Noise Pollution in Forest Environment Due to Forest Operations

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Abstract – Nacrtak

Noise is a disturbing and unpleasant sound and refers to subjective definition of sound. A sound can have a series of different physical features. However, it becomes noise when it has negative physiological or psychological impact on a human being, e.g. causes health impairments and behavioral disorders. In the animal kingdom the high levels of noise may interrupt natural cycles, such as animal eating habits, coupling, and migration paths, or even cause the extinction of animal species living in noise polluted environment. Undoubtedly, modern forest operations cause noise in the forest. The goal of this research is to study the level of noise pollution as well as stand and terrain conditions influencing noise spreading in forest environment. It was established that the total chain saw noise power equals the wind noise at the distance of 140 m, whereas the sound levels up with that of forest silence at 252 m. The chain saw noise is similar to background noise at distances of 60–80 m and frequencies below 80 Hz and above 12.5 kHz. Consequently, this means lesser impact on natural environment in these frequency bands. The hypothesis was not confirmed, i.e. that vertically screened forest attenuates noise spreading more successfully than vertically non-screened forest: the difference emerges due to sound reflections in vertically screened forest, causing less sound absorption. However, the differences were confirmed at the distance of 80 m regarding noise attenuation in different seasons: winter – summer (difference of 11.92 dB), spring – summer (difference of 6.89 dB), and insignificant between winter and spring.

Key words: *noise attenuation, noise frequency, forest operations, noise pollution, forest*

1. Introduction – *Uvod*

Be it a tone, sound, rustle, or bang, definitions of noise, implying that a feeling of noise is related to human hearing impression and mood, are quite similar and consistent. Noise is regarded as an unpleasant sound and relates to subjective definition of sound. A sound can have a series of different physical features. However, it is regarded a noise only when it has negative physiological or psychological impact on a human being. Biological definition of a noise is: every sound that disturbs a human being, causes agitation, interrupts work, and harms health and well-being.

Protection against noise in urban areas of modern societies is becoming more and more important, since the number of urban as well as rural population that feels endangered by noise is increasing. It was established that almost 25% of European population is exposed to noise above 65 dB(A) caused by traffic (Berlund and Lindvall 1995).

The excessive noise can cause health injuries and behavioral disturbances. The unpleasant and unwanted noise can cause a feeling of annoyance, aggressiveness, hypertension, stress, gradual hearing loss, and other injuries depending on exposure and noise level (Berlund and Lindvall 1995).

⇒ Hearing impairment – it has been proved that exposure to noise causes injuries of inner ear that can lead to hearing loss. Studies in the USA showed that the majority of people have impaired hearing in old age due to the exposure to loud sound, and not as a sole consequence of old age.

⇒ Cardiovascular impairment – exposure to sound above 70 dB at ordinary work post for eight hours a day causes the increase of blood pressure, leading to artery injuries and stress.

High noise levels can interrupt natural cycles of animals, such as eating habits, coupling, and migration paths. Exposure to noise can cause the extinction of animal species in noise polluted environment.

Kaseloo (2006) sums up the findings that grassland birds are sensitive to traffic noise, which is reflected in decreasing population in noise polluted environment: 7 out of 12 grassland bird species moved their nests 20 to 1700 m from the road with traffic load of 5000 vehicles a day, whereas in areas with 50 000 vehicles a day, birds withdrew their nests 65 to 3535 m away from the road. 26 of 43 studied forest birds (60%) reacted to noise by decreasing their population density at the distance of 50 to 1500 m (traffic load of 10 000 vehicles a day) and 70 to 2800 m (traffic load of 60 000 vehicles a day).

English recommendations (Anon. 1995) deal with buffer zones of badger setts according to performance of forest operations. They suggest 20 m zone around the sett entrance and avoiding the use of heavy mechanization due to relatively shallow tunnels (60 cm). On the other hand, they advise at least 100 m distance of construction site from setts in building forest infrastructure (drilling, hard surface mining).

The study conducted by (Fang and Ling 2003) summarized experimental data in a single map, incorporating the relationships between relative attenuation and both visibility and width. This study provides data of use to environment designers. For example, designers can reduce noise by 6 dB(A) via suitable plantings. Also, belts of trees and shrubs could be planted based on 1 m visibility and 5 m width, or 10 m visibility and 18 m width.

The chain saw noise is one of the most important noise sources, depending on the type of motor oil used for chain lubrication (Wojtkowiak et al. 2007). Measurement results showed that noise levels observed were high and varied with oils used, ranging from 99.6 dB(A) for a vegetable oil to 105.2 dB(A) for a mineral oil.

A chain saw is regarded problematic even when compared to helicopter noise (Delaney et al. 1999) based on the example of reaction of owls. Spotted owls did not flush when the noise level of helicopters was less than 92 dB(A) and the level of chain saws was less than 46 dB(A). Chain saws were more disturbing to spotted owls than helicopter flights at comparable distances. Results indicate that a 105 m buffer zone for helicopter overflights would minimize spotted owl flush response and any potential effects on nesting activity.

On the other hand, Tempel and Gutiérrez (2003) tested the physiological response of 9 non-breeding wild male owls to the sound of a chainsaw operating 100 m from their roost site. The chain saw exposure did not result in a detectable increase of physiological response, which suggests that spotted owls can tolerate low-intensity human sound in their environment without eliciting a physiological stress response.

Pal (2000) studied the effect of green belt on coalmine noise attenuation. Eight plantation sites in Jharia (JCF) and Raniganj (RCF) coal fields in India were investigated. The maximum total noise attenuation for ¸*eq* at 50 m depth of the green belt was found to be within 18.8 to 21.1 dB(A) in JCF and 18.7 to 21.0 dB(A) in RCF. Excess noise attenuation (¸*eq*) exclusively due to green belts in JCF and RCF was 3.3 to 6.0 and 3.6 to 5.7 dB(A), respectively. Excess attenuation for higher frequencies (> 250 Hz) was more (> 4 dB(A)) than that for lower frequencies (≤ 125 Hz).

2. Objectives – *Ciljevi*

On the basis of previous studies and research problems observed in-situ, we formed two primary objectives of the study, i.e. research questions:

⇒ What is the level of noise pollution in forest environment due to forest operations,

⇒ What is the influence of natural and stand factors on noise spreading in the environment.

When constructing scientific hypothesis, we assumed that vertically screened stands and winter time, due to sound absorption of snow cover, have greater influence on noise attenuation.

