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TREE STANDS IN URBAN NOISE ABATEMENT

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SELOSTE:

PUUSTO YHDYSKUNTAMELUN TORJUNNASSA

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The aim of the paper has been to study the characteristics of tree stands suitable for urban noise control and their application in urban forestry. The results show

1. that excess noise attenuation caused by trees can be, under good conditions, 60 % of the attenuation caused purely by geometric spreading when attenuation is expressed in energy units
2. that the total amount of needles or leaves and branches is the most important factor, although the density and height of the stand also have rather high values in predicting the behaviour of noise in a tree stand
3. that the noise level at any distance from the noise source can be predicted rather precisely, tf the sound level of the noise source and the tree species composition, height and density of the iree stands between the noise source and the observation point are known
4. that early successional stages of stand give better attenuation than mature stands.

On the basis of these results the nomograms were developed with which the noise level at a certain point can be predicted when the tree stand characteristics, the distance from the noise source and the sound level of the noise source are known and vice versa.

The goals of urban forestry are discussed based on different functions that urban forestsm must fulfill.

INTRODUCTION

Noise is sound energy which can cause psychical or somatic disturbances in human beings, and is one of the most problematic environmental factors in urban areas. In particular, the problem of traffic noise is well known in urban societies. Attempts have been made to try to decrease noise disturbance by changing the quality of the noise or noise level and by suppressing noise propagation with green belts or man-made constructions.

The sound energy from a point source exhibits spherical spreading. When the sound energy spreads out, the intensity of the energy decreases and the sound attenuates. If this happens in a space where there are no reflecting and absorbing sur-

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faces, the phenomenon is called noise attenuation by geometric spreading. The geometric attenuation decreases the sound level by 6 dB every time the distance is doubled. Therefore even geometric attenuation can be used as a noise abatement tool (cf. BROCH 1973). Besides geometric spreading, the noise level is also lowered by absorption, reflection, scattering, refraction and other phenomena. The amount of excess attenuation depends on the quality of noise as well as on the quality of the environment. Sound of high frequncies, especially, attenuates rapidly as a result of reflection and surface absorption. On the other hand, sound of low frequencies goes through or around bodies smaller than the wave length of the sound (cf. EMBLETON 1963, LYON 1973).

In a natural environment or built-up area the amount of excess attenuation is dependant on numerous factors. WIENER and KEAST (1959) have paid attention to the relationship between attenuation and meteorological factors. Especially wind direction, wind speed and air turbulance caused by wind action may be decisive in reducing the noise level at a certain point. In addition, air absorption and scattering, and reflection in connection with temperature or wind gradients attenuate noise (EYRING 1946, INGÅRD 1953). Meteorological factors may cause many problems in noise level measurements and in making comparisons between different noise abatement techniques.

LYON (1973) has paid attention to topography, vegetation and different manmade constructions in urban noise control. Absorption, reflection and dispersion of the sound waves can increase geometric attenuation decisiveley and inhibit the spreading of harmful sound energy. According to BECK (1965) the propagation of noise can be effectively inhibited by a combination of vegetation and topography. Although the effect of the vegetation alone is much smaller then that of topography and manmade constructions of various kinds, its effect can be increased by bush and tree plantations (cf. BECK 1968, COOK and HAVERBEKE 1971, MIETTINEN 1972 a, b, COOK and HAVERBEKE 1973).

BECK (1965) has found in studying the attenuation properties of different tree and bush species, that the leaves and needles of trees are the most important factors causing excess attenuation The differences were caused by variations in size, shape, mutual position and weight of the leaves or needles. COOK and HAVERBEKE (1971, 1973) have also, however, stressed the importance of tree height and density. They assume, that the amount of excess attenuation caused by trees depends on sound spreading rather than on surface absorption. In this case the properties of leaves and needles would not be as important as BECK has suggested.

COOK and HAVERBEKE (1971) have also

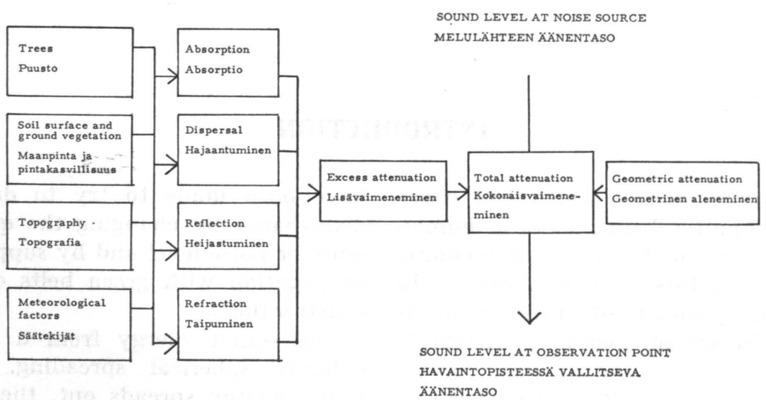

Figure 1. Factors effecting on noise attenuation.

Kuva 1. Melunvaimenemiseen vaikuttavia tekijöitä.

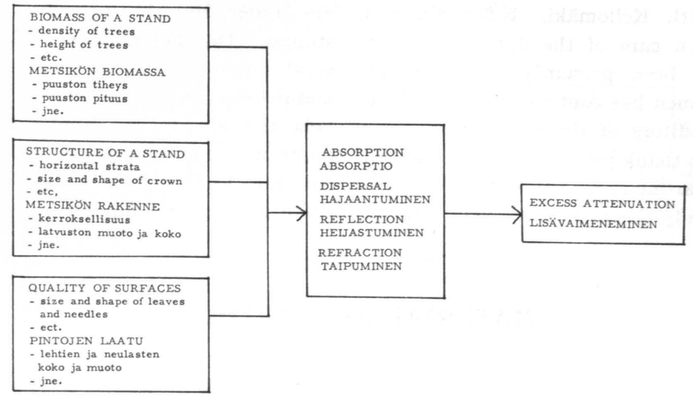

Figure 2. Characteristics of a stand effecting on noise attenuation.

Kuva 2. Melunvaimenemiseen vaikuttavia metsikön ominaisuuksia.

studied the importance of the vertical structure of a stand in noise control. If there are several tree and bush storeys in the stand, there are also more surfaces to participate in absorption and scattering of sound. Mixed stands made up of coniferous and broadleaved tree and bush species would be the most effective. BECK (1965) has also found, that bushes at the stand edges may have a great influence on the sound attenuation properies of the stand. The bushes facing the sound source are especially important. The factors affecting noise propagation and noise attenuation are summarized in Fig. 1—2.

Manipulation of the vegetation provides many different alternatives in urban noise control. The tree species composition and other qualitative characteristics, such as the successional stage of a stand including the bush storey, seem to be most promising features as far as noise attenuation is concerned. The density, height and biomass of a stand also seem to be worth investigating as quantitative characteristics. Since almost none of the meteorological factors can be manipulated directly, they fall outside the scope of this study. However, the diagram does reveal how important it is to control the various factors when making comparisons between different noise control techniques.

In this study the noise attenuation capacity of the main Finnish tree species, Scots pine *(Pinus silvestris)*, Norway spruce *(Picea abies)* and birch (*Betula verrucosa* and *Betula pubescens* these mostly mixed with conifers) has been surveyed. Special attention has been paid to the following possibilities:

1. to consider the extent of noise attenuation in relation to the tree stand characteristics such as the volume, height and density of tree stand and
2. to develop planning methods which could be used to predict the noise level at a certain distance from a known noise source when the noise level at the noise source and certain characteristics of the tree stands lying between the noise source and the planning object are known.

Studies have only been carried out during the summer time, when the noise attenuation capacity of the vegetation is apparently at its maximum. The effect of the vegetation on the attenuation of noise at different frequencies is omitted in this study. Frequency bands from 63 Hz to 4000 Hz have been dealt with together.

The study has been carried out at the Department of Silviculture, University of Helsinki, in cooperation with the Department of Environmental Conservation, University of Helsinki. It has been planned by Seppo Kellomäki and Antti Haapanen. Hellevi Salonen has made the field measurements

in conjunction with Kellomäki. Kellomäki and Salonen have taken care of the data processing. The models have been primarily developed by Kellomäki. Haapanen has contributed to the final compilation and editing of the manuscript.

It is our duty to thank prof. Paavo Yli-Vakkuri, Head of the Department of Silviculture, for encouraging us to study this type of problem. Heikki Smolander, Msc., has helped us carry out the field studies. Dr. Pertti Hari's ideas have been of great importance in solving problems concerning methodology and data processing. Dr. Matti Leikola and Mr. Juhani Nuotio have read the manuscript and given valuable criticism. The Finnish cultural Fund (Suomen Kulttuurirahasto) has given us financial support.

