, 7
	14. Microclimate regulation	3
	15. Visual beauty	3
Desirable species	16. Life span	1, 2, 3, 7
	17. Plasticity	5
	18. Growth rate	1, 2, 3, 5, 7
	19. Suitability for restrictive soil volumes	(new)
	20. Non-aggressive rooting systems	1, 7
	21. Species with low VOC emissions	(new)
	22. Phenology (deciduous/perennial)	1, 3, 7
	23. Resistance to branch breakage	2, 5
Aesthetics	24. Flowering and fruiting	1, 2, 3, 6, 7
	25. Fragance	1
	26. Foliage color	1, 2, 3, 6
	27. Crown shape	2, 3, 6
	28. Bark texture	2, 3, 6
Economics	29. Establishment cost	4
	30. Maintenance cost	4
	31. Removal and cleanup cost	4

resulting in a total of 1851 species (Tab. 3). In the revision of the first list, repetition, exotic species and shrubs were cut off resulting in a new list with a total of 869 potential native tree species.

Subsequently, those species that appeared consistently in most of the 12 primary bibliographic sources were selected, giving higher weight to those that appeared in any of the combinations of listings 1, 2, 11 and 12, as they are native species with an adjacent distribution to the

Tab. 2 - Example of a comparison matrix to determine the weight of the criteria for Mexico City tree species selection (consistency index = 0.1)

Criteria	Environmental	Urban environment tolerance	Functional	Desirable species qualities	Aesthetic	Economic	Weight
Environmental	1	1	1/5	1/7	8	2	0.1169
Urban environment tolerance	1	1	1	1/3	3	1	0.1249
Functional	5	1	1	1	8	3	0.2822
Desirable species qualities	7	3	1	1	7	3	0.3511
Aesthetic	1/8	1/3	1/8	1/7	1	1/5	0.0288
Economic	1/2	1	1/3	1/3	5	1	0.0962

Tab. 3 - Bibliographical sources to identify species with potential for tree diversification in Mexico City. (1): Calderon De Rzedowski & Rzedowski 2005; (2): Olmedo & Rocha 2004; (3): CONAFOR 2007; (4): Batis et al. 1999; (5): Benavides et al. 2011; (6): Guadarrama-Martínez et al. 2012; (7): Martínez 2008; (8): Chacalo & Corona 2009; (9): GDF 2000; (10): Niembro 1990; (11): Rzedowski 2015; (12): Rzedowski & Calderón De Rzedowski 2009.

Source	Source topic	No. species
1, 2	Native tree species with adjacent distribution to the study area	122, 79
3	Tree species used for different purposes, mainly reforestation	168
4	Native tree species of Mexico	70
5, 7	Frequent tree species in the green areas of Mexico City	131, 57
6	Tree species with adjacent distribution to the study area and ornamental potential	65
8	Tree species recommended for cities	27
5, 9	Tree species recommended for Mexico City	53, 59
10	Tree species of Mexico	300
11, 12	Tree species with ecological affinity to the study area	487, 233
-	*Total*	*1851*

study area (listings 1 and 2) and for belonging to regions with ecological affinity to the area (listings 11 and 12). It was considered that these species could have a high potential to settle and survive under harsh conditions. This last procedure generated a list including 74 tree species; later, because the plantation spaces in the city are diverse in size, the species were categorized according to height, with those up to nine meters being considered as small, those from nine to 15 meters as medium-sized, and those more than 15 meters in height as large. Mature tree size is the first characteristic to consider based on the plantation site. Finally, the 15 most suitable species were selected to fulfill the purpose of this study; five from each height category. The final number of species were considered based on the required resources and time to qualify of all attributes for all the chosen species during the experts' evaluation step.

