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ORIGINAL ARTICLE

Noise-reduction Function and its Affecting Factors of Plant Communities

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Abstract

In this study, we investigated the relationship between noise reduction and the community structure of nine groups of typical plant communities as well as the reduction in noise at different frequencies. The semantic differential method was adopted to explore the perception of noise reduction. The results indicated that there was a significantly positive correlation between noise reduction and coverage , a significantly negative correlation between noise reduction and bifurcate height, and a negative correlation between noise reduction and bare rate. However, there was no significant correlation between noise reduction and height, diameter at breast height, or crown width. The reduction of middle-frequency noise was better than that of low- and high-frequency noise. The indicators "quiet" and "calm" showed that plant communities could reduce the noise perceived by humans. However, overly dense woodland caused nervousness, fear, depression, and other negative effects. Relatively open environments and those with large forest gaps obtained the highest evaluation.

Key words : Plant community, Noise reduction, Community structure, Psychological noise reduction, Semantic differential method

1. Introduction

With the speed of urbanization, environmental pollution is more and more serious. Noise pollution, especially traffic noise, is more prominent because of its universality and ubiquitousness. It is reported that, traffic noise equivalent sound level of some urban trunk road was even more than 70 dB (A) in the daytime. At present, sound insulation screen was mainly used as management method of urban traffic noise, but it was costly and affects the urban landscape, which limits its wide application. Urban green space can play a similar role as sound insulation screen, and taking advantage of this plant characteristic to construct urban greenbelt can achieve both landscape effect and ecological effect. urban greenbelt for noise reduction, taking into account the landscape effect and ecological effect, is a kind of economical and effective urban noise control means.

Embleton(1963) proposed that forests had the function of noise reduction. Subsequent research had focused on the effects of structures of green and vegetation (such as density, leaf size, leaf orientation

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and so on) on the noise reduction and frequency reduction effect. Fang et al.(2003) found that visibility and width of vegetation were the main factors not leaf size which affected the noise reduction. Renterghem et al. also found that traffic noise reduction was closely related to stem diameter and planting density. Later research extended to the effect of vision and environments on noise reduction of the vegetation (Hong and Jeon, 2014). In China, Yu(2000) earlier introduced the concept of plant noise reduction, and put forward to using higher hedgerows (5 m high) to reduce noise in the northern city. Domestic studies mainly focused on the factors affecting the plant noise reduction, such as the correlation between noise reduction and community structure (branch under high, coverage, crown, etc.) (Zhang et al., 2007). Guo and Hu found that the green land and plants can reduce more low-frequency noise than high frequency one (Guo et al., 2009; Hu et al., 2014) when noise through.

Now the research on the noise reduction of the green space and the plant community is gradually connected with the physiological and psychological and visual factors. For example, Li et al.(2010) found that Hong Kong residents think Wetland Park and garden are more effective than green, mountain to reduce noise annoyance by using questionnaires; Yang et al.(2011) also found that the plant landscape can alleviate the effect of noise on the human being by testing people watching the crowded traffic and plant landscape in the EEG, α and β brainwave activity; Hong and Jeon(2014) analyzed noise reduction ability and visual impact of aluminum, wood, translucent acrylic acid, concrete and plant sound insulation screen and found plant insulation screen can provide noise reduction ability and enhance the aesthetic preference. However, the study focused on the objective physiological changes and subjective perception of noise, but lack of the analysis of relation between environmental noise and the subjective perception.

Research on noise reduction of plant community turns gradually to the combination of plant community objective noise reduction and human subjective noise reduction, but relationship between the noise reduction effect of the specific plant community and human feeling has not been explored. This study aims to fill that gap. Nine groups of typical plant community in south campus green space of Shandong Agricultural University were chosen as objects. And the relationship between noise reduction and community structure, and the noise reduction at different frequencies were analyzed. At the same time, semantic differential method was adopted to explore the perception on noise reduction. The conclusions can provide more accurate noise control basis for urban green space design.

2. Materials and Methods

2.1. Materials

The 9 groups of typical plant communities in the South Campus of Shandong Agricultural University were selected as the objects. The width of the community was about 15 m, the length over 30 m, and the concrete was selected as the control group. Plant communities were located in the flat ground; elevation is less than 0.5 m, communities there being more than eight years, with intact structure and good growth. Determination of time was in early July 2014. The campus background noise value was 48.5 ± 2.5 dB.

