FAR FROM THE NOISY WORLD? MODELLING THE RELATIONSHIPS BETWEEN PARK SIZE, TREE COVER AND NOISE LEVELS IN URBAN GREEN SPACES OF THE CITY OF PUEBLA, MEXICO

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SUMMARY

To better understand the role of park size and tree cover of green spaces in improving environmental quality in urban settlements, an assessment was made of noise levels in 21 sites (urban green spaces) in the city of Puebla, Mexico, and its metropolitan area (AMPC). Park size, tree density and tree canopy cover were determined, and the equivalent noise level (LEQ) during 8-23min per site was measured. Then, the existence and significance of linear relationships between park size, tree density and tree canopy cover with LEQ were explored. Equivalent noise levels varied between 47.3 and 78.4dBA; in 9 out of the 21 urban sites LEQ was higher than 65dBA, and also above the World Health Organization guideline for moderate annoyance (50dBA) in 19 of the 21 sites. Only at a distant, protected natural area were LEQ values below those standards. Park size and total tree canopy cover significantly reduced noise levels, irrespectively of park location and tree species composition. Noise pollution is a real annoyance even at the supposedly quiet urban green spaces of the AMPC, but the multiple linear regression model obtained suggests that noise levels could be significantly abated if specific combinations of park size and tree canopy cover are taken into account. This conclusion reinforces the important role of urban green spaces in ameliorating environmental quality.

Urbanization can be seen as a huge experimental manipulation of environmental conditions, including landscape structure or economic factors (McDonnell and Pickett, 1990), that is causing ecological responses like the conversion of natural land uses into urban and suburban environments (Pickett *et al*., 2001). In this framework, cities can be considered as emergent ecological phenomena, in which typical urban problems such as traffic congestion or air pollution appear from interactions between myriad variables (Alberti *et al*., 2003).

Among the many environmental problems linked to urban environments, noise is currently recognized as a common nuisance in cities all over the world, and is regarded as one of the most important contaminants degrading people's everyday life. In contrast to many other environmental problems, noise pollution is still growing, and public complaint about noise problems have increased in developed countries in recent times (Gidlöf-Gunnarsson and Öhrström, 2007). Although noise has been less studied than other forms of environmental pollution (Mansouri *et al*., 2006), some authors have considered it as a hot topic in scientific research (Zannin *et al*., 2002), especially in developing countries (Ozer *et al*., 2007). Negative effects of noise on ecosystem components (Brown and Raghu, 1998; Warren *et al*., 2006), human health (Stansfeld and Matheson, 2003; Babisch, 2005; Sobotova *et al*., 2010), and human behavior (Elizondo Garza, 2004) have been documented. Therefore, noise pollution in urban environments should be evaluated and its adverse effects controlled or minimized, which is not an easy task, since the characteristics of noise contamination depend on factors such as degree of development, population density or local habits and culture (Canter, 1996; Barrigón Morillas *et al*., 2002; Elizondo Garza, 2004).

A city is a patchy ecosystem that appears as a highly developed matrix in which remnants of vegetation can be scattered (McIntyre *et al*., 2000). Notwithstanding that less than 20% can remain as vegetated areas in urban locations (McKinney, 2002), city parks and other open green spaces are important leisure resources in these environments (Dwyer *et al*., 1991; Bengoechea Morancho, 2003; Gidlöf-Gunnarsson and Öhrström, 2007), where they can contribute to a cleaner air or to reduce noise pol-

KEYWORDS / Canopy Cover / Environmental Quality / Mexico / Trees / Urbanization / Vegetation /

Received: 09/14/2009. Modified: 05/07/2010. Accepted: 05/19/2010.

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lution depending on their size and location (De Ridder *et al*., 2004; Lam *et al*., 2005; Zannin *et al*., 2006; Jim and Chen, 2007). Urban vegetation may act as an acoustic screen between noise sources and receivers (Fang and Ling, 2003, 2005). When large areas are provided in urban ecosystems, the tree and other plant cover may play an important role in the reduction of noise levels (Ozer *et al*., 2007); however, given the often small size of urban green spaces and the expected large scale of urban pollution, some authors are skeptical about the usefulness of green spaces in improving environmental quality in cities (Lam *et al*., 2005 and references therein).

In this paper noise pollution is evaluated in green spaces with variable amounts of greenery in the city of Puebla, Mexico, a developing country in the middle of urban transition (Bárcena, 2001). Probably more than in other countries, a large number of problematic situations regarding noise have been reported in Mexico, where urban settlements are growing in a chaotic and irresponsible way (Elizondo Garza *et al*., 2002). Human population in Mexico >105 000 000 inhabitants, with a high 70% concentrated in urban areas, which is aggravating water, soil and air pollution in urban environments (Sarukhán, 2006). Currently, the city of Puebla and its metropolitan area (henceforth, AMPC) is absorbing part of the human growth of Mexico City (Garza, 2002); the human population in the AMPC has multiplied 3.2 times between 1970 and 2000, and by 2005 it was ~1 700 000 inhabitants (INEGI, 2007). A number of factors reduce environmental quality in the AMPC, among which the increase in noise pollution has been properly remarked by local authorities (Puebla, 2005).