MATERIAL AND METHODS

Study stands

The study was carried out at the Forestry Training Station of the University of Helsinki in 1974. The affect of tree stands on sound attenuation was studied in pine and spruce stands at different development stages from seedling stands to mature stands. As the study area did not include any pure birch stands, mixed birch-coniferous stands which met the requirements were used instead. These mixed stands also represented a development series as in the case for the coniferous stands. The mixed stands contained at least 20 % by volume birch or other broadleaved trees.

There were from two to four replications for each development stage representing each tree species. The stands in the pine series were growing on *Vaccinium* and *Calluna* type sites and the spruce and mixed stand series on *Myrtillus* type (cf. Cajander 1949) or drained bog sites. Other stand characteristics are given in Table 1. In order to measure the effect of ground vegetation on noise attenuation of tree stands, four clear cut areas of the *Calluna* type were included in the study. The study areas were situated on fairly flat terrain.

Noise measurements

The measurement equipment included an electronic sound source and sound level meter, both battery operated (Table 2). The sound source consisted of a noise generator, amplifier and sound radiator, which radiated the noise as spherical waves. The noise was so called white noise (octave bands 20 Hz – 100 kHz) and at a distance of one meter from the sound source the noise level was 100 dB(A). The sound level meter gave the results in dB(A) units.

The sound source was places at a distance of 12 meters from the edge of the study stand, usually on a road, so as to make the measurement situation as natural as possible. On the other side of the noise source there was either forest or an open area. There were altogether 24 measurement points situated along tree lines 12 meters apart from each other as presented in Fig. 3. During the measurement period the sound source was kept on all the time. The sound level meter was directed towards the sound source (1.2 meters above the ground). The data from the three lines was pooled, their mean values were used in the analysis. The background noise was measured before

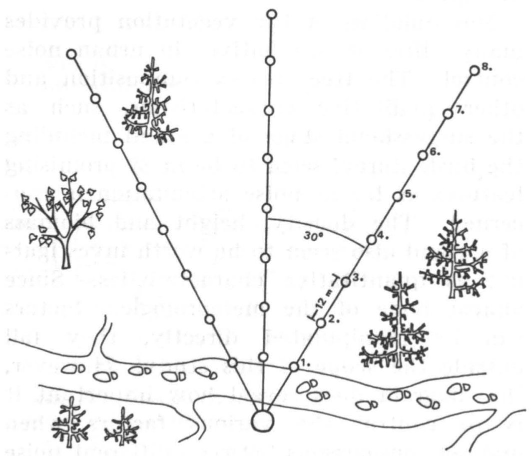

Figure 3. Lay-out of measurements.
Kuva 3. Mittausten suoritustapa.

Table 1. General description of the study stands.
Taulukko 1. Tutkimusmetsiköiden yleiskuvaus.

Study stand *Tutkimusmetsikkö*	Density, stem number per hectare *Tiheys, kpl/ha*	Mean height *Keskipituus* m	Volume *Kuutiomäärä* m^3/ha	Tree species composition *Puulajisuhteet* %			Development stage *Kehitysluokka* [1])	Density of understorey, stem number per hectare *Alikasvuksen tiheys kpl/ha*	Percentage of dominated trees *Vallitusjakson osuus* %	Percentage of self pruned stem *Paljaan rungon osuus* %
				Scots pine *Mänty*	Norway spruce *Kuusi*	Deciduous trees *Lehtipuut*				
1	500	16	128	99			3	240	14	55
2	700	15	134	99			2	333	8	40
3	1000	15	108	99			2	2033	10	38
4	867	3	1	99			1	4267		0
5	1633	15	152	99			2	533	5	50
6	3766	7	50	99			1	1567	14	27
7	389	19	198	99			3	707	2	41
8	1200	3	1	99			1	1600		0
9	222	19	133	99			3	140	1	45
10	900	19	208	11	80	9	2	3100	3	22
11	600	18	287	31	57	12	3	11067	2	24
12	1633	5	11	18	64	18	1		9	6
13	1400	17	352		99		2		1	36
14	1145	13	164	6	89	8	2	4133	10	15
15	783	23	176		98	1	3	2800	2	28
16	551	6	32		99		1		1	8
17	1056	18	423	6	93	1	3	3430	1	28
18	1655	17	169	10	67	24	2	4600	5	22
19	2766	5	32	69	6	25	1	7033	9	11
20	3050	16	126		46	54	1	1900	6	22
21	2433	8	71	2	32	66	1	2933	4	13
22	1133	10	195	6	71	23	2	2033	1	19
23	2967	8	113	9	80	11	1	10550	10	22
24	1066	14	153	64	12	24	2	3600	5	38
25	600	22	227	28	57	15	3	1202	1	36
26	3934	8	161	16	80	4	2	1867	9	31

[1]/1 is seedling stand – *taimisto*
2 is middle aged stand – *harvennusmetsikkö*
3 is mature stand – *uudistuskypsä metsikkö*

and after sound level measurements in order to control the experimental conditions (cf. Broch 1973, pp. 75–77). Most of the measurements were carried out during the night in order to eliminate the effect of wind. It can be assumed, that the meteorological conditions in other respects, too, were similar each time.

Preliminary analysis of the material

The geometric spreading of sound from a point source can be presented with Equation (1), where the sound level is in energy units.

$$E(x) = \frac{1}{X^2} E(0), \qquad (1)$$

Table 2. Equipment used in the study.
Taulukko 2. Mittausvälineiden kuvaus.

Instrument — *Väline*	Model — *Malli*	Observations — *Huomautuksia*
	Transmitting unit *Lähetinyksikkö*	
Noise generator *Kohina generaattori*	Brüel & Kjaer, model — *tyyppi* 1405	Frequency band 20 Hz—100 kHz *Melun taajuusalue 20 Hz—100 kHz*
Amplifier *Vahvistin*	Paso, model — *tyyppi* T 40	
Sound radiator *Säteilijä*	Brüel & Kjaer, model — *tyyppi* 4241	Transmitting level 1.2 m *Säteilypiste 1.2 m korkeudessa maanpinnasta*
	Receiving unit *Vastaanottoyksikkö*	
Sound level meter *Äänitason mittari*	Brüel & Kjaer, model — *tyyppi* 2209	Measuring level 1.2 m *Mittaus 1.2 m korkeudelta*
Microphone *Mikrofoni*	Brüel & Kjaer, model — *tyyppi* 4145	
Wind screen Tuulisuoja	Brüel & Kjaer, model — *tyyppi* UA0237	
Tripod *Jalusta*	Brüel & Kjaer, model — *tyyppi* UA0049	
Sound level calibrator *Kalibrointilaite*	Brüel & Kjaer, model — *tyyppi* 4230	94 dB ± 0.25 dB, 1000 Hz

where X is the distance from the sound source,
E(x) is the sound level at the distance x from the sound source,
E(0) is the sound level of the sound source.

Equation (1) shows the sound attenuation under conditions where no reflection and surface absorption is found (cf. LYON 1973). When excess attenuation caused by trees or other phenomena is apparent, the behaviour of sound energy can be presented with Equation (2).

$$E(x) = \frac{P}{X^2} E(0), \qquad (2)$$

where P is the attenuation coefficient,
X is the distance from the sound source,
E(x) is the sound level at the distance x from the sound source
E(0) is the sound level of the sound source.

The attenuation coefficient includes only the excess attenuation (cf. GIVENS et. al. 1946). In different conditions the coefficient can have the following values:

P = 1 when geometric spreading only takes places
P < 1 when vegetation, ground surface and other factors cause excess attenuation because of absorption or dispersion,
P > 1 when environmental factors, eg. meteorological conditions, increase the sound level.

The sound attenuation caused by trees can be obtained, if the coefficient for the clear cut area is subtracted from the coefficient of the stand under study. In so doing factors other than tree characteristics are assumed to be of similar magnitude in both areas.

The sound level was measured in dB(A) units. Since the dB(A) scale measures human response to sound level, the measurements in dB(A) units can not be used for estimating the coefficient of attenuation. Therefore measurements made in dB(A) units were converted to energy units according to the concept of the dB scale as presented in Equation (3) (BROCH 1973).

$$\text{Sound pressure level} = 10 \, \text{Log}\left(\frac{P^2}{P_0^2}\right) = 20 \, \text{Log}\left(\frac{P}{P_0}\right) \text{dB}, \qquad (3)$$

where P_0 is the reference sound pressure level at the threshold of hearing $2 \cdot 10^{-5} N/m^2$,
P is the observed sound pressure level in N/m^2.

The values of the attenuation coefficient can be estimated for each of the stands studied using the method of least squares (HALD 1952, pp. 207—245) according to Equation (4).

$$\min_{P} \left\{ \sum_{i=1}^{n} \left(E_i - \frac{P}{X_i^2} E(0)\right)^2 \right\}, \qquad (4)$$

where X_i is the distance from the sound source to the measurement point,
E_i is the sound pressure level in energy units at the distance X_i,
E(0) is the sound pressure level of the sound source in energy units.