3. Methods – *Metode*

The research was conducted in natural fir-beech (*Omphalodo-Fagetum*) forests of southern Slovenia with prevailing features of high karst and AMSL ranging from 1030 to 1220 m. The wider area of research belongs to the protected area (SPA) of Natura 2000 as special areas of conservation (SAC). In this research dealing with noise spreading due to forest operations, especially due to cutting, we used an approximately 1 year old professional chain saw STIHL MS 460 as the noise source. The chain saw, which was regularly maintained, represents a common type of working means for cutting in the above described conditions. To acquire data about maximum noise during work operations, we conducted preliminary measurements of noise for all cutting operation stages. On the basis of 2 hour long measurements and seven trees cut down, we established that the chain saw makes the loudest noise during notch cutting and cross-cutting operations. Due to easier work execution, we conducted the experiment by cross-cutting beech trunks of approximately 30 cm in diameter. The selection of working op-

Table 1 Experiment design (Number of measurements (repetitions) by distance from the noise source, season, relief and noise screening)
Tablica 1. *Postavke pokusa (broj mjerenja /ponavljanja/ u odnosu na izvor buke, godišnje doba, odmor i zaklon od buke)*

Season *Godišnje doba*	Distance from the noise source, m *Udaljenost od izvora buke, m*	Stands without regeneration *Sastojine bez pomlatka*			Stands with regeneration *Sastojine s pomlatkom*		
		Uphill *Uzbrdo*	Downhill *Nizbrdo*	Flat *Ravnica*	Uphill *Uzbrdo*	Downhill *Nizbrdo*	Flat *Ravnica*
Summer *Ljeto*	5	3	3	6	3	3	4
	10	3	3	6	3	3	4
	20	3	3	6	3	3	4
	40	3	3	6	3	3	4
	60	–	2	–	1	1	–
	75	3	–	–	1	1	–
	80	–	1	6	1	1	4
Spring *Proljeće*	5	–	–	6	–	–	–
	10	–	–	6	–	–	–
	20	–	–	6	–	–	–
	40	–	–	6	–	–	–
	80	–	–	6	–	–	–
Winter *Zima*	5	–	–	6	–	–	–
	10	–	–	6	–	–	–
	20	–	–	6	–	–	–
	40	–	–	6	–	–	–
	80	–	–	6	–	–	–

eration was thus partly in accordance with standard measurement of noise level caused by chain saws at woodcutter's ear (ISO 7182:1996). Cross-cutting of trunks was always conducted on the ground and perpendicularly to direction of noise recording. The side of cross-cutting was selected randomly (left or right), for it is typical of forest production.

We included three factors according to the purpose of the study: screening of noise source, relief and season. They are regarded to have influence on noise spreading in the forest. The influence of noise source screening was studied at two levels: screened and unscreened. The screening corresponded to the presence of regeneration in a stand, which usually screened the noise source already at the distance of 5 m. The influence of relief was analyzed at three levels: downhill, flat and uphill. It has to be mentioned that the noise source was positioned on the slope and skid road with slope cut. The influence of different ground surface and leaf density on trees was established by partial repetition of measurements in different seasons (Table 1): summer, winter and spring. In the described area we tried to select 12 series of measurement points with 10 measure points per series according to the number of factors and their levels. The measurement points were situated at the distances of 5, 10, 20, 40, and 80 meters left and right from the noise source. It is possible that the last two measurement points were closer than intended (60 or 75 meters) due to terrain roughness (great slope cut of forest road, slope crest). Due to natural conditions, we managed to conduct 11 out of 12 planned series of measurements; without 1 series in combination of factors: unscreened-level.

Noise measurements were conducted successively from 5 to 80 m distance from the noise source. At each measurement point, the measurements lasted for 10 seconds (10 × 1 s). Only the loudest 5 second intervals were included in noise analyses, since for 10 second duration of noise we would have to cross-cut the trunk again. To acquire data about background noise, we also recorded »natural« forest noise in times of silence together with other noise sources (overflights) in different recording days and intervals.

While it is generally recognized that the various components of attenuation may be inter-related and not simply additive, investigations have not proceeded as yet to the extent that it is possible to quantitatively express all of the possible inter-relations in one encompassing algorithm, but rather approximated as a linear sum of effects (Hansen 2005).

The measurements were conducted with Sound Level Meter Brüel and Kjaer 2250, by which total equivalent noise level in second intervals was recorded as well as equivalent noise level by 1/3 octaves of frequency spectrum; both with F (Fast) time and Z (Zero) frequency balancing (Equation 1). Measurements without frequency balancing were conducted due to the fact that all existing frequency weights – filters (A – D) adjust sound pressure sensation to human hearing, which definitively differs from other species. The noise measurement ranged in frequency spectrum from 12.5 to 20 kHz. The microphone (Brüel and Kjaer ZC 0032) was set approximately 150 cm above the ground. While conducting measurements, the windscreen-foam ball microphone cover was used (Brüel and Kjaer UA 0237).

$$LZ_{eq}(T) = 20\,\lg\left[\sqrt{(1/\Delta t)\int_{T}^{T+\Delta t} p_z^2(\xi)d\xi / p_0}\right], \text{dB} \quad (1)$$

Where:

LZ_{eq} equivalent continuous sound level

T start time

Δt averaging time interval

Z zero frequency weighting

ξ dummy variable of time integration over the averaging time interval

$p_Z(\xi)$ Z frequency weighted instantaneous sound pressure

p_0 reference sound pressure (20 μPa).

Simultaneously with noise measurements, the measurements were also conducted of meteorological factors (Metrel MI 6401 Poly euro set), air temperature, relative air humidity, and wind speed in 5 minute intervals that could influence noise measurements. The estimated air pressure at AMSL of 1125 m was 885 hPa.

To process the acquired data, we calculated total equivalent value of sound and equivalent value by 1/3 frequency bands from the loudest 5-second intervals. Since the repetition of measurements (Table 1) was not done for all combinations of factors, we conducted the analysis by individual factors to decrease variability due to other factors. Thus, we eliminated the influence of season from the analysis of influence of terrain and screening, whereas the influence of terrain and screening was eliminated from the season analyses. In other words, we only applied the data recorded in summer to conduct analyses of terrain and screening influences, whereas the analyses of season influence used the data of flat relief and without screening.

To correctly conduct the analysis of covariance, it is necessary to consider preliminary conditions of application among which the most important are independence, normal distribution and homogeneity of variance. The independence of measurements was provided, since every measurement was conducted as a real repetition. The test of normality (Kolmogorov – Smirnov test with Lilliefors significance correction) showed that abnormal data distribution was only present at individual distances of covariance (most frequently at the distance of 40 m), whereas the greatest violations occurred in preliminary condition of variance homogeneity (Levene's test). The reason for this can be in the fact that the influences of different factors in inhomogenous environment accumulate themselves by the distance from the noise source, consequently causing the increase of data variability. Since we believed the increasing of variability to be natural, we used untransformed data for our analyses.

