

Integration of Ecological Indices in the Multivariate Evaluation of an Urban Inventory of Street Trees

J. Grabinsky, A. Aldama, A. Chacalo, and H.J. Vázquez

Abstract.—Inventory data of Mexico City's street trees were studied using classical statistical, arboricultural and ecological statistical approaches. Multivariate techniques were applied to both. Results did not differ substantially and were complementary. It was possible to reduce inventory data and to group species, boroughs, blocks, and variables.

Urban areas are increasing at a fast pace. In developed countries they can cover even more than the rural share of a state's surface (Endress 1990). The advantages of and desires for urban forested areas are well documented and even recommended. Several international organizations, including the United Nations and the Interamerican Development Bank (Nilsson *et al.* 1996, Sorensen 1996) have shown great interest in developing street trees, forested areas, and parks in cities. There have been big loans and expenditures for planting campaigns and maintenance, with public acceptance.

Mexico City, which has become one of the biggest urban areas in the world, invests many resources each year in its trees, public and private. However, few and not very adequate studies have preceded or influenced the planting campaigns and maintenance operations. From 1993 to 1994, an inventory by sampling of Mexico City's street trees was conducted, and the results were presented to city authorities and to the arboricultural scientific community.

Inventories by sampling should have statistical validity to infer characteristics about populations. To evaluate and unify concepts, an adequate set of descriptors must be constructed and these must have statistical validity to infer characteristics of the whole forest. The goal of this article is to present results with this aim, integrating the points of view of urban arborists and natural ecologists.

URBAN AND NATURAL FOREST INVENTORIES

It is not common to use ecological statistical modeling techniques in urban forest inventories, but the use of statistical indices in natural forests and ecology is well

established (Ludwig and Reynolds 1988). Some attempts to translate these ideas and methodologies to the more complex urban settings have been made; for example, the concepts linked with "sustainable forest" (Clark *et al.* 1997). Multivariate techniques have been used to describe and to classify urban areas (Moll 1989, Sanders 1984).

Fewer published papers exist on the dynamics of urban forests or "street tree forests." The human side of this might be a deterrent on the usual natural diffusion processes and on the self-regulatory characteristics of the natural systems (Clark *et al.* 1997, Richards 1993).

Many aspects of the possible "optimal urban forest" have not been adequately identified and even less well managed; this is not surprising given, among other factors, the "short tenure of the administrators" (Richards 1993).

In the present state of the art in urban arboriculture, these formal mathematical and statistical approaches seem very difficult to follow. Nonetheless, some studies have been conducted to define guidelines to evaluate and manage urban systems (Richards 1993). Such guidelines may come from the adoption of a robust and very well chosen set of indices to identify decisive properties of the urban trees. Some of these characteristics are density, age distribution, species diversity, quality of planting sites (studied from the economical, geographical, biological, and edaphological points of view) and sanitary conditions. As mentioned before, some attempts have been made in urban arboriculture to evaluate these characteristics quantitatively, but the results have not been generally approved.

In natural ecology, the experience is much more extensive. Different indices exist to evaluate some properties such as *spatial distribution*, *diversity*, and *interspecific association* (Ludwig and Reynolds 1988):

- **Spatial distribution** is evaluated using the Index of dispersion (**ID** defined as sample variance over sample mean), **Green's Index**, and the relation between the

Professor, Departamento de Ciencias Básicas; Professor, Departamento de Sistemas; Professor, Departamento de Energía; Professor, Departamento de Sistemas, respectively, Universidad Autónoma Metropolitana, Ave. San Pablo 180, Col. Reynosa Tamaulipas, 02200 Mexico D.F. Mexico.

observed species histogram and typical species distributions.

