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URBAN HEDGES AS NOISE BARRIERS: DOES PLANT SPECIES CHOICE AFFECT INSERTION LOSS?

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ABSTRACT

Noise in urban environments is responsible for annoyance and adverse health effects. Noise barriers are used to mitigate noise and are effective when properly designed and installed, but provide little visual or biodiversity benefit. Hedges are frequently used as boundaries in urban spaces around parks and playgrounds, schools and gardens, and have been demonstrated to provide valuable ecosystem services (e.g. biodiversity support, flood mitigation, air quality improvement). This study aims to determine what sound attenuation is provided by hedges, and how that varies with plant species. The normal incidence insertion loss of vegetative parts of two hedge species commonly used in the UK, and with different canopy characteristics (crown density, leaf thickness and size) was measured. Tests were done on 'instant hedges' planted in grow-bags, in their winter state. Measurements were carried out in a hemi-anechoic chamber to provide controlled conditions. Insertion loss results are presented showing that evergreen *Prunus laurocerasus* provides a greater insertion loss than deciduous *Fagus sylvatica*. Losses are seen at mid to high frequencies only. The marcescent leaves of *F. sylvatica* are shown to provide some acoustic benefit compared with the same plant without leaves.

Keywords: *green infrastructure, hedge, species, insertion loss.*

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1. INTRODUCTION

Noise has been identified as the second greatest environmental cause of ill-health in Europe by the World Health Organisation [1]. Road traffic is the biggest contributor to noise, in terms of population affected [1]. In urban areas neighbour noise, including from human outdoor activities and domestic pets, is also a cause of annoyance [2]. Noise mitigation measures such as barriers and bunds are frequently included in the design of new road schemes. These measures may provide additional services such as security, or visual screening, but come at a cost in terms of greenhouse gas emissions through materials consumption and construction. Green infrastructure offers a potential alternative or adjunct to conventional noise mitigation measures, providing additional ecosystem services within the natural environment [3].

The paper reports results that form the first part of a wider project to investigate whether noise control can be included in the set of ecosystem services provided by urban hedges. For this paper, a hedge is defined as a row of plants forming a semi-permeable barrier [3].

Insertion loss of hedges has been reported in the literature but is subject to significant uncertainties, particularly those from experiments performed outdoors. This paper presents the insertion loss (IL) of the vegetative part of hedges with reduced uncertainties compared with previous studies, by carrying out tests in a controlled acoustic environment.

2. LITERATURE REVIEW

The literature below is focused mainly on the effects of the vegetative parts of plants. Few studies have been published that deal specifically with hedges.

The HOSANNA project [4, 5, 6] made a significant contribution to recent literature on the role of green

infrastructure in noise reduction (e.g. an overview of natural noise control for surface transportation [5]).
Van Renterghem et al [6] presented results from various measurement methods for determining the insertion loss of a hedge for noise from light vehicles, demonstrating the issues with the different methods. Although hedge species were identified for some of the tests within those papers, direct comparison of the species could not be made from the results due to the different test methodologies.
Ground effect was identified as the dominant contributor to attenuation at low frequencies and hence relevant for road traffic noise. At 1 kHz and above, scattering of sound due to the vegetative elements was noted as the mechanism reducing transmission loss, with losses increasing with frequency, confirming earlier findings [7]. Leaf/branch vibration and visco-thermal losses were also mentioned as possible sound attenuation mechanisms. Insertion losses for light vehicle road traffic noise were low, and dependent on the test method.
The results demonstrated the importance of consistent methodology when investigating small sound reductions, especially considering ground effect in the reference case for insertion loss. In this respect, the findings were consistent with earlier works [7, 8, 9) where IL was calculated (for some of the tests) based on the difference between measured sound levels across vegetation compared with levels measured across nearby open ground. This approach assumes that the ground effect in the open and that below the vegetation are the same, which is not always the case [6], [7]. The assumption can lead to reductions or increases in sound level due to ground effect inadvertently being ascribed to the vegetation.
Field tests using a consistent methodology [6] indicated that *Prunus* sp. (laurel), an evergreen hedge gave greater high frequency attenuation (between 3dB and 6dB in the 1/3rd octave bands from 1.6kHz to 6.3kHz) than *Fagus* sp. (beech), a deciduous hedge. The test methodology used a range of angles of incidence for the sound on the hedge.
Further study by van Renterghem [10] provided guidelines for optimizing road traffic noise shielding by non-deep tree belts. The term 'tree belt' is used to describe a linear area of planting too narrow to be described as a woodland but significantly deeper than a hedge. The acoustic effects of tree belts have been more widely studied than those of hedges. Acoustic attenuation from tree belts may be due to similar mechanisms to that from hedges, as they both comprise plants with trunks and leaves, planted directly in the ground, in linear strips. Beneficial properties identified in [10] were close spacing of plants with large diameter trunks, and deeper tree belts.

