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NOISE CONTROL FOR A BETTER ENVIRONMENT

Using vegetation to tackle environmental noise problems – combining exposure level reduction and noise perception improvement.

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ABSTRACT

The use of vegetation in the (peri)-urban environment performs a myriad of ecosystem services, and improving the sound climate is one of them. However, well-thought out application is essential to benefit from both the physical noise level reduction and perception improvement green might bring. For surface transport noise sources, the interaction with ground/growing substrates, multiple scattering and absorption by above-ground plant material, and the impact on the micro-climatology are the main physical effects of practical concern. This contrasts with past research focusing largely on the effect of leaves only. The perception improvement by vegetation is often experienced by the population as very strong. In order to understand this, existing research has been scrutinized in view of three potentially explaining mechanisms namely source (in)visibility, the mere presence of visible green, and vegetation as a source of natural sounds. When following the restorative hypothesis of visible vegetation, most consistent conclusions could be drawn. In order to make such perception related improvements more tangible and useful during planning, equivalent sound pressure level reductions were derived for a main environmental noise indicator namely self-reported noise annoyance.

Keywords: Environmental noise, Outdoor sound propagation, Vegetation, Nature based solutions, Noise Annoyance, Environmental perception

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1. INTRODUCTION

Although using vegetation to tackle environmental noise is a topic of continued interest since several decades, its potential for physical sound pressure level reduction has typically been undervalued. Historical exploratory measurements led to very conservative calculation schemes like those found in the ISO 9613-2 standard.

Nevertheless, some earlier work already pointed at the fact that it should be possible to reduce much more decibels with vegetation. A main message in this paper is that vegetation, just as any other noise abatement measure, needs to be carefully designed.

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In addition, even in cases where objectively measured sound pressure level reductions are limited, removing such vegetation often leads to strong reactions from dwellers. This points at the positive effect vegetation has on the perception of environmental noise. Note that the discrimination between physical noise reduction and the improved perception is typically not made by the public at large.

In this paper, current knowledge on using vegetation to physically reduce noise exposure is summarized, with a focus on tree belts along roads. Secondly, the mechanisms behind the perception improvement will be explored based on meta-analysis of published works.

2. PHYSICAL NOISE REDUCTION BY TREE BELTS ALONG ROADS

Only the soil and trunk layer are able to sufficiently interact with the low sound frequencies from road traffic. Leaves, in contrast, only impact high sound frequencies due to their small dimensions, and thus have an effect on a minor part of the road traffic spectrum only (see Ref. 1). Notwithstanding, there has been a lot of research on the interaction between leaves and acoustic waves, given this dominant visual (but not acoustical) feature of vegetation. Note that leaf scattering might be even (slightly) negative when crowns are positioned at a larger height than both source and receiver.

2.1 Forest floor effect

Below vegetation, an acoustically very soft (porous) soil (see e.g. Ref. 2) is typically present due to humus layer formation, with possibly plant litter on top, and due to plant rooting. This results in a shift in the ground effect towards lower frequencies compared to e.g. sound propagation over grassland (3). Due to the typical low height sound sources in road traffic, specular reflection points are most often located inside the vegetation belt when being positioned close to a road.

2.2 Trunk effect

The most relevant process at medium-low sound frequencies is multiple scattering in between the tree trunks. Multiple scattering will redirect sound energy away from the (direct) path between source and receiver. As a result, sound energy gradually decreases during transmission through the trunk layer. Bark absorption can contribute to the noise reduction due to the many interactions between sound waves and trunks, although the absorption coefficients are typically modest (4). In addition, complex effects like the occurrence of stop bands and pass bands might appear in case of ordered planting schemes. Such effects have been observed near trees as reported in Ref. 5. However, pronounced band gap effects are unlikely as the trunk filling fractions where such effects appear exceed those possible in tree belts, as discussed in Ref. 6.

2.3 Design guidelines for physical noise reduction by tree belts

There are accurate models to describe reflection from forest floors and the necessary input data is available. Scattering by finite-impedance cylinders can be accurately simulated with full-wave techniques. Furthermore, it has been shown that scattering in the horizontal plane (i.e. trunk layer) and ground reflections (in the vertical plane) generally do not interact. This means that two-dimensional techniques are applicable and are able to provide guidelines to maximize sound reduction by tree belts (7).

As a general rule, a rather high biomass density is needed, which can be achieved by limiting the spacing in between trees and/or by increasing the trunk diameter. Introducing some randomness in either stem centre location or trunk diameter, which is likely to occur by nature anyhow, slightly enhances noise reduction. Tree height is unimportant, while there is a more or less linear relationship between noise shielding and belt depth (orthogonal to the road). Moving receivers away from the belt will not decrease the shielding performance since sound reduction is obtained during transmission, which is a major advantage upon e.g. a noise wall, whose efficiency largely drops with distance. However, wider tree belts might be needed for receivers further away. Optimized and closely packed low-diameter trunks were predicted to yield higher overall A-weighted road traffic noise reductions than thicker trees at the same basal area.

