Influence of urban trees on noise levels in a central Chilean city

Influencia del arbolado urbano sobre los niveles de ruido en una ciudad de Chile central

Felipe Calquín P. [1] , Mauricio Ponce-Donoso [2], Óscar Vallejos-Barra [2], Exequiel Plaza T. [3]

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Abstract

The effect of urban trees as a noise mitigating element was determined on Alameda Avenue in the city of Talca, Chile, a Mediterranean continental area. Maximum and minimum noise, especially generated from vehicles, was recorded at 13 points in four sections of the avenue for twelve days, three times a day at different distances from the edge of the street way, which generated a total of 2,080 noise records. At each point a circular plot of 201 m^2 was established to determine tree and shrub coverage. The results showed significant differences of noise between the classes of coverage; however there was no relationship significant between the noise level and the increase in coverage, which can be explained by the large amplitude in the noise registers. The vegetation located at 6.5 meters from the sound source shows lower levels of noise when the coverage is increased, proving the environmental function of the vegetation in the mitigation of this pollutant agent. Regarding theses of the findings, it is necessary to implement public policies that consider urban planning, incorporating in its design greater and better availability of tree species and that certain public space are located away from sources of noise pollution.

Keywords
urban trees • noise mitigation • urban pollution • ecosystem service • noise pollution

1 Corporación Nacional Forestal. Cuatro Norte 1673, Talca, Chile.
2 Universidad de Talca. Facultad de Ciencias Forestales. Avda. Lircay s/n. Casilla 747. Talca. Chile. mponce@utalca.cl
3 Universidad de Talca. Facultad de Ciencias de la Salud. Escuela de Fonoaudiología. Avda. Lircay s/n. Casilla 747. Talca. Chile.

Resumen

Se determinó el efecto del arbolado urbano como elemento mitigador del ruido en la avenida Alameda de la ciudad de Talca, Chile, ubicada en el área continental. Se registró durante 12 doce días el ruido máximo y mínimo, especialmente proveniente del tránsito vehicular, en 13 puntos en cuatro secciones de la avenida, en tres horarios durante el día a diferentes distancias del borde de la vía, generándose un total de 2.080 registros de ruido. En cada punto se estableció una parcela circular de 201 m^2 para determinar la cobertura arbórea y arbustiva. Los resultados mostraron diferencias significativas entre las clases de cobertura, sin embargo no se observó una relación significativa entre el nivel de ruido y el aumento de la cobertura, lo que se puede explicar por la gran amplitud en los registros de ruido. La vegetación ubicada a 6,5 metros de la fuente sonora muestra menores niveles de ruido cuando se incrementa la cobertura vegetal, comprobando la función ambiental de la vegetación en la mitigación de este contaminante. En consideración a los hallazgos, es necesario implementar políticas públicas que consideren una planificación urbana que incorpore en su diseño mayor y mejor disponibilidad de especies arbóreas y que ciertos espacios públicos, como el estudiado, se localice alejado de las fuentes de contaminación acústica.

Palabras clave

arbolado urbano • mitigación de ruido • contaminación urbana • servicio ecosistémico • contaminación sonora

Introduction

Noise pollution in the city is a growing problem, whose main cause is vehicular transport (2, 4, 13, 23) as well as the growth experienced by cities in the areas of services and construction (38). The World Health Organization (1999) defines as noise all sources except for industrial areas. In Chile, the Ministry of the Environment defines it as any sound that is qualified as annoying, unpleasant or inopportune by those who perceive it (24). It should be understood then that this definition is based on human perception of psychoacoustics such as loudness that as a primarily psychophysiological perception of loudness is related to sound pressure level (SPL).

Thus human functioning (16) can be affected since besides a deficiency on human organs that can be acquired, a limitation of activity and restriction of social participation can take place due to the environmental factors (41).

Martínez (2005) shows that the traffic of light vehicles, medium and heavy trucks, at a speed of 50 km/h over a distance of 15 meters, the sound level reaches 62 dBA, 73 dBA and 89 dBA, respectively. If the speed is increased to 110 km/h, the noise pollution levels are 76 dBA, 86 dBA and 89 dBA in each one.

