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General Health Condition in Forest Species in Three Parks in Mexico City: Crown Condition

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ABSTRACT

The crown condition indicator is used to know the proportion of trees that display a crown dieback or a foliage density considered lower than normal: Thick and large crowns relate to high growth rates whilst small ones suggest sites with unfavorable conditions and it can provide reliable and adequate information to diagnose the urban trees' general health condition. The chosen sites are three parks within Mexico City known as Alamedas. Three samplings were carried out during the rainy season (May to October) and one during the dry season (November to April) of 2011. Variables registered were crown density (dnc), crown dieback (mr) and foliage transparency (trpf) as percentual increases (5%) on a scale of 0 to 100. Normality tests, variance analysis and a non-parametric Kruskal-Walis analysis were carried out to find the distribution of data and significant differences in the values of the three variables, showing that the value of significance for each variable was lower than the significance value established ($\alpha = 0.05$). According to the results, species with better health status were those with highest values for the variable dnc and the lowest values for variables trpf and mr. Outstanding species were *Cupressus sempervirens*, *Ligustrum lucidum*, *Populus alba* and *Fraxinus uhdei*.

Key words: Crown density, crown dieback, alamedas, foliage transparency

INTRODUCTION

Parklands in urban areas have a positive influence on the health of users, since they reduce the sensation of stress and they remove polluting particles from the environment. Likewise, trees contribute to intercepting water; therefore keeping them healthy reduces erosion and the loss of the soil profile, which is a considerable and very important long-term benefit (Escobedo and Chacalo, 2008; Peck *et al*., 2009; Rowntree and Nowak, 1991; Westphal, 2003; Wolf, 2003; Xiao *et al*., 1998). So, in 1987 begins the Alamedas Project, with the aim of increasing recreational parklands in every point of the city, using species that easily adapt to the particular conditions of the city, as well as attempting to recover soils that have been degraded by industrial activity in Mexico City (DF) and the State of Mexico (GDF, 2000, 2010, 2011, 2012a, b). There have been studies in Mexico related to parklands that are focused on their conscious planning and the economic and environmental value they provide. However, no work has yet been done focusing on the health condition of trees through the characteristics and structure of the foliage. Investigations on the quality of urban trees, such as that by PAOT (2010) analyze the diversity and distribution of species to evaluate their general condition and therefore suggest which adapt better to the city (Aguillon and Castillo, 2002; Nunci *et al.*, 2005; Garcia *et al.*, 2010). Other investigations consider only the dasometric variables, like crown diameter, to evaluate the condition of the canopy by registering the percentage of missing foliage, or the percentages of defoliation of the crown according to the geographic areas determined and their specific weather conditions (for instance, rain patterns) as indicators of the health condition of the trees (Carnicer *et al.*, 2011; Johnson and Jacob, 2009).

The information provided by the crown condition indicator is used to know the proportion of trees (by species or type of forest) that display a crown dieback or a foliage density considered lower than normal, in an established area (FIA, 2012; INFyS, 2012). In a tree, the crown is where physiological functions such as photosynthesis and respiration take place. The dimensions reflect, in a general way, the tree's health condition: Thick and large foliages are easily related to high growth rates; on the other hand, small ones would suggest places with unfavorable conditions (competition with other trees for light and nutrients, water stress, excess humidity and high pollution levels) or other factors (damage related to pests and diseases). This is the reason why crown condition indicator is included in the forest health indicators of the INFyS (2012) in Mexico and the FIA (2012) in the US and it is applied in natural areas and suburban forests to diagnose the general condition of these communities of trees. Therefore, the use of the main variables of the indicator (crown density, crown dieback and foliage transparency) in parks within urban areas could be considered efficient to gather reliable and sufficient information, while giving a new perspective of the species that predominate in the selected parks of Mexico DF. This new approach of the tools used in forests within urban areas will integrate the information obtained through the indicator variables with earlier work in the phytosanitary diagnose category by identifying the main species in the three parks selected and by registering whether or not the methodology of the crown condition indicator is suitable to evaluate trees in these urban parklands, in order to give a general diagnosis of their health condition.

MATERIALS AND METHODS

The sites chosen were Alameda Oriente-Iztacalco (19°26'7.63"N/99°03'18.53"W), Alameda Norte-Azcapotzalco (19°30'4.25"N/99°10'41.08"W) and Alameda Sur-Coyoacan (19°18'32.70"N/99°7'22.29"W) (Fig. 1). Satellite images were used to establish the potential sampling sties. These sites were selected after considering security aspects and the distribution of forested areas. According to the methodology of the crown condition indicator provided by FIA (2012) but considering the guidelines of i-TREE (2010), specific for urban areas, circular plots with a radius of 11.4 m and a surface of 408.30 m^2 each were established. Groups of four plots were defined at a distance (center to center) of 36.6 m forming an inverted Y-shape (i-TREE, 2010; Nowak *et al.*, 2006; FIA, 2012; INFyS, 2012). In Alameda Norte, 20 plots were set up (total surface 8 166 m^2) and in both Alameda Sur and Oriente, 16 plots were established (total surface 6 532 m^2). Three samplings were carried out during the rainy season (May to October) and one during the dry season (November to April) of the year 2011. All trees within the limits of the circular plots were evaluated after being numbered progressively, starting from the magnetic north and anticlockwise. The dasometric variables registered for each tree were height (m), with a Haga equipment; diameter (cm), with measuring tape and crown width (measures N-S and E-W) (m) with measuring tape. Bushes, shrubs, palm trees or herbaceous vegetation were not registered.

