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Environment

Use of green vegetable barriers as environmental noise attenuators: a case study in Irati, Parana

Uso de barreiras vegetais verdes como atenuadoras do ruído ambiental: estudo de caso em Irati, Paraná

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ABSTRACT

The present study aims to evaluate the potential of the Secondary Mixed Ombrophilous Forest as a vertical noise-attenuating green barrier. The methodology calls for the development of an analysis of proximity between sampling points of omnidirectional noise monitoring to be measured at various distances from the source from the beginning of the barrier and inside the forest. A sound source reproducing amplified pink noise was used. In this research, an experimental strategy was used to prove the influence of this type of green plant barrier as a noise attenuator as one enters the interior of a fragment of Mixed Ombrophilous Forest, carrying out successive measurements of the sound pressure level at distances from the proximity of the source and the distances from the edge towards the interior of the forest that can prove the significant attenuating function of this type of green vertical barrier. In fact, the analyses performed for Leq A and Z (dB) confirm a significant correlation for distance from the source regardless of the sound amplitude for measurements performed outside the barrier (in front of the source, 6 m behind the source, 6 meters in front of the source), as noise attenuation occurs as the sound propagates. However, the analyses inside the barrier (at 12m, 18m, and 24m) present a negative correlation for distance, confirming the hypothesis of the effectiveness of the attenuation by the vegetal barrier.

Keywords: Noise pollution; Attenuating barriers; Mixed Ombrophilous Forest

RESUMO

O presente estudo tem por finalidade avaliar o potencial da Floresta Ombrófila Mista Secundária como barreira vertical verde atenuadora de ruídos. A metodologia prevê a elaboração de uma análise de proximidade entre pontos amostrais de monitoramento omnidirecional do ruído a ser mensurado em diferentes distâncias de proximidade da fonte, desde o início da barreira até dentro da floresta. Foi utilizada uma fonte sonora reproduzindo ruído rosa amplificado e uma estratégia experimental para comprovar a influência desse tipo de barreira vegetal verde como atenuadora de ruídos, a medida em que se adentra ao interior de um fragmento de Floresta Ombrófila Mista, realizando medições sucessivas do nível de pressão sonora a distâncias de proximidade da fonte e a distâncias a partir da borda em direção ao interior da floresta, que possam comprovar a função atenuadora deste tipo de barreira vertical verde. De fato, as análises realizadas para Leq A e Z (dB), confirmam uma correlação significativa para distância da fonte independentemente da amplitude sonora para medições realizadas fora da barreira (em frente à fonte, 6 metros atrás da fonte, 6 metros à frente da fonte) a atenuação do ruído ocorre à medida que há a propagação sonora. Contudo, as análises dentro da barreira (12m, 18m e 24m) apresentam correlação negativa para distância, confirmando a hipótese de eficácia da atenuação pela barreira vegetal.

Palavras-chave: Poluição sonora; Barreiras atenuadoras; Floresta Ombrófila Mista

INTRODUCTION

The development of society associated with economic and social progress has allowed for advancements in quality of life and improvements to infrastructure. As a result, on average, approximately half of humanity lives in large urban concentrations. Therefore, the evolutionary changes caused by this scenario have brought with them environmental problems and adverse effects on human health (De Queiroz *et al.*, 2018).

Environmental noise is characterized as one of the main pollutants of modern society, caused mainly by vehicular traffic, industrial, construction and recreational activities, thereby directly affecting the well-being of the population itself (Chávez *et al.*, 2009) and faunal components (Kunc and Schmidt, 2019). For Bistafa (2018), noise is an undesirable sound, so that continuous, intermittent or impact exposures, at high levels, can precipitate difficulties in the quality of life, implying potential risks of deafness and consequences in the development of other diseases, include discomfort, sleep disorders, impairment of the auditory system leading to hearing loss, increased mortality, negative effects on speech, cardiovascular systems and loss of cognitive performance (Basner *et al.*, 2014; Duarte *et al*., 2015).

The mapping of noise from traffic and other emission sources can serve as qualitative, conceptual and definitive tools for improvements in the study of environmental management and urban planning in a city (De Queiroz *et al.*, 2018). Currently, noise pollution occupies the second position among the largest polluting sources, second only to air pollution, according to the WHO (World Health Organization, 2020). In general, all these factors influence the reduction of quality of life by compromising the individual's physical, physiological and psychosocial activities.

These impacts also directly affect animal life, which, when exposed to noise pollution for a long time, develop watch behavior, showing greater aggressiveness, abandoning activities such as nest building (Gil and Brumm, 2014) and territory defense (Zwart *et al.*, 2016).

