The effects of vegetation on reducing traffic noise from a city ring road

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(Received: 21 May 2010; Revised: 16 November 2010; Accepted: 27 November 2010)

This study was designed to investigate the reduction road noise by vegetation along the ring road of Thessaloniki. Road noise was measured at two sites, one through a belt of trees and the other on a grass-covered ground. 245 measurements were taken from each site over a two-month period and expressed as differences in L_{Aeq} (equivalent constant A- weighted sound pressure levels). Also measurements of the number of vehicles per minute, the type of vehicles and analytic description of vegetation were taken at both sites. The results showed higher noise reductions through the belt of trees than over the grass-covered ground. According to the results of this research the largest reduction, 6 dB, was seen in the *Pinus brutia* belt of trees, 60 m away from the road. This noise reduction is considered satisfactory due to the tree belts extending on both sides of the ring road.

Primary subject classification: 24.5; Secondary subject classification: 52.3

1 INTRODUCTION

Noise is not simply a local problem, but a global issue that should concern us all.[1] In the European Union over 40% of the population is exposed to motorway noise, which exceeds 55 dBA during the day and another 20% to levels over 65 dBA.[2,3] The level of road noise on highways depends on many factors: 1) traffic congestion, 2) speed of vehicles and 3) percentage of heavy vehicles 4) road surface type 5) gradient of the road, 6) number of lanes and 7) road lane separation. Overall, the levels of the noise increases with traffic volume, vehicle speeds and percentage of heavy vehicles. Noise produced by vehicles is a combination of noises (engine, exhaust and tire).

Noise continues to expand with an increasing number of complaints from the residents. Most people are usually exposed to more than one source of noise of which road noise is the main source.[4] In order to study noise, the following should be considered: a) different types of noise (i.e road noise) b) its origin (i.e engine, exhaust, tire) measurement type and d) determination of its effect on people. In 1993, the World Health Organization (WHO) recognized the following effects on the health of the population that can emanate from noise: sleep patterns, cardio respiratory and psycho physiological systems, and hearing impairment. It also affects us negatively in learning, communication, productivity and social behavior.[5–7]

The aim of this research is to locate and to evaluate the effect of vegetation on the reduction of road noise. In particular:

1. Is road noise decreased by vegetation and to what degree?
2. What are the characteristics of vegetation (type, structure) that affect the reduction of road noise?
3. What is the necessary vegetation treatment for a significant reduction in road noise?

2 METHOD

The ring road of Thessaloniki is bordered by the peri-urban forest of the city named "Cedrinos Lofos." The traffic flow on this road is heavy, with three lanes of traffic per direction and cement isle along the length of the entire road.

Measurements were taken at two different sites close to residential areas. The first site consists of a grass-covered ground while the second is covered by a forest of *Pinus brutia* trees. The size of each site was 500 m^2 which is the smallest sampling plot for the forest research.[8] The two tree belts in the forest and the grass-covered ground were 60 m perpendicular to the road. Both sites are at the same road segment and at the same side of the ring road (Fig. 1). Both sites were 4 metres higher than the road and level (0–5%). The terrain was selected so that the two sites would be roughly similar. Thus, the influence on the noise by parameter other than the vegetation was similar. Weighted sound pressure levels were measured by using the sound level meter

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Fig. 1—Sites where the measurements of road noise were realised. Grass covered ground (1); forest (2).

407735 Extech Instrument, which has 2 measurement weighting networks, A and C. We used only the A-weighting. The instrument was placed at a height of 1.8 m above the ground as it is proposed by FHWA[9] and the microphone was orientated for perpendicular incidence. In both sites a straight line of measurement was made on the right side of the road to point 60 m away. The distance between the two measurement lines for the two sites was 150 m. Measurements were made at 7 locations every 10 m along this line, starting at the edge of the road at point 0.[10] At each microphone location seven 5-minute equivalent sound level measurements were taken. The measurements were taken downwind as referred to ISO 9613-2. The above procedure was repeated 35 times at both sites over a period of 2 months from 9.00 a.m. to 2.00 p.m. In total 245 measurements were taken in each site. The measurements along the two lines were taken concurrently.

The main silvicultural parameters, height in m, breast diameter in cm and the crown length in m, were measured in the forest area. The height and the crown length of trees were measured by using the Haga altitude.