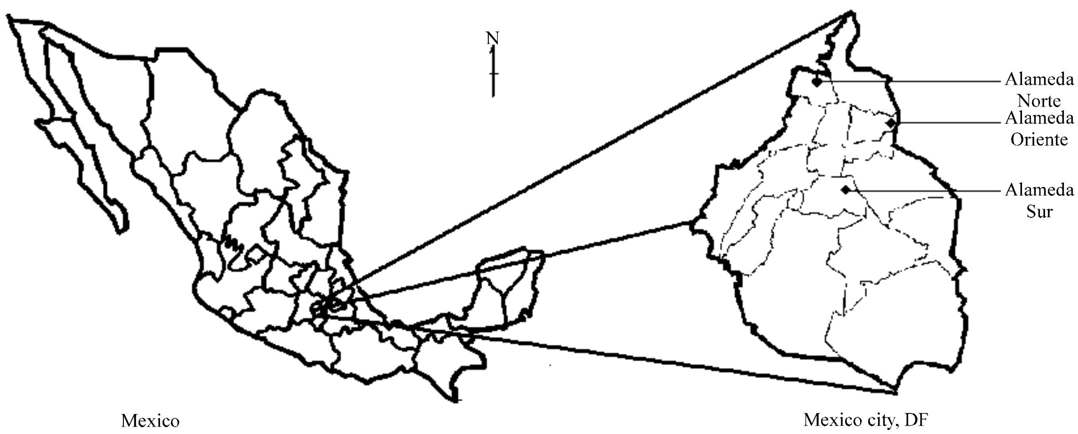

Fig. 1: Map of Mexico City, DF, including the three parks within the study

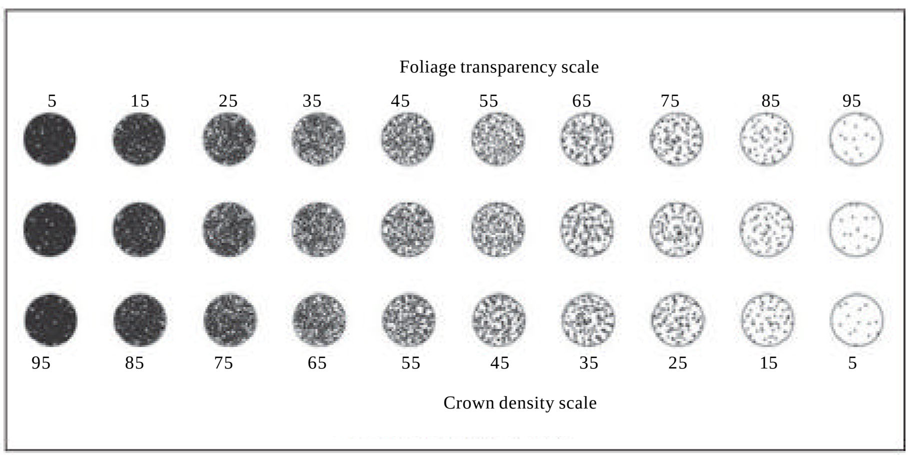

Fig. 2: Card used to evaluate the variables of the crown condition indicator: crown density and foliage transparency. Taken from FIA (2012)

Species were identified using photographs and books on the subject. The variables of the crown condition indicator were crown density (dnc), crown dieback (mr) and foliage transparency (trpf). The dnc estimates the amount of branches in the treetop, foliage and reproductive structures that block the light that travels through the treetop, considering that every species has a normal top that varies with the place, genetics, damage to the tree and others; also, the tree's silhouette was established, projecting a complete mirror image around the central axis of the main trunk, based on the tree's natural shape, including missing or dead tips. The trpf variable was registered by estimating the percentage of live foliage that allows the passage of light, considering that this value varies if the tree has undergone defoliation due to stress or recent damage, particularly in urban areas. In this case, the foliage of parasite plants was excluded, along with dead branches in the lower area of the live crown, missing branches or areas with no foliage. These two variables were evaluated using the card designed by the FIA (2012) (Fig. 2). The variable mr was evaluated as recent mortality of branches with small shoots beginning in the terminal portion of the branch and internally towards the trunk. The percentual increases (5%) were registered for the three variables (on a scale of 0-100). The distance of evaluation of the tree was between half and once the total length of the tree, for a better view of the crown (FIA, 2012; INFyS, 2012; Randolph, 2006, 2007).

Data analysis: Normality tests were carried out to find the distribution of data: Kolmogorov-Smirnov (if n_{obs} = 2000) and Shapiro Wilk (if $n_{obs} \leq 2000$) both tests with an $\alpha = 0.05$. The data obtained in the collection of samples were analyzed for frequency distribution, descriptive statistics, dispersion measures and box plots. A variance analysis and comparison of means were carried out to find significant differences in the values taken from the three variables of the indicator in the parks. A non-parametric Kruskal-Walis analysis was carried out for n independent samples (with an $\alpha = 0.05$) to contrast the values of the main species identified. The groups of data were analyzed statistically, considering that trees with values of dnc = 0%; mr = 100% and trpf = 100% can be defined as having no crown and therefore were omitted from the analysis (Randolph, 2006). The SAS® statistical package was used in versions 9.0 and 9.3, along with SPSS® for Windows version 15.0.

RESULTS

Identification of species: In Alameda Oriente, the species with the highest relative frequencies were *Casuarina equisetifolia* and *Eucalyptus camaldulensis* (Table 1), which predominated in areas with trees and windbreakers in the perimeters of the parks. In Alameda Sur an abundance of broadleaves was recorded, with a high relative frequency of *F. uhdei* (Table 1). Alameda Sur presented a greater diversity of species in the sample than Alamedas Norte and Oriente. In Alameda Norte, *Cupressus lusitanica* var. *lindleyi* was the species with the highest relative frequency (Table 1). Other genera that stood out were *Pinus* and *Eucalyptus*. A high population density problem was found in sections of this park, which limited the adequate growth of some

Table 1: Relative frequencies of main species identified in alamedas of Mexico DF in 2011