In the preliminary analysis of the material the attenuation coefficients for each stand were calculated according to the method described above. The results are presented in Table 3. The validity of the method was tested by means of the correlation between calculated and observed noise levels

Table 3. The attenuation coefficients for each stand and the correlations between calculated and observed sound levels in the stands.
Taulukko 3. Melun etenemisen analysointiin käytetyn mallin pätevyys: metsikkökohtaiset vaimennuskertoimet ja mittauspisteiden lasketun ja todetun melutason korrelaatiot.

Stand *Metsikkö*	Attenuation coefficient *Vaimennuskerroin*	Correlations between calculated and observed sound levels *Lasketun ja todetun äänentason väliset korrelaatiot*	
		r	r²
1	0.86	.996	.992
2	0.87	.982	.964
3	0.63	.982	.964
4	0.98	.999	.998
5	0.25	.971	.942
6	0.58	.986	.972
7	0.65	.980	.960
8	0.66	.997	.994
9	0.77	.998	.996
10	0.47	.994	.988
11	0.44	.985	.970
12	0.35	.988	.976
13	0.26	.981	.962
14	0.31	.975	.950
15	0.40	.996	.992
16	0.47	.998	.996
17	0.62	.998	.996
18	0.59	.994	.988
19	0.36	.986	.972
20	0.24	.981	.962
21	0.31	.988	.976
22	0.21	.993	.986
23	0.22	.980	.960
24	0.37	.972	.944
25	0.80	.993	.986
26	0.23	.973	.946
27	0.66	.994	.988
28	0.76	.993	.986
29	0.82	.994	.988
30	0.88	.998	.988

at each point in the study stands. The values of the attenuation coefficient used in the calculations were estimated from the study material. The results are presented in Table 3, too. According to the correlation coefficients, the method can be considered to be satisfactory despite the autocorrelation between sequential observations. Only slight discrepancies between the calculated and observed values were found in each study stand (Fig. 4). The main task of the analysis described further on is to relate the variance in the attenuation coefficient presented in Table 3 to certain stand characteristics.

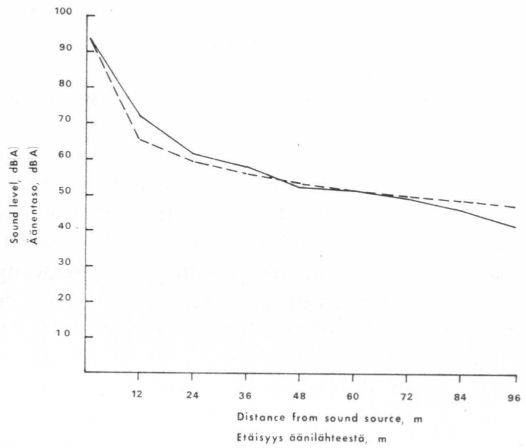

Figure 4. Correlation between observed and with Equation (2) calculated values of sound level in the stand number 6.

Kuva 4. Todettujen ja yhtälöllä (2) laskettujen äänentason arvojen välinen korrelaatio metsikössä 6.

RESULTS

Noise attenuation and tree species composition, development stage and vertical structure of a stand

Means for the attenuation coefficient in categories formed according to tree species and development stage are presented in Table 4. It is evident that spruce and mixed stands have lowered the noise level more efficiently than the pine stands. On the other hand the attenuation coefficient received its lowest values in seedling stands and middle aged stands. The differences between both the tree species composition and the development stage proved to be statistically significant ($p < 0.01$) when tested with analysis of variance. The interaction between tree species composition and development stage was not statistically significant ($p > 0.05$).

Table 4. Values of the attenuation cofficient as a function of tree species composition and development stage of a stand.

Taulukko 4. Puuston vaimennuskerroin puulajisuhteiden ja metsikön kehitysasteen mukaan ryhmiteltynä.

Tree species composition *Puulajisekoitus*	Development stage — *Kehitysluokka*: Seedling stand *Taimisto*	Middle aged stand *Harvennus metsikkö*	Mature stand *Uudistuskypsä metsikkö*	Mean *Keskimäärin*
Pine — *Mänty*	.740	.583	.825	.716
Spruce — *Kuusi*	.307	.346	.510	.388
Mixed — *Sekametsä*	.340	.290	.518	.383
Mean — *Keskimäärin*	.462	.406	.617	.495

Value for clear cut area is .780 — *Avohakkuualan arvo on .780.*

Table 5. The excess attenuation of the tree stands in relation to the clear cut area.

Taulukko 5. Puuston aiheuttama lisävaimennus avohakkuualan vaimennukseen verrattuna.

Tree species composition *Puulaji*	Development stage — *Kehitysluokka*: Seedling stand *Taimisto*	Middle aged stand *Harvennus-metsikkö*	Mature stand *Uudistuskypsä metsikkö*	Mean *Keskimäärin*
Pine — *Mänty*	105	125	96	109
Spruce — *Kuusi*	161	156	135	151
Mixed — *Sekametsä*	156	163	134	151
Mean — *Keskimäärin*	141	149	122	137

Value for clear cut area is 100 — *Avohakkuualan arvo on 100.*

The noise attenuation of the stands must be compared with clear cut areas and the geometric spreading. In the latter case the value of the attenuation coefficient is one. Thus the values of the attenuation coefficient show the attenuation in a stand in relation to the geometric spreading. Table 4 shows that a clear cut area will increase the attenuation, compared with the geometric spreading, by 20 % (in energy units). In the tree stands the attenuation is increased by 20—60 % depending on the stand characteristics. A forest area with a balanced tree species and development stage composition would attenuate the noise level by one half compared with the pure geometric spreading. According to the results of the t-test, the differences between the geometric spreading and the attenuation in the stands are statistically significant ($p < 0.01$).

The excess attenuation caused by trees is shown in Table 5. The clear cut area has been given the value 100. The excess attenuation of pine stands is very poor at all development stages. In mature stands the noise level even increases in relation to a clear cut area. The differences between the clear cut areas and the pine stands are

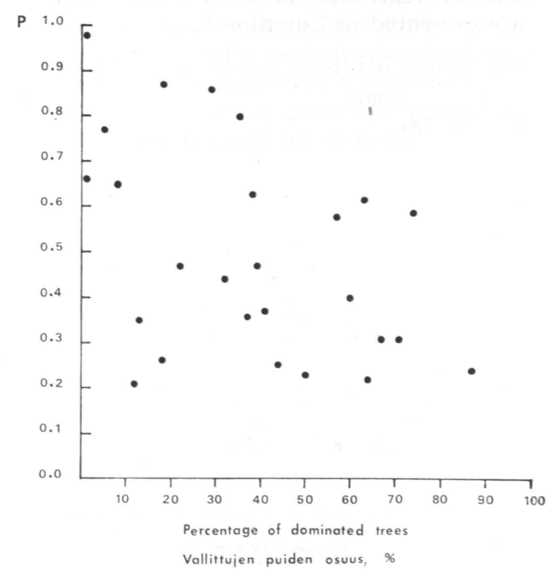

Figure 5. Attenuation coefficient as a function of percentage of dominated trees.

Kuva 5. Vaimennuskerroin metsikön vallittujen puiden osuuden funktiona.

not statistically significant ($p > 0.05$), as is the case of spruce and mixed stands ($p < 0.01$). In the latter case the excess attenuation is 40—60 % higher than that of the clear cut areas, depending on tree species composition and development stage. A forest area with a balanced composition of tree species and development stages would increase the noise attenuation by 40 % compared with a clear cut area.

The vertical structure of a stand in relation to noise attenuation can be described in several different ways. The following characteristics were included in this study and their effect on the noise attenuation was tested: percentage of dominated trees (two meters <height< three quarters of dominating trees), percentage of self pruned stems in relation to the mean height of a stand and density of bush storey (stem number per hectare of under storey 0.5—2.0 meters tall). In order to investigate the effect of these variables on the noise attenuation correlation and regression analysis were carried out for each variable.

The relationship between the attenuation coefficient and the percentage of dominated trees is a linear one (Fig. 5). The parameters for the regression between these variables are presented in Equation 5.

$$P = .696 - .005 \text{ (Percentage of dominated trees)}, \quad (5)$$
$$\qquad\qquad (.001)$$
$$R = - .554$$

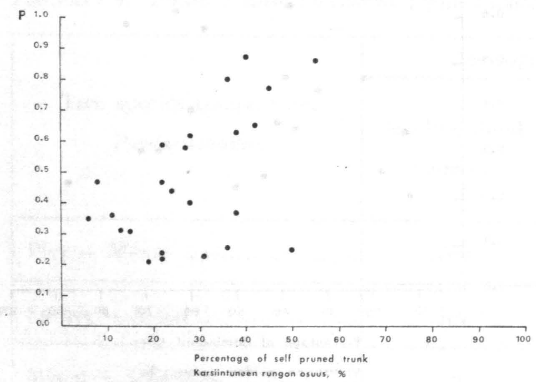

Figure 6. Attenuation coefficient as a function of percentage of self pruned trunk.