- **Species diversity is assessed in terms of** two distinct components: (1) abundance and (2) evenness. Abundance, number of species, is evaluated by indices such as **N0** the number of all species in the sample, **N1** related to the number of "abundant" species in the sample, **N2** related to the number of "very abundant" species. For evenness, different indices have been proposed, one of the most useful is the modified Hill's ratio: $E5 = ((N2-1)/(N1-1))$; (Ludwig and Reynolds 1988).
- **Interspecific association**, "how frequently" two species are found in the same location, is measured with the Jacard index, based on presence-absence matrices per block.

RESULTS OF MEXICO CITY'S STREET TREES INVENTORY

The inventory was done following accepted practices in urban ecology. Sixty-two variables and 1,260 trees were studied. Some of the main variables were height, diameter at a certain height, species, location, structure, wounds, interferences, dendrological characteristics, sanitary conditions, soil compaction, and sidewalk width (Chacalo *et al.* 1994).

Univariate and Bivariate Study

Broad main univariate and bivariate results were (Chacalo *et al.* 1994, 1996):

- Only eight species (dominant species described in table 2) had more than 5 percent of the individuals in the sample. In some boroughs two or three species accounted for the vast majority of the trees present in them.
- General Condition of the tree and Site Evaluation were significantly associated by borough, by blocks, by species, and in the whole sample as well.
- Plenty of damages and injuries were present in the trees. Vandalism was widespread.
- An average of 36.4 trees per block was calculated for the 866 blocks sampled.
- Maintenance was unsatisfactory, pruning was inadequate; earth and dead-tree removals were needed; too many interferences such as electric and telephone lines or other trees were present.
- Spatial distribution showed strong differences between boroughs in species and in number of trees in streets.
- Variety (number of species needed to account for 80 percent of the total number of individuals) in the boroughs ranged from 4 to 13.

Ecological Indices

An ecological evaluation of the sample trees in the Mexico City's urban forest using the ecological indices presented before gives the following results:

- **Spatial distribution.** The eight most dominant species are spatially clumped by borough and block.
- **ID** is greater than 1 for boroughs (ranging from 2.18 for Bluegum to 6.82 for Cedar) and close to 2 for blocks. The observed species histogram has a good fit to a **negative binomial distribution**, a probability distribution model commonly observed when a population is clumped. **Green's index** has numbers close to 0, meaning low clumpiness. This result is somehow inconsistent with **ID** and the observed species histogram. These spatial distribution results might mean weak overall (city) planning but strong local (borough) planning—not a big intervention of central or of individual planting decisions.
- **Diversity.** Ranges for the abundance values are **N0** (32–192), **N1** (5.46–16.51), **N2** (5.12–13.63); range for the evenness index **E5** is (0.59–1.11). Correlations among indices are in table 1.

The quantities obtained for the diversity indices and the evenness index are not very different from some

Table 1.—Correlation table among indices related to diversity at borough level

	N0	N1	N2	Variety	E5
N0	1.0				
N1	0.8452	1.0			
N2	0.8050	0.9505	1.0		
Variety	0.8417	0.9836	0.9305	1.0	
E5	-0.0086	0.0995	0.3817	0.0898	1.0

Table 2.—Views obtained for the multivariate study

View	Individuals	Variables
Tree	1,260	62
Species	more than 50	8 (for abundant species)
Dominant species ¹	CLR, ECL, CSR, FRS, TRN, JCR, CDR, OLM.	8
Borough	16 (official subdivisions)	6
Block	229	3

¹ Coral tree (CLR), bluegum (ECL), Australian pine (CSR), ash (FRS), privet (TRN), Brazilian rosewood (JCR), cedar (CDR), Elm (OLM).

mentioned for natural systems (Ludwig and Reynolds 1988).

- **Interspecific association.** Some slight associations between species exist: (bluegum and cedar), (bluegum and Australian pine), and (cedar and Australian pine). These were ratified with a multivariate study of the presence-absence matrices per block. Since trees in urban areas are not free to "choose" their habitats the low level of these associations is not surprising, taken in pairs or taken together.