	Alameda Norte-Azcapotzalco		Alameda Oriente-Iztacalco		Alameda Sur-Coyoacan	
Species	Absolute frequency (Fi)	Relative frequency (Fri)	Absolute frequency (Fi)	Relative frequency (Fri)	Absolute frequency (Fi)	Relative frequency (Fri)
Eucalyptus globulus	0	0.00	0	0.00	41	18.30
E. camaldulensis	72	14.60	36	14.36	0	0.00
Acer negundo	0	0.00	0	0.00	29	12.72
Fraxinus uhdei	61	12.32	1	0.40	50	22.21
Populus alba	2	0.46	0	0.00	4	1.79
Populus tremuloides	10	1.98	3	1.00	1	0.45
Cupressus lindleyi	139	28.09	0	0.00	5	2.34
Cupressus sempervirens	1	0.20	0	0.00	12	5.36
Ulmus parvifolia	1	0.20	6	2.31	6	2.57
Ligustrum lucidum	40	8.11	0	0.00	18	8.15
Pinus sp.	51	10.34	0	0.00	0	0.00
Several species	36	7.20	2	0.80	19	8.37
Casuarina equisetifolia	27	5.48	186	74.60	0	0.00
Dead trees	54	11.00	16	6.53	40	17.75
Total	493	100.00	249	100.00	224	100.00

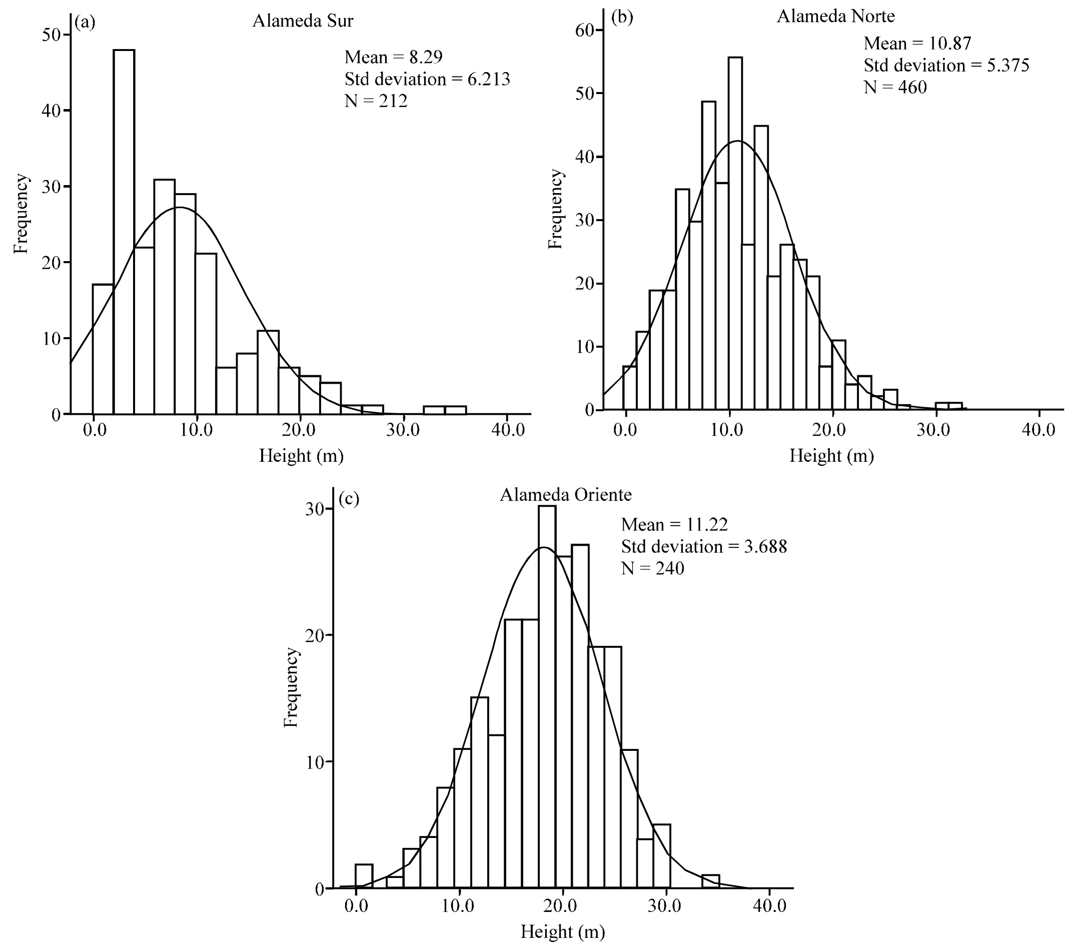

Fig. 3: Tree height distribution in parks of Mexico City DF

trees. This feature helped to set a crown classification into dominant, intermediate and suppressed trees, which could be related to the values of the variables of the indicator (Fig. 3). In Alamedas Sur and Norte, a removal of specimens registered in the first sampling was observed due to damage caused by parasite plants and local management practices in the sites.

Crown condition: The Kolmogorov-Smirnov tests were applied to the entire set of data to analyze their distribution, also, the Shapiro-Wilk test was applied to every set of data per species identified. The null hypothesis, (H_0) = data is distributed normally, was rejected in both tests for the three variables analyzed (dnc, mr and trpf), for every species identified. There was much variation in the kurtosis values for the three indicators (Table 2) for every species. *C. equisetifolia* had a much higher crown dieback kurtosis (29.42) than those of the rest of the species whose values were relatively low. In contrast, foliage transparency kurtosis was higher for *Ligustrum lucidum*. The KS test for normality by species group was rejected for all of the identified species ($p<0.01$); but the Q-Q plots indicate that the conclusion of nonnormailty is appropriate for the three variables (Fig. 4).