The selected sound source, i.e. chain saw, does not allow the analyses of differences between combined influences of individual factors, since we assume that the variability of sound source can be greater than the established influences of factors. On the other hand, we can analyze how the influential factors affect the noise spreading. Mathematically,

Table 2 Averaged meteorological data by seasons

Tablica 2. *Prosječni meteorološki podaci po godišnjim dobima*

Season *Godišnje doba*	Days *Dani*	Air temperature, °C *Temperatura zraka, °C*			Relative air humidity, % *Relativna vlažnost zraka, %*			Wind speed, m/s *Brzina vjetra, m/s*		
		Min. *Min.*	Avg. *Srednja*	Max. *Maks.*	Min. *Min.*	Avg. *Srednja*	Max. *Maks.*	Min. *Min.*	Avg. *Srednja*	Max. *Maks.*
Summer – *Ljeto*	2	14.5	18.6	22.6	46.3	59.5	71.0	0.0	0.5	3.3
Winter – *Zima*	1	–2.7	–2.1	–1.6	77.5	80.9	85.4	0.0	0.6	3.0
Spring – *Proljeće*	1	10.8	12.1	14.9	44.9	53.6	62.4	0.0	0.7	2.2

we can say that we are interested in differences of strait line inclinations and not in their deviation. In practice, we conducted the analysis of covariance (ANCOVA), where, considering the influence of factor, the significant interaction between factor and covariance (distance from the sound source) showed us differences between inclinations of straight lines. When conducting spectrum analysis, we relativized noise attenuation according to the distance from the source. Thus, we compared noise by all frequency bands at the distances above 10 m with the noise measured at 5 meters or we compared noise between two neighboring points. In this way we eliminated differences between potentially different sound power of the source and also frequency structure of the sound. The spectrum analysis was conducted through the means of frequency bands. The statistical analysis of frequency spectrum was conducted by analysis of variance (ANOVA) or by conducting Tamhane T2 *post-hoc* test (*MD = mean difference*). The statistical software SPSS 16.0 was used for all statistical processing.

4. Results and discussions – *Rezultati s raspravom*

The comparison between sound spreading in the forest and geometrical sound spreading (As) shows us that sound power in the forest does not attenuate only due to the distance from the noise source but also on account of other factors (Fig. 1).

By inserting the distance from the source in linear regression model (Equation 2), we found out that noise in the forest averagely attenuates by 8.4 dB (95% CI 8.07 – 8.79), if the distance from the noise source is doubled. This means that atmospheric absorption and other factors contribute additional 2.4 dB of noise attenuation, if noise generally attenuates by 6 dB with doubling the distance from the noise source.

$$LZ_{eq}(\text{dB}) = 109.765 - 28.016 \times \log(\text{dist})$$

$$N = 170, \quad R^2 = 0.927, \quad P < 0.001 \qquad (2)$$

Where:

LZ_{eq} equivalent zero weighted sound level

dist distance from the noise source in meters.

The noise of chain saw was compared with the noise of a plane overflying the areas of measurement. By applying the model (Equation 1) and average values of the plane noise (68.9 dB), we found out that the total plane noise power was equal to the chain saw noise at the distance of 28.6 meters. In the same way, we also calculated two distances of balance with noise caused by wind and with »noise« of forest silence. Thus, the total chain saw noise power at the distance of 140 m equals the wind noise, and at the distance of 252 m it matches forest silence noise. The results are comparable to recommendations about 105 m buffer zone (Delaney et al. 1999), where the chain saw noise is obviously more disturbing than that of a helicopter. However, the physical presence of human being in nature as a disturbing element was not analyzed.

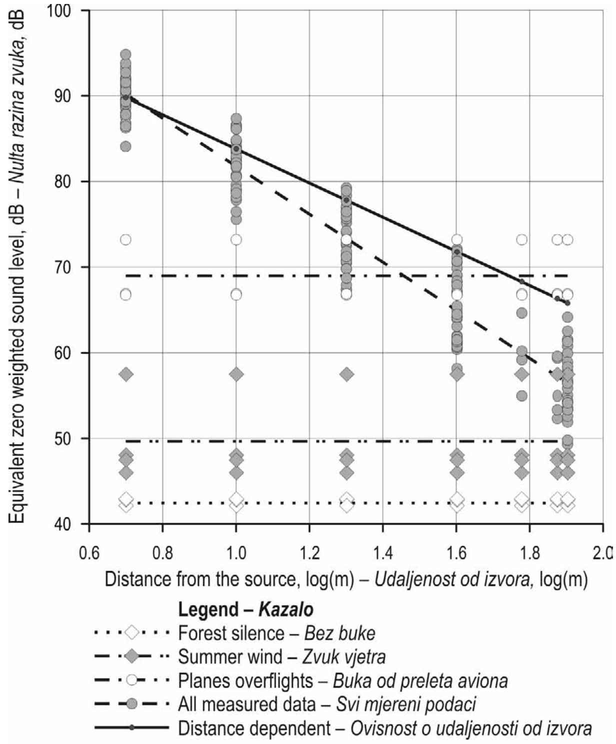

Fig. 1 Attenuation of sound by the distance from the noise source according to geometrical decreasing and some other noise sources in the forest

Slika 1. *Smanjenje razine buke s promjenom udaljenosti od izvora buke prema geometrijskomu smanjenju i nekim dodatnim izvorima buke u šumi*

In fact the equivalence with forest silence noise is never achieved because the silence represents the background noise and as such the limit of influence of the chain saw noise.

On the basis of our findings, we should not assert that the noise source at the calculated distances »disappears« in the background noise or that it becomes undetectable since the applied sources have very different frequency spectra (Fig. 2). Since low frequencies prevail in background and wind noise, whereas chain saw noise is of high frequency, it would be still possible to detect chain saw noise in higher frequency bands despite the equalization of total noise power.

The frequency spectrum of noise changes with increasing distance from the noise source. The most

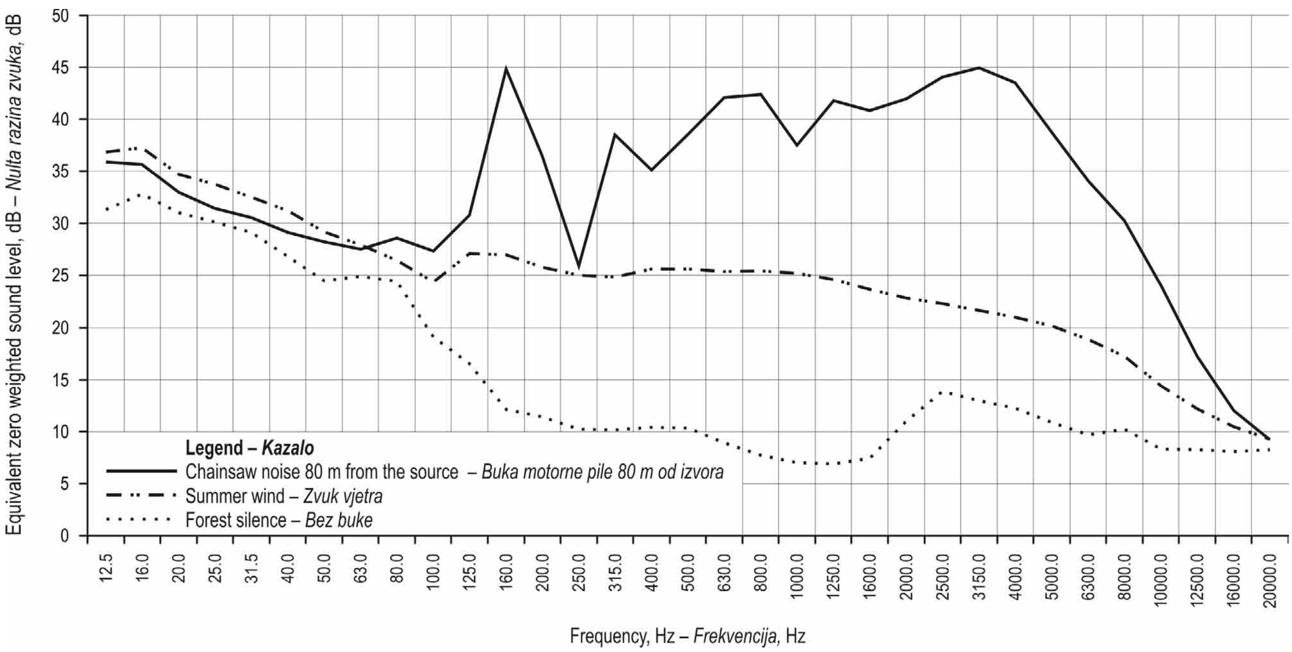

Fig. 2 Frequency spectrum at 80 meters from the noise source and frequency spectrum of natural noise sources
Slika 2. *Frekvencijski spektar na 80 metara od izvora buke i frekvencijski spektar prirodnih izvora buke*