Heimann (2003) points out that the propagation of sound depends on its state, since the sound level is determined by its absorption in the atmosphere, its refraction and energy dispersion. The United States Environmental Protection Agency (1974) establishes guidelines for exposure to noise based on the protection of 96% of the population, defining levels lower than 55 dBA in outdoor and 45 dBA indoor. Similar to that suggested by the WHO (29).

In Chile, the dispositions only regulate acoustic pollution produced by fixed sources, while mobile sources only have standards for urban and rural public transport. Unlike other pollutants, noise leaves no residue, has no taste, odor, texture, so it is often said that noise is an invisible contaminant. It has important physiological, psychological and economic effects on people's health (14) which surpasses the strictly auditory ones, since it generates stress, hinders the processes of communication and learning, affects the recovery of patients, rest and alter the circadian cycle playing a negative role on people´s quality of life (22). In this country, the regulation of noise emission for both fixed and mobile sources is stated in Supreme Decree N° 38/2011 of the Ministry of the Environment (22) which establishes maximum noise and time zones according to zones.

Zone I: urban boundary and residential use or public space and/or green area, is 55 dBA from 7 to 21 hours and 45 dBA between 21 and 7 hours.

Zone II: of urban limit, includes uses of the Zone I more equipment of any scale, is 60 dBA between 7 to 21 hours and 45 dBA between 21 to 7 hours.

Zone III: urban boundary includes the uses of Zone II plus productive and/or infrastructure activities, is 65 dBA between 7 to 21 and 55 dBA between 21 and 7 hours.

Zone IV: urban limit, allows only productive activities and/or infrastructure, is 70 dBA at any time. It is estimated that in metropolitan area of Santiago, about 13% of the population would be exposed to levels above 65 dBA, which could addressed as a health risk (22).

The different levels of noise can be mitigated by the green infrastructure, such as trees and shrubs, because they are considered to be a very good barrier and could be used in their control (19, 27) for this reason, one of the ecosystem services that identify the urban trees links it to noise attenuation. Peng *et al*. (2014) demonstrates how the tree is used as an acoustic barrier, while Fang and Ling (2005) recommend increasing the length of the green barrier for greater noise attenuation, placing it at the same height as the emitter.

The ecological role of urban green infrastructure is clearer than ever before, due to its contribution to the ecosystem that integrates human society with its environment (31).

Nowak *et al*. (1998), Ochoa de la Torre (1999), Acero *et al*. (2010), and Kontogiannia *et al*. (2011) indicate that urban vegetation has a direct and indirect relationship in the local and regional microclimate, through the alteration of environmental and atmospheric conditions, improving the quality of the environment, a correlation of comfort and existence of green areas, which increases as the wooded area or green area is larger (Gómez, 2005; Rosatto *et al.*, 2016).

Reethof *et al*. (1976) determine in laboratory conditions the amount of acoustic absorption generated by the bark of six types of trees, with different moisture contents, with presence and absence of litter and moss. The results show that the bark of *Carya tomentosa* (L.) Nutt., generate the greatest mitigation, due to its flaky form.

Burns (1979) measure the sound absorption capacity in pine branches and needles in a reverberating chamber, finding that the attenuation factor with the greatest contribution is the thermo-viscous absorption of the branches.

Martens and Michelsen (1981) using a laboratory vibrometer determine the attenuation achieved by leaves of four plant species, noting that the amount of energy absorbed by a single leaf is very small, admitting that plant communities contribute as a mechanism to the attenuation of sound, since the number of leaves of an adult tree can reach 200,000. Different field tests show that properly planted trees and shrubs can reduce noise.

Eyring (1946) experience the propagation of sound in the Panama jungle, placing a fountain and a receiver 1.5 meters above the ground, emulating the height of the human ear, finding that attenuation is inversely related to visibility. Fang and Ling (2003) studying 35 strips of subtropical evergreen trees in Taiwan, propose a reverse logarithmic function between visibility and relative attenuation and a direct logarithmic relationship between the relative attenuation and the width, length and height of the belts, in addition they demonstrate that the noise measurement 10 times per point, with a duration of at least 30 seconds, gives stable and representative values.