The crown condition indicator was evaluated in 12 outstanding species in the total sample of the three parks. Species identified with a lower presence (less than or equal to five specimens per

Table 2: Descriptive statistics for each species identified in three parks of Mexico City DF

Species	N	Mean	Standard deviation	Median	Minimum	Maximum	Kurtosis	Skewness
Eucalyptus globulus								
dnc	41	49.48	9.98	50.00	27.50	67.50	0.10	-0.27
mr	41	8.26	6.16	8.75	0.00	30.00	5.65	1.51
trpf	41	50.00	9.40	50.00	30.00	70.00	0.64	0.80
Eucalyptus camaldulensis								
dnc	108	47.54	10.00	47.50	17.50	65.00	1.46	-0.71
mr	108	10.88	15.70	4.38	0.00	63.13	5.29	1.95
trpf	108	54.39	9.98	53.75	35.00	80.63	1.32	0.39
Acer negundo								
dnc	29	39.27	15.50	43.13	10.00	62.50	-0.55	-0.38
mr	29	15.04	21.07	8.13	0.00	81.25	4.34	2.13
trpf	29	63.05	14.48	62.50	38.75	90.00	-0.69	0.19
Fraxinus uhdei								
dnc	112	48.50	11.50	50.83	29.58	62.08	0.79	-0.65
mr	112	5.09	10.43	1.25	0.42	33.33	8.18	2.55
trpf	112	47.90	10.73	52.08	39.17	72.08	1.95	0.85
Populus alba								
dnc	6	45.88	8.77	55.00	40.63	57.50	-1.15	-0.87
mr	6	8.66	6.35	5.63	3.13	15.00	0.13	1.20
trpf	6	46.15	8.23	48.75	44.38	60.63	-0.07	0.57
Populus tremuloides								
dnc	13	37.14	16.41	36.04	24.17	47.92	-0.41	-0.39
mr	13	30.54	40.86	38.13	2.08	58.33	-1.47	0.00
trpf	13	59.82	16.80	60.83	50.00	75.00	-0.59	0.46
Cupressus lindleyi								
dnc	144	47.64	9.03	55.00	29.38	65.00	1.55	-1.09
mr	144	7.72	10.04	3.75	0.00	43.13	3.64	1.90
trpf	144	41.30	7.79	43.13	34.38	65.00	1.65	0.68
Cupressus sempervirens								
dnc	13	62.19	15.56	70.94	51.25	75.63	0.50	-1.06
mr	13	3.75	0.00	3.75	3.75	3.75	0.00	0.00
trpf	13	29.33	17.24	27.81	22.50	49.38	0.87	1.03
Ulmus parvifolia								
dnc	13	45.52	9.08	49.58	40.42	55.83	0.88	-0.38
mr	13	10.22	4.88	8.96	7.92	15.42	0.58	0.99
trpf	13	49.56	8.05	52.50	46.67	60.83	0.97	0.62
Ligustrum lucidum								
dnc	58	50.51	9.80	55.31	33.13	68.75	0.48	-0.43
mr	58	8.13	12.27	0.00	0.00	43.13	5.30	2.25
trpf	58	43.62	8.92	49.38	33.75	70.00	2.89	0.47
***Pinus* sp.**								
dnc	51	42.94	8.15	42.50	26.25	56.25	-0.63	-0.26
mr	51	26.13	21.38	19.38	0.00	77.50	0.37	0.93
trpf	51	54.80	7.75	55.63	41.25	75.00	0.05	0.33
Casuarina equisetifolia								
dnc	213	51.01	9.27	52.50	20.63	70.63	1.45	-0.59
mr	213	2.62	7.50	0.00	0.00	52.50	29.42	4.76
trpf	213	50.99	9.02	48.75	27.50	76.88	0.82	0.36

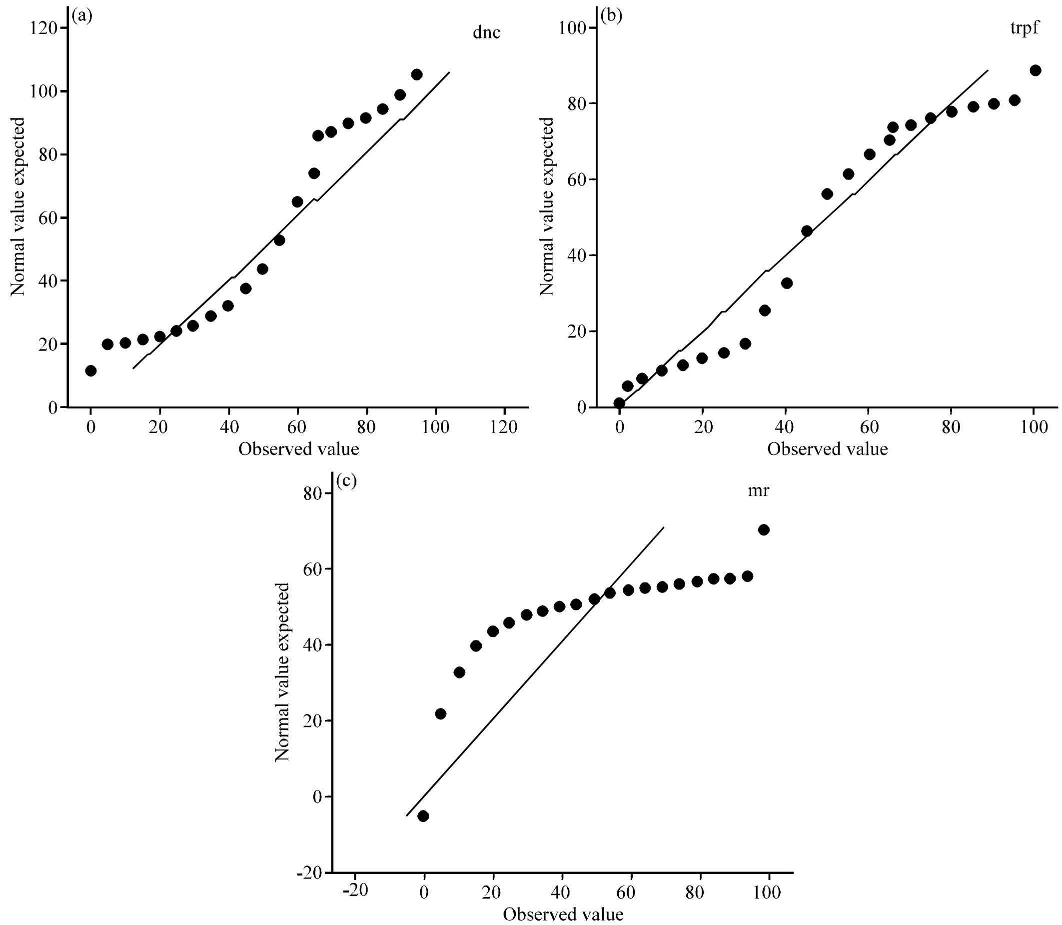

Fig. 4: Q-Q normal probability plots for the three variables of the crown condition indicator

park) were grouped in the number 12 category (several species) for their analysis, whilst number 14 category corresponded to death or removed trees throughout the sampling period.