All the measurements were analysed by using of the SPSS statistical package version 10.0. To check the dependence of the vegetation on highway noise, the t-test was used. Levene's test was used to check the homogeneity of fluctuation.[11] Diagrams of the box-and-whisker plot of both studied sites were made.

3 RESULTS

The mean traffic flow is 120 (± 7) vehicles/min, the number of heavy vehicles 30 (± 2) vehicles/min and their proportion is 25 (± 0.50) (all the measurement are represented as mean$\pm$standard error). From 9.00 a.m. to 2.00 p.m. the Thessaloniki ring road is particularly busy and there is a high proportion of heavy vehicles. These heavy vehicles raise the level of road noise as they pass (Table 1).

3.1 Description of Vegetation

The grass-covered ground consists of plants belonging to *Compositae, Solanaceae* families and various other broad-leaved plants, which characterize degraded soils. Horses occasionally graze there (Fig. 2). Forest consists of *Pinus brutia* trees planted at 3×3 m intervals. There are no shrubs under the crown of the trees, only a few plants (Fig. 2). The main silvicultural parameters of the green belt were: tree height $8.68(\pm 0.22)$ m, tree diameter $18.94(\pm 0.78)$ cm, the crown started above ground at $1.04(\pm 0.17)$ m and finally the total crown length was $6.72(\pm 0.19)$ m (all measurement are represented as mean$\pm$standard error).

3.2 Reduction of A-Weighted Sound Pressure Levels

It was found that at 60 m from the road the A-weighted sound levels in the forest were on average 6 dB less than in the grass-covered ground. A presentation of the results of statistical analysis in the two sites is given in Table 2 and Fig. 3 with box-and-whisker plots.

From Table 2, the following were observed: At the distance 0 m from the road, the factors of variation which are the unique characteristics of relative variation are large in both cases. In the forest the variation is 0.87, smaller than the value of 1.09 for the grass-covered ground. The variation in SPL was higher at site 1 close to the road due to the different traffic composition because the measurements at each site were not taken simultaneously.

At the distance of 60 m from the road the factors of variation of A-weighted sound level and in the two sites are roughly equal. This is due to the gap that exists in the forest from 50–60 m, therefore there is no positive effect of the crown of trees and the sound behaves as in a region that does not have high vegetation.

The variation of SPL in the forest is considerably smaller than the equivalent for the grass-covered ground. Measurements of variation in the forest are considerably smaller. The crown of trees functions as a filter decreasing A-weighted sound levels.

The box-and-whisker plot shows a graphic presentation of information on the distribution of data that are examined. The values of inferior and superior percentile (25th and 75th percentile) determine the beginning and the end of the box-and-whisker, which contains the

Table 1—The A-weighted sound pressure levels due to motorcycle, medium goods vehicles with 2 axes and heavy vehicles with more than 2 axes.

Sites	Distance from street	Noise intensity (dB)	Max A-weighted sound pressure level with the passage of heavy vehicles (dB)	Type of heavy vehicles
Grass-covered ground (1)	0	76	81	lorry
	0	81	86	lorry
	0	78	93	ambulance[a]
	0	79	85	motorcycle
	0	79	85	lorry
	10	71	75	lorry
	10	73	78	lorry
	20	68	71	lorry
	30	66	68	lorry
	30	65	73	lorry
	40	65	67	lorry
	40	65	75	lorry
	40	65	69	motorcycle
	50	63	70	lorry
	60	62	66	lorry
Forest (2)	0	80	90	lorry
	0	80	83	lorry
	0	79	83	lorry
	10	70	75	lorry
	10	70	78	lorry
	20	66	80	ambulance[a]

[a]The ambulance had in operation the sirens.

intermediate 50% of the data. The horizontal line that cuts the box-and-whisker depicts the median.

4 DISCUSSION

Data analysis revealed that the vegetation acts as a barrier reducing the A-weighted sound levels.

The A-weighted sound levels are reduced as the distance from the road increases on the grass-covered ground. The A-weighted sound level at a distance of 0 m from the road is 78 dB and at a distance of 60 m, which was the greatest distance measured, the A-weighted sound level was reduced to 60 dB meaning a 18 dB decrease. Similarly, at the wooded area beside the road noise, the level was 79 dB while 60 m away from the road it was 55 dB, meaning that the reduction of noise was 24 dB. As shown above the decrease of the A-weighted sound levels were greater in the second area. Statistically a significant contribution to this reduction is the existence of the forest of *Pinus brutia*. It is critical to point out that Pinus brutia is an evergreen species. Its needles absorb acoustic energy all year round. Plant

(1)

(2)

Fig. 2—General view of sites where the measurements of road noise were realised. Grass covered ground (1); forest (2).