The primary goal of the study was to evaluate noise pollution in the urban green spaces of the city of Puebla and its metropolitan area. Comparisons between measured noise levels and permissible limits set by both regional and international criteria were performed, and it was also assessed whether urban green spaces can reduce environmental noise pollution as a function of park size, tree cover, or a combination of both.

Materials and Methods

Study area

The city of Puebla, the capital of the State of Puebla, Mexico, is located in the Angelopolis region of the State; ~2 200 000 inhabitants live in this region, where the near San Andrés Cholula and San Pedro Cholula also form part of the conurbation (Puebla, 2005). During the last 30 years, the population has grown at a more accelerated pace in the AMPC than in any other region of the State (Puebla, 2005).

TABLE I
NAMES OF THE 21 URBAN GREEN SPACES AND THE POSITIVE REFERENCE (SITE #22) IN THE CITY OF PUEBLA AND ITS METROPOLITAN AREA*

Site number	Site names	Type of site	City sector	Park size (ha)
1	Cerro Amalucan	Seminatural area	Outer city	140.9
2	Baldío de La Paz	Brown field	Inner city	2.3
3	Paseo Bravo	Urban park	Downtown	2.6
4	Benemérita Universidad Autónoma de Puebla	School/University campus	Inner city	92.8
5	El Carmen	Urban park	Downtown	0.3
6	Colegio Especial 'Niños Héroes de Chapultepec'	School/University campus	Downtown	13.0
7	Parque Ecológico 'Revolución Mexicana'	Urban park	Inner city	56.5
8	Los Fuertes	Urban park	Inner city	65.4
9	Universidad Iberoamericana	School/University campus	Inner city	18.1
10	Parque Juárez	Urban park	Inner city	4.6
11	Parque Asta Bandera	Urban park	Inner city	0.7
12	Panteón La Piedad	Cemetery	Inner city	12.1
13	Panteón Municipal	Cemetery	Downtown	16.2
14	Pirámide de Cholula	Seminatural area	Outer city	13.0
15	Centro Comercial 'Angelópolis'	Parking lot	Inner city	27.2
16	Laguna de San Baltasar	Urban park	Inner city	13.8
17	Parque El Tamborcito-Museo del Ferrocarril	Urban park	Downtown	7.9
18	Universidad de las Américas Puebla	School/University campus	Outer city	70.2
19	Zócalo de San Andrés Cholula	Main square	Outer city	2.4
20	Zócalo de San Pedro Cholula	Main square	Outer city	1.4
21	Zócalo de Puebla	Main square	Downtown	5.8
22	Reserva Ecológica 'Flor del Bosque'	Natural area	Outer city	700+

* See also Figure 1.

A total of 21 urban green spaces were considered in this study, located in the following three sectors of the AMPC (Table I; Figure 1): a) the downtown area (SECTOR 1), the main square of the city of Puebla, characterized by a square-meshed road network with low buildings and narrow roads; b) the inner city (SECTOR 2); and c) the outer city (SECTOR 3). The 21 sampling sites included: 1 abandoned, brown field; 2 cemeteries; 3 main squares; the *campuses* of 4 local schools or universities; 8 urban parks, and 2 other seminatural, green spaces; besides, a large parking lot was included. Urban park size ranged from the very small site #5 (0.28ha, an urban park in downtown Puebla) to the largest one, site #1 (140.9ha, a seminatural area in the outer city); however, differences in park sizes between urban sectors were not statistically significant (one-way analysis-of-variance (Zar, 1996): $F_{2,18}$= 0.98; P= 0.394). A very large (~702ha) protected natural area (Reserva Ecológica Flor del Bosque) was also sampled as a positive reference site (site #22; Table I; Figure 1).

Tree vegetation

Following methods in Brower *et al.* (1997) from 3 to 7 sampling quadrats (20×20m) were located at each of the 21 urban green spaces, and all the trees with a diameter at breast height (DBH) ≥5cm inside each quadrat were counted, identified and their DBH-measured. The tree vegetation structure at each sampling site was described in terms of density (trees/ha) and canopy cover (m^2 canopy/ha; see Barillas Gómez, 2004; Bonache Regidor, 2005). Canopy cover (CC) was calculated for each individual tree by measuring its DBH and applying a species-specific linear model describing the true relationship between CC and DBH. Models were empirically obtained from an average number of 20 trees of 13 species present in the same study area (9 angiosperm, 1 palm and 3 gymnosperm trees). Canopy cover of some taxa (*Acacia* sp., *Phoenix canariensis* or *Salix* sp.) was estimated by applying models of closely related species (*Acacia retinodes*, *Washingtonia robusta* and *Salix humboldtiana*, respectively). For more details and models linking DBH to tree canopy cover, see González-Oreja *et al.* (in press).

