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Perceived Occurrences of Soundscape Influencing Pleasantness in Urban Forests: A Comparison of Broad-Leaved and Coniferous Forests

Xin-Chen Hong [1,2,*], **Zhi-Peng Zhu** [1,2,3], **Jiang Liu** [4], **De-Hui Geng** [2], **Guang-Yu Wang** [2] and **Si-Ren Lan** [1,5,*]

[1]   School of Landscape Architecture, Fujian Agriculture and Forestry University, Fuzhou 350002, China
[2]   Faculty of Forestry, University of British Columbia, Vancouver, BC V6T 0B2, Canada
[3]   College of Landscape Architecture and Urban Planning, Fujian University of Technology, Fuzhou 350002, China
[4]   School of Architecture, Fuzhou University, Fuzhou 350002, China
[5]   Engineering Research Center for Forest Park of National Forestry and Grassland Administration, Fuzhou 350002, China
*   Correspondence: xch.hung@alumni.ubc.ca (X.-C.H.); lkzx@fafu.edu.cn (S.-R.L.)

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Abstract: Perceived occurrences of soundscape reflect cognitive responses to perceived soundscapes. This research focuses on the relationship between perceived occurrences and pleasantness of soundscape in urban forests, and models these parameters. Soundscape information was gathered at 60 observation sites in urban forests, including perceived occurrences of soundscape (POS), pleasantness of perceived soundscape in urban forests (PSUF), and equivalent continuous A-weighted sound pressure level (L_{Aeq}). Twelve trained participants were exposed to the soundscape at each site for five minutes and filled out a questionnaire about POS and PSUF. The weight-ratio of perceived occurrences of soundscape (WPOS) was obtained from the POS. Pearson's correlation coefficients and Stevens' power law were conducted to test the applicability of the perceived occurrences of soundscape in psychophysical models. Results show that there is an interaction between the WPOS and PSUF in urban forests, and that psychophysical models are able to assess pleasantness of perceived soundscapes in urban forests. Findings show that pleasantness trends of geophony and biophony in broad-leaved forests and those in coniferous forests are opposite when the L_{Aeq} is increasing. Furthermore, by combining the WPOS, PSUF, and L_{Aeq}, the models were able to link the PSUF of geophony, biophony, anthrophony, and total soundscape in urban forests. Overall, results revealed that perceived occurrences of soundscape play a key role in linking the pleasantness of geophony, biophony, and anthrophony in urban forests.

Keywords: soundscape; pleasantness; occurrences; urban forests

1. Introduction

Urban forests are important components of urban green infrastructure, which include trees, forests, greenspace, and related abiotic, biotic, and cultural components in areas extending from the urban core to the urban-rural fringe [1,2]. Given the fast pace of urban life, urban residents enjoy access to nature via urban green infrastructure [3]. Soundscape is one of the most important components of the landscape in urban green spaces, natural spaces, and cultural landscapes [4,5], and soundscape plays an important role in the perception of residents [6,7], especially in quiet areas [8]. Fortunately, urban forests are suitable habitats for many plants and animals, which play a key role in producing soundscape [9–11]. The leaves contribute to absorb noise and produce the sound of leaves which

benefit communication between animals [12], suggesting that the soundscape of urban forests may indicate ecological service functions, positive ecological value, and reduce the negative impacts of traffic noise in urban core regions [13,14]. If urban noise is not filtered by an urban forest which stands between the noise source and the living environments, in specific conditions they can lead to an attenuation of 7 dB per 30.48 m at frequencies below 2000 Hz through the absorption and radiation of leaves and wood [15], the noise can invade residential areas and public spaces, thereby negatively effecting recreation, leisure, and even health [16].

The perception of sounds generated from ambient natural sources is very important in soundscape research. There are various soundscape classifications, such as Krause [17,18]. He defines three main-class active acoustic sources that comprise a soundscape: geophony—non-biological natural sounds originating from the geophysical environment, which include wind, water, thunder, geophysical activity, etc.; biophony—non-human biological sounds produced by all organisms in a given habitat; and anthrophony—anthropogenic sounds arising from stationary (e.g., air conditioner) and moving (e.g., vehicles) man-made objects. Geophony and biophony vary seasonally and diurnally in urban areas, and anthrophony is the main source of unwanted sounds (noise) [19]. Soundscape is a part of the living habitat of organisms before a source of psychological and physical rehabilitation [12,20,21].