The species with the highest values for the variables of the crown condition indicator were *C. equisetifolia* with a median for dnc of 55%; *C. lusitanica* var. *lindleyi*, with a value of 55%; *E. globulus*, with 52.5%; *E. camaldulensis*, with 50% and *F. uhdei* with 50% (Fig. 5). Variable trpf presented higher values than variable dnc, since many of the trees in each category per species had scarce canopies or canopies affected by an external stress factor such as intense trimming, removal of branches due to vandalism or damage due mostly to parasite plants. Among the species with high values for trpf were *Populus tremuloides* with a median of 65%, *A. negundo* with 60% and *Ulmus parvifolia* with 50% (Fig. 6). In the sample, these species were severely affected by parasite plants in Alamedas Norte and Sur, which was reflected in the high trpf values.

High values for mr were interpreted as a poor general health condition of the trees (in contrast to high values for dnc) (Randolph, 2006). Therefore, the species *Populus tremuloides* with a value of 50%; *Pinus* sp. with 20% and *C. lusitanica* var. *lindleyi* and *A. negundo*, both with 5% were considered to be in the poorest health conditions (Fig. 7). The species with the highest values for dnc (with 82.5%) and the lowest values for mr and trpf (with 0 and 20%, respectively) was *Cupressus sempervirens*.

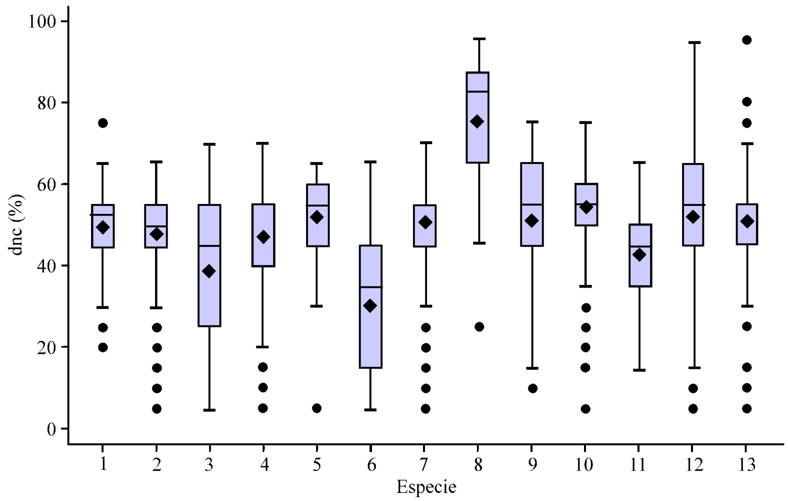

Fig. 5: Percentages obtained for crown density (dnc) variable in identified species in alamedas of Mexico DF in 2011, Where: 1: *Eucalyptus globulus*; 2: *E. camaldulensis*; 3: *Acer negundo*; 4: *Fraxinus uhdei*; 5: *Populus alba*; 6: *P. tremuloides*; 7: *Cupressus lusitanica* var. *lindleyi*; 8: *C. sempervirens*; 9: *Ulmus parvifolia*; 10: *Ligustrum lucidum*; 11: *Pinus* sp.; 12: Several species; 13: *Casuarina equisetifolia*

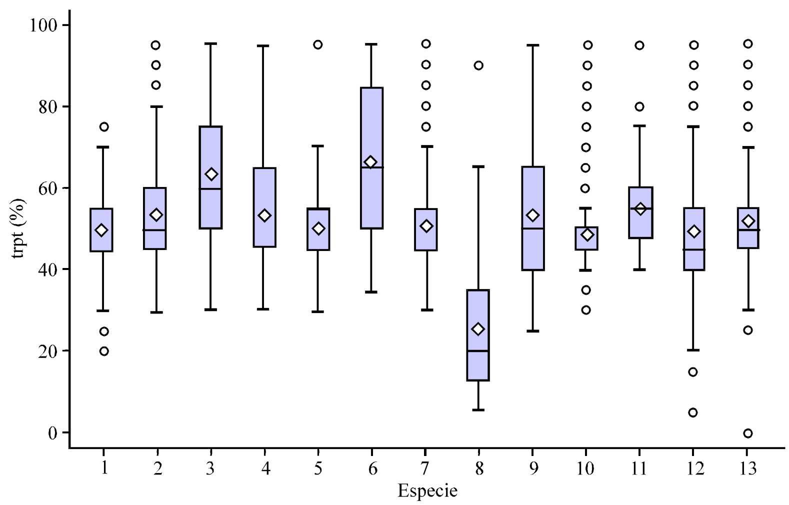

Fig. 6: Percentages obtained for foliage transparency (trpf) variable in identified species in Alamedas of Mexico DF in 2011, Where: 1: *Eucalyptus globulus*, 2: *E. camaldulensis*, 3: *Acer negundo*, 4: *Fraxinus uhdei*, 5: *Populus alba*, 6: *P. tremuloides*, 7: *Cupressus lusitanica* var. *lindleyi*, 8: *C. sempervirens*, 9: *Ulmus parvifolia*, 10: *Ligustrum lucidum*, 11: *Pinus* sp., 12: Several species and 13: *Casuarina equisetifolia*

Comparison of the crown condition indicator using the Kruskal-Wallis test: For this analysis 13 of the 14 grouping categories were taken, since the last one corresponded to dead trees standing at the end of the sampling period. To compare more than two independent samples, the Kruskal-Wallis test was recommended, after discovering that the data were not normally distributed (with the Kolmogorov-Smirnov and Shapiro-Wilk tests results). The null hypothesis (H_0)