Table 2—Effects of vegetation type on the sound pressure level in different distances from the road.

Sites	Variable	Distance from the road	Mean	Median	Standard deviation	Min	Max	Range	Coefficient of variation
Grass-covered ground (1)	dB	0	78.36[a]	78.40	0.86	76.1	81.0	4.9	1.09
		10	72.80[a]	72.35	1.27	69.3	73.3	4.0	1.76
		20	68.07[a]	68.00	0.49	67.3	68.8	1.5	0.71
		30	65.50[a]	65.50	0.28	64.7	66.0	1.3	0.42
		40	63.96[a]	63.75	0.64	63.0	65.3	2.3	1.00
		50	61.94[a]	61.80	0.50	61.1	63.2	2.1	0.80
		60	60.50[a]	60.45	0.68	59.3	61.9	2.6	1.12
Forest (2)	dB	0	78.70[a]	78.55	0.69	77.6	80.4	2.8	0.87
		10	69.56[a]	69.60	0.20	69.0	69.9	0.9	0.28
		20	65.43[a]	65.40	0.29	65.0	66.0	1.0	0.44
		30	62.51[a]	62.50	0.26	62.0	61.1	1.1	0.41
		40	59.50[a]	59.50	0.27	59.0	59.9	0.9	0.45
		50	56.51[a]	56.60	0.26	56.0	56.9	0.9	0.46
		60	54.72[b]	54.60	0.54	54.2	57.7	3.5	0.98

Values that have as exhibitor different letter differ significantly at the 5% level (t-test).

leaves absorb acoustic energy by transferring the kinetic energy of the vibrating air molecules in a sound field to the vibration pattern of the leaves. Therefore, vibration energy is withdrawn from the acoustic field and part of this energy is lost by transfer to heat since leaf friction occurs in a vibrating plant.[12]

Although the forest has not been managed systematically in order to have the appropriate composition and structure for noise reduction, its contribution is significant. In order to render the forest more satisfactory for the reduction of noise, it should be so dense that an observer would not be able to see the road from inside and there should be foliage on the ground to the desired maximum height. If the foliage of forest species is deciduous the conclusions of this study are likely to be quite different.

The use of vegetation and foliage to reduce the road noise has been studied considerably over the last years. Their effectiveness in reducing the noise has been studied both inside the laboratories and outside in rural areas1.[10,13] The studies conducted on noise reduction have focused on two following questions. First, if the plant barrier is a factor in reducing the noise and second, how the trees and shrubs, with their leaves, reduce the noise. Most research on the first issue was conducted in the laboratory. The precise way by which the foliage affects the sound has not yet been found.[14] From an experiment conducted in the laboratory[15] it was shown that the foliage can act as an amplifier at the mid frequencies (500–2000 Hz). Some examples of plants studied[16] and the range of frequencies where the sound is reinforced are: the birch in the frequency range of 200 to 3200 Hz, the hazelnut in the frequency range of 200 to 2000 Hz, the olive tree in the frequency range of 640 to 5000, and dense forest with 15 m height in the frequency range of 200 to 5000 Hz.

The majority of the investigation for the second question was also investigated in the laboratory and dealt with the quantification of the noise reduction in anechoic rooms for the imitation of the conditions of rural areas. In 1995 Hendricks found that a row of oleander of about 2.5 m height and width equal to 4.5–6 m can reduce the A-weighted noise levels by 1 to 3 dB at a distance of 15 m from the roadside. Similarly, pine trees of 12 m height and 9 m diameter at a distance of around 3–6 m were found to reduce A-weighted noise levels by only 1 dB at a distance of 5.5 m from the roadside.[17] In our research the pine trees of 8.7 m height, 18.9 cm breast diameter, and 6.7 m total crown length were found to reduce the A-weighed noise level by 2. dB at a distance of 10 m from the roadside.