However, this study did not make full use of the possibilities opened by the huge database, more than 75,000 entries. So, a full multivariate analysis was pursued constructing new variables and integrating ecological indices. *Among the main objectives of this study were: to reduce and select a number of significant variables, to obtain a multidimensional view, and to identify groups of variables, species, boroughs, and blocks.* For this, the database was studied under three different points of view: the tree itself, the species, and the site (borough or/and block).

Multivariate Study

A first multivariate study, using Multiple Correspondence Analyses (MCA), was done for the 1,260 trees and for different sets of variables. Some of the main results were:

No reduction in the number of included variables in the sampling could be achieved. That is, the

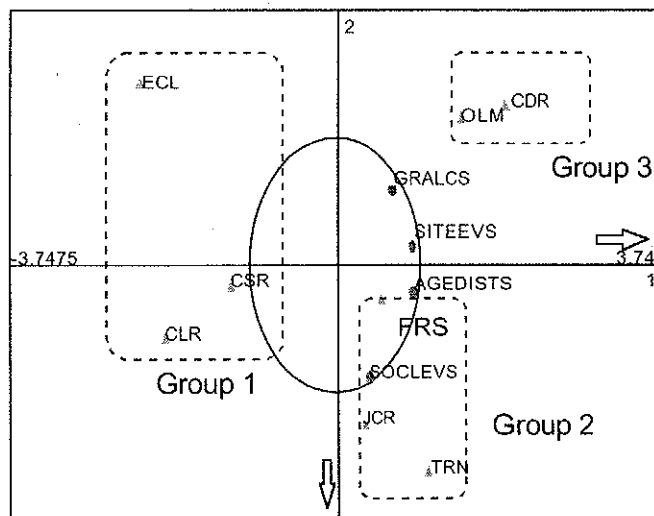


Figure 1a.

Species: Coral tree (CLR), bluegum (ECL), Australian pine (CSR), ash (FRS), privet (TRN), Brazilian rosewood (JCR), cedar (CDR), elm (OLM).

62 measured or observed characteristics of the tree and the site in which it was located, could not be grouped into a smaller set of clusters of variables. This may confirm that there were no conceptual redundancies, and that no variable could be "inferred" from other(s).

The two constructed indices General Condition and Site Evaluation were consistent with its constituent variables and correlated for all the views (block, borough, tree, species).

Concerning the other views (8 Dominant Species, 16 Boroughs, and 229 Blocks), variables and indices constructed were obtained from the 62 original variables. Our results yielded a reduction in dimensionality (high percentage of variance explained by a reduced number of variables) for these three statistical views; using Principal Component Analyses (PCA), it was possible to concentrate an important percentage of variance into two axes.

Principal Component Analyses, Cluster Analyses, and the Spearman rank test confirmed the following results:

By SPECIES, four variables were initially used: General Condition, Site Evaluation, Socioeconomic Level, and Age Distribution. Just the first two variables formed a group.

Three groups of species were detected (fig. 1a). **Group 1**, which has the worst General Condition, is located in bad sites (physically and

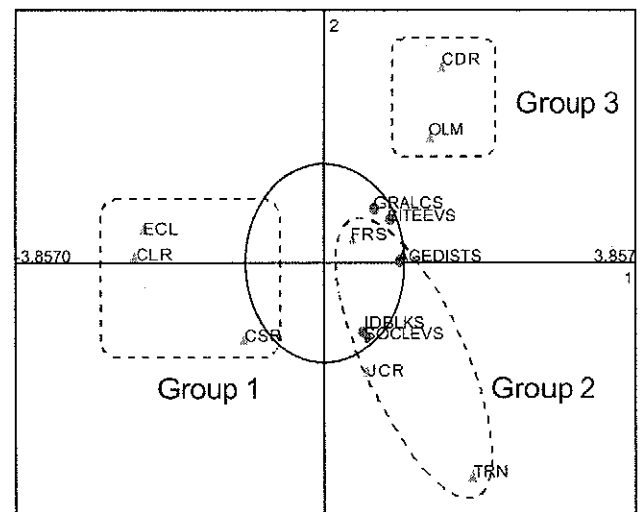


Figure 1b

Figure 1.—Principal component analysis by species.

economically) and is far from the Age Distribution used as reference. **Group 2** is located at the best Socioeconomic Levels. **Group 3** has the best General Condition and is located in the better sites. Both Groups 2 and 3 have good Age Distributions.