Studies in Taiwan [11] and [12] reported similar tests to those of [7], having measured a large number of single species evergreen tree belts. The species were mainly suitable for a subtropical, rather than temperate, climate. The influence of density (of tree leaves and branches), height, length and width of belts were investigated based on the characteristics of the plant species, and found to have that order of importance for attenuation. The characteristics were (in addition to the above) visibility through the belt (as an analogue for density), average canopy diameter, bifurcate height, average interval, and tree arrangement.

3. METHODS

The normal incidence insertion loss of two samples was tested. The method was selected as it was anticipated to be suitable for discriminating between samples with low transmission loss performance in a laboratory setting. Other techniques will be trialed in future. The method is similar to that used by previous researchers in a field environment [6] to [9] incl., [11] and [12], adapted for use in a hemi-anechoic chamber.

3.1 Theory

Acoustic pressure was recorded (for post processing to obtain rms pressure) at a specific location behind the position of the test sample, both without the specimen in place (p_{wo}) and with the specimen in place (p_w).
The insertion loss (IL) is given by Eqn. (1) [13]:

$$IL = 20 \log_{10}(|p_{wo} / p_w|) \qquad (1)$$

3.2 Experimental methods: test details

3.2.1 Overall setup

The IL measurements were carried out in the hemi-anechoic chamber at the University of Salford. The chamber measures 4.10 m × 3.25 m to the tips of the foam wedges and is 3.0 m high. Acoustic foam wedges cover the walls and ceiling, and the floor is smooth concrete. The chamber is considered to perform as a hemi-anechoic space at frequencies of 250 Hz and above.
The centre of the speaker driver was set in line with four microphones (mics.), two either side of the sample, 1.16 m above ground. Only one microphone has been used to calculate the IL. The length of the chamber imposed a practical limitation on the distances between speaker, microphones and sample. The distance between the microphones and the sample was dependent on the depth

and nature of the sample. The *Prunus laurocerasus* sample had branches which protruded further from the sides of the hedge than those of *Fagus sylvatica*, increasing the width of the sample. Microphone locations and numbers were determined by their placement for an extended set of tests using a different technique (the four-microphone method, to be reported in future work). Microphone supports, the floor and the hedge bag were covered with a combination of acoustic foam and mineral wool to reduce parasitic reflections.

3.2.2 Signal chain

The source signal was a linear sine sweep from Aurora plugins ver.2.4.1 [14]. The signal was reproduced using a soundcard, amplifier and a Kef Q150 loudspeaker. The loudspeaker had a concentric driver, and the reflex port was blocked with acoustic foam and tape.
The receiving chain was Bruel and Kjaer type 4966 microphones and a Dewesoft Sirius i-8xSTGM data acquisition unit.
The test signal sweep covered the frequency range 112 Hz to 24 kHz (the Nyquist frequency). The range was chosen to ensure results were obtained in mid and high frequencies where the literature had indicated that effects might be observed for vegetation.