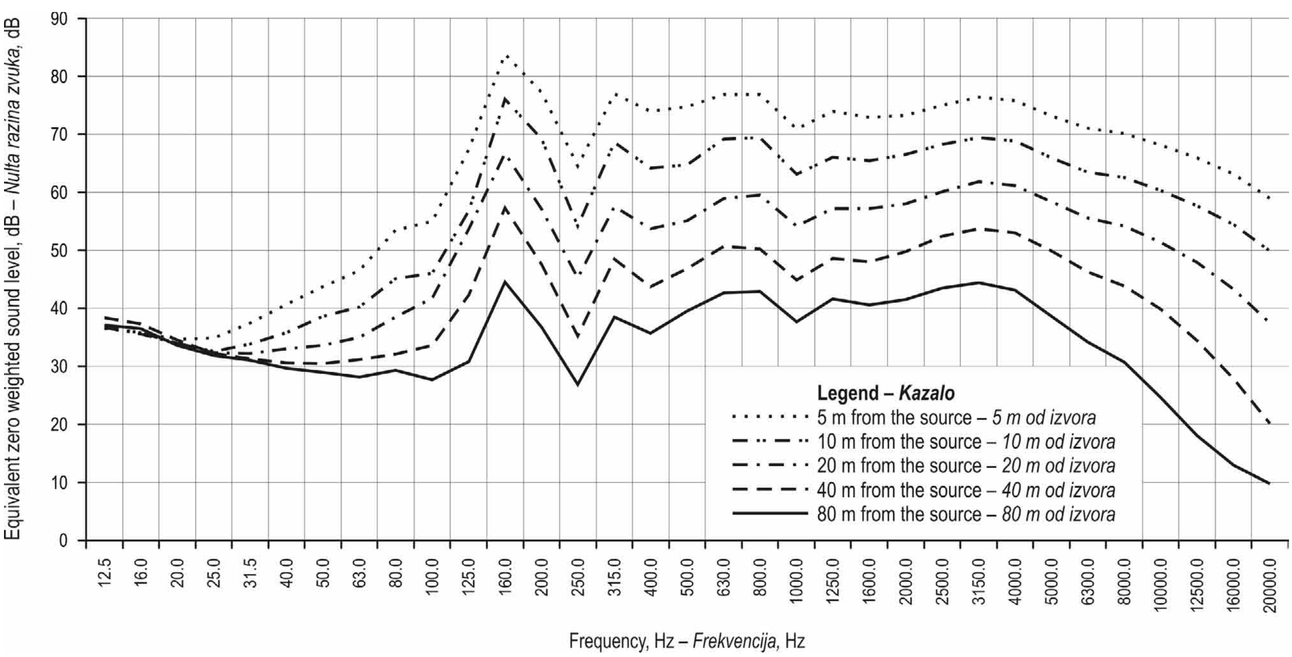

Fig. 3 Frequency spectrum of chain saw noise depending on the distance from the noise source
Slika 3. *Frekvencijski spektar buke motorne pile ovisno o udaljenosti od izvora buke*

prominent differences are recorded for frequencies below 100 Hz where influence of background increases according to the distance from the source, as shown in Fig. 3.

The already mentioned general noise attenuation by the distance (5 m to 80 m) from the source (8.4 dB) is not constant throughout the whole frequency spectrum as it could be concluded from Fig. 3. If we compare noise attenuation at the double distance from the noise source by frequency bands (Fig. 4), we can see that in general the noise up to 80 Hz attenuates less as predicted by geometrical sound spreading; at 200 Hz

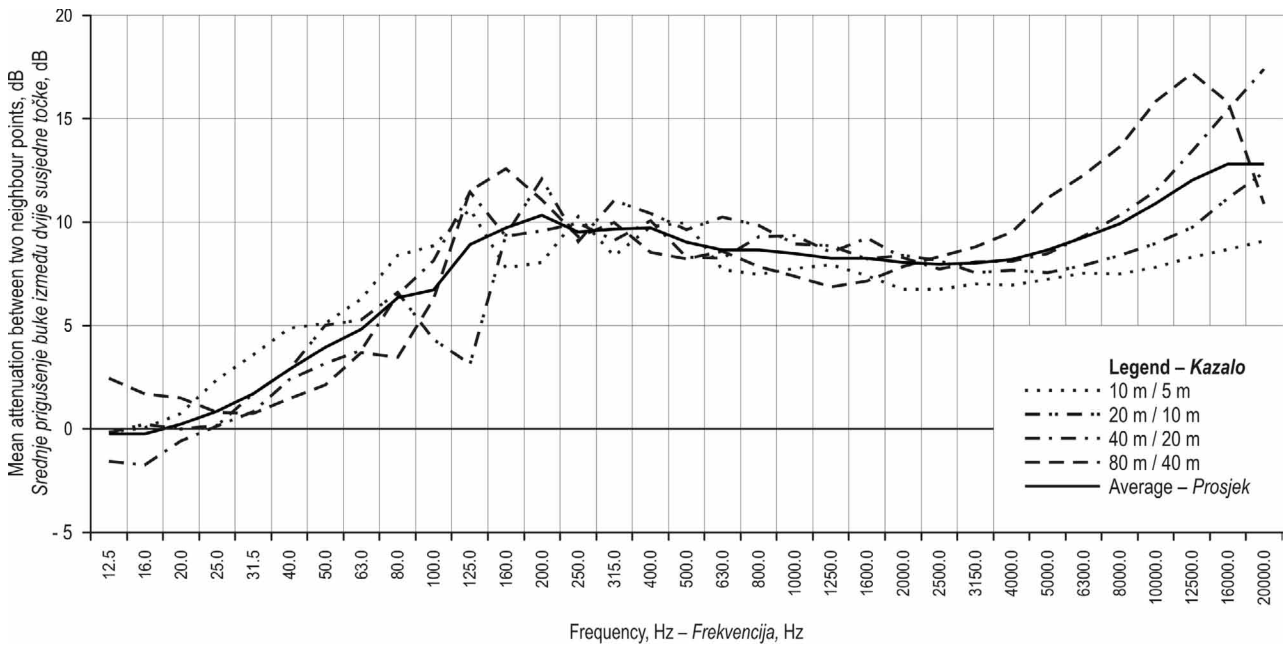

Fig. 4 Noise attenuation in relation to distance between two neighboring points of measurement and noise frequency

Slika 4. *Prigušenje buke u odnosu na razmak između dviju susjednih točaka mjerenja i na frekvenciju buke*

it reaches the local maximum (10.3 dB), up to 2.5 Hz attenuates (8.0 dB), and then intensifies up to the maximum at 16 kHz (12.8 dB). The prominence of both noise extremes increases according to the distance between two points, thus reaching the highest level at the double distance; from 40 to 80 meters. This is expected because the resistance of environment (ground, atmospheric absorption, studied factors) accumulates with the increasing distance between two points. Due to great variability of data by frequencies, in general the noise at 16 kHz is significantly louder than noise with the frequency ranging between 250 Hz and 8 kHz, and below 200 Hz. Both maximums are insignificantly different.