Evaluation of attributes and synthesis of results

The 15 selected tree species were evaluated (rated) on their suitability for planting by a group of six botanists specialized in the taxonomy and with experience in the

Valley of Mexico flora for the suggested attributes (subcriteria). The information was gathered through an evaluation format where the ratings were expressed based on a nine-level qualitative scale, with one assigned as the lowest value and nine the highest to rate the performance of the species about a specific attribute. For example, concerning the drought tolerance sub-criterion, taxonomists rated 7, 5 and 1 to *Alnus jorullensis*, *Populus tremuloides* and *Clethra mexicana* respectively, indicating with their evaluations that the former is more tolerant than the latter. Of the 2790 possible assignable ratings (31 subcriteria × 15 species × 6 taxonomists), 2027 corresponded to complete qualifications of each attribute by all the botanists. From the 763 missing ratings, 279 corresponded to nine cases in which some specialists did not know the information about all the attributes in six species, so these ratings were not considered in the analysis. The remaining missing ratings (484) were assigned based on the other botanist answers with the statistical software R through a Random Forest algorithm (Badler et al. 2004). As a result of this procedure, the required series of attribute ratings were obtained using the statistical

mode as an estimator to obtain a single value that served as input for the analysis.

Finally, to obtain the final score that indicates the degree of suitability of the tree species for the conditions of Mexico City's urban environment, the following equation was used (eqn. 1):

$$T_i = \sum_{i=1}^{n} (R_i \cdot r_i \cdot W_i) \qquad (1)$$

where T_i is the total score of the species, n is the total number of subcriteria, R, r and W are the weight of the criteria (determined by the pairwise comparisons), the weight of the subcriteria and the rating of the attribute i, respectively (Li et al. 2011). The points are added to indicate the final selection priority of each of the species; therefore, the higher the score, the higher the degree of suitability for incorporation into Mexico City's trees.

Results

The AHP goal of this study was the selection of suitable native trees for planting in Mexico City conditions (first level). Among the six criteria (second level) involved in the selection of tree species, the opinion of the experts through the pair-wise questionnaires indicated that for Mexico City's conditions the most important one was the environmental. In the case of the 31 subcriteria (third level), pest and disease resistance, soil compaction tolerance, microclimate regulation, non-aggressive rooting systems, crown shape and maintenance costs result as the most important in each criteria group (Tab. 4).

The bibliographic research showed up a list of 74 potential species for Mexico City, but only 15 alternative species grouped by height were analyzed for ranking the suitability degree with the AHP approach (Tab. 5). From the 15 species (fourth level), only 10 obtained a score higher than five (Tab. 5); therefore, in general the five remaining species could be considered in a smaller proportion for incorporation into Mexico City's trees. After analyzing the scores obtained, it was decided to establish an arbitrary limit in order to issue the best possible recommendation, that is, that the suggested species have the best chance of surviving and establishing themselves according to the opinions issued by the various experts. Five species presented the highest scores: *Buddleja cordata*, *Pinus leiophylla*, *Litsea glaucescens*, *Quercus glaucoides* and *Ceanothus caeruleus*. After grouping the species according to their height (large, medium-sized and small), the results highlighted that the species in first place in each of the three size categories, all with a score higher than 5.6, were among the top five species.

Discussion

The AHP allowed the qualification of suitable native trees to be planted in green areas of Mexico City. The methodology facilitates the incorporation of bibliographical

Tab. 4 - Relative weight of the most important criteria and subcriteria. (1): The estimated weight of the criteria is shown in descending order; (2): the subcriterion corresponds to the highest weight in each criteria group.

Criteria	Weight [1]	Subcriteria	Weight [2]
Environmental	0.2576	Pest and disease resistance	0.3179
Urban environment tolerance	0.2337	Soil compaction tolerance	0.3111
Functional	0.1884	Microclimate regulation	0.3285
Desirable species qualities	0.1791	Non-aggressive rooting systems	0.2019
Aesthetic	0.0817	Crown shape	0.3342
Economic	0.0596	Maintenance costs	0.6349

information, the experience of specialists, and a multicriteria approach to qualify the suitability of potential native species. Of the final 15 species analyzed, *Buddleja cordata, Populus tremuloides* and *Clethra mexicana* are already reported as part of the diversity of species that make up Mexico City urban forest (Mizerit 2006, Martínez 2008, Benavides et al. 2011); however, neither the number of specimens, genera, nor botanical families (Scrophulariaceae, Salicaceae and Clethraceae, respectively) are currently within the group of highly recommended species by literature. Therefore, their integration into the urban tree composition would be of great importance to avoid the small number of species that dominate the urban forest (Mizerit 2006, Benavides et al. 2011).