3.2.3 Procedure

Measurements were made in the same locations in both the presence and absence of the sample, with absorption on the floor in the gap left when the sample was removed. It was not practical to carry out the without sample test with a soil filled bag in place of the hedge sample. This formed a limitation of the test, and could influence the results. Distances between the microphone and sample for determining the IL are shown in Tab.2.

3.2.4 Hedge samples

The details of test samples are shown in Figs. 1-3. The live hedge samples consisted of a number of plants (Tab. 1) growing in an organic rich soil in a rectangular planting bag (0.8 m x 0.3 m x 0.3 m). The plants had been grown in this hedge form for a minimum of six months. Tests were carried out on both evergreen (*P. laurocerasus*) and deciduous (*F. sylvatica)* species. The plants in the test sample had a relatively low level of sub-branching. *P. laurocerasus* has large, ovoid waxy leaves, borne on both woody and green branches. It was not possible to see through the sample. Tests were carried out at the end of winter. The deciduous subject had marcescent leaves (i.e. retained dead leaves from the previous growth year) which were unevenly distributed through the hedge, with a larger number at higher levels where the branching was greater, and towards the right-hand side. There was clear sight through the sample at lower levels of the trunks, and an obscured view at the test location and higher parts of the plants, as a result of the retained dead leaves. The deciduous hedge was tested twice, once with the leaves in place, and then with the leaves stripped to examine whether the dead leaves made a measurable difference to the IL. The test line was off-centre for *F. sylvatica* (Fig.2) as there were more leaves to the right side of the sample, and the intention was to investigate the effect of the leaves.

Table 1. Sample types and dimensions.

Sample type	No. of plants within bag	Hedge length, m	Hedge height above soil, m	Hedge width, m
P. laurocerasus	3	1.45	1.80	0.59
F. sylvatica	5	1.05	1.45	0.50

Figure 1. *P. laurocerasus* – mics and test sample.

Measurements were carried out with a boom supporting the microphones passed through the test sample in the locations indicated in Tab. 2.

Table 2. Microphone locations.

Sample type	Horizontal dist. from left-hand end of bag, m	Height above soil, m	Mic dist. behind sample, m
P. laurocerasus	0.49	0.86	0.37
F. sylvatica	0.52	0.86	0.20

Figure 2. *F. sylvatica* test with leaves – view from loudspeaker.

Figure 3. *F. sylvatica* after leaves were stripped, side view.

The moisture level of the soil in the bags was measured using WET sensor attached to HH2 probe (Delta-T Devices, Cambridge, UK) at the time of the tests; values were between 19 and 33%, suggesting plants were optimally watered (Blanusa, personal communication).
The canopy leaf density of the model hedges used in the experiment was estimated by counting the leaves in a 0.5 m square centered on the horizontal line between the microphones.

3.2.5 Source level corrections

The source level was consistent between tests with and without the sample for *P. laurocerasus*, but not for the two *F. sylvatica* tests. The insertion loss tests were carried out as part of a wider investigation that did not require consistent source levels. The test set-up included a microphone between the sample and the loudspeaker (mic 1, not used directly for the IL tests). The sound pressure levels (SPLs) for mic 1, and at the location used for the IL calculations were inspected for *P. laurocerasus* (the sample anticipated to have the highest IL), with and without the sample. Mic 1 had 1/3rd octave band SPLs within 0.2dB with and without the sample, in the frequency range 630Hz to 1.6kHz. It was therefore concluded that the levels recorded at mic 1. could be used for corrections. This was supported by the fact that any reflection from the *F. sylvatica* samples was likely to be lower than that for *P. laurocerasus*, meaning that the error introduced through the correction procedure was likely to be less than 0.2 dB. To provide corrections for the source levels, the average difference between with and without sample SPLs was calculated in the range 630Hz to 1.6kHz. This correction was then applied to the without sample 1/3rd octave band results, prior to calculation of the insertion losses. The corrections applied were 7.5 dB for *F. sylvatica* with retained leaves, and 2.6 dB for the without leaves case.