Pal et al.(2000) found out that the noise attenuation due to green belt can be assessed from 3.3 to 6.0 dB(A), depending on actual conditions. This implies that it is fairly difficult to obtain general findings of noise pollution because all results come from case study. Also Crocker (1998) concludes that for sound attenuation through foliage and trees, the main effect at low frequencies is to enhance ground attenuation, the roots making the ground more porous. On the other hand, at high frequencies, where dimensions of leaves become comparable with the wavelength, there is also a significant attenuation by scattering.

Noise attenuation at frequencies above 2.5 kHz and comparisons up to 40 meters is linearly dependent on frequency and it also varies from the location of comparisons (Fig. 5). Therefore, the noise intensification with frequency is the smallest when doubling the distance from 5 to 10 meters from the noise source, and the highest when doubling it from 20 to 40 meters. In the same order, the significant relation between noise and frequency also increases ($R^2_{10/5} = 0.05$, $R^2_{20/10} = 0.19$, $R^2_{40/20} = 0.50$; all $p < 0.001$). The order corresponds to the increased influence of atmospheric absorption (Aa) on noise attenuation, since it increases linearly with the distance from the noise source. Dependence between frequency and noise in compared measurements above 40 meters is best described by parabolas ($R^2_{60/40} = 0.338$, $p < 0.001$; $R^2_{75/40} = 0.084$, $p = 0.128$; $R^2_{80/40} = 0.319$, $p < 0.001$) with apex around 12 kHz, meaning that noise at frequencies above 12 kHz attenuates. The reason for different forms of relation between frequency and noise can be ascribed to the influence of background. If we sum up the results from Fig. 2 – 4, we find out that the chain saw noise, measured at the distances from 60 to 80 meters and frequencies below 80 Hz and above 12.5 kHz, approaches the level of background noise, and that background noise prevails over other influential factors. Consequently, a decreased influence on natural environment is shown in these frequency bands. Due to the influence of background, the calculated general noise attenuation in forest (8.4 dB) is slightly underrated.

The influence of stand with regeneration on sound spreading was established on the sample of

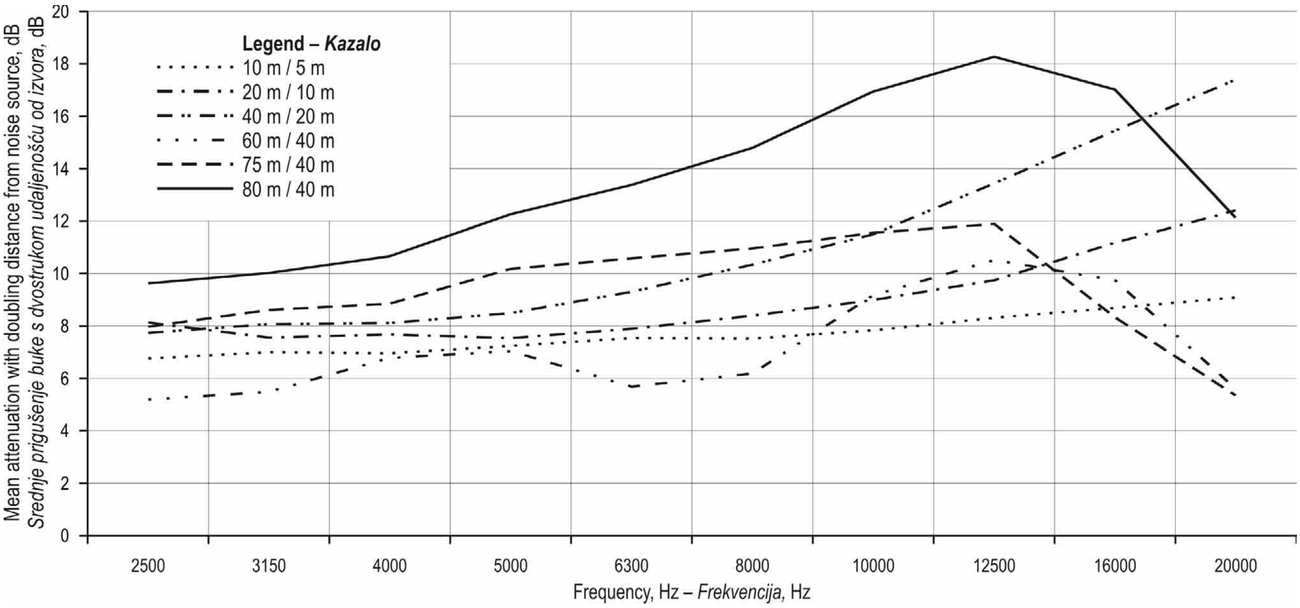

Fig. 5 Intensification of noise in relation to distance between two neighboring points and frequencies above 2500 Hz
Slika 5. *Povećanje buke u odnosu na razmak između dviju susjednih točaka mjerenja i na frekvenciju iznad 2500* Hz

summer measurements (Table 1). The analysis of covariance showed that when all measurements are included into analysis, the noise spreading in the forest with regeneration was not significantly different from noise spreading in the forest without regeneration (F (1,106) = 2.192; p = 0.142). If we further limit the sample only to flat relief, the noise spreading in the forest with regeneration becomes significantly different (F (1,46) = 7.751, p = 0.008) compared to the forest without regeneration (Fig. 6). In this case, the noise spreading attenuates by 9.1 dB (CI 95% 9.93 – 8.36) in the forest with regeneration, and by 7.7 dB (CI 95% 8.38 – 7.10) in the forest without regeneration (Equation 3).

$$LZ_{eq}(\text{dB}) = 111.397 - 1.725^{ns} \times noreg - 25.705 \times noreg \times \log(dist) - 30.374 \times \text{reg} \times \log(\text{dist})$$

$$N = 50, \quad R^2 = 0.962, \quad P < 0.001 \qquad (3)$$

Where:

LZ_{eq} equivalent zero weighted sound level
dist distance from the noise source in meters
reg forest with regeneration
noreg forest with no regeneration
ns not significant (p = 0.456).

On the other hand, some experiences show that vegetation is not generally considered as an effective (traffic) noise barrier, although it does have an effect in attenuating noise at frequencies above 2 kHz (Hansen 2005). The psychological effect of vegetation as a barrier between a noise source and an observer should not be overlooked – in many cases if the noise source is not visible, it is less noticeable and thus less annoying, even if the level is not significantly changed.