Species that tolerate stressful conditions such as *Pinus leiophylla, Alnus jorullensis, Quercus glaucoides* and *Viburnum elatum* are not reported in Mexico City, although the genus and families to which they belong (Pinaceae, Betulaceae, Fagaceae and Adoxaceae, respectively) are also represented with a small number of specimens. The species *Litsea glaucescens* is not also reported, nor are others of the same genus but the family (Lauraceae) is, so their incorporation would be useful regarding expanding the potential species for urban reforestation.

The introduction of the species *Ilex tolucana, Garrya laurifolia, Berberis moranensis, Cornus disciflora, Ceanothus caeruleus, Rhamnus serrata* and *Ternstroemia lineata*, at a reasonable scale into the Mexico City urban forest would contribute to its diversification given that neither species, genera nor botanical families (Aquifoliaceae, Garryaceae, Berberidaceae, Cornaceae, Rhamnaceae and Pentaphylacaceae, respectively) are reported as part of the current urban forest composition. This group of species can be the pioneers in the introduction of new native species, which is essential regarding the health of an urban ecosystem (Clark et al. 1997).

Species selection based on scores derived from the analysis of performance concerning specific criteria had a 6.44 rating as the highest score; however, the average was around 5.28, so a threshold could be established for better management of species. For example, the species *Ilex tolucana, Berberis moranensis, Cornus disciflora, Viburnum elatum* and *Ternstroemia lineata*, which had scores lower than five, would be temporarily excluded from the recommendations. Therefore, before being able to implement the results of this research and rule out in advance species with low scores, it would be beneficial to incorporate species trials (Gazca & Benavides 2012), a procedure that has already been used to evaluate other species under the trial and error approach.

Regarding the species that obtained the three highest scores, namely *Buddleja cordata* (6.44), *Pinus leiophylla* (5.90) and *Lit-

Tab. 5 - Degree of the suitability of native species by height type using AHP, to be suggested in Mexico City's green areas.

Height	No.	Species	Score
Large (>15 m)	1	*Buddleja cordata* Kunth	6.46
	2	*Pinus leiophylla* Schiede ex Schltdl. & Cham.	5.92
	3	*Alnus jorullensis* Kunth	5.37
	4	*Populus tremuloides* Michx.	5.02
	5	*Ilex tolucana* Hemsl.	4.88
Medium-sized (9-15 m)	1	*Quercus glaucoides* M. Martens & Galeotti	5.67
	2	*Garrya laurifolia* Hartw. ex Benth.	5.18
	3	*Clethra mexicana* DC.	5.11
	4	*Berberis moranensis* Schult. & Schult. f.	4.95
	5	*Cornus disciflora* DC.	4.85
Small (<9 m)	1	*Litsea glaucescens* Kunth	5.75
	2	*Ceanothus caeruleus* Lag.	5.40
	3	*Rhamnus serrata* Schult.	5.34
	4	*Viburnum elatum* Benth.	4.79
	5	*Ternstroemia lineata* DC.	4.56

sea glaucescens (5.74), the first one is widely distributed in the Valley of Mexico, in scrubland, grasslands and forests. It is commonly found naturally as part of the secondary vegetation, in severely disturbed places, including urban areas (Calderon De Rzedowski & Rzedowski 2005). *Buddleja cordata* is a species of great ecological importance because it grows in shallow soils and tolerates low humidity (Castillo-Argüero et al. 2009); this makes *Buddleja cordata,* a species with attributes appropriate to the conditions of the city, where the reduced planting spaces and lack of irrigation are prevalent.

The National Forestry Commission (CONAFOR 2007) reports important characteristics of *Pinus leiophylla* that need to be considered for incorporation into Mexico City's trees. For example, its wide altitudinal gradient (from 1600 to 3000 m a.s.l.), its recommendation in reforestation of degraded soils because of drought tolerance and ability to grow in low-depth soils, and a known protocol for its sexual and vegetative propagation; thus supporting the potential use of this species mainly in open spaces such as parks or gardens.