According to the NBR 10151 Standard for Acoustic Comfort for External Environments set forth by the Brazilian Association of Technical Standards (ABNT), the classification of sound pressure levels according to the types of inhabited areas is between 40 to 70 dB for daytime periods and between 35 to 60 dB for nighttime periods.

Like in other nations, research is carried out to qualify and quantify urban noise in Brazil.

According to Bistafa (2011), every sound source releases a specific amount of sound power, which determines sound levels and displays noise attenuation mechanisms, and is dependent on the path the wave takes as it travels to the receiver. Therefore, a mechanism to attenuate noise is acoustic barriers, which have several types, such as the vegetal barrier. Between the source and the receiver, the sound level is attenuated as the sound propagates; this occurs due to the increase in distance, considerable high frequencies present greater attenuation when reaching shorter distances. Attenuation through absorption by atmospheric air along the trajectory depends on frequencies, relative humidity of the medium, atmospheric pressure and temperature and through reflection by the ground. Likewise, it is also possible to intervene in the sound propagation phase by placing, for example, obstacles such as natural or artificial barriers, interfering with the sound propagation, attenuating its level of intensity (Arbetarskyddsfonden, 1986).

Botari *et al*. (2013) states that, generally, this type of barrier (natural), does not guarantee efficient sound reduction, compared to concrete barriers and other acoustic materials. Although these parameters demonstrate efficiency, the choice of these barriers does not aim at the well-being and quality of life of people but at the physical aspects of noise pollution. Bento-Coelho *et al.*, 2016 and Van Kempen *et al.*, 2016, highlight aspects of vegetation barriers that provide visual comfort by hiding the source of noise and psychoacoustics, which provide the sensation of attenuation of environmental noise.

The action of the vegetation present in the barrier is able to soften the noise, either by absorbing it by deviation, which changes its direction by reflection, which causes the sound waves to change moving around an object, or by concealment, when the unwanted sound is covered with a more pleasant one. (Botari *et al*., 2013).

A recognized methodology for testing noise barriers is the use of a sound source meter, a controlled measurer of SPL's (sound pressure levels). Bistafa (2018) points out that sound pressure (N/m^2) is the most relevant quantity and is related to the intensity of the sound. Furthermore, the pressure of the vibration that the sound exerts on the human ear. Sound intensity (W/m^2) is an energy magnitude indicator used to measure the direction and sense of sound wave propagation in a unitary area.

As a sound source, several researchers have focused on a smoother and more refined version of white noise, called "pink sound", detected from numerous signals generated by various natural and artificial processes, this pink sound or pink noise (also known as flicker noise, pink noise, 1/f noise or fractional noise) has intermediate characteristics of white noise and red noise. The terms white noise, pink noise, red noise derive from the light spectrum. In the case of white light, it refers to a statistical model of the combination of white intensity in all colors. In the case of white noise, it refers to the combination of equal intensities for all frequencies (f) of the acoustic spectrum. In other words, the signal contains equal power within a fixed bandwidth at any center frequency (Rezaei-Hachesu *et al.* 2023). The use of pink noise for field tests for environmental purposes is still rare, but can be seen in Lisot and Soares (2008), Matsunaga and Watanabe (2012), Potvin *et al*., (2016) and Sousa (2017). The purpose is to use a pink noise source to evaluate the potential of a fragment of Mixed Ombrophylous Forest in the secondary stage, as a green vertical noise attenuating barrier.

MATERIALS AND METHODS

The present research was developed in the municipality of Irati, located in the Southern-central region of the state of Paraná (PR), having as its limits the municipalities of Fernandes Pinheiro, Imbituva, Prudentópolis, Rebouças, Rio Azul and Inácio Martins. Presenting the geographic coordinates 25º 40’ South latitude, 51º11’ West longitude and 25º 1’ South latitude, with intersection with the meridian 50º 37’ 51” West longitude. According to the Köppen-Geiger classification, Irati is a region that it has a climate of the cfc type with a temperate climate with relative humidity of 79.58% and average rainfall of 137mm, with temperature variations of 24.0ºC in the hottest season and 13.0ºC in the coldest season (IAPAR, 2017) The characterization of the spatial structure and density of the forest fragment tested as a vertical green barrier was studied by Roque *et al*. 2017, Campus Irati is shown in table 1.