The analysis of differences in the influence of revegetation was conducted within the frequency

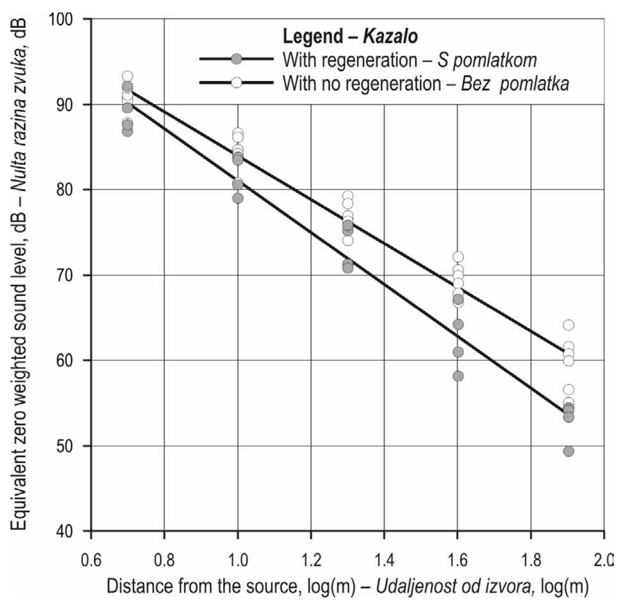

Fig. 6 Noise attenuation according to the distance from the noise source and presence of regeneration in a stand
Slika 6. *Prigušenje buke u odnosu na udaljenost od izvora i na prisutnost pomlatka u sastojini*

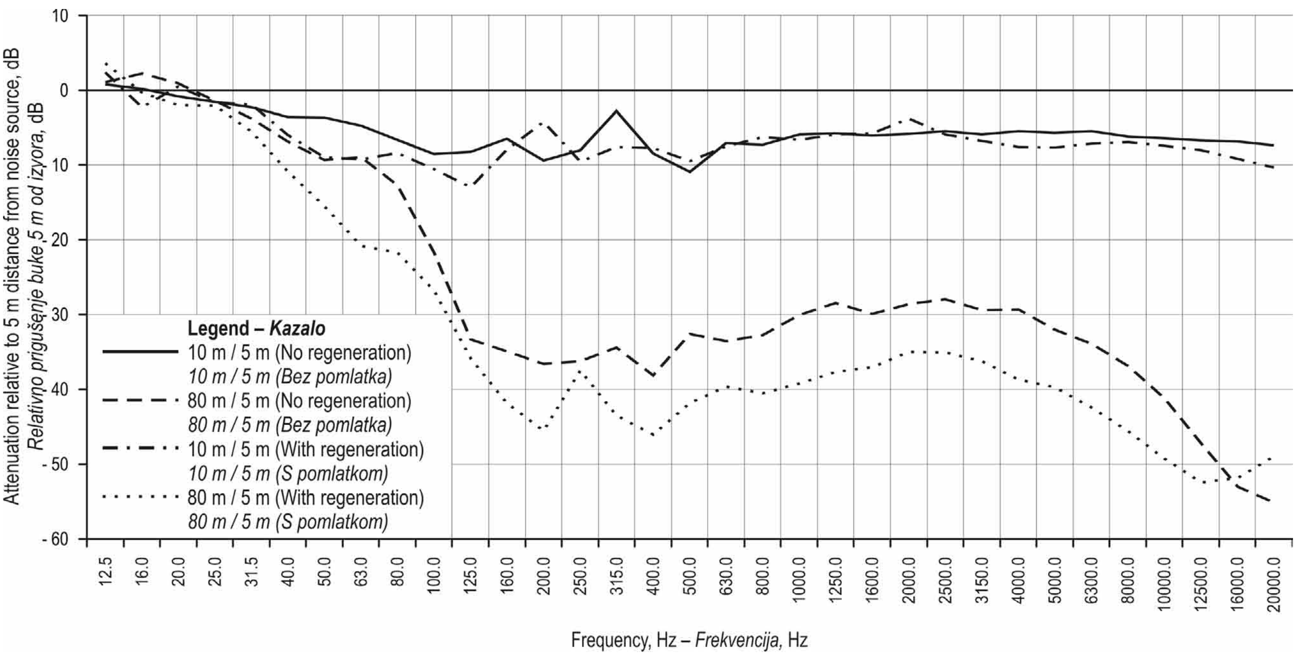

Fig. 7 Noise attenuation by frequency bands according to the distance from noise sources and presence of regeneration in the stand
Slika 7. *Prigušenje buke po frekvencijskim pojasima ovisno o udaljenosti od izvora buke i o prisutnosti pomlatka na mjernom mjestu*

range from 630 Hz to 10 kHz, which corresponds to the greatest assessed tree diameters at chest height and average cross section of beech leaf according to wavelength (66–3 cm). The comparison of relative noise attenuation by frequency bands shows (Fig. 7) that differences caused by revegetation increase by the distance from the noise source. Thus, the analysis of variance showed insignificant differences in relative noise attenuation in the forest with or without regeneration at 10 meters from the noise source ($F(1,138) = 0.788$, $p = 0.376$) and significant differences at the distance of 80 meters ($F(1,138) = 77.750$, $p < 0.001$). Assuming that the other conditions are the same, we can ascribe the average difference of 7.96 dB to the influence of regeneration. Therefore, we could not confirm the set up hypothesis that the vertically screened forest attenuates noise spreading better than the vertically unscreened one. We assume that the insignificant difference occurred due to sound reflection in the vertically screened forest and caused lesser sound absorption.

On the sample of summer measurements we also conducted the analysis of relief influence on noise attenuation in the forest. Due to the sunny position of the slope and occasional light wind blowing upward the slope we expected noise attenuation downward the slope to be the highest, and the lowest in the opposite direction. However, the analysis of covariance showed that there are no differences in noise attenuation by distance according to relief ($F(2,104) = 1.417$, $p = 0.247$). Otherwise insignificant greater noise attenuation upward the slope could be ascribed to the influence of skid road slope cut acting as reflective object (Fig. 8).

The analysis of season influence on sound spreading complexly encompasses the changes of meteoro-

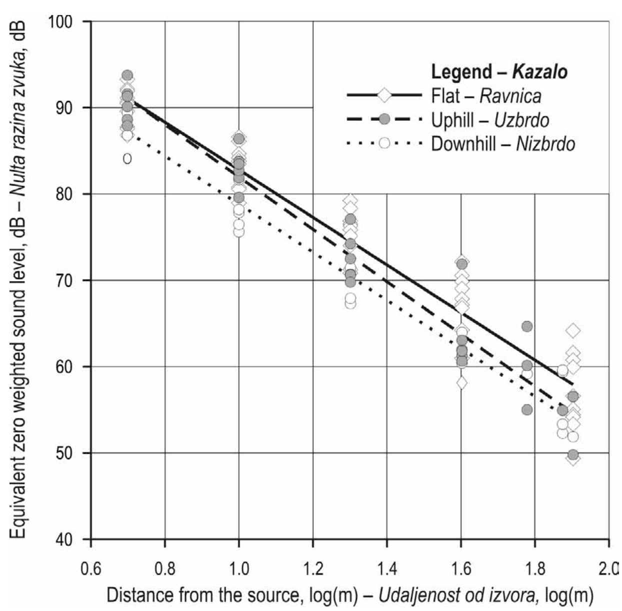

Fig. 8 Noise attenuation according to the distance from the noise source and relief
Slika 8. *Prigušenje buke ovisno o udaljenosti od izvora i o reljefu*