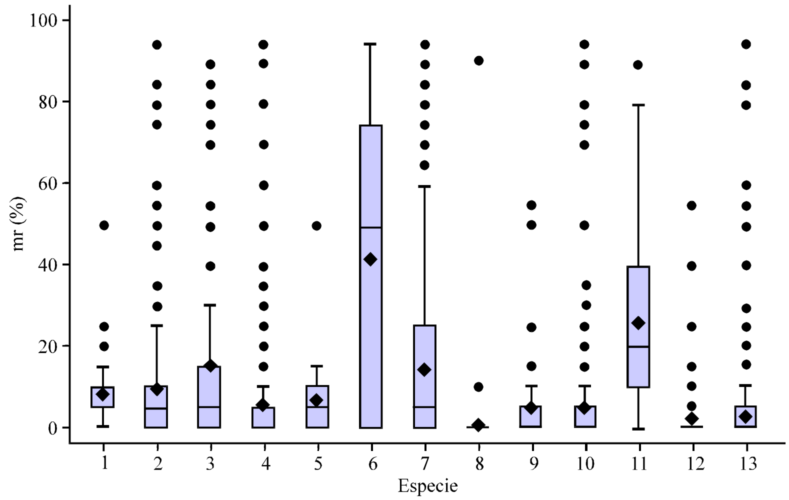

Fig. 7: Percentages for crown dieback (mr) variable in identified species in Alamedas of Mexico DF in 2011. Where: 1: *Eucalyptus globulus*, 2: *E. camaldulensis*, 3: *Acer negundo*, 4: *Fraxinus uhdei*, 5: *Populus alba*, 6: *P. tremuloides*, 7: *Cupressus lusitanica* var. *lindleyi*, 8: *C. sempervirens*, 9: *Ulmus parvifolia*, 10: *Ligustrum lucidum*, 11: *Pinus* sp., 12: Several species and 13: *Casuarina equisetifolia*

Table 3: Results of the Kruskal-Wallis test by group category: Species identified

	Kruskal-Wallis test[a]		
Factors [b]	dnc	mr	trpf
Chi-squared	365.962	822.751	292.49
Degrees of freedom	12	12	12
Asymptotic Sig.	0.000	0.000	0.000

A level of significance $\alpha = 0.05$, [b]where, dnc: Crown density; mr: Crown dieback and trpf: Foliage transparency

indicated that the values of the medians in the three variables of the crown condition indicator were statistically similar for each identified category, with no influence from the sampling site, that is: $H_0 = \theta_{esp1sitio1} = \theta_{esp2sitio1} = ... = \theta_{esp^n sitio^n}$, whereas the alternate hypothesis (H_a) indicated that there were differences for each identified category, with no influence from the sampling site. After performing the test, the value of significance (asymptotic significance) for each variable was lower than 0.0001, less than the significance value established for $\alpha = 0.05$, therefore rejecting the null hypothesis (H_0), which was interpreted as the values of the three variables of the crown condition indicator for each group of species identified were statistically different and there could be an influence of the sampling site where each one developed (Table 3 and 4).

DISCUSSION

The distribution of frequencies obtained varied due to the maintenance programs of the delegaciones, or boroughs, which included plans to remove diseased or damaged trees, as well as modifications in the infrastructure of the parks due to maintenance and improvement. Two of the species with the highest relative frequencies, *C. equisetifolia* and *E. camaldulensis* were widely used in earlier years, since they were considered excellent options for rural and urban reforestation,

Table 4:. Average ranges obtained of the Kruskal-Wallis test by group category: Species identified

Variable[a]	Species	N	Average range[b]
dnc	*Eucalyptus globulus*	164	1694.63
	E. camaldulensis	432	1590.40
	Acer negundo	114	1189.30
	Fraxinus uhdei	451	1588.65
	Populus alba	25	2054.50
	Populus tremuloides	53	727.63
	Cupressus lindleyi	575	1806.14
	Cupressus sempervirens	52	3057.07
	Ulmus parvifolia	52	1896.52
	Ligustrum lucidum	234	2132.86
	Pinus sp.	208	1090.05
	Several species	226	1968.73
	Casuarina equisetifolia	851	1803.02
mr	*Eucalyptus globulus*	164	2213.20
	E. camaldulensis	432	1950.07
	Acer negundo	114	2170.70
	Fraxinus uhdei	451	1551.69
	Populus alba	25	1757.50
	Populus tremuloides	53	2516.52
	Cupressus lindleyi	575	2051.06
	Cupressus sempervirens	52	983.04
	Ulmus parvifolia	52	1512.03
	Ligustrum lucidum	234	1460.37
	Pinus sp.	208	2750.42
	Several species	226	1183.98
	Casuarina equisetifolia	851	1278.18
trpf	*Eucalyptus globulus*	164	1613.91
	E. camaldulensis	432	1836.02
	Acer negundo	114	2410.00
	Fraxinus uhdei	451	1810.64
	Populus alba	25	1511.96
	Populus tremuloides	53	2478.70
	Cupressus lindleyi	575	1559.56
	Cupressus sempervirens	52	351.56
	Ulmus parvifolia	52	1735.73
	Ligustrum lucidum	234	1388.06
	Pinus sp.	208	2079.67
	Several species	226	1524.89
	Casuarina equisetifolia	851	1742.15

[a]where, dnc: Crown density; mr: Crown dieback and trpf: Foliage transparency, [b]Outstanding values in bold