Cook and Van Haverbeke (1971) find that tree belts can reduce noise levels between 5 and 10 db. However, this should be 20 meters or more in length, dense, at least 14 m high and established by several kilometers to reduce noise, both in residential areas and on roads. Samara and Tsitsoni (2007) study the attenuation of traffic noise by vegetation along the ring road of Thessaloniki, Greece, results indicating that a reduction of 6 dB is achieved with *Pinus brutia* Ten., located at 60 Meters from the road. Pudjowati *et al*. (2013) use a series of sonometers located at varying distances from the Waru-Sidoarjo highway east of Java, Indonesia, one with tree vegetation, one without it but with vegetation at ground level and one control without it; the result shows that the noise reduction occurs for certain distances according to the specific species. Van Renterghem *et al.* (2013) showed the ability of hedges to reduce vehicle noise; those dense with a width from 1.3 to 2.5 m and heights of 1.6 to 4 m, generate attenuations ranging from 1.1 to 3.6 dB.

In South America, Posada *et al.* (2009) measure noise levels within 10 meters of a high vehicular traffic road in urban public areas with different vegetation cover in the Aburrá Valley, Colombia. The results do not show significant differences between sites with and without vegetation; however, the sampled areas have a few shrubby and sparse shrubs, suggesting the establishment of wider, longer, higher and denser live barriers. Cataño and Bonivento (2005), also in Colombia, show the efficiency of a tree cover of 50% as a vehicle noise attenuation barrier, of the order of 3 dB, in the campus of the National University of Medellín, near the North highway, measuring the noise at different distances from the transmitter source in four time zones of two hours each, at heights of 1.2 and 3.0 m. Ponce *et al.* (2016) measured the noise in three main streets in the city of Talca, Chile, at different times, days and tree coverings; the results indicate that although relevant findings were found, there were no significant differences according to the sources of variation.

The objective of this article is to show the results of a research intended to determine the influence of existing tree and shrub coverage at the level of vehicular noise present in a main avenue, with an important green infrastructure in the city of Talca, Chile. Location, distance to noise source and daytime hours were the sources of variation considered in this study.

Materials and methods

The study was conducted in the city of Talca, Maule Region, Chile, with a population of 201.8 thousand inhabitants, distributed over an area of 232 km^2. It is situated at 35°25'59'' South Latitude and 71°40'00'' West Longitude at 102 ma.s.l. (5). The site was located on Avenida Bernardo O'Higgins, also called "La Alameda". This avenue is located in the central area of the city and serves as the main communication artery that extends for 20 blocks long. La Alameda is a double track avenue that is widely used by motorists and emergency vehicles. During the past seven years it has gained commercial importance with new buildings such as hotels, public and private edifices, playgrounds for children, educational establishments, clinical centers, restaurants and recreation places, among others. It concentrates great number of arboreal species, some over 80 years old that are located in the central dividing belt of the avenue.

The selection zones and measurement points were done by a non-probabilistic, directed and intentional sampling. It comprised a selection of population units through personal judgment (3). Noise generated by vehicular traffic was considered, discarding other sources of noise, which coexist, but are generally masked by traffic (22).

Through the information provided by the Secretariat of Transport Planning (37), that indicates the high vehicular flow along the avenue, four zones (1, 2, 3 and 4) were selected with a similar vehicular flow and presence of tree and shrub vegetation, involving 12 blocks (figure 1).

Each measurement zone was separated for two blocks, in order to achieve greater representativeness. In each zone were located 13 measurement points, equidistant located were established to cover the area comprehensively (table 1 and figure 2, page 46).

Figure 1. Zones select at Bernardo O'Higgins Ave. (Alameda), Talca.

Figura 1. Zonas selecionadas en la Avenida Bernardo O'Higgins (Alameda), Talca.

Distance (m)	Measurements points
6.5	A – E – I – M
13.7	B – D – F – H – J – L
27.3	C – G – K

Table 1. Point´s distance from track edge.
Tabla 1. Distancia de los puntos al borde de la vía.