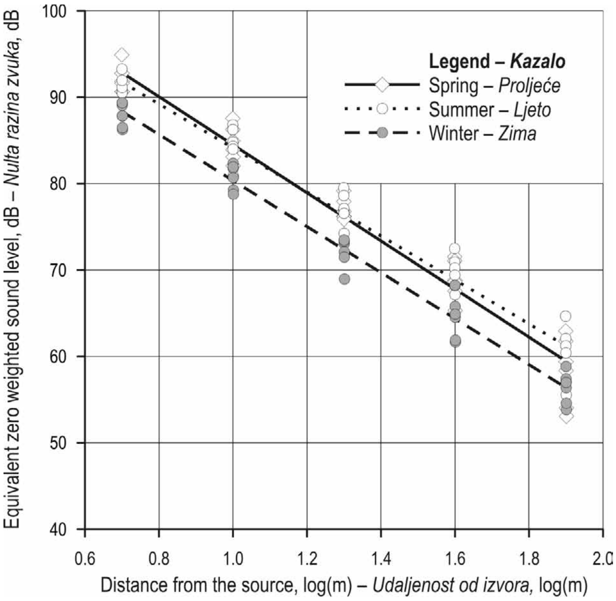

Fig. 9 Noise attenuation according to the distance from the noise source and season

Slika 9. *Prigušenje buke u odnosu na udaljenost od izvora buke i na godišnje doba*

logical (air temperature, air humidity) as well as stand conditions (leafiness, ground). By comparing summer and spring time, the influence of leafy roof of the stand should be evident, for it increases the reflective surface. The comparison between winter and spring should highlight the influence of the surface (snow cover, ground mainly covered with leaves), air temperature and air humidity, whereas the comparison between summer and winter should show the joint influence of all four factors (air temperature, air humidity, surface, leafiness of stand roof). In the analysis, the sample was limited to flat relief and forest without regeneration.

The results of noise attenuation according to the distance from the source show (Fig. 9) that attenuation is not significantly dependant on the season (F (2,84) =1.575, p = 0.213), which can be ascribed to opposing effect of the mentioned factors on noise spreading. For example, in summer the high air temperature attenuates, whereas leafiness of stand roof increases noise spreading; in winter the low air temperature increases, whereas the snow cover attenuates noise spreading.

The noise analysis by frequency spectrum was expected to show that the forest would have higher stifling level at higher frequencies due to lack of leafiness in winter and spring time, since the sound reflective surface is smaller, and that the influence of snow cover would be evident in winter at lower frequencies. The frequency spectrum of relative noise attenuation according to 5 meters from the noise source shows us, that the differences between seasons are best evident at the distance of 80 m and mainly at the frequencies lower than 500 Hz, i.e. in the areas with background and ground influence

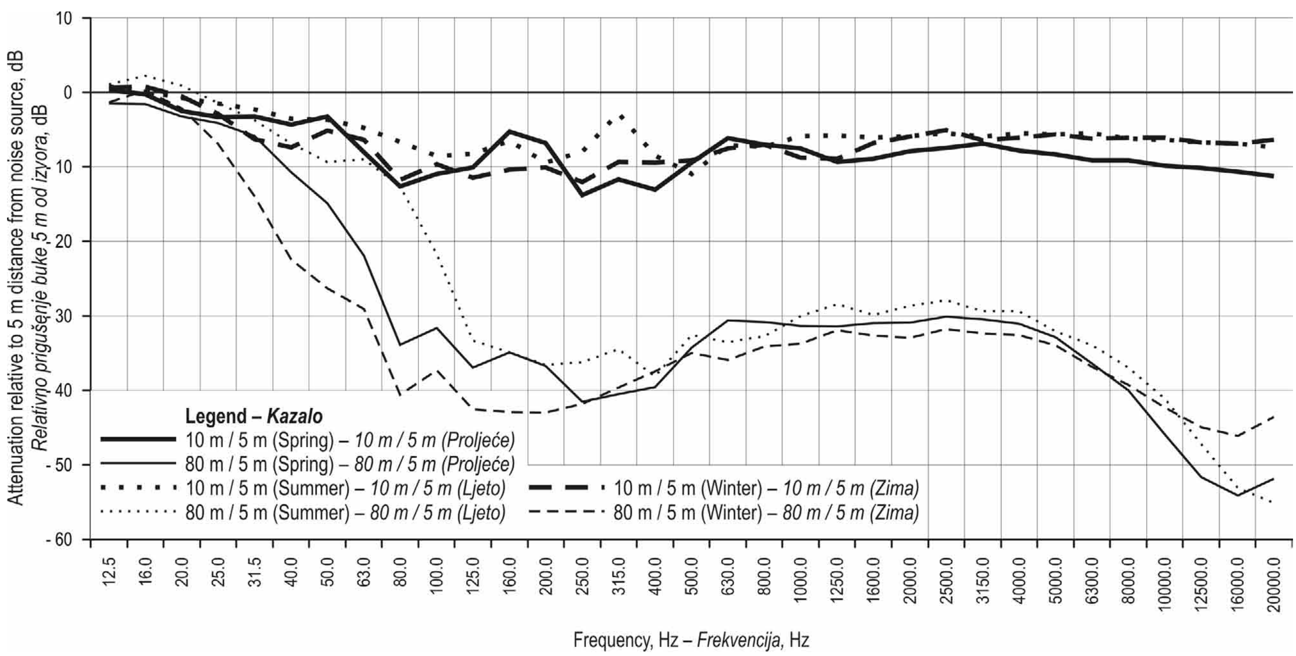

Fig. 10 Noise attenuation by frequency bands according to the distance from the noise source and season

Slika 10. *Prigušenje buke po frekvencijskim pojasima ovisno o udaljenosti od izvora buke i o godišnjem dobu*

(Fig. 10). The analysis of variance in the frequency area below 100 Hz shows us that the background noise and consequently its influence is the lowest in winter and spring, and the highest in summer. The differences in noise are at the distance of 80 meters significant between summer on the one hand and winter and spring on the other (T2, $MD_{Summer/Winter}$ = 11.92 dB, p < 0.001; $MD_{Summer/Spring}$ = 6.89 dB, p = 0.002), and insignificant between winter and spring (T2, $MD_{Winter/Spring}$ = 5.04 dB, p = 0.140).

To establish the influence of ground surface, we analyzed the frequency range between 200 and 500 and found out statistically insignificant influence of seasons on noise attenuation at 80 meters from the noise source (T2, all p > 0.05). Plausible reason for this can be attributed to too wide frequency range. The highest attenuations by seasons pertain to different frequency bands; in winter at 160 Hz, in spring at 250 Hz, and in summer at 400 Hz. If we limit the analysis to the frequency range between 160 Hz and 400 Hz, we confirm different noise attenuation for summer and winter time (T2, $MD_{Summer/Winter}$ = 4.87 dB, p = 0.008), meaning that the snow cover and unleafy stand roof have higher influence on noise attenuation than the influence of forest ground surface and leafy stand roof. The same reason can be attributed to significant differences between summer and winter (T2, $MD_{Summer/Winter}$ = 2.79 dB, p = 0.005) in the frequency range from 630 Hz to 10 kHz.