due to their fast growth. *C. equisetifolia* is an atmospheric nitrogen-fixating tree, whose use as a windbreaker was proven as effective in several areas of the city and its characteristics have allowed it to survive and grow in very adverse conditions (Valdes *et al*., 2004). These species were introduced and used to counteract against the harmful effects of deforestation and soil degradation, which explains why it was so common to see this species as part of the city landscape. Common ash (*F. uhdei*) is one of the most distributed species in parks within Mexico City and it was widely identified in Alameda Sur. Chacalo and Corona (2009) indicated that 6% of the total of species inventoried in Mexico DF are *F. uhdei*, *Jacaranda mimosaefolia*, *Erythrina coralloides*, *Eucalyptus* sp., *Ulmus parvifolia* and *C. equisetifolia* which speaks of a poor diversity and particularly, of the presence of species that are not native of the country. *F. uhdei* is a native Mexican species considered easily adaptable, quick growing and an excellent option for the recovery of degraded soils (CONABIO, 2011a) and that is why it is widely distributed in Mexico City. On the other hand, *C. lusitanica* var. *lindleyi* was the species with the highest relative frequency in Alameda Norte (Table 1); this species has been considered helpful in controlling erosion and preserving soils, as well as a good wind breaker (CONABIO, 2011b), making it a common species in the city. As a part of the improvement programs of the Delegacion Iztacalco, open spaces in Alameda Oriente have been filled with new sets of trees and more infrastructures for users (GDF, 2012b), without affecting the existing forested areas in the park. Establishment and the continual removal of new arboreal specimens explained the difference between height and crown classification (dominant, intermediate and suppressed) found in every one of the parks (Fig. 3). In urban conditions, the gap between crown classifications is not only related to the age of trees but also to site conditions and maintenance practices. Sometimes, interferences with power lines or buildings lead to the inadequate pruning, affecting directly the health and appearance of the trees. For that reason, it is important to design future plantations considering the natural shape and potential growth of the trees (Chacalo *et al*., 1994). According to the crown classification obtained, in the three Alamedas the highest frequency corresponded to intermediate trees due to the constant removal of damaged trees of larger size and higher density plantations.

For this type of data, the median tends to be more appropriate than the statistical mean for interpreting the behavior of the variables after proving there is a non-normal distribution and that there is both positive and negative skewness of data (after observing extreme values) that could influence the mean of the sample. The median is the mid-point or 50% mark, of which half of the observations of the sample are below and half are above (Schomaker *et al*., 2007). The data summarized for the median indicated that the dnc variable varies by species. At the species level, the range in average dnc was 34.9%, from 36.04% for *P. tremuloides* to 70.94% for *C. sempervirens* (Table 2). Such great variability inhibits direct comparisons of species because some species clearly tend to have denser crowns than others. Interspecies variability also complicates individual park-level analyses in which species are combined to calculate plot averages. One way to accommodate the species (and stand condition) influences is stratification, by grouping together sets of homogeneous observations and making comparisons only among those sets, which would reduce variation in descriptive statistics but it does not necessarily facilitate further inferential analyses (Randolph, 2006; Schomaker *et al*., 2007). In the evaluation of the three crown condition variables, one limitation was the perception of the evaluator regarding what was considered the natural shape of the tree, which largely depends on the season of the year and the species (deciduous or perennial). Occasionally, the sides of trees, or the tips of the crown were not simultaneously visible (overlapping canopies in areas with high population densities), such as in Alameda Norte for the genus *Pinus*, where trees requiring more space for their optimum development survive in reduced spaces, which modified the development of its foliage and therefore the values registered for the variables dnc and trpf. The extreme values for the variables showed that there were forest specimens with age heterogeneity, differences in their capacity of adapting to the area's conditions (water stress, variations in the environmental temperature, high levels of pollutants, scarce or no fertilization, attack of pests and diseases) and a major influence of the maintenance program of each park. Factors that changed the perception of the value of dnc was the increase in the trees' growth following the removal and death of neighboring trees, or the recovery of the tree after a severe defoliation due to some stressing factor. In Alameda Sur, *Acer negundo* specimens sampled underwent sanitary trimmings as a part of improvement programs in each borough, where the specimens most affected by the presence of parasite plants were removed (and the changes between first and last sampling were registered), which reflected on the variation for dnc in this species. However, the crown density tended to drop in time, as a result of competition and the age of the tree; stress and the lack of nutrients and water lead to the trees losing branches, thus leaving spaces in the live canopy of each specimen, not allowing an adequate growth of new foliar sprouts; breakage of branches may also occurred due to vandalism or atypical weather phenomena (FIA, 2012; Schomaker *et al.*, 2007), which are very common in urban areas of Mexico DF, where the flow of people increases most on weekends and holidays and the weather is highly variable during rainy season (SMN, 2013).

Individually, the percentages of dnc were relatively low, although it is important to consider that many of the registered specimens had little vital space to grow its canopy in an optimum way, unlike species such as *C. equisetifolia* in Alameda Oriente, that had larger growth spaces; or the species of the genus *Eucalyptus*, that even in limiting conditions can easily adapt to soils that are poor in nutrients and survive prolonged drought periods, which was reflected on the values of the variable. In Alameda Norte, *C. lusitanica*, a species considered as having little tolerance to shades, registered low values for the variable, probably because most of the specimens were suppressed by taller species and they also presented loss of leaves in the lower parts of the crown. When considering the type of tree and its behavior during the sampling period, there was the case of *F. uhdei,* a deciduous tree, which displayed variations in the values for the variable dnc throughout the sampling year (CONABIO, 2011a, b; Rodriguez and Cohen, 2003). In studies on *Picea abies*, the crown condition was calculated using the parameters of defoliation and discoloring, grouping the variables by factors that have a direct effect, such as systematic methodological influences and anthropogenic and natural factors (for example tree age) (Mues and Fischer, 2001). In urban environments, these factors did apply but with restrictions. There was a relation between defoliation due to age and a geographical area in which the species develops, such as *Picea abies* in Europe, although in the alamedas of Mexico DF there was a relation between each variable of the indicator, the season of sampling, the species involved and its level of adaptation to urban conditions. Species such as *F. uhdei* and *C. equisetifolia* in good general crown condition and a wide distribution in Mexico City, were used mostly due to their tolerance to pollution, with a low level of susceptibility to ozone, since they could hold suspended particles and dust in their foliage but they also adapted to low levels of humidity in the soil and prolonged droughts (CONABIO, 2011b; Rodriguez and Cohen, 2003; Garcia *et al.*, 2010; Valdes *et al.*, 2004).