Also many studies were conducted in order to examine the influence of vegetation on the reduction of noise in the countryside. For example, Huddart in 1990 showed that a dense, impervious to sight, stand of trees of 30 m in width reduces the A-weighted noise level by 6 dB compared to a meadow. Also in a survey conducted by Perfater in 1979 on a road where the vegetation was replaced by a solid barrier, the residents stated that the vegetation provided greater noise reduction.[14,18–20] In other research[21–23] it was found that plant barrier caused

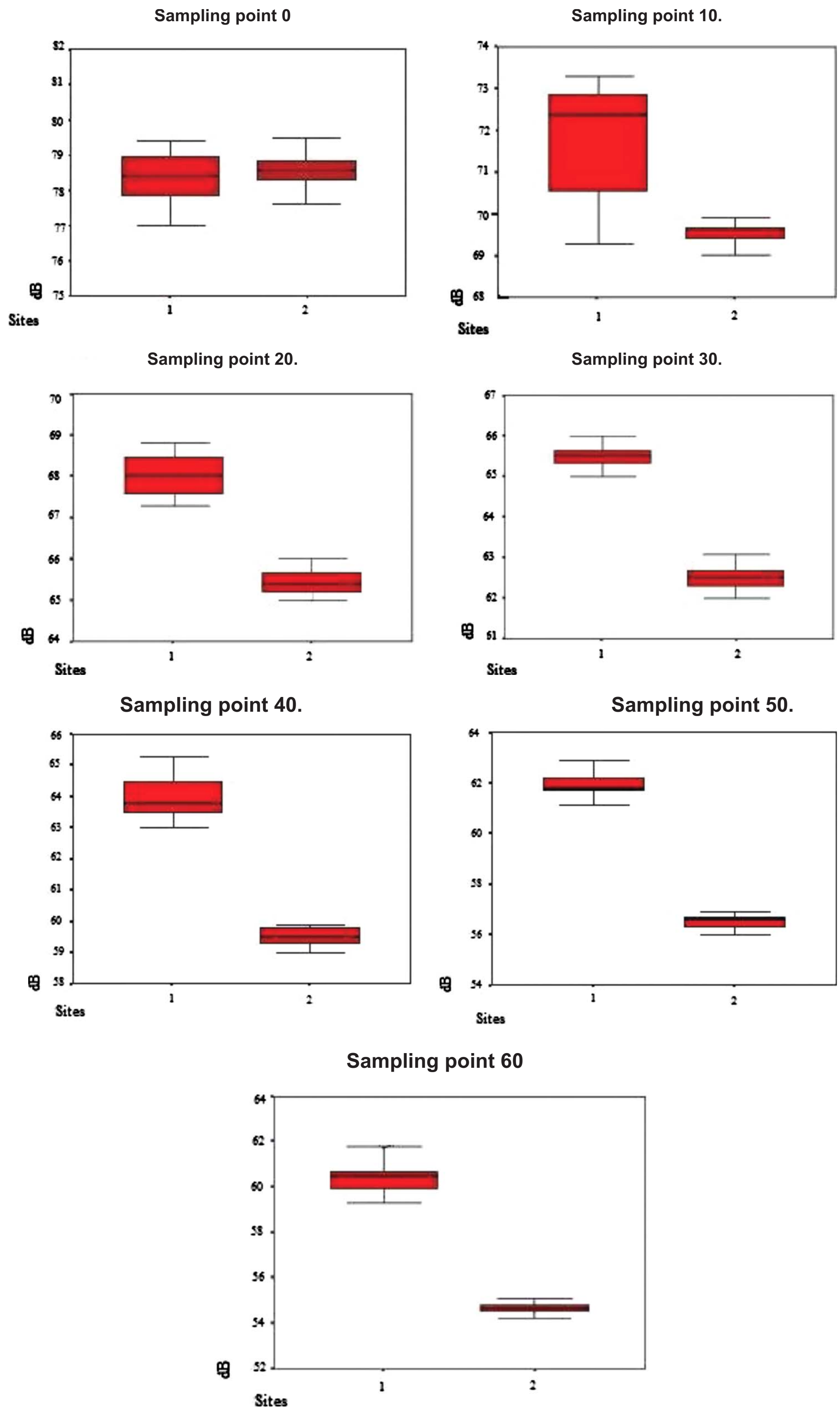

Fig. 3—Box-and-whisker plots of A-weighted sound pressure levels at the grass-covered ground (1) and at the forest (2) at distance 0, 10, 20, 30, 40, and 50, 60 m from the road.

traffic reduction in the A-weighted noise levels from 3 to 5 dB.