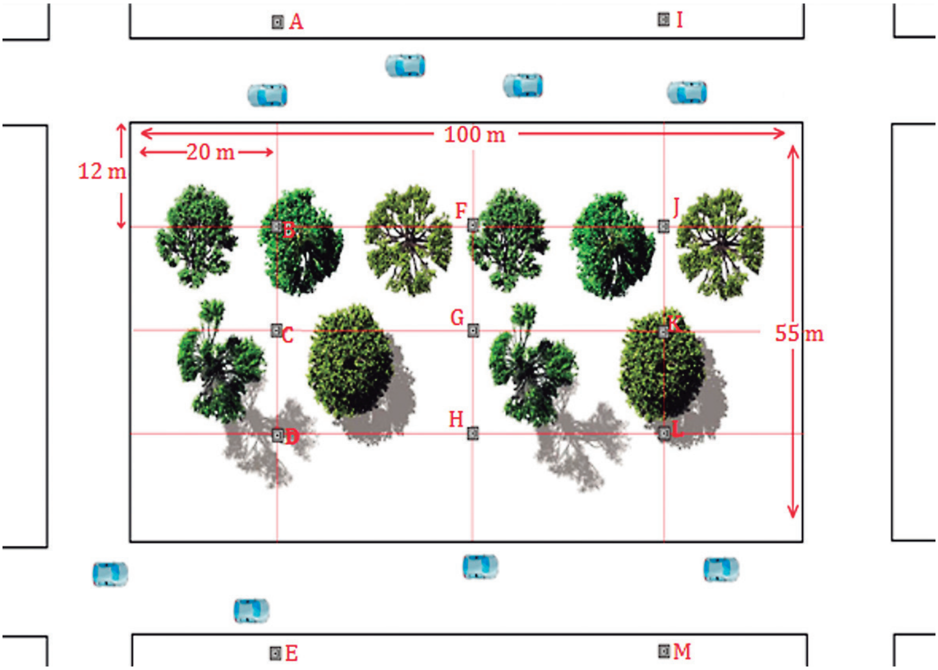

Figure 2. Schematic measurement points and plot centers.
Figura 2. Esquema de puntos y parcelas de medición.

Maximum and minimum noise, in decibels (dBA), was measured for twelve days from March 7 to April 1, 2016, twice a day, in the morning (7:30-8:30) and in the afternoon (18:00-19:00); the chosen period represent a normal period of activities during final summer term and beginning of autumn. Ten measurements of 60 seconds of duration each were carried out at each point (A, B, C... M, figure 2). This broadens the scheme proposed by Fang and Ling (2003). In each of one 13 point of measurement area was registered 260 data for both noises, totalizing 2,080 registrations.

A Lutron LT model SL-4012 was used to measure the noise, which has an automatic measurement scale between 30 dB and 130 dB. An a frequency weighting similar to the human ear response which is used on regulatory tests and workplace design by the United States Occupational Safety and Health Administration (OSHA). The meter position was located 1.5 m from the ground, as pointed out by Pudjowati *et al.* (2013).

A dendrometric survey was carried out at each measurement point using a circular plot of 8 m radius with no overlap between them. Each individual was individualized and the diameters at breast height (DBH, cm), height (m) and tree projection coverage area (m^2) were measured, the last one was organized in quintiles.

For the analysis of the maximum and minimum noise the median values were used, considering that this statistic helps to reduce the extreme values, proposing the following hypotheses:

H0: Ωi = Ωj / i ≠ j (there are no statistically differences between the medians of the measurements in each source of variation).

H1: Ωi ≠ Ωj / i ≠ j (there are statistically differences between the medians of the measurements in each source of variation).

An analysis of variance (ANOVA) was performed for each of the recorded variables (maximum noise and minimum noise), regarding the different sources of variation established: a) Zone, b) Moment, c) Distance and d) Coverage ratio.

The rational was to determine if the noise levels vary in the different situations. For this, normality assumptions were verified through the Kolmogorov-Smirnov test ($p < 0.05$) and homoscedasticity through the Levene's test ($p < 0.05$). Since only the normality assumption was fulfilled, Kruskal-Wallis's non- variance analysis (K-W) was used to identify significant statistical differences. The Tukey HSD test ($p < 0.05$) was employed to identify how the variables grouped. For the statistical analysis the Statgraphics Centurion version XVI.I program was utilized.