The axis, formed by General Condition, Site Evaluation and Age Distribution, was interpreted as a measure of **ecological quality**; the second one was just related with Socioeconomic Level.

The inclusion of ecological indices, Spatial pattern **ID** and **Green's**, did not produce, at first glance, substantial changes. The same three groups were detected. In the first two PCA axes (70.41 percent of total variance), these two indices appeared together with the variable Socioeconomic Level (fig. 1b). This was not confirmed clearly by cluster analyses; for this reason, it seemed important to consider PCA's third axis.

On the plane formed by axes 1 and 3 (66.15 percent of total variance), just two groups appeared: **Group 1**: ash (FRS), privet (TRN), Brazilian rosewood (JCR), cedar (CDR), and elm (OLM); **Group 2**: coral tree (CLR), bluegum (ECL), and Australian pine (CSR). The **ID** index

appears close to General Condition and not far from Site Evaluation; when both groups of species are superimposed, **ID** appears close to **Group 1**. This means that species in Group 1 are located in better sites, at better Socioeconomic Levels; have Good General Condition and bad Age Distribution; and are more clumped.

By **BOROUGHES**, initially six variables were used: Variety (number of species in 80 percent of the individuals), General Condition, Site Evaluation, Socioeconomic Level, Tree Density per Block, and Age Distribution.

PCA results for the first two axes are (fig. 2a):

Set 1: view General Condition-Site Evaluation as already observed on the tree view study.

Set 2: Socioeconomic Level-Tree Density per Block—more trees are found on average in richer neighborhoods.

Set 3: Variety-Age Distribution—greater Variety corresponds to better Age Distribution.

General Condition and Site Evaluation, **Set 1**, appears related with the first axis, and Variety

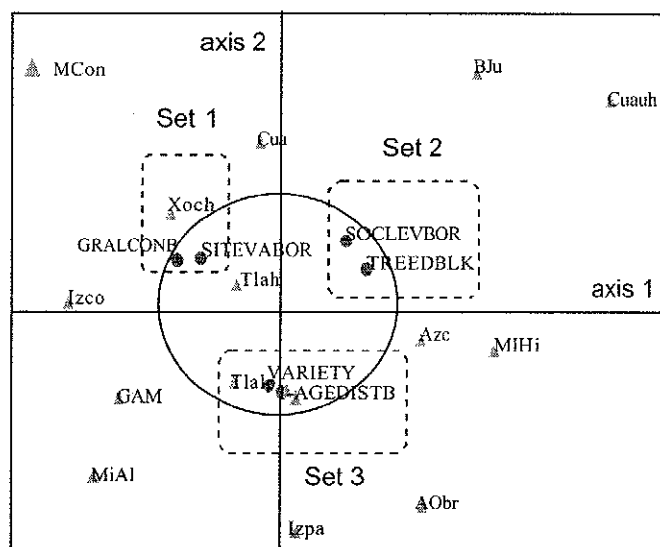


Figure 2a.