Kuva 6. Vaimennuskerroin karsiutuneen rungon osuuden funktiona.

The calculated regression is statistically significant at a risk of 1 %. However, the model explained only 31 % of the total variance of the attenuation coefficient. The result supports the hypothesis concerning the relationship between the vertical structure of a stand and noise attenuation. A favourable result as far as noise abatement in concerned would be obtained, if a stand could be grown in several storeys. Thus, the stands containing substoreys attenuate noise more effectively than those without.

The linear correlation between the attenuation coefficient and the percentage of self pruned stems was tested. The result is shown in Fig. 6. Equation (6) shows the regression.

$$P = -.144 + .192 \text{ (Percentage of self pruned stems)} \quad (6)$$
$$\qquad\qquad (.050)$$
$$R = .609$$

The regression between the attenuation coefficient and the percentage of the bare stem area is statistically significant ($p < 0.01$). The model explained 37 % of the total variance in the attenuation coefficient. The poor degree of determination is dependent partly on the unlinear nature of the correlation, but not so much as in the case of the correlation between the attenuation coefficient and the percentage of dominated trees. However, the result supports the

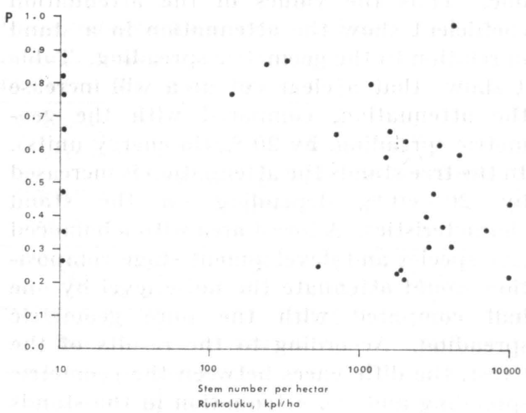

Figure 7. Attenuation coefficient as a function of density of under storey.

Kuva 7. Vaimennuskerroin pensaskerroksen tiheyden funktiona.

assumption concerning the importance of vertical structure in noise attenuation.

The noise attenuation capacity of a stand in relation to the bush storey is shown in Fig. 7. This correlation is apparently a hyperbolic one, but owing to the great variance in the relationship this kind of regression did not give better results than a linear one. The parameters for the latter dependance are given in Equation (7).

$$P = .600 - .0003 \text{ (Density of bush storey)}, \quad (7)$$
$$\qquad\qquad (.0001)$$
$$R = -.338$$

The regression is not statistically significant ($p > 0.05$) as is also indicated by the degree of determination of 11 %. The result, however, gives no evidence that stands with several storeys would not be more efficient in noise attenuation than stands with a single storey. Owing to the contradiction with earlier studies (c.f. Cook and Haverbeke 1971, 1973) a more representative material as regards the to bush storey is needed in order to determine the importance of undergrowth in noise attenuation.

Noise attenuation and density, basal area, height and volume of a stand

The density of the tree stands was initially surveyed by means of the total number of

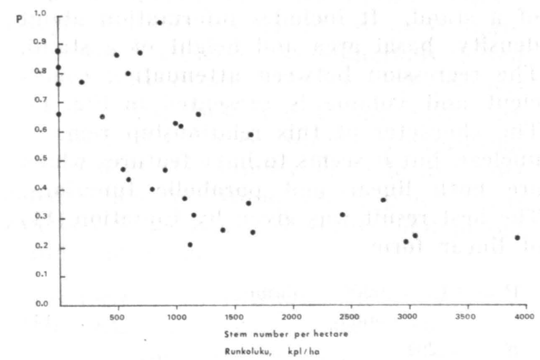

Figure 8. Attenuation coefficient as a function of total stem number of dominating and dominated trees.

Kuva 8. Vaimennuskerroin metsikön kokonaisrunkoluvun funktiona.

stems per hectare in the stands. Only the trees taller than two meter were included (see Fig. 8). Negative correlation of logarithmic form exists between the attenuation coefficient and the stem number. The parameters for this relationship are presented in Equation (8).

$$P = 0.903 - .064 \text{ Log (Total stem number)}, \quad (8)$$
$$\qquad\qquad (.015)$$
$$R = -.653$$

The regression is statistically significant at a risk of 1.0 %. The total stem number of a stand explained 43 % of the total variance in the attenuation coefficient, As the value of the attenuation coefficient begins to decrease not earlier than when the total stem number is above 500—700 per hectare, it is evident that the logarithmic function does not describe the dependence between the attenuation coefficient and total stem number correctly. When the total number of stems approaches 2000—2500 per hectare, the decrease in the attenuation coefficient ceases. The result supports the earlier presented assumption concerning the importance of early successional stages of a stand in urban noise control.

The basal area of a stand was also used to describe the density of the study stands. The dependance of the attenuation coefficient on this stand characteristic is presented in Fig. 9. Equation (9) gives the parameters of this dependance in linear form.

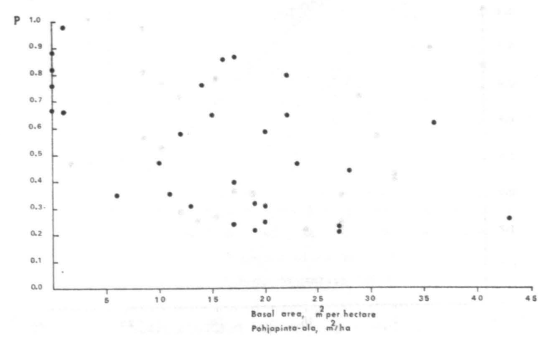

Figure 9. Attenuation coefficient as a function of basal area.

Kuva 9. Vaimennuskerroin pohjapinta-alan funktiona.

$$P = .705 - .011\ (\text{Basal area}), \quad (.003) \qquad (9)$$
$$R = -.493$$

The regression is significant at the risk of 1 %. The model does not explain more than 24 % of the total variance in the attenuation coefficient. It is evident that the assumption concerning the linearity of the relationship between the attenuation coefficient and the basal area is not valid. However, the parabolic function did not give better results than Equation (9).

The correlation between the attenuation capacity and the height of the stand is presented in Fig. 10. This correlation is a parabolic one. The turning point of the parabola is at a height of 10—12 meters. The following regression (10) is based on the parabolic correlation with a turning point at a height of 12 meters.

$$P = .389 + .003\ (\text{Height} - 12)^2 \quad (.009) \qquad (10)$$
$$R = .535$$

The regression between the attenuation coefficient and the stand height is statistically significant at a risk of 1 % when the parabolic transformation described above is carried out. The model explained 30 % of the total variance in the attenuation coefficient. The low degree of determination

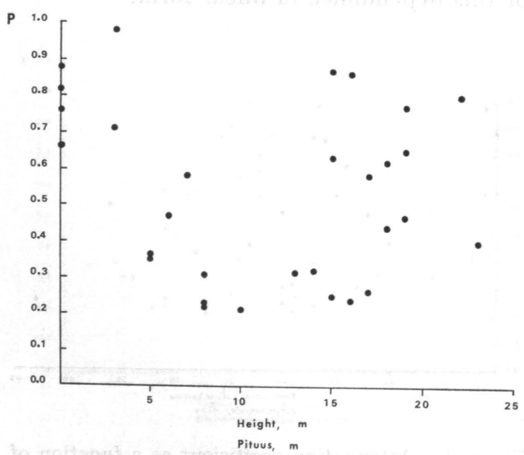

Figure 10. Attenuation coefficient as a function of height.

Kuva 10. Vaimennuskerroin pituuden funktiona.

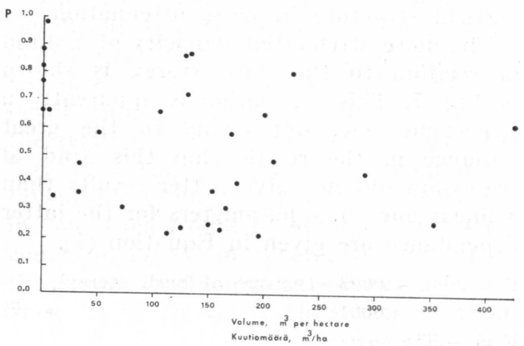

Figure 11. Attenuation coefficient as a function of volume.

Kuva 11. Vaimennuskerroin kuutiomäärän funktiona.

is partly due to the fact tht the applied transformation does not give the relationship the linear form needed in calculations of regression. The parabolic relationship between the attenuation coefficient and the height can be explained by the fact that there are branches right down to the ground level in seedling and middle aged stands, whereas in mature stands the percentage of the bare stem area is high. The result also gives additional evidence for the importance of early stages of forest succession in urban noise control.