Also the decrease in the A-weighted sound levels from cars was studied along the main roads between Peshawar and Islamabad in Pakistan. It was found that rows of trees individually or in combination with shrubs may reduce the intensity of the noise by 5 to 8 dB. The trees in combination with shrubs have a reduction in the intensity of noise by 8 dB.[24,25]

5 CONCLUSIONS

The following conclusions can be drawn from the present study of the influence of roadside vegetation on the reduction of road noise:

- The levels of noise along the ring road of Thessaloniki are above the limits stated by Greek legislation 29087/2295 (i.e., Leq < 67 dBA). This is due to the high velocity of passing vehicles, the large amount of traffic and the percentage of heavy vehicles with more than 2 axes.
- Vegetation can satisfactorily decrease A-weighted sound levels along highways. In forest site, those reforested with *Pinus brutia*, a significant reduction was observed (of 6 dB at a distance of 60 m from the road), as opposed to grass-covered ground. It is important to underline that Pinus brutia is an evergreen species, so its tree needles absorb acoustic energy during the whole year.
- The vegetation of the forest site has the following silvicultural characteristics: High vegetation is represented by *Pinus brutia* trees, without shrubs or any underbrush vegetation in general. The average height of the trees was 8.7 m, the average breast diameter was 19 cm and the average length of the crown was 6.7 m.
- Although the forest was not managed systematically, so as to have a suitable structure and composition for reducing noise, its contribution is still important. In order to render the contribution of the forest to noise reduction more efficient, it should be so dense that an observer would not be able to see the road through the vegetation. Additionally, the level of ground vegetation should be as high as possible. This is achieved by a combination of trees and shrubs.
- Because the ring road is bordered on both sides by the peri-urban forest, the reduction of noise levels is ensured almost throughout the length of the road.

6 PROPOSALS

For a successful planning of a noise barrier, the approach should be multidimensional, with scientists of various fields involved, such as foresters, civil engineers, traffic engineers and landscape architects. The efficiency of tree barriers depends, not only on the expected acoustic results, but on other factors, such as safety, maintenance, aesthetics, cost and its acceptance by local communities. The plants used and the methods of manufacturing noise barriers can combine themselves in a variety of ways.

- The suggested treatment that should be applied to studied sites, would be mainly planting evergreen shrubs along the roadside so that a living barrier of vegetation is created, dense enough that any casual observer would not be able to see the road through the vegatation. There should be more than one row of bushes for more satisfactory results. The trees' initial planting space will be dense. Only then will the trees, with suitable forestry interventions, maintain the highest density and the largest live crown length possible. It is proposed that the trees planted to form a triangle for better coverage of space and to reject uniformity in the trees' distribution altogether.
- The areas of vegetation that will initially be created along highways should have the following silvicultural characteristics: shrubs should have a height of at least 2–3 m, the height of the trees, at a mature age, should reach 15 m. Finally, evergreen species are preferred, because they maintain their foliage all year round resulting in better noise protection. The shrubs that are to be used should be planted along the roadside and be followed by lines of trees. The total width of the planted area should be at least 20 m.[26]
- At intervals some deciduous trees can be used, consisting of species with colors that break evergreen monotony during the seasons, thus forming a more pleasing aesthetic landscape. Even within the same plant species, the color of the leaves differs in shades, since it changes from light green of the new foliage in the spring, to the dark green of summertime and the yellow-green, golden or orange of autumn. Flowers and fruits are also sources of color as well.[26] Additionally, trees and shrubs adapted to the prevailing conditions should be used, which will guarantee better chances of survival in the particular ecology of the urban and suburban environment.[28–32] Proposed deciduous trees within the scope of this research are: *Cercis siliquastrum, Celtis australis, Fraxinus ornus, Ostrya carpinifolia, Carpinus orientalis* and *Acer campestre* Suggested evergreen trees are pine species which are selected according to the vegetation zone. Suggested shrubs (which should be evergreen for better noise protection throughout the year) are the following: *Ligustrum vulgare, Pitosporum tobira, Pyracantha coccinea* and *Phillyrea latifolia*.[33] Also *Olea europea* can be used, pruned into the shape of compact hedges, even though it would be outside its normal ecology, thus running the risk of

frost damage. An additional reason for pruning the *Olea europea*, would also be for the allergenic of its flowers, which have unfavorable repercussions in humans.[34]

7 ACKNOWLEDGMENTS

Authors are pleased to express their thanks to the unknown reviewers for their substantial comments and corrections, to M. Tsakaldimi and Th. Tsoulpha for the critical reading of the manuscript and to Ai. Kontogianni, G. Goudelis G. and I. Spanos for technically supporting our work.

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