Noise levels

All noise sampling was done on working days, from 7 to 11am, under ideal meteorological conditions (no wind and no rain). Noise levels, expressed in A-weighted decibels (dBA) were measured by using an Extech 407735 digital sound level meter. At each sampling site, between 8 and 27 randomly selected sampling points were considered and, at each sampling point, instantaneous noise levels were registered every 10sec during 1min; then a cumulative noise metric was calculated, the equivalent sound level (LEQ) for 1min. In theoretical terms,

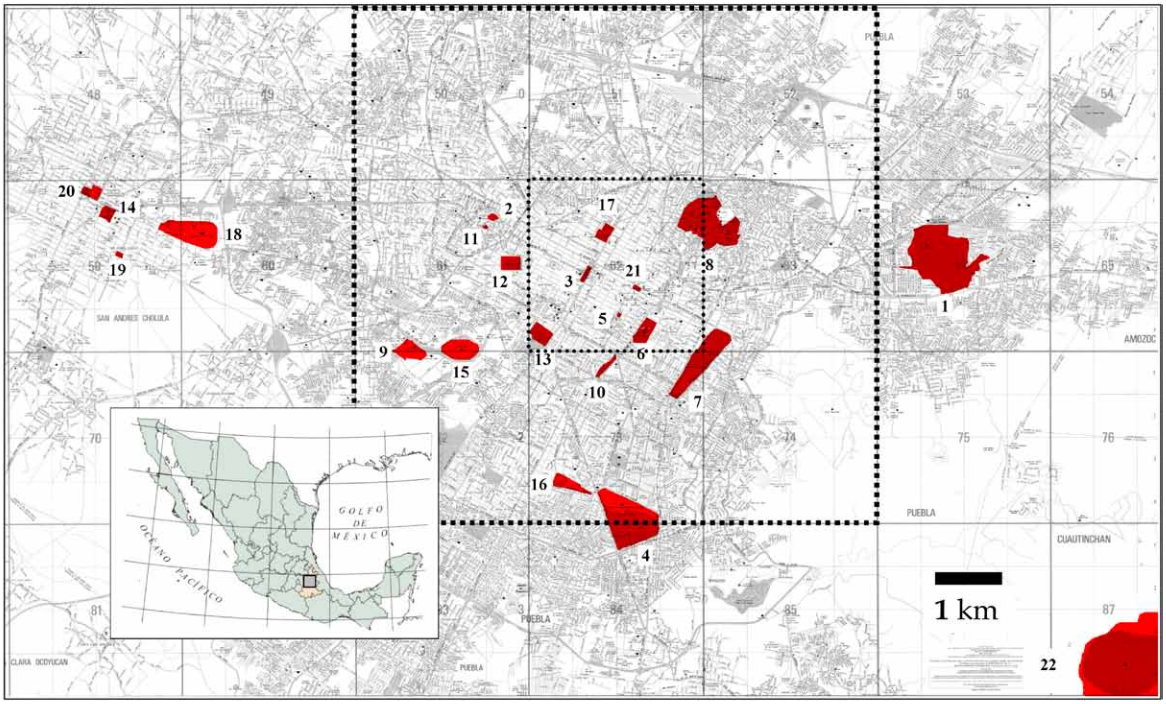

Figure 1. Location of the 21 urban green spaces (sites #1-21) and the positive reference (site #22) in the city of Puebla and its metropolitan area. The approximate park size and shape is also indicated. The inset shows the location of the study area in Mexico (square). See also Table I.

Leq may be thought of as the constant sound level over the period of interest that contains as much sound energy as the actual time-varying sound level; in practical terms, Leq is the usual variable employed in acoustical studies (Wilson, 1989; Canter, 1996; Berglund *et al*., 1999). After pooling all the sampling points at each sampling site, the corresponding equivalent sound levels (LeqN) were obtained. For example, Leq23 is the equivalent sound level registered at the 23 sampling points located in a site; in this paper, LeqN values were considered as measurements of “time average noise levels” (Berglund *et al*., 1999).

No legislation has been approved in Mexico (country) or Puebla (state) for the regulation of ambient noise levels. So, in order to put noise pollution within a broader context, equivalent noise levels in the green spaces of the city of Puebla and its conurbation have been compared with 1) the limits set for community noise in outdoor living areas by the World Health Organization (WHO maximum 1, for moderate annoyance, 50dBA; and WHO maximum 2, for serious annoyance, 55dBA; Berglund *et al*., 1999), and 2) the recently passed NADF-005-AMBT-2006 environmental standard for noise emissions in Mexico’s Distrito Federal, of 65dBA between 6am and 10pm (Gaceta, 2006).

Statistical analyses

Both nonparametric and parametric statistical tests (Zar, 1996) were used. Since equivalent noise level is not a linearly additive variable (i.e., for different background levels, a given noise source does not produce the same increase in the variable; Barrigón Morillas *et al*., 2002) the contrasting of arithmetic means by standard parametric tests is not applicable. Instead, the possible existence and statistical significance of spatial differences in equivalent sound levels for 1 minute (Leq1) were explored by means of the nonparametric Kruskal-Wallis 1-way ANOVA by ranks (1 way K-W ANOVA), with Leq1 as dependent variable and park (21 levels) or sector (3 levels: downtown, inner city and outer city) as categorical predictors (Barrigón Morillas *et al*., 2002, 2005a). In case of statistical significance (α= 0.05), the 1-way K-W ANOVA was followed by nonparametric multiple comparisons tests. Given the unbalanced nature of the design (groups of sites had different numbers of data), the Dunn test was employed for this purpose, being a more powerful test than others like the Tukey-type Nemenyi test (Zar, 1996). Nonparametric analyses were performed by running the ‘ANOVA on ranks’ module as implemented in the SigmaStat (1997) software.