Table 1 – Phytosociological parameters of the species sampled in the FOM fragment by the multiple plot method where N (Nº of Individuals), DA (Absolute Density), DR (Relative Density), DOA (Absolute Dominance), DOR (Relative Dominance), FA (Absolute Frequency), FR (Relative Frequency) and IVI (Importance Value Index)

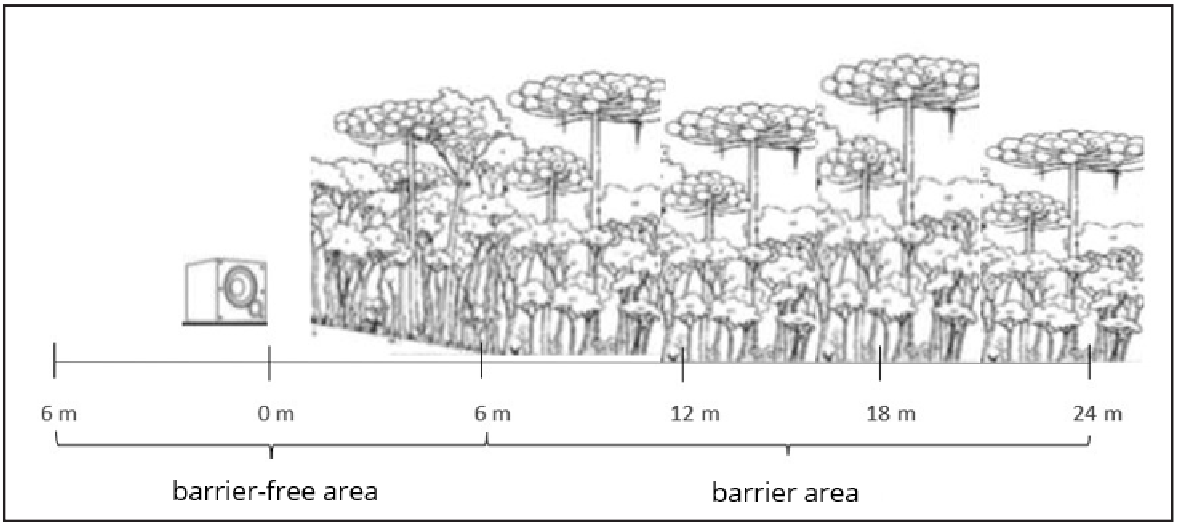
Species	N	DA	DR %	DOA	DOR %	FA %	FR %	IVI %
Allophylus edulis	1	33	3	0.041	3.40	33	4.70	11
Araucaria angustifolia	4	133	11	0.734	60.50	67	9.60	82
Casaeria decandra	3	133	11	0.004	0.30	67	9.60	21
Casaeria lasiophyllla	1	33	3	0.001	0.10	33	4.70	8
Casaeria silvestris	3	100	9	0.004	0.30	33	4.70	14
Cestrum sp.	1	33	3	0.001	0,10	33	4,70	8
Cinnamodendron sp	5	166	14	0.252	20.80	100	14.30	49
Cinnamomum sp	1	33	3	0.005	0.40	33	4.70	8
Cordyline spectabilis	2	67	6	0.003	0.30	33	4.70	11
Hovenia dulcis	4	133	11	0.006	0.50	67	9.60	22
Luehea divaricata	2	67	6	0.008	0.70	33	4.70	11
Ocotea puberula	1	33	3	0.005	0.40	33	4.70	8
Podocarpus lambertii	4	133	11	0.114	9.40	67	9.60	30
Schinnus sp	1	33	3	0.032	2.60	33	4.70	10
Vasconcellea sp	1	33	3	0.003	0.20	33	4.70	8
TOTAL	34	1163	100	1.213	100.00	698	100.00	300

Source: Roque *et al*. (2017)

The methodology for obtaining pink noise levels followed the ISO 9613-1: 1993 and ISO 9613-2: 1996 standards for sound attenuation during outdoor propagation. This standard specifies how to obtain the calculation of sound absorption by the atmosphere. The sequence of the work comprises the characterization of a single forest fragment as a green vertical barrier, located on the campus of the Universidade Estadual do Centro-Oeste-PR (Irati campus) during the vacation period, which allowed measurements to be carried out without undue external interference from cars. or people. Therefore, the only artificial sound practically emitted at the time of measurement gathering was pink noise.

The study comprised an area within the vertical system of the plant barrier, with the choice of six points represented (figure 2): at 6 meters behind the source (-6), at 0 meters, in front of the noise source, at 6 meters in front of the noise source and in front of the barrier, at 12 meters from the source and at 6 meters inside the barrier, at 18 meters from the source and at 12 meters inside the barrier, and at 24 meters from the source and at 18 meters inside the barrier. Measurements were performed at all points as well as at 2.6 and 10 dB (decibels), taking into account the density and spatial distribution of individuals and the source of noise emission.