4. RESULTS AND DISCUSSION

The calculated insertion loss (in 1/3rd octave bands) for the two samples is shown in Fig. 4, including the results for *F. sylvatica* for both the cases i.e. with retained dead leaves and without leaves. Each line plotted represents the average of three measurements (except for *P. laurocerasus* with the sample - average of two).
Insertion loss for *P. laurocerasus* is close to zero from 250Hz to 1kHz, with variations which are likely to be due to parasitic reflections (Fig. 4). The highest IL is seen between 4kHz and 10kHz. The general rise and the levelling-off in the IL above 1kHz are consistent with those presented by [6] and are expected to be due to scattering, and potentially thermo-viscous effects and leaf vibration. The effects are associated in the main with the leaves and to a lesser extent the branches, with the exception of vibration which is relevant only to the leaves.
F. sylvatica with retained leaves shows an increase in IL loss with frequency above 2kHz, although the increase is less than that for *P. laurocerasus* and does not reach the same magnitude of IL (maximum below 8dB).
The comparison between IL for *F. sylvatica* with and without retained dead leaves (dashed line compared with

dotted, Fig. 4) indicates the IL is attributable to the dead leaves. The curve for the sample without leaves shows minimal change in IL with frequency, even at higher frequencies except for a small increase between 12.5kHz and 16kHz. This finding indicates that for this sample, which had relatively sparse trunks and branches, these structures contributed almost nothing to the IL.

The results are generally consistent with those obtained under field test conditions in [6], and confirm those earlier findings without the confounding factor of the performance of a reference for the insertion loss measured at a different location.

F. sylvatica is an example of a deciduous plant that retains some of its dead leaves during the winter. There are also species which are semi-evergreen, that may lose their leaves in unfavourable winter conditions. The results of the with and without leaf comparative test indicates that marcescent and semi-evergreen plants could provide an acoustic benefit as hedges, despite not being evergreen.

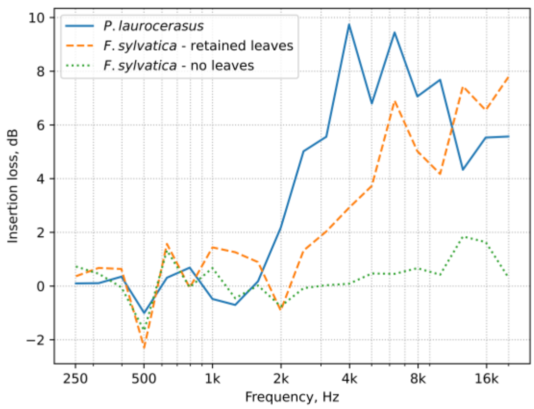

Figure 4. IL for *P. laurocerasus* and *F. sylvatica*.

5. CONCLUSIONS

Two types of hedge samples have been tested for insertion loss under controlled conditions, one evergreen and one deciduous. The evergreen (*P. laurocerasus*), which had consistent leaf cover to both sides of the hedge across the full area of the sample, had a positive insertion loss at mid to high frequencies. In comparison, the deciduous *F. sylvatica* showed a lower IL, only becoming significant at a higher frequency than the evergreen sample. With the marcesent leaves removed, *F. sylvatica* showed no insertion loss. This indicates that the trunks, branches and twigs of this sample provided no measurable reduction in sound energy.

6. FURTHER WORK

Additional hedge species and cultivars (with needle-like and scale-like leaves, and a semi-deciduous) will be tested under laboratory conditions. Tests will also be carried out under summer conditions for *F. sylvatica* for comparison with the winter states. The four-microphone method will be trialed which may be more suitable for comparative testing of the vegetative part of the hedge samples.

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