The volume of the trees represents the major share of the biomass of a stand, and hence is used as a measure of the biomass of a stand. It includes information about density, basal area and height of a stand. The regression between attenuation coefficient and volume is presented in Fig. 11. The character of this relationship remains unclear, but it seems to have features which are both linear and parabolic functions. The best result was given by Equation (11) of linear form.

$$P = .615 - .0006\ (\text{Volume}), \quad (.0003) \qquad (11)$$
$$R = -.291$$

The regression is not statistically significant ($p > 0.05$), as would be expected, since the degree of determination is only 8 %. The stand volume can therefore not be regarded as an important characteristic

in sound attenuation. The main reason for this result can be found in the high correlation between the volume and the late successional stage of a stand.

Noise attenuation in relation to distance and stand characteristics

When green belts for noise control are being planned it is important to know the sound level at different distances from a certain sound source when the characteristics of the tree stands lying between the planning object and the sound source are known or vice versa. Equation (12) can be applied to solve this problem.

$$E(x) = \frac{P}{X^2} E(0), \qquad (12)$$

where X is the distance from the sound source,
E(x) is the sound level at the distance x,
E(0) is the sound level at the sound source,
P is the attenuation coefficient.

In predicting the values of the attenuation coefficient the variables which are statistically significant in relation to the coefficient are of the greatest value. Since none of the stand characteristics satisfactorily explaines the situation, it is necessary to use a regression model based on several factors. Of the factors involved, the important ones have been shown to be the tree species composition, the development stage, the presence of different tree crown storeys, the density and the height are particularly important. Different combinations based on these observations were tested (Equations 13—15). The best results are given by Equation (15). Tree species composition was used as the dummy variable in model construction (cf. Roos 1971): pine stands received value zero and spruce and mixed stands value one.

$$P = 1.694 - .303\ (\text{Tree species}),\ R = -.640 \qquad (13)$$
$$P = 1.632 - .234\ (\text{Tree species}) - .139\ \text{Log}\ (\text{Total stem number}),\ R = .761 \qquad (14)$$
$$P = 1.368 - .247\ (\text{Tree species}) - .115\ \text{Log}\ (\text{Total stem number}) + .002\ (\text{Height} - 12)^2,\ R = .800 \qquad (15)$$

In Equation (15) the correlation between the combination of factors and attenuation coefficient is statistically highly significant ($p < 0.01$). All the regression coefficients are statistically significant with a risk of 5 %. The other variables which were tested in model construction increased the degree of determination by less than one percent. Model (15) explained 64 % of the variance studied.

Tre correlations within the factors in the model (15) are:

		1	2	3
Tree species	(1)	1.000		
Density	(2)	0.329	1.000	
Height	(3)	−0.09	−0.317	1.000

As the correlations are fairly low, they do not disturb the interpretation of the model, if the explanative properties of this model are stressed. When a model is used purely for prediction of the situation the intercorrelations between the factors become meaningless (cf. Roos 1971).

At the second stage of the analysis the theoretical values of the attenuation coefficient were calculated for each study stand using Equation (15). By means of these

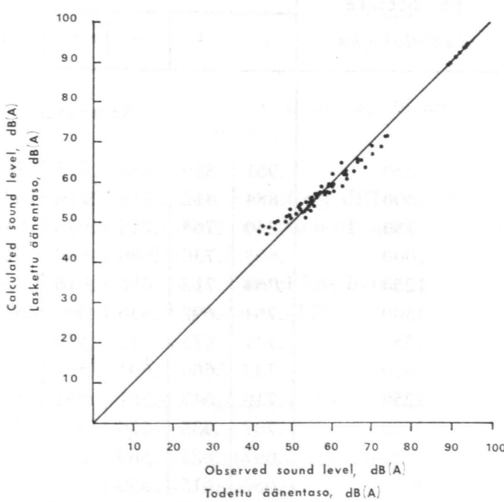

Figure 12. Calcutation of sound level with stand characteristics and distance: correlation between observed and calculation values.

Kuva 12. Äänen tason laskenta metsikön ominaisuuksien ja etäisyyden avulla: todettujen ja laskettujen äänentason arvojen välinen korrelaatio.

Table 6. Relationship between attenuation coefficient and the density and height of spruce stands.
Taulukko 6. Vaimennuskertoimen riippuvuus puuston runkoluvusta ja pituudesta. Kuusikot.

Stem number per hectare *Runkoluku/ha*	Mean height, m — *Keskipituus, m*												
	2	4	6	8	10	12	14	16	18	20	22	24	26
	Attenuation coefficient — *Vaimennuskerroin*												
250	.715	.643	.587	.547	.523	.515	.523	.547	.587	.643	.715	.803	.907
500	.638	.566	.510	.470	.446	.438	.446	.470	.510	.566	.638	.726	.830
750	.594	.522	.466	.426	.402	.394	.402	.426	.466	.522	.594	.682	
1000	.562	.490	.434	.394	.370	.362	.370	.394	.434	.490	.562		
1250	.538	.466	.410	.370	.346	.338	.346	.370	.410	.466			
1500	.518	.446	.390	.350	.326	.318	.326	.350	.390				
1750	.501	.429	.373	.333	.309	.301	.309	.333					
2000	.486	.414	.358	.318	.294	.286	.294	.318					
2250	.473	.401	.345	.305	.281	.273	.281						
2500	.461	.389	.333	.293	.269	.261	.269						
2750	.451	.379	.323	.283	.259	.251							
3000	.441	.369	.313	.273	.249	.241							

Table 7. Relationship between attenuation coefficient and density and height of pine stands.
Taulukko 7. Vaimennuskertoimen riippuvuus puustoon runkoluvusta ja pituudesta. Männiköt.

Stem number per hectare *Runkoluku/ha*	Mean height, m — *Keskipituus, m*												
	2	4	6	8	10	12	14	16	18	20	22	24	26
	Attenuation coefficient — *Vaimennuskerroin*												
250	.961	.889	.833	.793	.769	.761	.769	.793	.833	.889	.961	1.049	1.153
500	.884	.812	.756	.716	.692	.684	.692	.716	.756	.812	.884	.972	1.076
750	.840	.768	.712	.672	.648	.640	.648	.672	.712	.768	.840	.928	
1000	.808	.736	.680	.640	.616	.608	.616	.640	.680	.736	.808		
1250	.784	.712	.656	.616	.592	.584	.592	.616	.656	.712			
1500	.764	.692	.636	.596	.572	.564	.572	.596	.636				
1750	.747	.675	.619	.579	.555	.547	.555	.579					
2000	.732	.660	.604	.564	.540	.532	.540						
2250	.719	.647	.591	.551	.527	.519							
2500	.707	.635	.579	.539	.515								
2750	.697	.625	.569	.529									
3000	.687	.615	.559										

values the theoretical sound level for each point in the study stands were calculated.

The correlation between theoretical and observed values of the sound level is presented in Fig. 12. Since the correlation between these values was 0.984 the model can be regarded as being well suited for sound level prediction in the planning processes described earlier.

Equations (12) and (15) can be used

Table 8. Attenuation as a function of the attenuation coefficient and distance from the noise source.
Taulukko 8. Puuston aiheuttaman vaimennuksen riippuvuus puuston melunvaimennuskertoimesta ja melulähteen etäisyydestä.

Attenuation Coefficient *Vaimennus-kerroin*	Distance, m — *Etäisyys, m*								
	10	20	30	40	50	60	70	80	90
	Attenuation — *Vaimennus*								
.100	9.990	2.499	1.111	.625	.400	.278	.204	.156	.123
.150	14.978	3.749	1.666	.937	.600	.417	.306	.234	.185
.200	19.960	4.998	2.222	1.250	.800	.556	.408	.312	.247
.250	24.938	6.246	2.777	1.562	1.000	.694	.510	.391	.309
.300	29.910	7.494	3.332	1.875	1.200	.833	.612	.469	.370
.350	34.878	8.742	3.887	2.187	1.400	.972	7.14	.547	.432
.400	39.841	9.990	4.442	2.499	1.600	1.111	.816	.625	.494
.450	44.798	11.237	4.998	2.812	1.800	1.250	.918	.703	.556
.500	49.751	12.484	5.552	3.124	2.000	1.389	1.020	.781	.617
.550	54.699	13.731	6.107	3.436	2 200	1.528	1.122	.859	.679
.600	59.642	14.978	6.682	3.749	2.399	1.666	1.224	.937	.741
.650	64.580	16.224	7.217	4.061	2.599	1.805	1.326	1.016	.802
.700	69.513	17.469	7.772	4.373	2.799	1.944	1.428	1.094	.864
.750	74.442	18.715	8.326	4.685	2.999	2.083	1.530	1.172	.926
.800	79.365	19.960	8.881	4.998	3.199	2.222	1.632	1.250	.988
.850	84.284	21.205	9.436	5.310	3.399	2.361	1.734	1.328	1.049
.900	89.197	22.449	9.990	5.622	3.599	2.499	1.836	1.406	1.111
.950	94.106	23.694	10.544	5.934	3.799	2.638	1.938	1.484	1.173

to predict sound level in urban forestry and to develop different types of stands. For these practical purposes the sound level has been calculated at a distance of 10—90 m from the sound source when the noise level of the source is between 60—100 dB(A) and the density of the pine and spruce stands 250—3 000 stems per hectare and the height 2—26 meters.