Figure 1 – Schematization locating the acoustic box, respective observed points and their distances

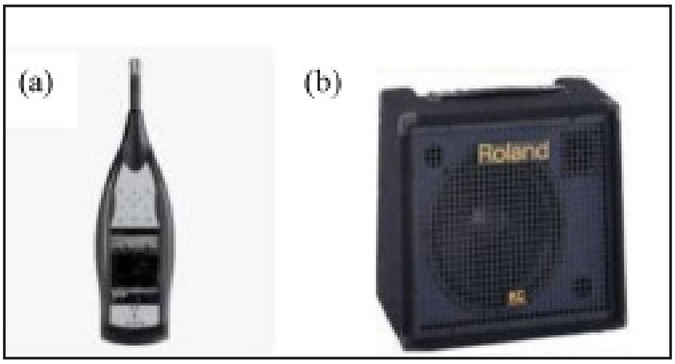


Source: Authors (2021)

The following characteristics were considered for SPL (Sound Pressure Level) measurements: A class 1 multidirectional meter (figure 3a) was used, with an omnidirectional microphone, a Bluel & Kjaer SPL analyzer type 2250-Light, a spectrum of 1/3 octaves with central frequencies (12.5Hz to 16kHz), with A, B, C and Z frequency weighting (linear), with fast, slow and impulse response times, according to the manufacturer's manual. For these analyses, the A-weighting curves were considered, which mechanically reproduce the way the human ear hears and which approximates the discomfort felt. The Z weighting, on the other hand, captures all emitted frequencies.

The NPS sound pressure meter has the appropriate specifications for outdoor measurements of environmental noise as per the manufacturer's manual. The source was placed 6 meters in front of the selected vegetation barrier for noise emission. Using Pink Noise version 1.0, this noise source was produced in a Roland KC-150 professional speaker (figure 3b).

Figure 2 – NPS Bluel & Kjaer NPS analyzer type 2250-Light, a 1/3 - octave spectrum with central frequencies from (12.5Hz to 16kHz), with A, B, C and Z frequency weighting (linear) (a) and a Roland loudspeaker (b))



Source: Authors (2021)

The measurements followed with 1 minute intervals distributed every 6 meters to obtain the greatest amount of data. Measurements were also obtained in front of and behind the noise generating box for future comparisons, with an amplitude (volume) 2. 6 and 10 and the other measurements were followed within the barrier every 6 meters from the noise source maintaining the same settings. Adhering to the recommendations of NBR 10151, measurements were conducted in meteorological conditions devoid of rain and strong wind. Meteorological effects such as wind and temperature gradients influence sound propagation and attenuation which may interfere with the noise wave to the receiver (Bistafa, 2011) . The collections were performed in the morning and the temperature ranged from 23°C at the beginning to 30°C. With the Leq frequency data (dB A and Z) obtained at different distances, statistical procedures were performed using the R-Studio software, to test whether the distance factor helps to reduce noise in open areas and determine how it behaves in open areas. presence of the green vertical barrier as one enters the fragment of Mixed Ombrophylous Forest in a secondary stage. Spearman's Rank Correlation Coefficient cluster and independence analysis tests were performed for categorical variables.

RESULTS AND DISCUSSION

Data from Leq A and Z, the weighting curve A represents frequencies that are more sensitive to human hearing, then focused on environmental noise and Z characterized as unweighted, that is, it captures all frequencies, considered sensitive for fauna. In addition, the measurements can be characterized as outside the vegetation barrier and inside the barrier, as shown in figure 2.

As expected, the measurements in front of the box at 0 meters, in all sound amplitudes, presented values higher than the other measurements (table 2), for weighting (A) we obtained 76.3 dB amplitude 2, 91.7 dB amplitude 6 and 112, 1 dB amplitude 10. The measurements without weighting (Z), for amplitude 2, 78.26 dB, and amplitude 6, 93.65 dB and amplitude 10 obtained 113.62 dB. Measurements at -6 meters, i.e., behind the box and 6 meters in front of the box, did not show statistical significance compared to each other for both Leq A and Z weighting.