Litsea glaucescens obtained the third-highest rating, thus representing an excellent diversification alternative to the current tree species. The species is within the Official Mexican Standard NOM-059 (SEMARNAT 2010) under the category of endangered species because of its overexploitation without regulations due to multiple traditional uses such as medicinal, culinary and even religious (Dávila 2011). Therefore, *Litsea glaucescens* is one of the non-timber forest species with high development potential in Mexico City.

Among the critical points to consider to achieve a healthy urban forest, the species diversity is recognized as a crucial factor, mainly because experience has shown that

in the face of specific pests and unusual climate patterns, one cannot depend on a single species (Clark et al. 1997). Four out of the 15 species evaluated in this research are endemic to Mexico (*Buddleja cordata, Quercus glaucoides, Berberis moranensis* and *Viburnum elatum*). Also, the species are naturally distributed adjacently in the region known as the Valley of Mexico (Calderon De Rzedowski & Rzedowski 2005), in which Mexico City is located.

The use of the AHP approach emphasizes that the identification of appropriate criteria and subcriteria for species selection made necessary to incorporate all the actors involved in the different levels and stages of green area planning and maintenance (Li et al. 2011). Unfortunately, there is little knowledge of this technique in urban tree selection, but its applicability could improve the planning of maintenance activities in urban green areas that involve making decisions. The present study is important on a practical level since these criteria were weighted by specialists based on the conditions of Mexico City. Within the group of environmental subcriteria, pest and disease resistance obtained the highest score. Under limited diversity, the attack of a pest can spread rapidly causing severe damage to trees, as has happened with the red gum lerp psyllid (*Glycaspis brimblecombei* – GDF 2004), and recently with the mistletoe infestation reported in at least 17 species of ten different families (Arriola et al. 2013).

Within the subcriteria of tolerance to the urban environment, tolerance to soil compaction stood out as the one with the greatest weight; in fact, soil compaction is the main interference that occur between trees and urban infrastructure conditions and that creates problems in the medium and long-term (Chacalo et al. 1997). Soil compaction affects both the quality of tree

life and of the site itself. The two species with the highest degree of tolerance to soil compaction according to the results were *Buddleja cordata* and *Pinus leiophylla*.

Finally, crown shape and maintenance costs turned up as the most crucial subcriteria of the aesthetic and economic criteria, respectively. Problems in this regard can be attributed to a lack of planning, training, budget and proper maintenance practices. Generally, the inappropriate selection of species to be planted results in establishing species with crowns that are mostly incompatible with the urban infrastructure, as they may, for example, interfere with aerial service lines, a problem that results in constant and poorly executed pruning, so-called topping, which leads to frequent expenses (Chacalo et al. 1997, PAOT 2003). A central point in this research was to classify the tree species according to their height; such consideration will allow making small trees such as *Litsea glaucescens and Ceanothus caeruleus* compatible with the planting space in terms of dimensions and existing infrastructure.

The incorporation of AHP into decision making gave different advantages over other methodologies for the selection of species in urban environments with the specific criteria for each case. For example, the weighting of criteria reflects the actual decision-making process in which each factor to be considered has a different degree of importance (Asgarzadeh et al. 2014). Besides, it allowed the incorporation of important bibliographic information and admitted the participation of specialists in the different areas involved (Li et al. 2011), which is essential when the scientific literature is incomplete. The above characteristics allowed an evaluation of the alternatives with a grade that reflects their degree of aptitude for the task in question. Finally, due to the mathematical support behind the AHP process, the degree of subjectivity is reduced during the process of comparing the criteria and subcriteria involved (Osorio & Orejuela 2008). The next step after using AHP in the selection of suitable tree species to Mexico City would involve the development of propagation studies and management plans.

Conclusions

The implementation of a multicriteria methodology (AHP) helps to adequately address the complex nature of selecting the most suitable tree from among a large number for some cities. The selection process contributes to the potential incorporation of an excellent availability of native species. Although most of the tree species evaluated in this work are not propagated at present, this should not be a constraint on promoting their use by local government and municipalities. Finally, the flexibility of this methodology could allow the combination with new criteria or tools to strengthen the results during its practical implementation.

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