In addition, by means of simple and multiple linear regressions (a robust, parametric statistical technique with respect to possible violations of underlying assumptions; Zar, 1996), relationships were evaluated between average noise levels in urban green spaces (LeqN, measured in dBA) and the following quantitative predictors: park size (area, in ha), total density of trees (tdens, in trees/ha) and total canopy of trees (tcov, in m^2 canopy/ha). As possible predictors of LeqN were also considered the density and cover of both the gymnosperm species *Casuarina equisetifolia, Cupressus* sp.pl. and *Pinus* sp.pl., and the non-gymnosperm ones (a total of 30 species more; see Barillas Gómez, 2004; Bonache Regidor, 2005; González-Oreja *et al*., in press). The existence of a linear relationship between the response variable (y) and the possible predictors (x) was previously explored by means of xy biplots; cases with standardized residuals >2.1 were considered as outliers, and removed from further analyses. Parametric analyses were done by running the ‘multiple regression’ module of the Statistica vers. 6.0 (StatSoft, 2001) software.

Results

Tree vegetation

A total of 33 tree species were registered in the 21 urban green spaces, although richness per site ranged from only 2 species (site #2, a brown field) to 10 (site #4, a university *campus*). Total density (Figure 2) varied between urban green spaces from a minimum of 55 trees/ha (site #14, a seminatural area) to a maximum of 405 (site #8, an urban park), with mean= 232 trees/ha and coefficient of variation= 40%. According to their density, the dominant trees were the natives *Fraxinus udhei* (16.6% of total density) and *Cupressus lindleyi* (15.0%), and the exotics *Eucalyptus camaldulensis* (16.7%) and *Ligustrum japonicum* (10.7%). Total canopy cover (Figure 2) ranged from 1465 (site #15, a parking lot) to 14065 (site #21, a main square) m^2 canopy/ha, with mean= 7342m^2 canopy/ha and coefficient of variation= 47%. According to their canopy cover, the main tree species were the native *F. udhei* (27.3% of total canopy cover) and the exotic *E. camaldulensis* (25.4%).

Noise levels

A total of 2230 instantaneous noise measurements were registered, corresponding to a total of 373min (8-27min per site). For urban sites, a) instantaneous noise levels ranged from a low 40.2dBA (site #12, in fact, a cemetery) to a very high 91.9 (site #17, an urban park in downtown Puebla); b) minimum equivalent sound levels for 1 minute (min LEQ1; Figure 3) ranged from 41.1dBA (site #12) to 65.2 (site #3, a different downtown urban park), whereas maximum ones (max LEQ1; Figure 3) varied between 52.3 dBA (site #12) and 88.6 (site #17); and c) average noise levels (LEQN; Figure 3) varied from a minimum LEQ23= 47.3 (site #12), or the close LEQ18= 49.6 (site #13, a different cemetery), to a maximum LEQ14= 78.4dBA (site #17). At the positive reference, all noise measurements were lower than those registered in urban green spaces; instantaneous noise varied from 35.2 to 43.9dBA; LEQ1 ranged 36.8-43.2dBA, and average level was LEQ15= 38.9dBA.

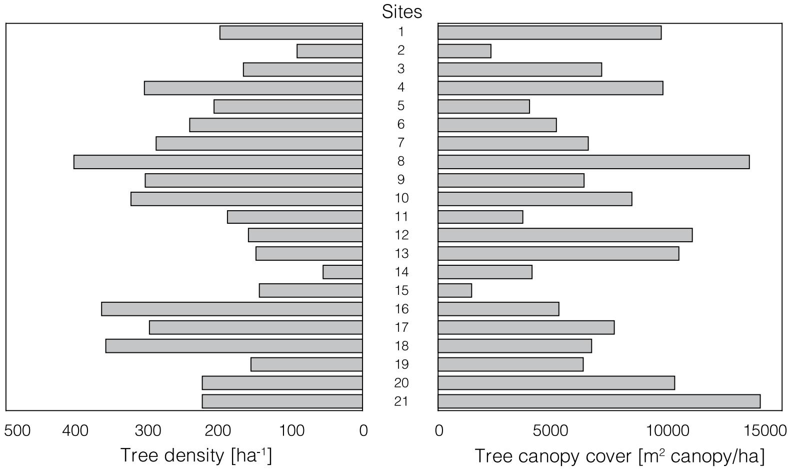

Figure 2. Tree density (ha^{-1}) and tree canopy cover (m^2 canopy/ha) in the 21 urban green spaces considered in this study. Note that tree canopy cover exceeds $10000m^2$ canopy/ha in some urban green spaces, where tree crowns overlap. See Table I for names and Figure 1 for location.