Among a relationship analysis, the noise measured directly in front of the source showed higher values than those measured behind the noise-producing source, except for sound amplitude 2, where 6 meters behind the source Leq (A) (table 2) resulted in 57.9 dB and in front of the source 56 dB with an increase of 1.9 dB, and for Leq (Z) in front of the box 73.78 and behind 76.19 an increase of 2.41. These data can be explained by the Doppler effect, with the source-receiver distance the wavelength increases and the frequency decreases in a way that captures bass sounds (Fernades *et al*., 2016)

Analyzes performed for Leq A and Z (dB), in fact, confirm a significant and negative correlation between source distance and Leq for amplitude 2 (Spearman r = -0.83; p-value = 0.04); 6 (Spearman r = -0.89; p-value = 0.02) and to 10 (Spearman r = -0.84; p-value = 0.04). Noise attenuation occurs as there is sound propagation, that is, the sound level reduces with distance as the sound diverges from the source (Bistafa, 2011). Significant correlation values greater than 0.8 indicate that the distance significantly interfered in the attenuation of the Leq (A) [dB], regardless of the amplitude of the sound source. The LZeq(A) [dB] noise reduction is greatest up to 6 meters away, becoming almost insignificant between 18 and 24 meters away. For the Leq (Z) (dB) values, the same patterns were observed: Significant influence of distance and volume for amplitudes 6 and 10. Amplitude 2 did not present a significant correlation (figures 4 and 5).

Correlatively, using the data obtained and represented in table 2, through a subtraction, the attenuations in dB were found for all measurements (table 3). The measurements with the presence of a plant barrier: 12, 18 and 24 meters, follow a logical sequence of attenuation, even if not significantly influenced by distance and sound amplitude, for Leq A the sound attenuation, except for amplitude 2 (table 3). Distances from 18 to 24 meters did not follow an attenuation pattern, with an increase of 0.1 dB.

Table 2 – Mean and Leq A (a) and Leq Z (b) attenuation values in dB for different source distances and loudspeaker volumes or amplitudes

(a)

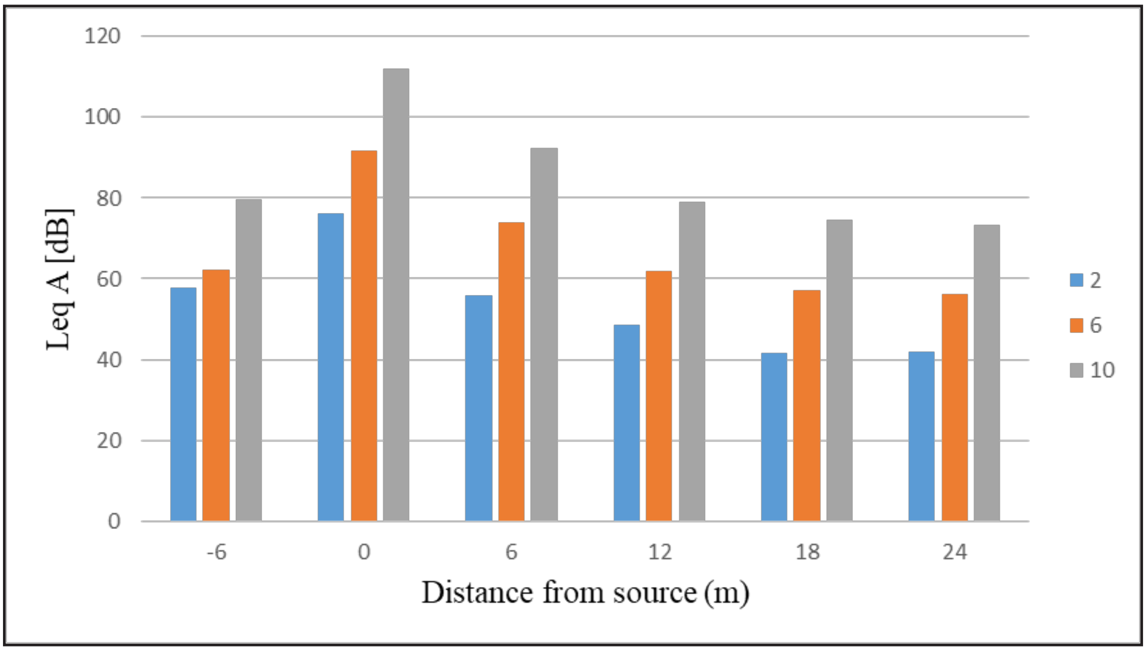
Amplitude	Distance from Source (m)	Leq A (dB)	Attenuation (dB)
Amplitude 2	0	76.3	76.3
	6	56	17.3
	-6	57.9	-1.9
	12	48.5	9.4
	18	41.7	6.8
	24	41.8	-0.1
Amplitude 6	0	91.7	91.7
	6	73.9	17.8
	-6	62.3	11.6
	12	61.8	0.5
	18	57.2	4.6
	24	56.2	1
Amplitude 10	0	112.1	112.1
	6	92.4	19.7
	-6	79.7	12.7
	12	79.1	0.6
	18	74.6	4.5
	24	73.4	1.2