PCA (16 boroughs/6 arboricultural variables)

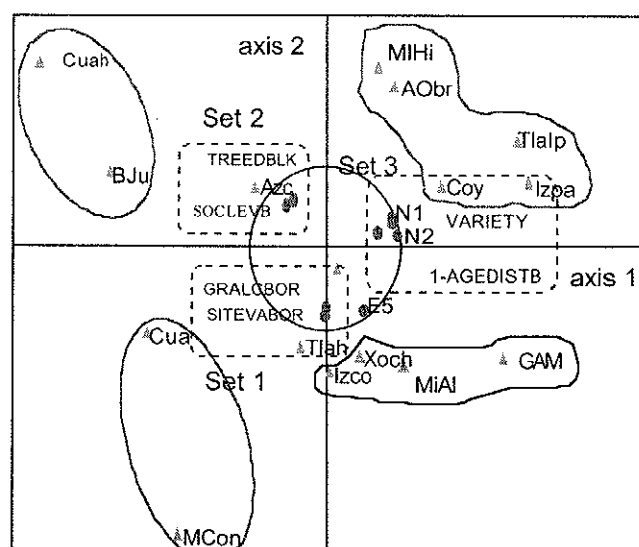


Figure 2b.

PCA (16 boroughs/ 6 arboricultural and 3 ecological variables)

Figure 2.—Principal component analysis by boroughs.

and Age Distribution, **Set 2**, appears related with the second axis. **Set 3** appears related to axis 1 and 2. Healthy boroughs characterized by good sites do not necessarily have good Socioeconomic Levels or high Tree Density.

The first axis was taken as the "*matching quality*" of specific sites and trees, while the second axis was roughly defined as an indicator of *biological* and *temporal diversity* of the forest.

PCA results (axes 1 and 2 representing 68.69 percent of total variance), with the inclusion of the abundance (**N1**, **N2**) and evenness (**E5**) indices to the initial six variables, gives the following (fig. 2b):

- The relative positions of the six initial variables did not change: **Set 1**: General Condition-Site Evaluation. **Set 2**: Socioeconomic Level-Tree Density per Block and **Set 3**: Variety-Age Distribution.
- Indices **N1** and **N2** join the **Set 3**, which is not surprising, because they are also measures of Variety.

The evenness index, **E5**, at first glance, joins **Set 1**. However, cluster analysis associates **E5** and Age Distribution. On the plane formed by axes 1 and 3 (14.35 percent of total variance), **E5** and Age Distribution appear together again. So, **E5** seems to be related with both General Condition and Age Distribution.

Evenness is better when matching quality between trees and sites increases and when abundance increases. When the 16 boroughs are superimposed with the variables on axes 1 and 2, the configuration of the boroughs does not change significantly; however, the inclusion of Evenness reduced distances inside the different groups, so they are more closely associated.

When the 16 boroughs are seen in clusters, some significant geographic patterns are detected, having to do with their distance to the older downtown areas of the city, closeness to the mountains and ravines, on the environs of the remaining lakes and forests (fig. 3c).

By **BLOCKS**, five characteristics—General Condition, Site Evaluation, Socioeconomic Level, Block Variety, and Age Distribution—are considered. For the 229 blocks studied, the two global indices, General Condition and Site

Evaluation, are seen to be grouped on the two first PCA axis (58 percent of total variance). This meaning that two axes can explain 58 percent of the information represented by the five original variables.

Block Variety and Age Distribution also appear to be grouped. Socioeconomic Level does not seem to play a role in the constitution of the first two axes. However, on axes 1 and 3 (54 percent of total variance), the 229 blocks split in two groups as a function of Socioeconomic Level.

Of the 229 blocks, 166 are in the lowest socioeconomic level and 63 in the highest. For the variables General Condition, Site Evaluation, and Block Variety, five groups are observed. This corresponds with the number of species found on each of the 229 blocks.

CONCLUSIONS

Techniques such as satellite photos, geographical information systems, and rapid sampling (Jaenson *et al.* 1992 mentioned in Richards 1983) have been used recently for characterizing urban trees. Nonetheless, we believe that this has to be complemented with a more detailed description of the urban forest, if one aspires to understand the dynamics and evaluate the actions that have been or should be taken. Such a description might include environmental, neighborhood, and individual tree information of biological, physical, edaphological, economical, geographical, and historical types. Street tree inventories and their analysis using multivariate techniques constitute an important source of information to describe the structure of the forest and how it is affected and how it should be managed to improve it.