Average noise levels (LEQN) were ≥65dBA in 9 urban sites (~43% of the total, 21 urban green spaces), although max equivalent noise levels in 1min were above that figure in 3 of the remaining 12 sites (#7, 15 and 20; Figure 3); max LEQ1 was <65dBA in 9 urban green spaces (continually quiet sites; open triangles in Figure 3), whereas min LEQ1 was >65dBA in 2 sites (permanently noisy sites: #3 and 16; black squares in Figure 3). LEQN was above WHO maximum 2 (55 dBA) in 16 sites (~76% of the total) and, finally, LEQN was above WHO maximum 1 (50dBA) in 19 urban green spaces (a large ~90.5%). Only the positive reference (site #22; Figure 3) conformed all the standards considered.

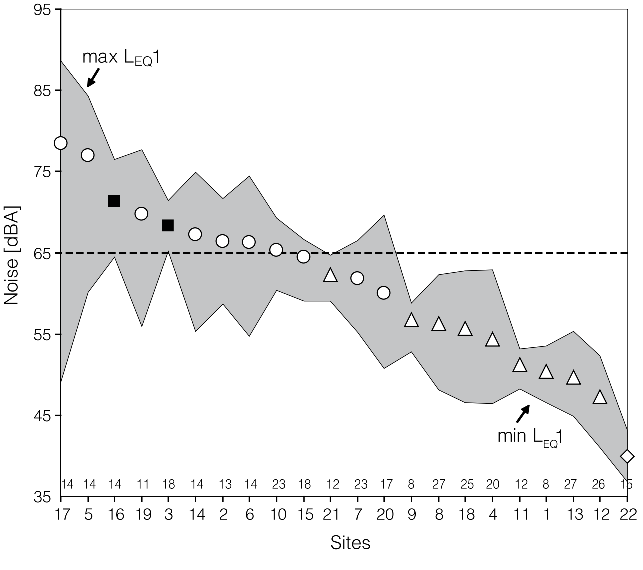

Figure 3. Average noise levels in the 21 urban green spaces considered in this study (circles, squares and triangles: sites #1-21) and the positive reference (site #22: diamond); minimum and maximum equivalent sound levels for 1min (LEQ1) are also shown (lines). Open triangles show sites with max LEQ1 <65dBA, whereas closed squares mark sites with LEQ1 >65dBA. Small numbers above the horizontal axis are sample sizes (min). See Table I for names and Figure 1 for location.

The differences in LEQ1 amongst urban green spaces were statistically significant (1-way K-W ANOVA H_{20}= 272.97, P<0.001). Also, differences in LEQ1 between regions were statistically significant (H_3= 50.77, P<0.001); multiple comparisons test *vs* a control group (SECTOR 4, the positive reference, where median LEQ1= 39.12) showed that LEQ1 values registered at all the urban regions were statistically above those measured at the positive reference site (downtown, SECTOR 1, with median LEQ1= 61.12, Dunn's test Q= 7.06; inner city, SECTOR 2 median= 59.30, Dunn's test Q= 6.21; outer city, SECTOR 3 median LEQ1= 68.35, Dunn's test Q= 5.50; in all three cases, P<0.001); the remaining differences between urban sectors were not statistically significant (0.84<Dunn's test Q<2.62, P>0.05).

Effect of park size and tree vegetation on noise levels

For the 21 urban green spaces, both park size (AREA) and total canopy cover (TCOV) were statistically and negatively correlated to average noise levels (LEQN): for AREA, r= -0.47, P= 0.032 (Figure 4a); for TCOV, r= -0.44, P= 0.048 (Figure 4b); total tree density (TDENS) was not linked to LEQN (r= -0.01, P= 0.950). Tree density for both gymnosperm and non-gymnosperm species was not linearly correlated to average noise levels (in both cases, P>0.1), and the same was obtained for canopy cover by groups of species (P>0.1).

Since AREA was not statistically correlated with TCOV (r= 0.27, n= 21, P= 0.220), a multiple linear regression of LEQN was performed on these two variables as quantitative predictors. Although the model as a whole was statistically significant (P= 0.031), simple regression coefficients were not (b_1 [AREA], P= 0.079; b_2 [TCOV], P= 0.120). In fact, site #11 (a small urban park in the inner city) was identified as an outlier (observed LEQN= 51.24dBA; predicted LEQN= 67.33dBA). After excluding this case from the multiple linear regression analysis, the new model was statistically significant, both globally ($F_{2,\,17}$= 7.49; P= 0.005) and individually (b_1 [AREA], P= 0.029; b_2 [TCOV], P= 0.030) and expressed as

$$\mathrm{LEQN\ (dBA)} = 73.46 - 0.0998 \times \mathrm{AREA\ (ha)} - 0.0011 \times \mathrm{TCOV\ (m^2\ canopy/ha)} \quad (1)$$

where n= 20, R= 0.68 and standard error of the estimate= 6.66dBA. The goodness-of-fit of the whole model in Eq. 1 (R^2= 46.84%) was clearly higher than that previously obtained with only one parameter (AREA, R^2 = 21.96%; TCOV, R^2= 18.91%).