In species of the genus *Eucalyptus*, trpf values were related more to the opening of branches in the canopy, which allowed a greater penetration of light through the foliage. In general, the average trpf value in healthy trees is typical of the genus and species in question (Schomaker *et al.*, 2007). Inside the Alamedas the species belonging to the genera *Eucalyptus* and *Pinus* tended to develop in unsuitable conditions for an optimum crown and foliage status. High plantation densities lead to a noticeable decline in the growth space of each tree, which was a clear example of less-than-optimum conditions frequent in cities. On the other hand, there were species such as *F. uhdei* that displayed a natural defoliation throughout the year and have greater possibilities of being affected by foliage diseases brought about by the stressful conditions of the city, which could also modify the values of variable trpf throughout the growth season.

For the mr variable, *P. tremuloides* and *A. negundo*, in Alamedas Norte and Sur, registered a greater number of specimens affected by parasite plants, a factor that has started to be a severe problem in trees of Mexico City (Alvarado, 2012; GDF, 2012c). Also, *C. lusitanica* specimens, with high values for mr, had little space for growth and scarce light, mostly in Alameda Norte. The mr value can be used as an early indicator of loss of vitality and potential growth in response to damages or severe stress (Schomaker *et al*., 2007). A high mr value could indicate the presence of one or more factors affecting directly the growth and development of the tree foliage. Likewise, high mr values might have been a result of normal processes of the trees, such as an excessive seed production and they could not necessarily indicate an abnormal condition in them; furthermore, trees could not present crown dieback, unless they are in a severe declination process due to stress factors (Schomaker *et al*., 2007). Specimens of the genus *Pinus* in Alameda Norte registered higher mr values than the rest of the identified species, which could be a clear sign of severe stress such as reduction of the growth space. According to data obtained, *P. tremuloides* was the species most affected by the conditions of the site in the Alamedas of Mexico City, with the highest mr values and the lowest dnc values, as opposed to the rest of the species identified. This indicated a lower adaptation to the city's conditions. *P. tremuloides* grows best in open sunlight and in a soil with good drainage, rich in organic matter, nutrients and enough humidity. In natural areas, this species adapt to a wide range of soils and it may be tolerant to urban pollutants and to the scarce humidity in the soil. However, in Mexico City, water scarcity and high pollution levels throughout the season of growth were stress factors that contributed to the decline of this species. Furthermore, trees frequently drop twigs, yet it also regenerates its canopies once the stress factors are reduced or eliminated, or with each new growth period, which would explain the variations in the values of the variable mr in some of the identified species throughout the sampling period. Small and scarce crowns usually indicate unfavorable conditions of the area (USDA-NRCS, 2013; PAOT, 2010).

The changes in the tree canopies may be temporary, especially when stress conditions are eliminated or reduced, yet the poor site conditions were eventually reflected in the crowns, relating low dnc values with a reduction in growth, in comparison with trees with symmetrical and complete canopies (Randolph, 2006). In Mexico City there is a high competition level between trees, due to inadequate plantation designs; water stress, little water availability; excessive humidity caused by atypical weather phenomena; natural defoliation of trees and defoliation by insects and foliage diseases (FIA, 2012). Then, it is expected that trees with more foliage have greater potential for growth, reproduction, vitality and survival (particularly in urban environments) than a tree of the same species with less foliage. If low values for the variable dnc were related to the loss of vigor and growth potential, a tree could be considered as having a regular to poor health condition when it shows important and persistent losses of foliage in consecutive samplings, as well as high values for variables mr and trpf, as was the case with *P. tremuloides*, *A. negundo* and *C. lusitanica* specimens that lost foliage throughout the sampling, showing a reduction in values for the variable dnc and an increase for variables mr and trpf.

In the case of the specie with the highest values of dnc and lowest of mr, *C. sempervirens* adapted to low humidity conditions, is also tolerant to pollution, to low nutrient availability and to shade; likewise, the shape of its crown has been a factor for its increased use in windbreakers and its ornamental use in squares, gardens and sidewalks of the city (CONABIO, 2009). On the other hand, *C. equisetifolia* presented high dnc values and low mr values, which speaks of a great adaptation to city conditions and an overall good health condition, regardless of being a non-native species in the country and it has been also considered unattractive for landscaping and more adequate for windbreakers or for the regeneration of degraded soils. Finally, with the obtained data, *P. tremuloides* could be considered the least adapted species for city conditions, since it showed a low relative frequency, a low dnc value and a high mr value.

According to the Kruskal-Wallis test (Table 4), the species with the highest range value for the variable dnc and the lowest values for trpf and mr was *C. sempervirens*, found in Alamedas Sur and Norte. It means that this species developed in an optimal way, regardless of stress conditions, so common in Mexico DF. Likewise, the species with the lowest range values for variable dnc and highest for variable trpf was *P. tremuloides*, which was found in the three Alamedas. Meanwhile, the genus *Pinus*, identified in Alameda Norte, had the highest range value for variable mr, which means that this genus was more vulnerable to the poor site conditions in the park. Thresholds for the best general health condition were set as the following: dnc values of 10 to 20% would be considered as a poor crown condition; values of 25 to 50% would be considered as average crown condition and finally values of 55-100% would be classified as good crown condition (Randolph, 2006). Considering these classification at least 7 out of the 12 main species identified in the Alamedas in Mexico City could be classified within good crown condition category. When thresholds are set, shifts of observations into the poor category over time indicate declines in forest health. Furthermore, some species might tend to have better crowns than other species but then species-specific declines could be undetected. A second limitation of using good, average and poor classes is that information in the extreme tails of the distribution is lost when the data are grouped into so few categories. In urban conditions, the dynamics of the forest are subdued to several maintenance and management practices, which makes more difficult to keep track of each species throughout the growth season.

CONCLUSION

The general health condition in the identified species in Alamedas of Mexico DF can be considered from poor to average but it certainly depends on the species. There are species with a higher risk of declination and removal, which will reduce the diversity of species in the three parks. The variation in the values of the three variables show that trees have developed mechanisms to adapt to stressful conditions, which have helped them to survive with acceptable crown densities in order to carry out their processes of photosynthesis and respiration. However, in urban conditions a greater sampling frequency (a more concise follow-up) is required to accurately find the moment of changes in the values of all three variables for the different species.

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