2.2. Methods

2.2.1. Noise reduction determination of plant communities

Standard source (TYPE4204) was used as the measurement sound source, with the output sound pressure being at level of 94 dB, the output noise being white noise and similar to point source. The measuring instrument was AWA6228-3 noise spectrum analyzer (Hang zhou Aihua Instrument Co., Ltd.), and was adjusted by sound calibrator before measurement.

Equivalent continuous measurements included A levels and octave spectrum. Each measurement point was measured for 1 min.

Plant communities structure were investigated, including height, diameter at breast height, crown width, bifurcate height, spacing, bare ratio and coverage. Measuring tools included tape of 50 m, measuring tree steel enclosed ruler of 2 m, and direct-reading height measurement. The sample line was located in the center of the community. The standard source was placed at the starting point, with 1.2 m high, and the sound source was placed 1.0 m away from community. The setting measuring points were placed on the community sample line 0 m (community starting point), 10 m, 20 m and 30 m (Zhang et al., 2007). After the start of the standard source, the measuring sound level meter was placed in 1.2 m high, facing standard sound source and to measure the parameters, with no other noise interference. And the measurements were repeated 3 times and tested for 3 days.

2.2.2. Subjective perception evaluation of human to the noise reduction of plant communities

Status anxiety rating scale (SAS), and semantic differential method (SD) analysis were selected to evaluate the subjective feeling on the white noise in different plant communities, aiming at exploring the effect of plant communities on noise reduction of subjective effect (Song et al., 2012). The test was carried out at 8:30-10:00 a.m., with fine weather, from the end of June to early July 2014. The participants were 40 university students, 20 male and 20 female students in each group. At each time, 5 persons were randomly distributed in the community, and there was no exchange between them. After they settled down in the plant community, the output sound pressure value was 55 ± 0.5 dB of the white noise (reference the environmental noise standard of China, level 1 environment noise 55 dB in daytime). The participants could not see the noise source. After they stayed for 10 min in this environment, they filled in the evaluation forms. The test lasted for 15 days. The questionnaire consists of 10 indices in 2 sections. In the first section, they were asked to describe the sound level as: quiet-noisy, calm- agitated; and in the second section to describe the anxiety level as: safe- dangerous, relaxing-nervous, satisfied- dissatisfied, stable- fearful, confident- self-abused, comfortable- oppressive, composed- panic, joyful- rueful. A five point scale was used for the subjective assessment from -2 to 2 (Song et al., 2012).

2.3. Data processing method

Noise reduction was the difference value of sound level between the measuring point 10 m, 20 m, 30 m and the 0 m, excess noise reduction was the difference value of noise reduction between the measuring point and the control (reduction of noise reduction value of the concrete). SPSS software was used to analyze the correlation between the excess noise reduction and structure characteristics of plant communities.

3. Results and Discussion

3.1. Noise reduction and excess reduction of plant communities

Based on field surveys, the characteristics of community structure of the 9 groups of plant communities were listed in Table 1. The typical communities included deciduous broad leaved pure forests, evergreen conifer forest, and deciduous broad leaved mixed forest, coniferous mixed broad leaved forest, with common tree species, such as *Cedrus deodara*, *Metasequoia glyptostroboides*, *Ginkgo biloba*, and *Koelreuteria integrifolia*, which are representativs in North China.

Noise reduction of the communities was much higher than that of the concrete and the grass. The reduction difference value increased with the increase of distance, and the noise reduction effect was the best at the 30 m (Fig. 1A). Excess noise reduction reflected the actual noise reduction value, and the excess noise reduction value increased with the increase of distance, but not multiple incremental tread. And there were no significant differences in 20 m and 30 m of T1, T2 and T9 communities (Fig. 1B).

According to excess noise reduction, plant communities were divided into 3 groups: in the first group, excess noise reduction was equal to or more than 10 dB, such as T2 *Prunus blireana* cv. Meiren forest, T4 *C. deodara* forest, T9 *C. deodara*- *G. biloba*- *P. cerasifera cv.* pissardii -*Forsythia suspensa* forest; in the second group, excess noise reduction value between 6.0 - 10.0 dB, such as T5 *Koelreuteria integrifolia*- *Sabina chinensis* cv. Kaizuca forest, T6 *M. glyptostroboides*- (*Euonymus fortunei* + *Ligustrum vicaryi*) forest, T7 *Liquidambar formosana*- *Magnolia denudata*- *P. serrulata* forest, T8 *G. biloba* - *L. formosana* forest; in the third group, excess noise