Results and discussion

The data collected presented great dispersion due to the different sources of variation (table 2). Zone 4 had the highest median maximum noise (75.1 dBA), while highest median for minimum noise was in Zone 2 (62.5 dBA). This shows that noise levels in all zones exceeded the minimum parameters established by the WHO, EPA-USA and the MMA of Chile (9, 22, 29). Peak values for maximum noise reached records of 98.2 dBA and values for the minimum noise picked up to 74.8 dBA, which also exceeded the recommendations of the institutions already mentioned.

Dendrometric analysis identifies 48 species out of 330 individuals of trees and shrubs. The most frequent species was *Platanus orientalis* L. with 65 individuals. Only 7 species were native (14.6%): *Crinodendron patagua* Mol., *Cryptocarya alba* (Mol.) Looser, *Maytenus boaria* Mol., *Persea lingue* Ness., *Peumus boldus* (Mol.) Johnston, *Quillaja saponaria* Mol. and

Table 2. Summary of measurements.

Tabla 2. Resumen de las mediciones.

Zone	Maximum noise (dBA)				Minimum noise (dBA)			
	Median	**Mean**	**Range**	**VC* (%)**	**Median**	**Mean**	**Range**	**VC* (%)**
1	71.1	71.6	58.9 – 84.2	7.1	59.0	59.1	47.5 - 68.1	5.9
2	73.8	73.8	62.0 – 98.2	8.8	62.5	63.5	50.1 - 74.8	8.6
3	72.1	72.2	61.4 – 86.9	7.3	57.5	57.5	47.2 - 69.5	5.6
4	75.1	75.1	63.7 – 86.4	8.1	59.5	59.5	51.3 - 67.5	4.9

* Variation Coefficient / * Coeficiente de Variación

Schinus molle Rev L. The DBH fluctuated between 3.3 and 101.8 cm, the height was between 1.7 and 26.1 m and the tree project coverage had a range between 2.4 and 311.9 m^2. The data showed a wide variety of species and stages of development of individuals (table 3).

Kolmogorov-Smirnov test verified that the normality assumption is fulfilled, for both maximum and minimum noise ($p < 0.05$), while the Levene's test that proves the homoscedasticity assumption, is not met ($p < 0.05$), except for the daytime variation source for the maximum noise variable. Because the homoscedasticity assumption was not met, Kruskal-Wallis non-parametric analysis of variance was performed, which is also less sensitive to the presence of atypical values. Due to the existence of differences found ($p < 0.05$), Tukey HSD multiple comparison test was applied (table 4, page 49).

The results show that the noise presents significant differences by Zone, Daytime, Distance and Tree Coverage (table 5, page 49). The K-W test showed that the tree coverage has influence on the measured noise levels; however it is not possible to observe a negative or positive trend as the coverage increases, which could be due to the lack of information regarding of each tree coverage representations for all the distances considered (table 5, page 49).

Results (table 5, page 49) were similar to those obtained by Posada *et al*. (2009) and Ponce *et al*. (2016) whose tree coverage did not present significant differences, although it is possible to exhibit data that support that an increase of the coverage decreases the noise level (7, 11, 19, 28, 32). Authors conclude that the absence of significant differences would be due to the fact that the tree covers studied would not be large enough to be efficient noise barriers, as Cook and Van Haverbeke (1971) pointed out.

On the other hand, considering the noise as a function of distance and tree coverage (table 6, page 49, figure 3 and 4, page 50) was observed when these last increases, there is a decrease in noise, although it is not significant either, as it is observed in the maximum and minimum noise profiles of figures 3 and 4 (page 50).

The inverse relationship between coverage and noise at points 1, 2, 4 and 5, in figures 3 and 4 (page 50), would be due to the vegetation cover, while in point 3 it would be given also by the distance factor, which allows us to point out, like Fang and Ling (2003) and Pudjowati *et al*. (2013) that vegetation contributes to noise reduction.