(b)

Amplitude	Distance from Source (m)	Leq Z (dB)	Attenuation (dB)
Amplitude 2	0	78.26	78.26
	6	73.78	4.48
	-6	76.19	-2.41
	12	57.41	18.78
	18	63.95	-6.54
	24	62.78	1.17
Amplitude 6	0	93.65	93.65
	6	79.08	14.57
	-6	76.36	2.72
	12	66.11	10.25
	18	63.16	2.95
	24	61.43	1.73
Amplitude 10	0	113.62	113.62
	6	94.84	18.78
	-6	88.18	6.66
	12	82.43	5.75
	18	78.9	3.53
	24	77.04	1.86

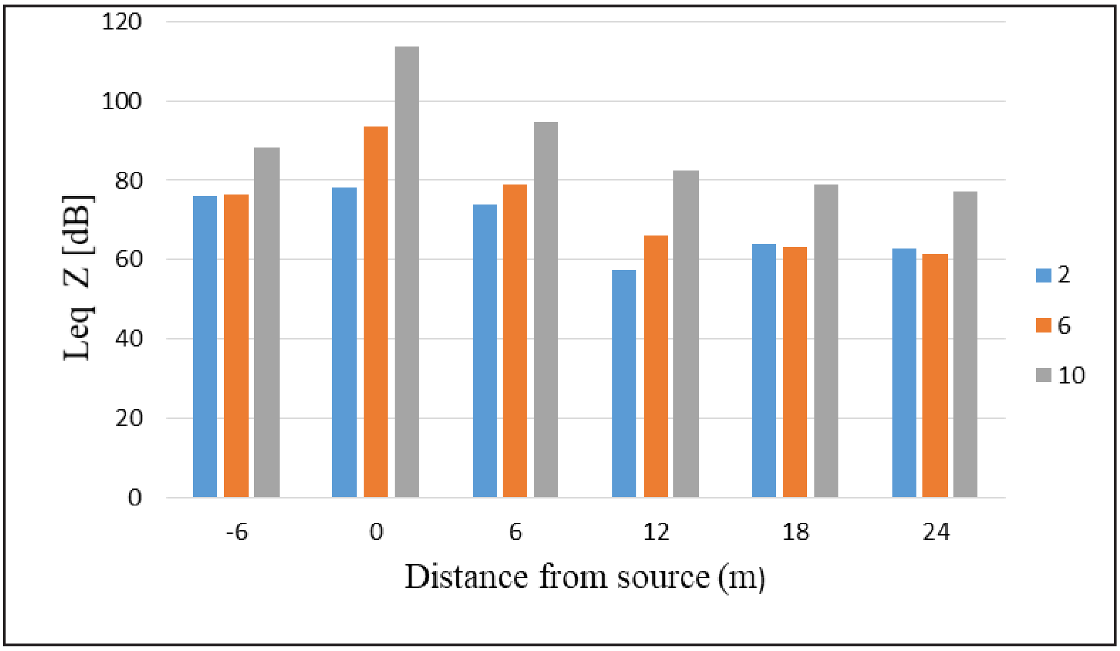
Source: Authors (2021)

Figure 4 – Average values of Leq A in (dB) for different source distances and enclosure amplitudes



Source: Authors (2021)

Figure 5 - Average values of Leq Z in (dB) for different source distances and enclosure amplitudes



Source: Authors (2021)

Also for Leq Z, (table 3) measurements from 12 meters to 18 meters showed an increase of 6.5 dB. There are two possible reasons for the data caveats. Firstly, the results can be affected by other sound sources found in the forest as well as by the characteristics of the trees (Bernatzky, 2012). Second, the attenuation for lower frequencies becomes less efficient compared to higher frequencies, since only amplitudes 2 did not follow an attenuation pattern for both Leq A and Z.

Table 3 – Attenuations for Leq A (dB) (a) and for Leq Z (dB) (b) by the plant barrier

(a)

Widths	Measurements	Attenuation Leq A (db)
	6 m – 12 m	7.5
2	12 m – 18 m	6.8
	18 m – 24 m	-0.1
	6 m – 12 m	12.1
6	12 m – 18 m	4.6
	18 m – 24 m	1
	6 m – 12 m	13.3
10	12 m – 18 m	4.5
	18 m – 24 m	1.2

(b)

Widths	Measurements	Attenuation Leq Z (db)
	6 m – 12 m	16.4
2	12 m – 18 m	-6.5
	18 m – 24 m	1.2
	6 m – 12 m	12.1
6	12 m – 18 m	4.6
	18 m – 24 m	1
	6 m – 12 m	12.4
10	12 m – 18 m	3.5
	18 m – 24 m	1.9

Source: Authors (2021)

A considerable and effective reduction of noise depends on the density of the vegetation. Trunk diameter, canopy structure and foliage density can considerably affect reduction through noise scattering. Azkorra *et al*. (2015) found that the absorption coefficient of plants is controlled by the density of the leaf area. As a result, the higher the values of the absorption coefficient, the larger the area occupied by foliage.