Table 1. Plant composition and structure characteristics of plant communities

Number	Plant composition and space type	Height (m)	Diameter at breast height (DBH) (cm)	Crown width (m)	Bifurcate height (m)	Bare rate (%)	Coverage (%)
CK	Concrete	-	-	-	-	100	0
T1	*Buchloe dactyloides* ground cover plant, constitute the open-type plant space	0.11	-	-	-	0	0
T2	*Prunusblireana*'Meiren'- *Oxalis corymbosa* (Flower) Small trees pure forest -ground cover plant constitute a closed plant space	2.88	8.46	2.75	0.78	70	85
T3	*Metasequoia glyptostroboides* - *O. corymbosa* Deciduous trees - ground cover plant, constitute a closed plant space	9.50	18.08	3.93	1.76	90	75
T4	*Cedrusdeodara* - *B. dactyloides* Evergreen conifer trees- ground cover plants, constitute a closed plant space	7.40	11.60	5.06	0.50	10	90
T5	*Koelreuteriaintegrifolia*-*Sabina chinensis* cv. Kaizuca- *B. dactyloides* Deciduous trees - shrub - ground cover plants, constitute a closed plant space	7.20	12.40	5.06	3.14	82	80
T6	*M. Glyptostroboides*- *Euonymus fortunei*-*Ligustrumvicary*- *B. dactyloides* Deciduous trees - shrub - ground cover plants, constitute a hydrophobic type grass land space	8.14	12.60	1.78	1.91	10	10
T7	*Liquidambar formosana*- *Magnolia denudata*-*Prunusserrulata*- *B. dactyloides* Deciduous trees-small trees (flower)- ground cover plants, constitute the semi-closed space	4.92	11.78	3.79	1.44	30	50
T8	*Ginkgo biloba* - *L. formosana* Deciduous trees, ground cover plants, constitute the semi-closed space	6.38	10.30	2.64	1.86	15	63
T9	*C. deodara*- *G. biloba*- *Prunus cerasifera* f. atropurpurea - *Forsythia suspensa* mixed broad leaf - deciduous forest-small trees (flower) - shrub, constitute the semi-closed space	7.03	17.10	4.46	0.96	0	100

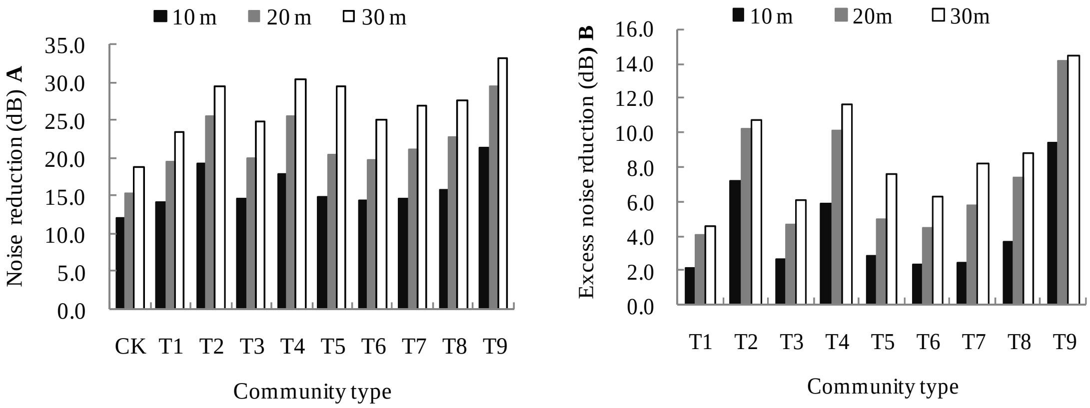

Fig. 1. Noise reduction and excess noise reduction of plant communities.

reduction was less than or equal to 6 dB, such as T1 *Buchloe dactyloides* glassland and T3 *M. glyptostroboides* forest.

3.2. Relationship between excess noise reduction and characteristics of plant community structure

The Spearman correlation analysis indicated that excess noise reduction was a positively correlated with coverage, negatively correlated with bifurcate height, and negatively correlated with bare rate (Table 2). And excess noise reduction was not significantly correlated with height, diameter at breast height and crown width. The model between excess noise reduction (Y) and coverage (CR) and bare rate (BR) was established by stepwise correlation analysis. Two models were established by stepwise regression analysis. Model 2 was better than model 1, and they were accord with the results of Spearman correlation analysis. And the plant community noise reduction was closely related with the characteristics of the plant leaves.

Model 1: $Y=2.265+6.97 X_{CR}$, its R, R^2, and adjusted R^2 values were 0.550, 0.303 and 0.271. F test $p< 0.05$.