Therefore, there is increasing research attention focused on soundscapes as people become more concerned about health, urbanization, globalization, etc. Soundscape elements can be identified by the soundwalk procedure [22,23]. There is a significant difference in subjective evaluation between non-semantic and semantic sounds with the same physical characteristics, as semantic sounds perform stronger cognitive sensitivity of sounds [24]. Spatial and temporal characteristics of soundscape, such as density of vegetation, diurnal variation of commuting, etc., are important factors affecting the perceived soundscape [25–30]. There is also a significant correlated relationship between the physical and psychological parameters of a soundscape [31–34]. Perceived occurrences of soundscapes have been found to correlate with the soundscape diversity index and perceived loudness of the soundscape in urban parks [35] (where perceived occurrences of a soundscape refer to the occurrence of sounds perceived in a given time period, reflecting the potential probability of cognitive stimulation from the soundscape).

There are various natural sounds in urban forests, including birdsong, which occurs seasonally and diurnally. Perceived occurrences of soundscape may play a key role in the soundscape of urban forests. Although some research has focused on the perceived soundscape in urban forests, such as soundscape harmony [20] and soundscape preference [36], there is an undefined relationship between perceived occurrences and pleasantness of soundscapes in urban forests. Thus, this research aims to: (1) Explore the relationship between perceived occurrences and the pleasantness of soundscapes in urban forests; and (2) test the applicability of perceived occurrences of soundscapes in psychophysical models.

2. Methodology

2.1. Study Area

Observation sites for this study are located in Qishan National Forest Park. This forest park is a key forested area in Fuzhou, China, located in the urban–rural fringe, 20 km from the urban core. The geographic coordinates are 118° 51′ to 119° 25′ E and 25° 47 to 26° 37′ N. This forested area, which extends 33.6 km across from north to south and 19.2 km across from east to west, is very close to the campuses of many universities. It experiences a subtropical oceanic monsoon climate with an average annual rainfall of about 900 to 2100 mm. The average wind speed during this survey was 1.4 to 1.9 m/s, the relative humidity was 75 m/s, and average sunshine was 1848 h. The highest altitude in the area is 775 m.

Qishan National Forest Park is covered by a variety of forests, including broad-leaved forests and coniferous forests. *Castanopsis carlesii*, the main tree species, which is widely distributed in this broad-leaved forested area, represents more than 21% of relative abundance in the whole area.

Pinus massoniana and *P. Cunninghamia* are the main tree species in the coniferous forested area, accounting for more than 42% and 36% of relative abundance in the whole area, respectively. Various animals inhabit this area, such as *Neofelis nebulosa*, *Hydropotes inermis*, *Passer montanus*, *Sterna hirundo*.

For this study, sixty observation sites were selected according to the potential view spots, paths, and junctions that may be developed in the park, including 30 sites in broad-leaved forests and 30 in coniferous forests (See Figure 1).
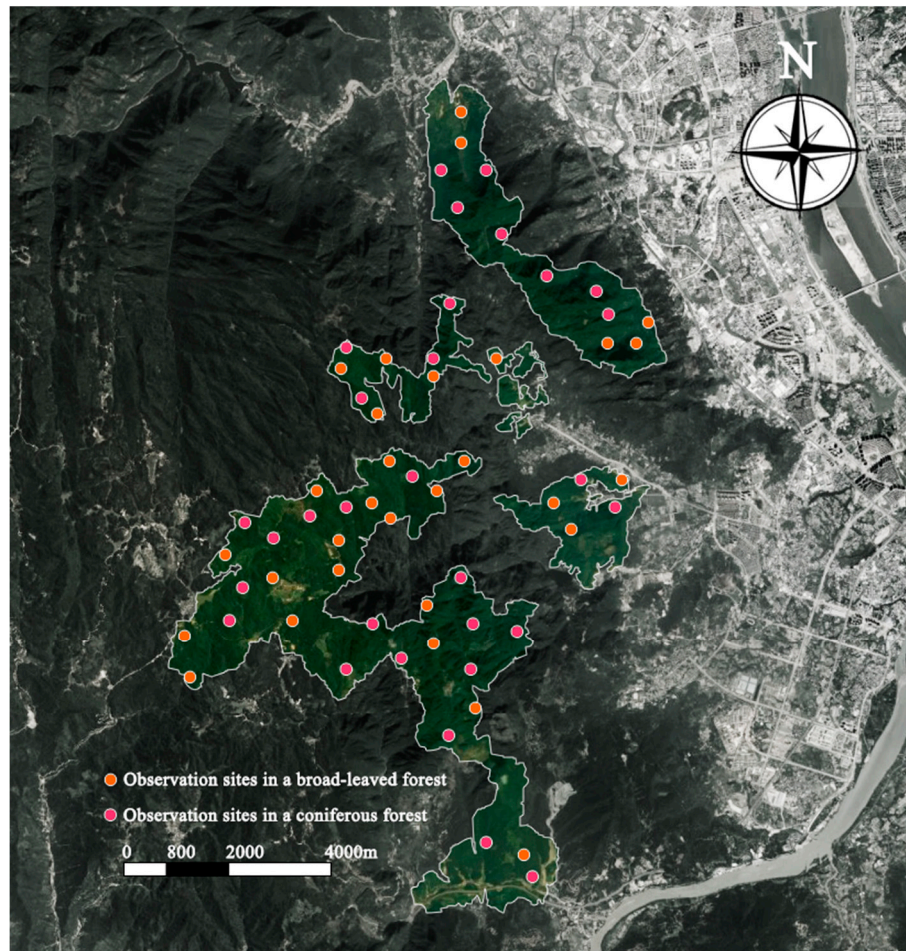
Figure 1. Aerial photo of Qishan National Forest Park.