Discussion

There are no universally accepted noise criterion for parkland and conservation areas, or for urban parks and other green spaces. For example, whereas WHO recommends an equivalent sound level of 55dBA as threshold for outdoor living areas (Berglund *et al*., 1999), the local authority of Mexico's Distrito Federal has passed a higher standard of 65dBA for noise emissions (Gaceta, 2006). The present results show that 9 out of the 21 urban green spaces studied in the city of Puebla and its metropolitan area exceeded even the more relaxed level set by the cited local authority. The problem is aggravated if the more stringent limits set by WHO are taken into account, since equivalent noise levels in some 3/4 of urban green spaces were above the intermediate 55dBA limit, and a large 9/10 exhibited levels above the low 50dBA criterion. Only at the positive reference

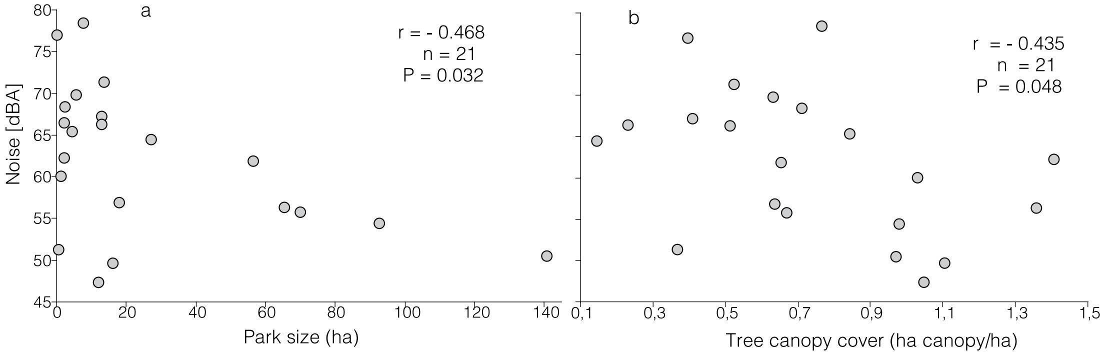

Figure 4. Scatter plots showing the relationships found between average noise levels per site with park size (a) and tree canopy cover (b).

site, a distant and large protected natural area, were noise equivalent levels below all these standards. Daytime guidance values for noise annoyance have been set by WHO at 50-55dBA, below which the majority of the adult population will be protected from becoming moderately to seriously annoyed (Berglund *et al*., 1999). It has been concluded that, among other elements, noise levels contribute to the subjective experience of quietness that, in turn, improves the quality of urban life (Van Herzele and Wiedeman, 2003). In fact, there is a large body of evidence that access to quiet green spaces close to residences may provide an important way to escape from tense and challenging everyday situations, like those derived from chronic noise pollution in urban settlements (Gidlöf-Gunnarsson and Öhrström, 2007). Nonetheless, taking into account the abovementioned standards and results, there is no evidence to suggest that people living in the Puebla-Cholula conurbation can expect to find a calm environment even in the hypothetically quiet urban green spaces of the city. In the case study, it is probably naïve to think that, by visiting urban green spaces, people can escape from environmental stressors or to rest and relax from the stressful rhythm of the city.

Noise pollution is not exclusive of large cities in rich, developed countries, since it has been documented in medium and small-size localities all over the world, including developing countries. For instance, noise levels in about 97% of sites in Kahramanmaraş (Turkey) were ≥55dBA, and 63% were ≥65dBA (Doygun and Gurun, 2007). In Latin America, the equivalent sound level in a large 96.3% of sites in Curitiba, Brazil, was >55dBA (Zannin *et al*., 2002), whilst ~60% of points in Valdivia, Chile, exceded 65dBA (Sommerhoff *et al*., 2004). In Mexico, noise pollution in the city of Guadalajara has been considered a severe environmental problem, since levels were <70dBA only in 3.9% of the cases (Orozco Medina, 2001; Orozco Medina *et al*., 2007). Noise pollution in green spaces has been studied by Zannin *et al*. (2006) for urban parks in Curitiba, the 'ecological capital' of Brazil; the average sound levels measured in some of them were well above the limit established for parks by the local law of the city, of 55dBA. Sommerhoff *et al*. (2004) found noise levels of 35-40dBA only for the countryside off Valdivia, Chile. As previously exposed, a comparable situation exists for the urban green spaces of Puebla and its metropolitan area.

Noise pollution in urban environments is characterized by a large diversity of sources (Doygun and Gurun, 2007), although traffic flow has been recognized as a main source in both developed (García Rodríguez, 1997; Sommerhoff *et al*., 2004; Barrigón Morillas *et al*., 2005a, b; Piccolo *et al*., 2005) and developing countries (Orozco Medina, 2001; Zannin *et al*., 2002; Mansouri *et al*., 2006; Doygun and Gurun, 2007). Additional factors should be taken into account to better understand the role of traffic noise in developing countries, such as the poor maintenance of circulating vehicles (Zanin *et al*., 2006) or the lack of modern traffic control equipments and planning (Mansouri *et al*., 2006). Special attention should be paid to heavy vehicles (with weights >3500kg, such as buses, trucks or vans; Barrigón Morillas *et al*., 2005b) since they can be considered as strong point sources (Mansouri *et al*., 2006), like the privately owned outdated and/or poorly maintained mass transportation vehicles in Turkey (Doygun and Gurun, 2007). In developing Mexico, the problem of noise has been tracked, among others, to the following main causes: large vehicle fleet, poor urban transport, shortage of open green spaces and insufficient regulation, inspection and legal frame (Orozco Medina, 2001). This also applies to the AMPC (Vergara Balderas, 2005), so measures to control noise pollution should be directed toward improving traffic problems. But, can park size and tree canopy cover help to reduce noise pollution in our urban green spaces?