Model 2: $Y=3.289+8.221 X_{CR}-5.027 X_{BR}$, its R, R^2 and adjusted R^2 values were 0.741, 0.548 and 0.505. F test $p< 0.05$. And coverage and bare rate had no linear (VIF=1.044).

Plant communities could reduce environmental noise, and noise reduction and excess noise reduction were higher than natural reduction in the air. Excess noise reduction was a better indicator than noise reduction to show the ability to reduce noise. T4 *C. deodara* forest and T2 *P. blireana* cv. Meiren forest had the stronger ability to absorb and reflect noise to

Table 2. Correlation analysis between the excess noise reduction and the structure of plant communities

Impact factor	The correlation coefficient	Significance level
Height	-0.323	0.123
Diameter at breast height	0.106	0.623
Crown width	0.260	0.219
Bifurcate height	-0.572**	0.004
Bare rate	-0.447*	0.029
Coverage	0.660**	0.000

Note: ** Indicates significance at p < 0.01. * Indicates significance at p< 0.05

reduce the noise with lower bifurcate height (0.78 m and 0.50 m), more branches, smaller and intensive leaves (Ba et al., 2013). T9 mixed forest had the best noise reduction effect, with *C. deodara* having intensive branches and lower bifurcate height, *F. suspensa* bush having intensive branches and leaves to form green wall to reduce noise through rate. T3 M. *glyptostroboides* forest had the poorer ability to reduce noise, with large plant spacing, high bifurcate height and sparse branches and leaves. Correlation analysis showed a significantly correlation between noise reduction and coverage, bifurcate height, height and bare rate. Zhang et al.(2007) found that noise reduction was related to leaf area index (LAI), bifurcate height, height, coverage and crown breadth by using factor analysis method. The conclusion was consistent with previous research, except that noise reduction was not related have height, DBH and crown breadth in the test. The reason probably was different plant communities with different structure character -istics, and may be height, DBH and crown breadth were related with noise reduction at the vertical level.

3.3. Reduction effect of plant communities on different frequency noise

Different frequency sound waves have different acoustic characteristics, and different reduction values of different plant communities on different frequency noise were also different. Fig. 2 indicated that different communities had different noise reduction value of 125-8000 Hz noise at 30 m. All communities had no obvious reduction effects on low frequency noise (<250 Hz), and even negative reduction. In the middle frequency noise, communities all enhanced reduction effects, especially broad leaved trees at 500-1000 Hz, such as T2 *P. blireana* cv. Meiren forest. T7, T8, T9 mixed forests, mainly composed of *G. biloba*, *L. formosana* and *M. denudate*, had obvious reduction effect on 8000 Hz, with slight decrease on 2000-4000 Hz. Coniferous trees, T3 *M. glyptostroboides* forest had better reduction effect on 1000-4000 Hz; reduction effect of T4 *C. deodara* forest was behind T9 mixed forest and higher than other communities, especially at 500-2000 Hz, and inferior to broad leaved trees on 8000 Hz. T5 *K. integrifolia*- *Sabina chinensis* cv. Kaizuca forest had better effect on 500-2000 Hz, and T1 grass land had better effect on 500-1000 Hz. In a word, communities had better reduction effect on middle frequency than on low and high frequency noise.

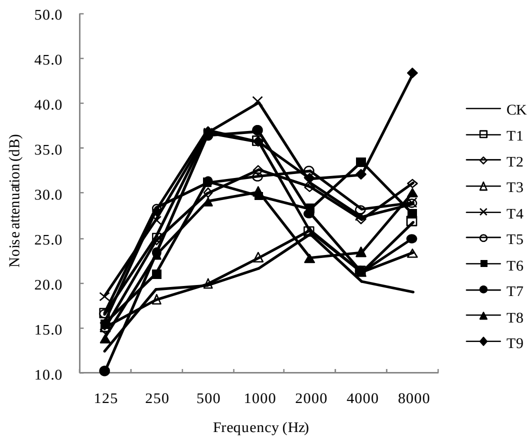

Fig. 2. Noise reduction at different frequencies by plant communities.

Previous research on plants reducing different frequency noise was different. Pal et al.(2000) found that noise reduction of green belt on 250 Hz was more than 125 Hz. Zhou et al.(2005) also found that forest belt could reduce high frequency traffic noise better than low frequency; humus soil could reduce medium and low frequency noise well, and the scattering and absorption of branches and leaves on high frequency noise resulting well reduction effect. Guo et al.(2009) concluded that green belt could better reduce medium and low frequency noise (≤2000 Hz) than high frequency noise. Hu et al.(2014) also found noise reduction ability of green belt on medium and low frequency noise (between 315-400 Hz) was better than high frequency one, and noise reduction improvement of broad leaved plants on low frequency noise was higher than that on medium and high frequency one. Yang et al.(2010) showed that noise reduction of plants was closely related to leaf morphology, texture and other morphological and physiological characteristics. Plants or green belt had different noise reduction effect on different frequency noise because of different method, objects of research, this study showed that noise reduction was better for middle frequency than for low and high frequency noise.