Rectangular planting schemes (where the spacing orthogonal to the road is larger than along the road), omitting a few rows parallel to the road length axis, and randomly removing some of the trees (thinning), do not lead to significant performance reductions. However, such actions help to limit the overall biomass density, and consequently, to be consistent with biological limitations. Road traffic noise reductions of 5 dBA (see Ref. 7) were predicted for the case of a 15-m deep tree belt bordering a 4 lane road with mixed traffic (with a trunk basal area of 1%).

3. OTHER CASES OF PHYSICAL NOISE REDUCTION BY VEGETATION

The impact on acoustic waves by other types of vegetation has been researched more recently. Building envelope greening allows the urban environment to become vegetated without competition for the limited available space. Experimental and numerically work convincingly showed that green roofs can help to achieve a quiet building side (8). The positive acoustic effect is mainly the result of absorption due to the growing substrates, strongly enhanced by the grazing incidence when sound waves diffract over e.g. a green roof. Also green walls are useful to limit e.g. street amplification; even low frequencies can be absorbed by substrate composition optimization (see e.g. Ref. 9) and by providing air gaps.

Vegetation is useful to increase the noise reducing performance of berms (earth mounds). Ensuring a soft soil will make the berm an ecological alternative for an artificial noise wall and might have a similar acoustical performance (10). When also accounting for (down)wind refraction in long-term assessments, a non-steep berm could even outperform a noise wall with the same top height (10).

The application of a single rows of trees was studied near noise walls in order to counteract the screen-induced refraction of sound in downwind conditions (see E.g. Ref. 9). This is a clear application where vegetation has a non-direct effect due to the improved micro-climatological condition. Tree belts of sufficient size where shown to limit downward refraction by mitigating the nocturnal ground-based temperature inversion that would appear above bare ground (see e.g. Ref. 9).

4. NOISE PERCEPTION IMPROVEMENT BY VEGETATION

4.1 Underlying mechanisms

Literature regarding noise perception improvement by vegetation considers three potentially explaining mechanisms. The findings from a meta-analysis (see Ref. 11 for details) are summarized below.

A first mechanism that received quite some attention is the ability of vegetation to visually hide a noise source. Two competing aspects play a role here namely audio-visual congruency and attention focussing. When following this first reasoning, sound sources should be preferably visible, for the second reason invisible. At high exposure levels, audio-visual congruency is expected to prevail, while at low levels attention focussing might be more important. Perception experiments like the ones reported in Ref. 12 and 13, however, point in different directions when only trying to explain findings using source (in)visibility arguments.

Natural sounds (birds, rustling of leaves, water, ...) have the ability to mask unwanted sounds, either in an energetic or informational manner. Natural sounds are typically highly appreciated. The presence of vegetation is directly linked to these natural sounds, either inherent to their structure (e.g. rustling of leaves) or due to its functioning as habitats (e.g. birds).

Although these two factors will play a role, studies have been reported where the sound sources were clearly visible and natural sounds were of limited importance. Still, strong reductions in self-reported noise annoyance were linked to vision on green infrastructure (see e.g. Refs. 14, 15). This stresses the importance of a third and seemingly dominant mechanism namely the restorative action of visible vegetation. Processing of environmental sounds occurs subconsciously and these sounds are often of no direct use for the listener. Nevertheless, they might occupy parts of the workload of the human brain. In addition, noise exposure is known to induce stress reactions in the human body. The positive effect of looking at vegetation is commonly explained by attention restoration (16) and stress recovery (17) theory. These hypotheses might counteract the aforementioned negative reactions to environmental noise exposure. Note that impervious dense vegetation will not induce such human reactions, and typically appear in case of park-like semi-open environments, providing feelings of being-away, fascination, etc.

4.2 Towards effect quantification

Estimating the equivalent noise level reduction of a perception-based approach is a common method to allow comparison with other measures. In Ref. 18, e.g., it was found that the aesthetic/natural make-up of a site could be as important as 5 dBA. Reference 19 reported that the perception of the visual appearance of a neighbourhood is an important predictor of road traffic noise nuisance, theoretically amounting up to 15 dBA.

References 14 and 15 both looked at the noise annoyance reduction by a green visual in the window pane. This data is combined (see Ref. 11) with the dose-effect curves (for at least moderately annoyed persons) for road traffic noise (20). The most conservative approach, where the upper and lower 95% confidence intervals were used, lead to a 10 dBA (14) and 11 dBA (15) equivalent L_{den} reduction when opposing no green at all to the most pronounced green views in the studied zones.

5. CONCLUSIONS

The use of vegetation to tackle road traffic noise should be promoted where possible. Significant physical noise reduction is possible when a tree belt (even when non-deep) is well designed. When this decibel reduction would turn out to be poor, a significant noise perception improvement due to visible vegetation is still likely. Meta-analysis of literature led to the finding that its restoration power is the dominant mechanism with relation to improved self-reported noise perception, on condition that the vegetation is visually attractive. A rough estimate of the equivalent decibel reduction corresponding to the self-reported road traffic noise annoyance mitigation may exceed 10 dBA.

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