Both points of view, urban and natural, allow a more systematic understanding of the multiple factors involved, their role, their interactions, and possible cause-effect relations. All these factors constitute a basis for developing and even defining an optimal forest for a given city. Multivariate techniques have proven to be useful in providing a solid basis for comparing and identifying criteria for management purposes.

The ecological indices in this urban database did not produce very different results from those obtained in the study of natural systems: negative binomial distribution of species and high correlation of the diversity indices.

The inclusion of the ecological indices corroborated previous multivariate results and validated their findings (Vázquez 1997). The results of both methods were complementary.

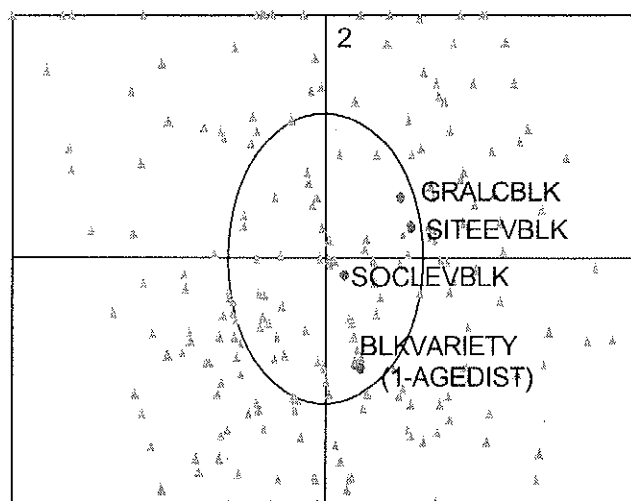


Figure 3a
PCA (8 blocks/ 5 arboricultural variables)

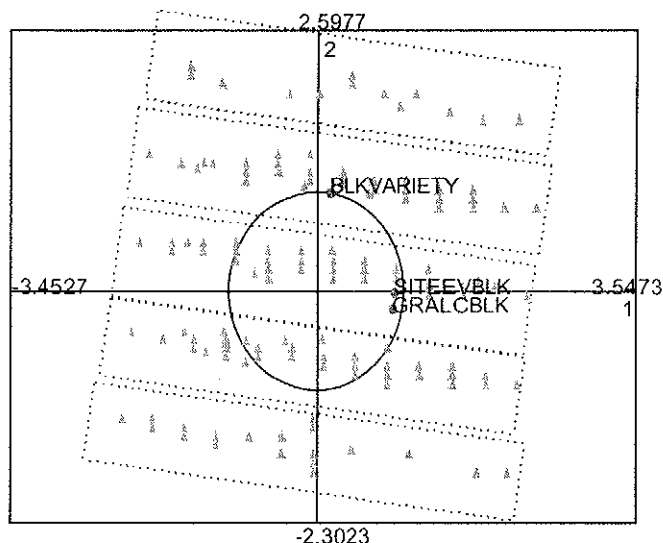


Figure 3 b
PCA (8 blocks/ 3 arboricultural).