The attenuation coefficients have first been calculated using Equation (15) for pine and spruce stands (Tables 6 and 7). Secondly the attenuation has been calculated according to Equation (16).

$$V_{ij} = \frac{P_i}{x_{ij}^2} \qquad (16)$$

where P_i is the attenuation coefficient of the stand i,
x_j is the distance from the sound source to the point j, in the stand i
V_{ij} is the attenuation at the distance j in the stand i.

The attenuation based on different values of the attenuation coefficient and distance is shown in Table 8.

Finally the sound level has been calculated according to Equation (17).

$$E_{ij} = V_{ij} \cdot E_j, \qquad (17)$$

where V_{ij} is the attenuation of the stand i at the distance j,
E_j is the sound level of the sound source at the distance j,
E_{ij} is the sound level at the observation point j in a stand i.

The results are presented in Table 9. The following example clarifies the possibilities of using these tables. If the noise level at the source is 90 dB(A), the density of the

Table 9. Sound level at the observation point as a function of attenuation and the sound level of the noise source.

Taulukko 9. Havaintokohteen äänenvoimakkuuden taso vaimennuksen ja melulähteen äänenvoimakkuuden funktiona.

Attenuation *Vaimennus*	Sound level of noise source, dB(A) *Melulähteen äänentaso, dB(A)*								
	60.0	65.0	70.0	75.0	80 0	85.0	90.0	95.0	100.0
	Sound level at observation point, dB(A) *Havaintokohteen äänentaso, dB(A)*								
0.1	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0
0.2	33.0	38.0	43.0	48.0	53.0	58.0	63.0	68.0	73.0
0.3	34.8	39.8	44.8	49.8	54.8	59.8	64.8	69.8	74.8
0.4	36.0	41.0	46.0	51.0	56.0	61.0	66.0	71.0	76.0
0.5	37.0	42.0	47.0	52.0	57.0	62.0	67.0	72.0	77.0
0.6	37.8	42.8	47.8	52.8	57.8	62.8	67.8	72.8	77.8
0.7	38.5	43.5	48.5	53.5	58.5	63.5	68.5	73.5	78.5
0.8	39.0	44.0	49.0	54.0	59.0	64.0	69.0	74.0	79.0
0.9	39.5	44.5	49.5	54.5	59.5	64.5	69.5	74.5	79.5
1.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
2.0	43.0	48.0	53.0	58.0	63.0	68.0	73.0	78.0	83.0
3.0	44.7	49.7	54.7	59.7	64.7	69.7	74.7	79.7	84.7
4.0	46.0	51.0	56.0	61.0	66.0	71.0	76.0	81.0	86.0
5.0	47.0	52.0	57.0	62.0	67.0	72.0	77.0	82.0	87.0
6.0	47.8	52.8	57.8	62.8	67.8	72.8	77.8	82.8	87.8
7.0	48.5	53.5	58.5	63.5	68.5	73.5	78.5	83.5	88.5
8.0	49.0	54.0	59.0	64.0	69.0	74.0	79.0	84.0	89.0
9.0	49.5	54.5	59.5	64.5	69.5	74.5	79.5	84.5	89.5
10.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0
20.0	53.0	58.0	63.0	68.0	73.0	78.0	83.0	88.0	93.0
30.0	54.8	59.8	64.8	69.8	74.8	79.8	84.8	89.8	94.8
40.0	56.0	61.0	66.0	71.0	76.0	81.0	86.0	91.0	96.0
50.0	57.0	62.0	67.0	72.0	77.0	82.0	87.0	92.0	97.0
60.0	58.0	63.0	68.0	73.0	78.0	83.0	88.0	93.0	98.0
70.0	58.5	63.5	68.5	73.5	78.5	83.5	88.5	93.5	98.5
80.0	59.0	64.0	69.0	74.0	79.0	84.0	89.0	94.0	99.0
90.0	59.5	64.5	69.5	74.5	79.5	84.5	89.5	94.5	99.5

spruce stand 1750 stems per hectare and the height 16 meters, then the noise level is to be known at a distance of 60 m. Table 7 gives the attenuation coefficient 0.333. Table 8 gives the attenuation of 0.868 using interpolation. Table 9 shows that there is a noise level of 69 dB(A) at a distance of 60 m. In the clear cut area the noise level would be 74 dB(A). The excess attenuation caused by trees is 5 dB(A). The tables can be used to calculate the opposite way a around too.

Noise attenuation and forest succession

A tree stand is dynamic and therefore the succession must be taken into account. It has been shown above that seedling and young growing stands have better noise control qualities than more mature stands. In order to find the best rotation for stands used in noise abatement, the attenuation coefficient was calculated as a function of time using Equation (15). The succession series for repeatedly thinned pine and spruce stands growing on sites of the *Myrtillus* type according to Koivisto (1959) were used. The results are shown in Fig. 13.

The lowest values for the attenuation coefficient both in pine and spruce stands were obtained when the stands were 30—40 years old. There is a clear difference between tree species which favours spruce stands. In mature pine stands the attenuation coefficient attains values greater than one as is expected according to earlier analyse. According to the results, such stands would increase the sound level instead of the attenuation. The results are, however, preliminary because of the limited material on which the applied regression equations are based. Thus, the equations can only partly cover the variance in different stand parameters included in the succession series by Koivisto.

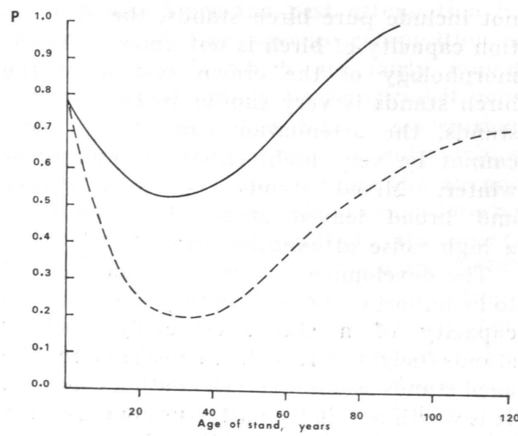

Figure 13. Attenuation coefficien as a function of age of a stand.

Kuva 13. Vaimennuskerroin metsikön iän funktiona.

DISCUSSION

As the noise in each stand was monitored for short periods only there is some doubt as regards the reliability of the results. For instance, the meteorological factors and background noise may have had an effect on the results. In order to minimise the error caused by these factors the measurements were carried out during the night time in the countryside. In particular, the effect of wind and air turbulance on the results will have been almost completely eliminated in addition to background noise. However, the temperature and moisture gradients may have decresed the reliability of the results as supposed on the basis of studies carried out by Eyring (1946), Ingård (1953), Wiener and Keast (1959) and Lyon (1973). In addition, the limited material must also be taken into consideration when judging reliability and applicability of the results. However, the method can be considered reliable if only the attenuation process is concerned, as indicated by the high correlation between the observed and calculated sound levels within different stands. Readers who are interested in obtaining more details about the methodology of noise control should turn to more advanced texts such as the review by Beck (1965).

Despite these weaknesses, the study shows that tree barriers can be used successfully in urban noise control. At its best, the excess attenuation of tree stands was 60 % greater than that of the geometric spreading based on energy units. The same value compared with the clear cut area was 40 %. The results are comparable with those reported by Beck (1965, 1968) and Cook and Haverbeke (1971, 1973). Since only the resultant of different frequencies of transmitted noise was included in the study, the behaviour of different frequency bands in relation to stand characteristics is not known. According to Embleton (1963) noise of low frequencies, in particular, can have such a spreading pattern that the attenuation by tree barriers remains very poor.

The tree species composition seems to play only a moderate role in noise attenuation. In particular, spruce and similar tree species can be recommended in the planting of noise barriers. Since the material does not include pure birch stands, the attenuation capacity of birch is not known. As the morphology of the crown system of the birch stands is very similar to that of pine stands, the attenuation capacity of birch cannot be very high, either in summer or winter. Mixed stands, especially spruce and broad leaved stands had, however, a high noise attenuation capacity.