The hypothesis of attenuation by the vegetal barrier is confirmed through the comparison with the control value of an open area of 6 meters with 12 meters attenuating from 12 to 13 dB for sound amplitudes, at 6 and 10 for Leq A and Z (figure 06). This finding was supported by other studies, including Ow and Ghosh (2017). They found that vegetation barriers with 5 m of vegetation depth resulted in

9 to 11 dB more attenuation than the same width of land without trees. Still using 6 meters as an "open area" that is, an area that did not present a vegetation barrier, comparing with measurements of 18 and 24 meters, that is, which represent 16 to 18 meters of area with a vegetation barrier (table 3), shows significant attenuation of the noise. These results reveal that the increase in vegetation cover, as well as in the density of plant biomass, enhances the reduction of noise levels.

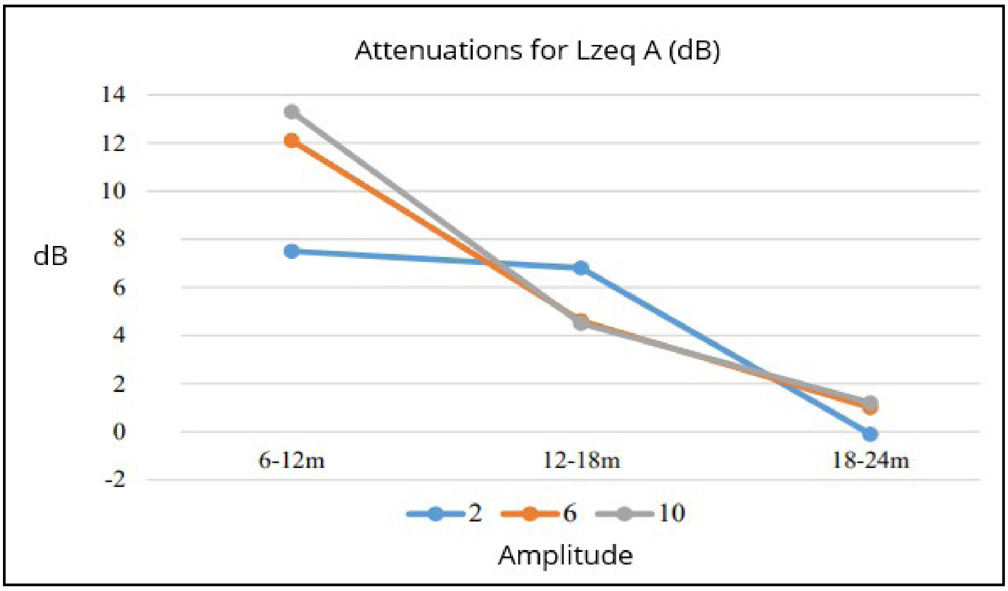
Other studies, such as those by Fang and Ling (2003), reveal that dense vegetation barriers with a considerable depth of vegetation of approximately 30 meters provide a greater surface area for sound attenuation, which can reduce approximately 4-8 dB.

This confirms that the width of the vegetation barrier is essential for efficient mitigation. Through the comparison analysis (table 4) of amplitude and distance, it is possible to observe that all amplitudes 10 are in group (cluster) 1, while all amplitudes 2 are in group (cluster) 2. Amplitude 6, which has an intermediate amplitude, was present in cluster 1, but the values present in group 1 are those closest to the source, that is, behind the source, in front of the source, and 6 meters from the source, and thus have the highest dB.