3.4. The human subjective perception of plant communities and noise reduction

Ten groups of adjectives were selected to evaluate noise reduction of communities (Table 3). Results showed that all communities scored higher than the control, especially *C. deodara* forest and mixed forest, according to two indicators quiet- noisy and calm-agitated. And these illustrated that plant communities could reduce environmental noise from subjective and objective aspects. But too dense forests, such as mixed forests, would lead to a negative feeling, such as being nervous, dissatisfied, fearful, self-abused and oppressive. Relatively open or large forests, such as grass land, *C. deodara* forest, short arboreal forest, gave a sense of security. T2 *P. blireana* cv. Meiren forest and T9 mixed forest were too dense to enter. And T1 grass land, T4 *C. deodara* forest, T7 short arboreal forest were appropriate dense and fit to enter.

The subjective evaluation on plant noise reduction was analyzed using SD method, and these affirmed psychological noise reduction of plant communities, but other physiological index need further research. Yang et al.(2011) found plant landscape could adjust and alleviate the impact of noise on the human body, by measuring EEG, such as α-wave and β-wave, and named these as psychological noise reduction. According to noise reduction and subjective feeling, we should take bifurcate height, coverage bare rate etc into consideration, when constructing green space, and we should built multilayer composite structure plant community. And function, characteristics, space type etc, should also be considered to meet people’s need.

4. Conclusion

Different plants or plant communities had different noise reduction ability. Communities with the same length and width, and different structure and

Table 3. The semantic differential analysis of perception on noise reduction

	CK	T1	T2	T3	T4	T5	T6	T7	T8	T9
Quiet- noisy	-1.8	-1.5	-1.38	-1.2	-0.98	-1.57	-1.46	-1.26	-1.02	-0.54
Calm- agitated	-0.9	-0.25	-0.43	-0.48	-0.31	-0.38	-0.32	-0.26	-0.31	-0.59
Safe- dangerous	0.26	0.56	0.32	0.49	0.67	0.42	0.48	0.68	0.58	0.71
Relaxing- nervous	-0.5	-0.23	-0.45	-0.36	-0.24	-0.31	-0.35	-0.28	-0.33	-0.73
Satisfied- dissatisfied	-0.53	-0.15	-0.37	-0.42	-0.16	-0.25	-0.34	-0.24	-0.27	-0.48
Stable- fearful	0.46	0.75	0.52	0.64	0.72	0.48	0.61	0.68	0.63	0.34
Confident- self-abused	0.43	0.69	0.55	0.52	0.63	0.62	0.46	0.58	0.59	0.48
Comfortable- oppressive	-0.35	-0.23	-0.12	-0.15	-0.16	-0.11	-0.15	-0.12	-0.16	-0.45
Composed- panic	0.59	0.72	0.76	0.69	0.72	0.64	0.64	0.68	0.73	0.52
Joyful- rueful	-0.25	0.18	0.23	0.15	0.25	0.21	0.32	0.35	0.41	0.13
Score	-2.59	0.54	-0.37	-0.12	1.14	-0.25	-0.11	0.81	0.85	-0.61

component, had different noise reduction effect, mainly caused by the different plant morphology. Mixed forest, *C. deodara* forest and *P. blireana* cv. Meiren forest had the best noise reduction ability in the test. The correlation analysis showed that there was correlation between noise reduction and coverage, bifurcate height and bare rate, but no significant correlation between noise reduction and height, DBH and crown width. Noise attenuation was better for middle frequency noise than for low and high frequency noise. These were consistent with previous research showing the scattering and absorption of leaves resulting in the noise reduction. Previous research focused on the relationship among green space, plants and noise, and lack of attention to that among plants, noise and human. This paper discussed the subjective evaluation on plant noise reduction, and affirmed the subjective noise reduction effect of plant communities. But mixed forests would lead to a negative feeling, such as being nervous, dissatisfied, fearful etc, and relatively open or large forests was given the highest evaluation. This paper focused noise reduction effect of plant communities on white noise and different frequency noise, and analyzed its relationship with the structure of communities. Nowadays there is no research on traffic noise, entertainment noise or other city noise. And noise reduction of plant communities on different frequency noise needed to be further research.

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