The development stage of a stand proved to be important in relation to the attenuation capacity of a stand, especially seedling stands (height of 1.5—4.0 meters) and middle aged stands had a high attenuation capacity. It is worth noting that attenuation in mature pine stands was smaller than in any other stands, even in clear cut areas. Embleton (1963) has paid attenuation to the resonance caused by stems and branches. This may also be the reason for increased sound levels observed in this study. Reflection from the crown system may also play an important role. In addition, the quality of the ground cover behind the noise transmitter must be taken into consideration, because differences in it can produce inaccuracies in the measurements. Some other diffeculties concerning the measurements are discussed earlier.

The density of a stand also proved to be an important factor in noise attenuation as expected according to Cook and Haverbeke (1971, 1973). This result agrees with the observations on the high attenuation capacity of early stages of forest succession. It remains, however, to be solved, whether the excess attenuation is caused by sound spreading resulting from stems and the crown system as postulated by Cook and Haverbeke. The results agree better with Beck's (1965) theory of the role of surface absorption in sound attenuation. In particular, the relationship between height and vertical structure of a stand and noise attenuation supports this idea (cf. Lyon 1973). Thus, the total amount of leaves or needles in relation to the volume between ground and crown levels is important. In addition, the way, in which this mass is distributed, can be decisive. Apparently the best situation is that when the needles or leaves are evenly distributed in the space between ground and crown levels. Beck (1965) has also found that the size of needles and leaves are important in noise attenuation in addition to shape and mutual position of needles and leaves.

A parabolic relationship between attenuation capacity and stand height was found. The attenuation capacity of a stand increased up to the stand height of 10—12 meters, after which a symmetrical decrease in attenuation capacity took place. The rapid self pruning of stems in successional stage indicated by a stand height of 10—12 meters can be regarded as the basic reason for this phenomena. On addition, the lower stem number in mature stands must be taken into consideration in explaining the curvilinear relationship between attenuation capacity and stand height. The material gives, however, only limited possibilities for analysing interactions between stand density and height and their importance in relation to the attenuation capacity of a stand. In summary, the development stage of a stand seems to play an important role as far as the attenuation capacity of a stand is concerned, and in this respect the stand height seems to be special importance.

Beck (1965, 1968) has paid attention to the importance of a bush storey in increasing the attenuation capacity of a stand. The present material did not give clear results in this respect. However, the results support Beck's idea, because a bush storey can be considered to give deversity of vertical structure in a stand. A bush storey situated at the edges of a stand opposite the noise source has proved important in noise control. According to Cook and Haverbeke (1971), favourable results could be obtained by combining trees and bushes together in such a way that they form an even vegetation barrier between the ground and crown levels. The existance of a bush storey is of particular importance in stands of late successional stages because of the self pruning of stems.

It was found that no single stand characteristic had a great enough explanatory power. The most important reason for this is the fact that none of the variables tested included the properties of the crown system, especially its vertical structure. However, these factors were found to play a major role in explaining the attenuation properties of a stand. The study approach did not include this kind of elucidification, for the main interest was concentrated on finding some easily determined stand characteristics which could be used in the practical forestry of urban areas. In future studies the main interest must be concentrated on the crown biomass and the volume between ground and crown levels in order to explain the causal factors concerning the noise attenuation in a stand.

The nomograms for estimating the attenuation capacity of stands of different character are the preliminary ones for the limited material. The authors believe, however, that they may give useful ideas for planners and foresters dealing with problems of urban environment. The nomograms include only stands in which development has been guided according to timber production goals. Thus, special stands for noise control could give better results than those obtained now. In particular, the density of seedling and middle aged stands could be higher. The nomograms give the basic values for which can be achieved in normal practice without any special noise control program.

In planning, the attenuation capacity of a stand must be related to the succession of a stand. Since the best attenuation independent of tree species composition is found in stands which are fairly young, a short rotation would be beneficial if noise control only is taken into consideration. However, recreational use, amenity values, the value of stands in cleaning the air and so on are important aspects of urban forestry which can not be omitted (Robinette 1972, Warren 1973, Kellomäki 1976). Since outdoor people prefer mature stands of pine and birch (Kellomäki 1975) short rotation can not be solely favoured in urban areas. On the other hand, young stands of mixed conifers and broadleaved trees are preferred in air pollution control (Jacsman 1971, Warren 1973). These partly controversial goals can be unified in fertile sites by growing stands in several storeys. The top storey of the highest trees should be open enough to let light penetrate to the lower storeys. The highest tree storey could be formed of pine and birch and the lower storey mostly of spruce. In the lower storey the rotation should be fairly short. This kind of forestry practice would satisfy the goals of urban forestry discussed above (cf. Kellomäki 1975, 1976).

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SELOSTE:

PUUSTO YHDYSKUNTAMELUN TORJUNNASSA

Tutkimuksen tarkoituksena on ollut selvittää puuston melunvaimennukseen vaikuttavia ominaisuuksia ja kehittää puuston avulla tapahtuvassa meluntorjunnassa tarvittavia suunnittelumalleja. Aineisto koostuu 31 metsiköstä, jotka edustavat männyn ja kuusen sekä sekapuustojen eri sukkessiovaiheita paljaaksi hakkuusta lähtien. Näiden metsiköiden melunvaimennusominaisuuksia on tutkittu mittaamalla keinotekoisen melun etenemistä metsiköissä. Puuston vaikutusta melun etenemiseen on analysoitu mallilla, jonka kehittämisessä on käytetty hyväksi äänen etenemistä hallitsevia fysikaalisia lainalaisuuksia. Mallin metsikkökohtaista parametriä, ns. vaimennuskerrointa hyväksi käyttäen on tutkittu, mitkä metsikkötunnukset soveltuvat parhaiten ennakoimaan puuston vaikutusta meluun.

Tutkimuksen tulokset osoittavat,

1. että puuston aiheuttama lisävaimennus verrattuna geometriseen vaimennukseen on parhaissa tapauksissa 60 % suurempi ilmaistuna energiayksiköissä,
2. että puuston lehtien ja oksien kokonaismäärä suhteessa maanpinnan ja latvustason väliseen tilaan on keskeisin metsikön melunvaimennuskykyyn vaikuttava tekijä, vaikkakin myös puuston tiheys, pituus ja puulajisekoitus vaikuttavat vaimennuskykyyn,
3. että melutaso millä tahansa etäisyydellä melutähteestä voidaan ennustaa suhteellisen tarkasti, jos melulähteen teho sekä melulähteen ja mittauspisteen välillä olevan puuston puulajisekoitus, tiheys ja pituus tunnetaan ja päinvastoin,
4. että sekä männyn että kuusen taimisto- ja tiheikkövaiheen metsiköt ovat melunvaimennuksessa selvästi tehokkaampia kuin uudistuskypsät metsiköt.

Tutkimustulosten perusteella on lopuksi laskettu nomogrammit, joiden avulla havaintopisteen melutaso voidaan määrittää, jos melulähteen melutaso sekä melulähteen sekä havaintopisteen välillä olevan puuston ominaisuudet tunnetaan tai päinvastoin.

Edellä esitettyjen tulosten perusteella kaupunkimetsien hoidon tavoitteita on käsitelty lyhyesti.

SAASTAMOINEN, OLLI & HEINO, JAN — O.D.C. 907 - - 01

1976. Research topics of multiple-use forestry. — SILVA FENNICA Vol. 10, No. 3, 17 p. Helsinki.

The purpose of the study was to gain an insight into research problems and themes in multiple use of forests from a practical viewpoint. An inquiry concerning multiple use problems was sent to 597 organizations whose work related to multiple use of forests. Replies yielded 1 851 suggested research themes which were divided between different uses of forests. The results of the study has been used in the planning of research in the multiple use of forests.

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KÄRKKÄINEN, MATTI — O.D.C. 812.31: 861.0

1976. Measurement of basic density of total tree chips. — SILVA FENNICA Vol. 10, No. 3, 14 p. Helsinki.

The paper describes a method for the measurement of basic density of total tree chips. In this method, the effect of air bubbles can be eliminated. Besides this, due to homogenization of the material to be measured only small number of samples are needed for the estimation of the average basic density.

Author's address: The Finnish Forest Research Institute, Unioninkatu 40 A, SF-00170 Helsinki 17, Finland.

MÄLKÖNEN, EINO — O.D.C. 114.52: 33

1976. Effect of whole-tree harvesting on soil fertility. — SILVA FENNICA Vol. 10, No. 3, 8 p. Helsinki.

This paper analyzes the nutrient losses caused by whole-tree harvesting on the basis of the literature data. It has been considered that traditional stemwood harvesting does not lead to impoverishment of the soil because the nutrient content of the wood is quite low. The nutrient loss occurring in connection with heavy thinnings and whole-tree harvesting has been considered so great that it has to be compensated by fertilizer application. In comparison with harvesting unbarked stem timber, whole-tree harvesting has been found to increase the nutrient loss at the stage of final cutting as follows: N 2 to 4 times, P 2 to 5 times, K 1.5 to 3.5 times and Ca 1.5 to 2.5 times. Depending on the conditions prevailing on the site, any one of these nutrients may be the limiting factor for tree growth during the next tree generation.