Table 3. Individuals, species and dasometric parameters.

Tabla 3. Individuos, especies y parámetros dasométricos.

Zone	N° Individuals	N° Species	DBH mean (cm)	Height mean (cm)	Tree Coverage projected mean (m^2)
1	78	24	34.8	10.4	101.8
2	83	11	20.8	7.2	47.9
3	93	26	27.8	8.2	73.2
4	76	20	25.5	6.7	64.3

Table 4. Tukey HSD multiple comparison test according to source of variation.

Tabla 4. Test de comparación múltiple de Tukey HSD según fuente de variación.

Source of variation	Level	Noise (dBA)							
		Maximum				Minimum			
Zone	1	71.1	a			58.9		e	
	2	73.3		b		62.9			f
	3	71.9	a			57.7	d		f
	4	74.9			c	59.9			
Daytime	Morning	71.9	a			61.2		e	
	Afternoon	73.8		b		58.5	d		
Distance	6.5	78.6	a			62.4	d		
	13.7	72.6		b		59.4		e	
	27.3	67.3			c	57.7			f
Tree Coverage	20	72.6	a	b		59.9		e	
	40	71.5	a			58.0	d		
	60	73.9			c	60.1		e	
	80	73.1		b	c	59.9		e	
	100	73.1	a	b	c	61.3			f

* Sub-index with different letters indicate significate differences

* Sub-índice con diferente letra indica diferencias significativas

Table 5. Statistics for noise, distance and tree coverage class.

Tabla 5. Estadísticos para ruido, distancia y clase de cobertura arbórea.

Distance Data (m)	Class Tree Coverage	Maximum noise			Minimum noise		
		mean (dBA)	Range (dBA)	VC* (%)	mean (dBA)	Range (dBA)	VC* (%)
6.5	20	78.9	66.0 - 98.2	6.0	63.5	51.4 - 74.8	6.9
	40	76.3	63.8 - 84.8	6.5	59.0	47.5 - 65.6	5.0
	60	79.1	74.0 - 84.6	3.7	60.6	56.2 - 65.1	3.6
13.7	20	71.5	63.0 - 80.3	5.9	57.6	47.2 - 62.5	5.1
	40	73.0	63.2 - 79.6	4.4	57.4	49.6 - 63.1	3.9
	60	72.6	64.2 - 84.9	5.5	58.8	50.2 - 68.9	6.4
13.7	80	73.5	63.7 - 86.4	7.9	59.8	50.1 - 66.2	5.3
	100	72.7	63.5 - 84.2	6.1	62.5	50.5 - 73.7	8.6
27.3	20	67.1	61.1 - 77.0	4.7	57.4	48.9 - 63.9	5.4
	60	68.6	58.9 - 76.6	5.8	57.9	50.1 - 62.5	4.4
	80	68.1	61.9 - 80.7	7.8	59.9	52.7 - 73.9	11.0
	100	65.6	62.9 - 70.5	2.9	58.5	53.2 – 2.2	4.3

* Coefficient of Variation. / * Coeficiente de Variación.

Distance	Noise (dBa)		Tree Coverage (%)
	Maximum	Minimum	
6.5 (north)	79.6	62.9	10.8
13.7 (north)	73.6	60.7	63.4
27.3 (central)	67.4	58.0	33.4
13.7 (south)	71.8	58.5	49.2
6.5 (south)	76.5	60.9	19.6

Table 6. Mean noise and tree coverage by distance.

Tabla 6. Promedio de ruido y cobertura arbórea por distancia.