Changes in noise levels have been documented as a consequence of park size. Other factors being equal, noise pollution levels in larger parks should be lower (Lam *et al*., 2005) because of noise reduction from the source with distance, which can follow different attenuation models (Canter, 1996; Fang and Ling, 2003). In the AMPC we have documented a statistically significant reduction in noise levels due to increasing park size (see Eq. 1); thus, noise pollution in urban green spaces is expected to decrease if large green, urban spaces are designed and created from the beginning. However, park size, shape or location in the AMPC have generally been determined by forces out of intelligent urban design; because of this, the capacity of urban parks and open green spaces to improve local acoustic environment could be limited. In this context, can urban trees ameliorate the situation? Changing the path of noise from the source to the receiver, and attenuating noise by absorption, have been included among the steps that can be taken to minimize the magnitude of noise pollution (Canter, 1996). Mitigation measures for traffic noise include barriers to obstruct or dissipate sound emissions, the absorption effects of landscaping by means of trees, bushes and shrubs (Canter, 1996), or the incorporation of porous noise absorbing surfaces into the urban fabric (De Ridder, 2004). In fact, it has been reported that if large vegetated areas remain around noisy streets, with the suitable species composition, in the right densities and with the right shapes, it is possible to provide a considerable amount of noise reduction (Fang and Ling, 2003, 2005; De Ridder, 2004; De Ridder *et al*., 2004; Ozer *et al*., 2007). Mansouri *et al*. (2006) documented a drop in noise levels of 2.5dBA between sites due to the damping effect of green trees, and recommended the development of dense barriers of trees at both sides of streets. In the city of Erzurum, Turkey, it has been documented that coniferous pine trees (*Pinus sylvestris*) resulted more effective in noise reduction along roads than deciduous poplar trees (*Populus nigra*); a significant difference of 6.3dBA was found between the two species at a distance of 25m (Ozer *et al*., 2007). We also found a significant, reducing effect of tree canopy cover on noise levels in urban green spaces (Eq. 1); however, no difference was found for gymnosperm or non-gymnosperm tree species. Thus, noise pollution in the green spaces of the AMPC could be significantly abated if tree canopy cover is enhanced, irrespectively of the park location inside the city or the tree species employed.

What is more, the relationships between park size, tree canopy cover and average noise levels documented throughout this paper (Eq. 1) could be used to guide the solution to the following questions: in the city of Puebla and the AMPC, which should be the minimum park size for LeqN values to be <65dBA, the environmental standard for noise emissions (Gaceta, 2006) in Mexico's DF? Or, which should be the minimum tree canopy cover for LeqN values to be <65 dBA? In the AMPC, if area= 20ha, then it is enough with tcov= 0.6ha canopy/ha to get an expected value of average noise level LeqN= 65dBA (see Figure 4a; 67.46 to 68.41 being the corresponding 95% confidence interval or CI). Also, if tcov= 0.75ha canopy/ha, then it suffices with area= 3ha to expect LeqN= 65dBA (see Figure 4b; 61.13 to 68.85 being the corresponding 95% CI). Thus, if these minimum values of park size and tree canopy cover are observed in the design and management of the urban green areas in the study area, average noise levels are expected to be <65dBA. Similar procedures could be applied to search for minimum values of park size and tree canopy cover in order to expect different noise levels, such as those established by WHO. This conclusion reinforces the important environmental role of urban green spaces, as reported by De Ridder (2004) and clearly contradicts Lam *et al.* (2005), who suggested that urban parks and other green areas should be designed to emphasize their social rather than environmental functions, at least in dense cities.

Noise management recommendations

The increasing prominence of urban areas worldwide is reason enough to study them, but ecologists also should inform decision makers in order to manage cities in a way that ensures that they are reasonable places to live in the near future (Pickett *et al*., 2001). Urban green spaces are one of the typical subjects of open space design, and play an important role in the daily life of the citizens. To strive for lower sound levels, to assure access to "noise-free" places, and to protect, preserve and even increase the supply of urban green spaces, have been deemed critical in order to attain a more sustainable and health-promoting urban residential environment (Gidlöf-Gunnarsson and Öhrström, 2007).

However, it has been also detected that even those leisure places can be a potential source of health problems, not fulfilling its intended role (Zannin *et al*., 2006). Several authors have pointed out that noise pollution abatement is less of a scientific problem than a policy problem, and this is not yet understood in cities located in developing countries (Zannin *et al*., 2002, 2006). Inaction would mean that noise problems could further increase, and, likely, future mitigation measures will become more expensive to implement (Sommerhoff *et al*., 2004).