Author's address: The Finnish Forest Research Institute, Unioninkatu 40 A, SF-00170 Helsinki 17, Finland.

LEHTONEN, I., WESTMAN, C. J. and KELLOMÄKI, S. — O.D.C. 160.2: 114.2

1976. Nutrient cycle in a pine stand I: Seasonal variation in nutrient content of vegetation and soil. — SILVA FENNICA Vol. 10, No. 3, 16 p. Helsinki.

The paper deals with seasonal variation in the nitrogen, phosphorous, potassium, calcium and magnesium content of vegetation and soil of a young pine stand of *Vaccinium* site type situated in central Finland. The material consists of sequential samples representing soil, ground vegetation and trees taken during summer 1974.

The amount of soluble nutrients in the humus layer decreased in June when maximum growth of trees and dwarf shrubs occured. The nutrient content of this layer subsequently began to increase towards the end of the growing period.

The variation in the nutrient content of the bottom and ground layers followed a similar pattern. Nitrogen content increases at the beginning of the summer. After this phase it starts to decrease and reaches its lowest values by the end of growing period. Phosphorus and potassium contents increase throughout the growing period.

The nutrient content of needles and wood are positively correlated with tree height and negatively with the age of material. The highest values for the nutrient content are for new cells.

Author's (Lehtonen) address: The Finnish Forest Research Institute, Unioninkatu 40 A, SF-00170 Helsinki 17, Finland.

KÄRKKÄINEN, MATTI O.D.C. 815.31

1976. Density and moisture content of wood and bark, and bark percentage in the branches of birch, Norway spruce, and Scots pine. — SILVA FENNICA Vol. 10, No. 3, 25 p. Helsinki.

In the study the properties of branch samples of various diameter were studied. The branches were taken from small trees to be harvested by total tree chipping methods. With the exception of the basic density of bark, there was a relationship between all the other properties which were studied and the diameter. Even when the effect of diameter was eliminated, in many cases the effect of the distance of the sample from the stem became apparent.

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KELLOMÄKI, SEPPO, HAAPANEN, ANTTI and SALONEN, HELLEVI O.D.C. 907.3

1976. Tree stands in urban noise abatement. SILVA FENNICA Vol. 10, No. 3, 20 p. Helsinki.

The aim of the study has been to determine which characteristics of tree stands could be used in urban noise control and to develope guidelines for practical urban forestry. The attenuation of artificially produced noise was measured in various types of stands. The effect of tree stands on noise attenuation has been analysed using a model based on the physics of sound propagation.
The results show that the excess noise attenuation caused by trees can be in good situations 60 % measured in energy units, compared with the attenuation caused by geometric spreading. This is 5—8 dB. The total amount of needles, leaves and branches of a stand proved to be the most important factors in noise attenuation. However, the density and height of a stand had rather high value in predicting the behaviour of noise in tree stands. Based on multiple regression between noise attenuation and tree species composition, density and height of a stand it was developed the nomograms with which the noise level at a certain point can be predicte when the tree stand characteristics, the distance and the noise level of the noise source are known and on the opposite way.

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KIRJOITUSTEN LAATIMISOHJEET

Silva Fennica-sarjassa julkaistaan lyhyitä metsätieteellisiä tutkimuksia ja kirjoituksia kotimaisilla kielillä tai jollakin suurella tieteellisellä kielellä. Julkaistavaksi tarkoitettu käsikirjoitus on jätettävä Seuran sihteerille painatuskelpoisessa asussa. Seuran hallitus ratkaisee asiantuntijoita kuultuaan, hyväksytäänkö kirjoitus painettavaksi.

Kirjoitusten laadinnassa noudatetaan Silva Fennican numerossa Vol. 4, 1970, N:o 3 painettuja kansainvälisiä ohjeita. Suureissa, yksiköissä sekä symbolien ja kaavojen merkinnöissä noudatetaan ohjeita, jotka ovat suomalaisissa standardeissa SFS 2300, 3100 ja 3101. Oikoluvussa noudatetaan standardia SFS 2324.

Kirjoituksen alkuun tulee julkaisun kielellä lyhyt yhdistelmä tutkimuksen tuloksista. Samoin laaditaan tutkimuksen yhteyteen lyhyt englanninkielinen tiivistelmä, jonka lisäksi kunkin Silvan numeron loppuun painetaan irti leikattavan kortin muotoon kustakin tutkimuksesta englanninkielinen esittely. Sisällysluetteloa ei käytetä. Mahdolliset kiitokset esitetään lyhyesti johdannon lopussa ja merkitään painettavaksi petiitillä.

Kuvien ja piirrosten viivapaksuudet ja tekstikoko on valittava siten, että ne sallivat painatuksen vaatiman pienennyksen. Kuvien ja piirrosten painatuskoosta on syytä neuvotella etukäteen toimittajan kanssa, sillä tarpeettomia kustannuksia aiheuttavaa painatuskokoa ei sallita. Valokuvien tulee olla teknisesti moitteettomia ja kiiltävälle valkealle paperille suurennettuja. Värikuvia ei yleensä hyväksytä painettavaksi. Kuvat ja taulukot numeroidaan kummatkin erikseen juoksevasti, ja niiden otsikoista laaditaan erillinen luettelo kirjapainoa varten.

Jos vieraskielisessä lyhennelmässä viitataan tiettyihin kuviin ja taulukoihin, on nämä varustettava vieraskielisin otsikoin ja selityksin. Muut kuvat ja taulukot voivat olla yksikielisiä.

Lähdeviittauksissa tekijännimet sijapäätteineen kirjoitetaan isoin kirjaimin mikäli tekijännimen vartalo on muuttunut. Muutoin taivutuspääte kirjoitetaan pienaakkosin. Esimerkkejä: Koskisen (1972) tutkimus . . ., Yli-Vakkurin (1972) tutkimus . . . Milloin tekijöitä on kolme tai useampia, mainitaan tekstissä vain ensimmäinen (esim. Heikurainen ym. 1961). Vieraskielisessä tekstissä ym. korvataan merkinnällä et al. Jos julkaisulla on kaksi tekijää viitteessä, pannaan tekijöiden nimien väliin ja-sana painatuskielellä. Esimerkki: Keltikangas ja Seppälä (1973, s. 222) osoittivat . . .

Viitekirjallisuus luetteloidaan tekijännimien (kirjoitetaan isoin kirjaimin) mukaisessa aakkosjärjestyksessä. Jos tekijöitä on useampia, nimet erotetaan pilkulla, paitsi kaksi viimeistä, jotka erotetaan &-merkillä. Tekijän etunimistä suositellaan käytettäväksi vain alkukirjaimia. Tutkimusten nimet kirjoitetaan lyhentämättä. Julkaisusarjoista käytetään niitä lyhenteitä, jotka on painettu Silva Fennican numerossa Vol. 5, 1971, N:o 2. Täydellisempi luettelo on nähtävissä Seuran toimistossa. Kirjoituksen löytämisen helpottamiseksi mainitaan aikakauslehdistä myös sivunumerot. Suomenkielisistä tutkimuksista otetaan mukaan vieraskielisen lyhennelmän nimi. Volyymi merkitään julkaisusarjan nimen jälkeen. Jos kyseessä on aikakauslehti tai vastaava, numero merkitään volyymin jälkeen suluissa. Sivunumerot erotetaan kaksoispisteellä volyymistä tai suluissa olevasta numerosta. Jos samalla kertaa ilmestynyt volyymi sisältää useita tutkimuksia, merkinnässä sovelletaan ko. julkaisussa noudatettua tapaa. Esimerkkejä:

Ilvessalo, Y. 1952. Metsikön kasvun ja poistuman välisestä suhteesta. Summary: On the relation between growth and removal in forest stands. — Commun. Inst. For. Fenn. 40.1.

Wilcox, W. W., Pong, W. Y. & Parmeter, J. R. 1973. Effects of mistletoe and other defects on lumber quality in white fir. Wood & Fiber 4 (4): 272—277.

Englanninkielisen lyhennelmän ja mahdollisten kuva- ja taulukkotekstien käännättämisestä ja pätevän kieliasiantuntijan tekemästä tarkastamisesta huolehtii kirjoittaja. Seura voi maksaa kustannukset valtiovarainministeriön antamien ohjeiden mukaan. Jos kääntäjän lasku on ohjeiden edellyttämää tasoa korkeampi, kirjoittaja vastaa ylittävästä osuudesta.
Lähempiä tietoja antaa Seuran julkaisujen toimittaja.

KANNATTAJAJÄSENET — UNDERSTÖDANDE MEDLEMMAR

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Hämeenlinna 1976, Arvi A. Karisto Osakeyhtiön kirjapaino