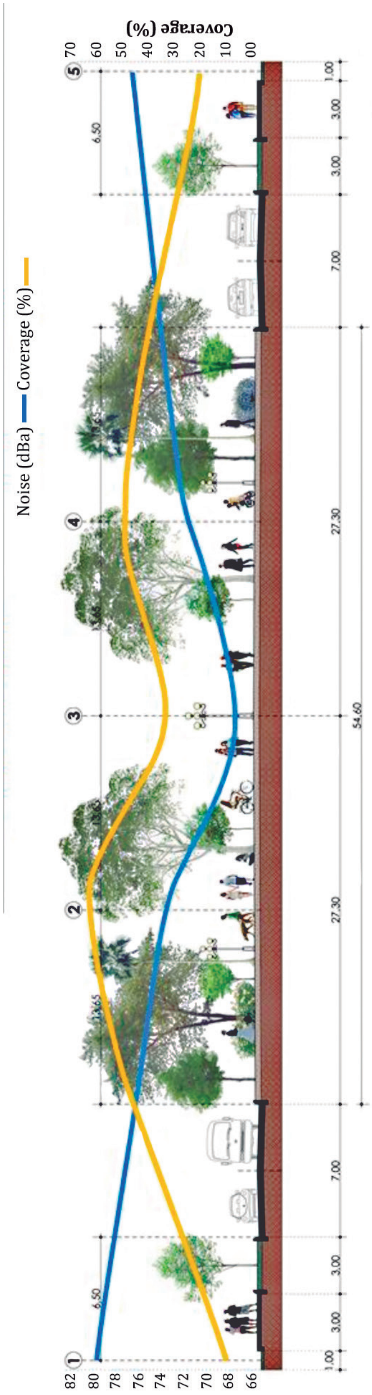

Figure 3. Maximum noise scheme.
Figura 3. Esquema de ruido máximo.

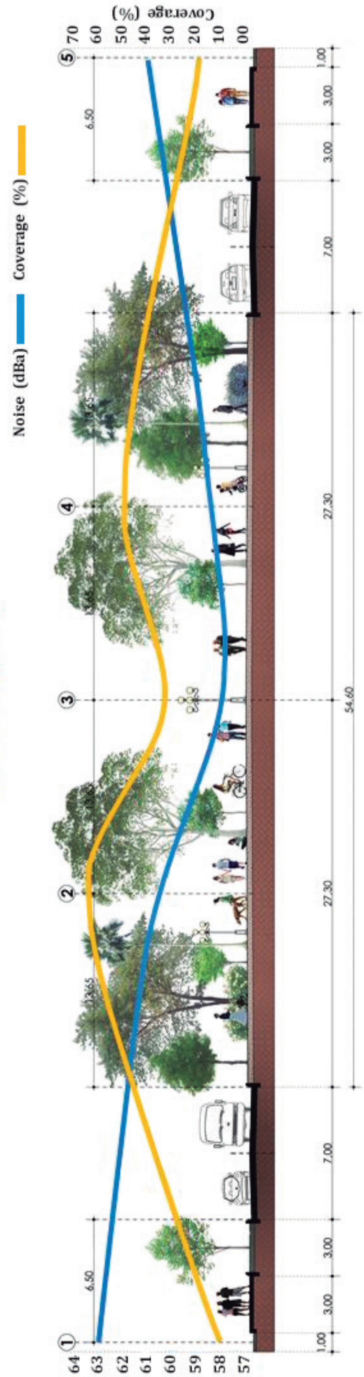

Figure 4. Minimum noise scheme.
Figura 4. Esquema de ruido mínimo.

Conclusions

The noise levels in the study area exceeded the minimum parameters established by the World Health Organization and Chilean regulations.

It was not possible to establish a statistical mathematical relation that allows demonstrating that to a greater presence of vegetation cover, the noise decreases.

The distance and daytime were the sources of variation that presented significant differences and a tendency in the reduction of noise. While in analysis for Zone and Coverage there were no significant differences, neither was a clear trend in noise reduction.

The different tree coverage showed significant differences in the noise level, but it was not possible to observe a trend that supports the variation of the noise level according to the coverage in all distances considered, except for the distance of 6.5 m, the closest to the source of noise. This last finding would be explained by the amplitude in the noise registers.

Given the vegetation structure studied, effective barriers for noise reduction are difficult to implement in urban areas. However, further studies must be carry out in order to correlate the present findings with hearing perception of noise reduction by people living and commuting in the studied zones.

Relevant data collected in this study, although not statistically significant, is valuable enough to propose a research that considers human functioning and well-being of the citizen in the area whose perception may provide a more comprehensive effect of the urban forest in noise reduction.

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