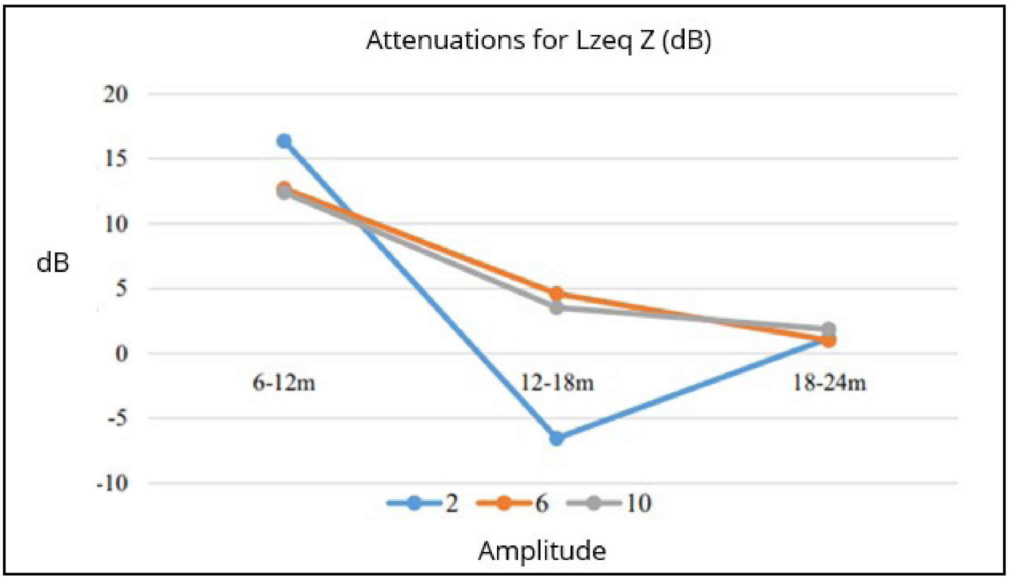
In grouping 2, there are the dB values of the greatest distances of amplitude 6, that is, 12 meters, 18 meters and 24 meters that report to the smallest dBs of box 6. As a result, in these comparisons of sound amplitude or volume and distance (6.0, 6, 12, 18, and 24), it is observed that the distance does not influence as much as the volumes or amplitudes in the box, since the distances 6 and 10 meters from the sound source were in the same group (cluster 2). Moreover, in this analysis, it

Figure 06 – Attenuation values for Leq A (dB) (a) and Leq Z (dB) (b) for distances 6m, 12m and 24m

(a)



(b)



Source: Authors (2021)

In grouping 2, there are the dB values of the greatest distances of amplitude 6, that is, 12 meters, 18 meters and 24 meters that report to the smallest dBs of box 6. As a result, in these comparisons of sound amplitude or volume and distance (6.0, 6, 12, 18, and 24), it is observed that the distance does not influence as much as the volumes or amplitudes in the box, since the distances 6 and 10 meters from the sound source were in the same group (cluster 2). Moreover, in this analysis, it is observed that the attenuation occurs from the vegetal barrier, and that the distance attenuates less than the plant barrier.

Table 4 – Grouping of variables A and Z according to different distances and volumes

Group	Box Width	Distance	A	Z
2	2	-6	57.9	76.1900
2	2	24	41.8	62.7800
2	2	18	41.6	63.9500
2	2	12	48.4	57.4100
2	2	6	55.9	73.7800
2	2	0	76.2	78.2600
1	6	-6	62.3	76.3600
1	6	24	56.1	61.4300
1	6	18	57.1	63.1600
1	6	12	61.8	66.1100
1	6	6	73.9	79.0800
1	6	0	91.6	93.6500
1	10	-6	79.6	88.1800
1	10	24	73.3	77.0400
1	10	18	74.6	78.9000
1	10	12	79.1	82.4300
1	10	6	92.4	94.8400
1	10	0	112.0	113.6200

Source: Authors (2021)

In fact, amplitude or volume had a significant effect on values in dB, both for A and Z, while distances only had a significant effect when evaluated separately, that is, without the effect of amplitude (volume) as can be seen in the table 5 through the independence test. This is because the greater its amplitude, the greater its intensity. However, for both weightings, the captured frequencies showed differences, as the receiving device carried out the measurements according to the sensitivity of the human ear, for A weighting, which attenuates bass sounds, and Z weighting considered without weighting, that is, it captured all the unfiltered frequencies.

Table 5 – Evaluation of the effects of amplitude and distance separately by independence test for categorical variables

	Df	Chi-squared	p-value	g-squared	p-value
Width	2	12.00000	0.00248	16.63553	0.00024
Distance	5	2.00000	0.84915	2.03879	0.84375

Source: Authors (2021)

4 CONCLUSIONS

It is concluded that the distance factor helps in the reduction of noise in open areas, without the presence of a barrier, however, the results with vertical barriers of vegetation are promising in the attenuation requirement, suggesting that the total noise reduction decreases as the density of vegetation increases, disturbing the acoustic waves producing greater diffraction phenomena and therefore even greater noise reduction effects.

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