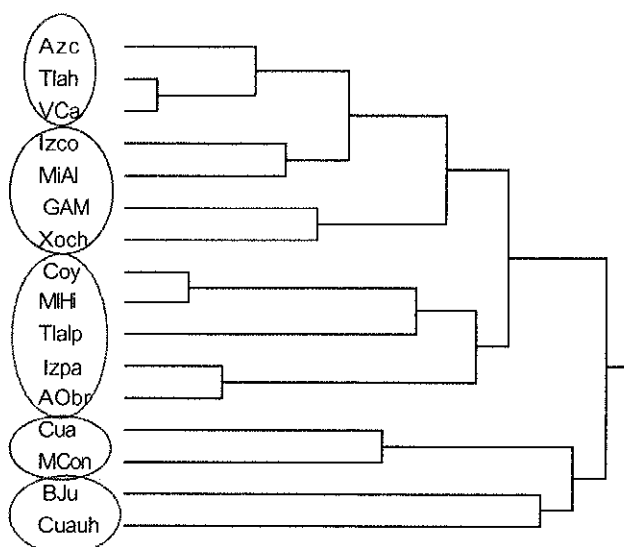


Figure 3c.
Cluster Analysis (16 boroughs/6 arboricultural
and 3 ecological variables)

16 official boroughs: AObr, MiHi, Cuauh, BJu, Azc, Izpa, MiAl, GAM, Tlalp, Tlah, Izco, Xoch, Cua, MCon, Coy, VC.

Figure 3.—Principal component analysis by blocks.

ACKNOWLEDGMENTS

The authors thank Dr. Alain Hartmann and Dr. Sophie Cliquet for their valuable comments.

The following people reviewed this manuscript: Alain Hartmann, National Research Aricultural Institut Dijon, CMSE, Labo.de Microbiologie des Sols, 17 rue Sully, 21000 Dijon, France, and Sophie Cliquet, IUP IIA, Université de Bretagne Occidentale, Creach Gwenn, 29000 Quimper, France.

LITERATURE CITED

- Chacalo, A.; Aldama, A.; Grabinsky, J. 1994. Street tree inventory in Mexico City. *Journal of Arboriculture*. 20(4): 222-226.
- Chacalo, A.; Grabinsky, J.; Aldama, A. 1996. Inventario del Arbolado de Alineación de la Ciudad de México. *Ciencia Forestal*. 21(79), México D.F., Mexico.
- Clark, R.J.; Matheny, N.P.; Cross, G.; Wake, V. 1997. A model of urban forest sustainability. *Journal of Arboriculture*. 23(1): 17-30.

- Endress, A.G. 1990. The importance of diversity in selecting trees for urban areas. *Journal of Arboriculture*. 16(6): 143-147.
- Harris, R.W. 1992. *Arboriculture: integrated management of landscape trees, shrubs and vines*. 2d ed. New Jersey: Prentice Hall, Inc.
- Jaenson, R.; Bassuk, N.; Schwager, S.; Headley, D. 1992. A statistical method for the accurate and rapid sampling of urban street tree populations. *Journal of Arboriculture*. 17: 185-191.
- Lebart, L.; Morineau, A.; Warwick, K. 1984. *Multivariate descriptive statistical analysis*. John Wiley.
- Ludwig, J.A.; Reynolds, J.F. 1988. *Statistical ecology*. Wiley.
- Moll, G. 1989. Improving the health of the urban forest. In: Moll, G.; Ebenreck, S., eds. *Shading our cities. A resource guide for urban and community forests*. Washington: Island Press: 119-103.
- Nilsson, J.; Randrup, T.; Tvedt, T. 1996. Technological aspects of urban greening. Draft presented at the International seminar on urban greening in Latin America and the Caribbean. Mexico City. DDF, BID, Gobierno del Estado de México. México.
- Sorensen, M. 1996. Introducción a la Creación de Areas Verdes Urbanas. No. ENV96-103. BID, 71 p. Washington, DC.
- Richards, N.A. 1983. Diversity and stability in street tree population. *Urban Ecology*. 7: 159-171.
- Richards, N.A. 1993. Reasonable guidelines for street tree diversity. *Journal of Arboriculture*. 19(6): 344-349.
- Sanders, R. 1984. Some determinations of urban forest structure. *Urban Ecology*. 8(1/2): 13-27.
- Vázquez, H.; Grabinsky, J.; Aldama, A.; Chacalo, A. 1997. Exploratory multivariate analyses of Mexico City's tree inventory data. SPRUCE IV Enschede, Holland September, 1997.