In the city of Puebla and its metropolitan area, it is necessary to think of a noise pollution abatement plan, as has been recently suggested by the local authority for the noise produced by heavy vehicles (buses and trucks; Puebla, 2007). This task should come only after a more comprehensive study of noise problems in the AMPC is done. Up to now, the results of the present study suggest that noise pollution could be improved (reduced) if tree canopy cover in urban green spaces is enhanced.

ACKNOWLEDGEMENTS

The authors thank Renato Xochitiotzi, Physics Laboratory, Universidad de las Américas Puebla (UDLA), Mexico, for allowing us to use the noise measurement equipment; JM Barrigón and PH Zanin for copies of some of their noise studies; A Figueroa Montaño, JF Mendoza Sánchez and MG Orozco Medina for help with studies from Mexico, and J Trujillo Carmona for guidance on statistical techniques. This study is a result of the Project *Estudios de la Avifauna de Puebla y su Entorno*, partially financed by the UDLAP.

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LEJOS DEL MUNDANAL RUIDO? MODELAJE DE LAS RELACIONES ENTRE TAMAÑO DEL PARQUE, LA COBERTURA ARBÓREA Y LOS NIVELES DE RUIDO EN ESPACIOS VERDES URBANOS DE LA CIUDAD DE PUEBLA, MÉXICO

José Antonio González-Oreja, Carolina Bonache-Regidor y Arturo Andrés De La Fuente-Díaz-Ordaz

RESUMEN

Con el objetivo de comprender mejor la función del tamaño del parque y de la cobertura arbórea de los espacios verdes en la mejora la calidad ambiental de los asentamientos urbanos, se realizó una evaluación de los niveles de ruido en 21 sitios (áreas verdes urbanas) del área metropolitana de la Ciudad de Puebla, México (AMPC). En cada sitio, se determinó el tamaño del parque, la densidad de árboles y la cobertura arbórea, y se midió el nivel de ruido equivalente (LEQ) durante 8-23 min. Después, se exploró la existencia y el significado de relaciones lineales entre el tamaño del parque, y la densidad y cobertura arbóreas, con LEQ. Los niveles de LEQ variaron entre 47.3 y 78.4 dBA; en 9 de los 21 sitios urbanos LEQ fue superior a 65 dBA, y en 19 de los 21 sitios estuvo por encima de 50 dBA, el valor de referencia de la Organización Mundial de la Salud para molestias moderadas. Los valores de LEQ estuvieron por debajo de tales umbrales sólo en una distante área natural protegida. El tamaño del parque y la cobertura total de árboles redujeron significativamente los niveles de ruido, independientemente de la ubicación del parque y la composición de especies de los árboles. La contaminación sonora es una molestia real incluso en los espacios verdes urbanos del AMPC, supuestamente tranquilos, pero el modelo de regresión lineal múltiple obtenido sugiere que se puede reducir significativamente los niveles de ruido si se consideran valores concretos de tamaño del parque y cobertura de árboles. Esta conclusión refuerza la función de las áreas verdes urbanas para mejorar la calidad ambiental

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LONGE DO RUIDO DA MULTIDÃO? MODELAGEM DAS RELAÇÕES ENTRE TAMANHO DE PARQUE, COBERTURA ARBÓREA E NÍVEIS DE RUIDO EM ESPAÇOS VERDES URBANOS DA CIDADE DE PUEBLA, MÉXICO

José Antonio González-Oreja, Carolina Bonache-Regidor e Arturo Andrés De La Fuente-Díaz-Ordaz

RESUMO

Para compreender melhor o papel do tamanho dos parques e a cobertura arbórea de espaços verdes no melhoramento de assentamentos urbanos, foram estudados os níveis de ruido em 21 locais (espaços verdes urbanos) da cidade de Puebla, México, e sua área metropolitana (AMPC). Determinaram-se o tamanho de parque, densidade de árvores e tamanho do dossel arbóreo, e foi medido o nível de ruido equivalente (LEQ) durante 8-23min por local. Enseguida, foi explorada a existência e significação de relações lineares entre LEQ e tamanho de parque, densidade de árvores e tamanho do dossel. Os níveis equivalentes de ruido variaram entre 47,3 e 78,4dBA; em 9 dos 21 locais foram maiores a 65dBA, e igualmente acima da pauta para incômodo moderado (50dBA) da Organização Mundial da Saúde em 19 dos 21 locais. Somente em uma área natural protegida distante, os valores de LEQ estivieram abaixo dessas normas. O tamanho de parque e o dossel arbóreo total reduziram significativamente os níveis de ruido, independente da situação do parque e da composição de espécies arbóreas. A contaminação sonora é um incômodo real inclusive nos espaços verdes urbanos supostamente tranquilos da AMPC, mas o modelo de regressão linear obtido sugere que os níveis de ruido poderiam ser significantemente reduzidos ao levar em conta combinações específicas de tamanho de parque e cobertura arbórea. Esta conclusão reforza o importante papel dos espaços verdes urbanos no melhoramento da qualidade ambiental.