In this way we confirmed the hypothesis that in winter time the noise spreading is less intensive than in other seasons due to influential factors.

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Sažetak

Zagađenje šumskoga okoliša bukom pri izvođenju šumskih radova

Svrha je istraživanja da se utvrdi razina zagađenosti okoliša bukom pri sječi i izradi stabala te terenski uvjeti koji utječu na širenje buke u okolišu. U istraživanju je kao izvor buke korištena redovito održavana profesionalna jednogodišnja motorna pila STIHL MS 460. Ispitivanje je provedeno pri trupljenju bukovih trupaca prosječnoga promjera 30 cm. Odabir radnih operacija bio je određen prema standardima za mjerenje razine buke motorne pile i njezina utjecaja na uho operatera (ISO 7182:1996).

U istraživanju su obrađena tri čimbenika koji imaju utjecaj na širenje buke u šumi: prigušivanje izvora buke, reljef i godišnje doba. Na prigušivanje izvora buke ključni utjecaj ima prisutnost pomlatka u sastojini koji uobičajeno zaklanja izvor buke već na udaljenosti od 5 m. Utjecaj je reljefa promatran s obzirom na širenje buke nizbrdo, uzbrdo i na ravnom terenu. Mjerne su točke postavljene na 5, 10, 20, 40 i 80 metara lijevo i desno od izvora buke. Na svakoj je točki mjerenje trajalo 10 sekundi. Samo je najglasniji interval od 5 sekundi uključen u daljnju analizu buke jer bi se za trajanje buke od 10 sekundi ponovno morao prerezati trupac. Kako bi se prikupili podaci ostalih izvora buke, također je snimana »prirodna« šumska buka zajedno s ostalim izvorima buke (prelet zrakoplova) u različitim danima i u različitim intervalima.

Mjerenja su provedena zvukomjerom Brüel&Kjaer 2250, pomoću kojega je snimana ukupna ekvivalentna razina buke u sekundnim intervalima i ekvivalentna razina buke s 1/3 oktave frekvencijskoga spektra, oboje s vremenskim i frekvencijskim uravnoteženjem (jednadžba 1). Mjerenje je bez frekvencijskoga uravnoteženja

provedeno zbog činjenice da su svi postojeći frekvencijski filteri (A – D) prilagođeni ljudskomu sluhu. Buka je mjerena u frekvencijskom spektru od 12,5 do 20 kHz. Mikrofon je (Brüel&Kjaer ZC 0032) postavljen otprilke 150 cm iznad zemlje. Za vrijeme mjerenja na mikrofon je postavljena zaštitna spužva (Brüel&Kjaer UA 0237).

Ustanovljeno je da se ukupna razina buke motorne pile izjednačava s bukom vjetra na udaljenosti od 140 m od motorne pile, a s prirodnom bukom u šumi na udaljenosti od 252 m. Buka je motorne pile slična pozadinskoj buci na 60 – 80 m i frekvenciji ispod 80 Hz, odnosno iznad 12,5 Hz. Iz navedenoga izlazi manji utjecaj buke na prirodni okoliš u tim frekvencijskim pojasima. Pretpostavka da šuma potpunoga sklopa smanjuje širenje buke puno usješnije nego šuma prekinutoga sklopa nije potvrđena. U šumi potpunoga sklopa odbija se zvuk te se zato manje apsorbira zvuk. Nadalje, razlika je uočena na udaljenosti od 80 m s obzirom na smanjenje razine buke u različitim godišnjim dobima: zima – ljeto (razlika 11,92 dB), proljeće – ljeto (razlika 6,89 dB), dok je neznačajna razlika između zime i proljeća.

Smanjenje buke s obzirom na udaljenost od izvora nije značajno pod utjecajem godišnjega doba, što se može pripisati suprotstavljenim učincima na čimbenike koji utječu na širenje buke. Tako, na primjer, ljeti visoka temperatura smanjuje, dok razdoblje bez lišća na krošnjama potpomaže širenje buke. Također, zimi niska temperatura povećava, dok snježni pokrov smanjuje širenje buke.

Očekivalo se da će analiza buke po frekvencijskim spektrima pokazati kako šuma ima veći prigušujući učinak pri višim frekvencijama zimi i u proljeće zbog manjka lisnoga pokrova, kada je površina za odbijanje zvuka manja, a da će snježni pokrov prigušiti buku pri nižim frekvencijama.

Frekvencijski spektar relativnoga smanjenja buke na 5 m od izvora pokazuje da je razlika između godišnjega doba najbolje uočljiva na udaljenostima od 80 m i frekvancijama nižim od 500 Hz (slika 10). Analiza varijance pri frekvencijama ispod 100 Hz pokazuje najmanji utjecaj pozadinske buke zimi i u proljeće, a najveći ljeti. Usporedba ljeta s jedne strane te zime i proljeća s druge strane pokazuje značajne razlike u razini buke ($T_2\,MD_{ljeto/zima} = 11{,}92$ dB, $p < 0{,}001$; $MD_{ljeto/proljeće} = 6{,}89$ dB, $p = 0{,}002$) i neznačajne između zime i proljeća (T_2, $MD_{zima/proljeće} = 5{,}04$ dB, $p = 0{,}140$).

Kako bi se utvrdio utjecaj površine tla, raščlanjene su frekvencije između 200 i 500 Hz. Utvrđen je statistički beznačajan utjecaj godišnjih doba na smanjenje razine buke na 80 metara od izvora (T_2, svi $p > 0{,}05$), vjerojatno zbog širokoga raspona frekvencija. Prigušenje se buke po godišnjim dobima razlikuje s obzirom na frekvenciju: zimi je najveće na 160 Hz, u proljeće na 250 Hz i ljeti na 400 Hz. Ako se ograniči analiza na frekvencijski raspon od 160 do 400 Hz, može se potvrditi različito prigušenje buke za ljeto i zimu (T_2, $MD_{ljeto/zima} = 4{,}87$ dB, $p = 0{,}008$), što znači da snježni pokrivač i krošnje bez lišća imaju veći utjecaj na smanjenje buke nego površina zemlje i olistale krošnje. Isti se razlog pripisuje značajnoj razlici između ljeta i zime (T_2, $MD_{ljeto/zima} = 2{,}79$ dB, $p = 0{,}005$) u frekvencijskom rasponu između 630 Hz i 10 kHz.

Ovo je istraživanje prvi korak u ispitivanju zagađenja prirodnoga okoliša bukom zbog obavljanja šumskih radova. Potrebno je nastaviti s daljnjim istraživanjima na ostalim izvorima buke (žičarama, traktorima, harvesterima, forvarderima i ostalom). Nadalje, ostaje otvoreno pitanje negativnoga djelovanja buke na divljač.

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