2.2. Soundscape Information

In this study, questionnaires (made up of two sections) were used to collect information about perceived occurrences and pleasantness of the soundscape in these urban forests. In the first section, the perceived occurrences of soundscape (POS) included the number of geophony, biophony, and anthrophony sound occurrences that participants recorded in each site [28]. Due to the diurnal variation of biophony in a given habitat, we considered non-mechanical sounds produced by humans to belong to biophony in urban forests because humans' activities are also diurnal variation in the cities [37].

Questionnaires included: Eight categories for geophony, including "leaves rustling", "branches swaying", "leaves falling", "wind", "water", and three freely filled items; nine categories for biophony, including "birdsong", "footsteps", "speech", "insects", "frogs", "barking", and three freely filled items; and eight categories for anthrophony, including "music", "plant pruning", "traffic", "plane", "field construction", and three freely filled items. Questionnaires included ten spaces for recording POS after each category.

The second section of the questionnaire used a five-point ordinal scale [10,38,39] for the pleasantness of perceived soundscape in urban forests (PSUF). This section included five options for geophony, biophony, anthrophony, and total soundscape, including: "not pleasant at all (−2)", "slightly pleasant (−1)", "moderately pleasant (+0)", "very pleasant (+1)", and "extremely pleasant (+2)".

2.3. Procedure

Previous studies have demonstrated that visitors of urban forests in China are mainly young and middle-aged, with 20–35 year olds making up more than 80% of visitors [40,41]. Twelve healthy participants (six female and six male, average 28 ± 3.5 years, five local residents and seven outside residents) with normal hearing, were selected to provide the soundscape information [28,35]. All participants underwent a training process, including being familiarized with all the major sounds and categories in the questionnaire, and performing pilot studies to practice the recording process and learn about the plant communities in the forested area in order to minimize recording bias [42]. The procedure consisted of five repeated training sessions each separated by a week, including that (a) the major sounds, which were recorded in this urban forest, corresponded to geophony, biophony, and anthrophony and were assessed by participants. Then the variation of assessment between two adjacent training sessions was reported to the participants, thereby adjusting their cognitive criteria. All stimuli were presented through Sennheiser HD 650 headphones with the sounds at 65 dB SPL; (b) the knowledge of plant communities in the study area was obtained by the participants through performing pilot studies. The purpose of the training process was also to minimize the impact of subjective factors which may conduct fluctuant and shaky results, including the cultural background of participants, and to capture only the ability of participants to perceive the soundscape in each observation site.

Before the test began, all participants were required to sign a consent form outlining the details of the study, including content, purpose, and methodology. Furthermore, participants could quit the study at any point if they felt uncomfortable during the process.

All trained participants were exposed to the soundscape at each site for five minutes together. L_{Aeq} and sound recordings (binaural, 96 kHz sampling rate and 24 bit resolution) were measured using a Type-1 sound level meter and a Sony digital audiotape recorder (PCM-D100). Loudness (LO) and sharpness (SH) of psychoacoustics were analyzed from the sound recordings. ISO 532B (DIN45631) and DIN45692 were used to calculate LO and SH. In addition, test conditions were selected to be sunny days in April 2018, May 2018, and July 2019, not including holidays. The test included three time periods: morning (8:00–10:00), noon (11:00–13:00), and afternoon (14:00–17:00). Questionnaires and equipment measuring were repeated three times in each observation site. The total duration of the test was 900 min, during which 2160 questionnaires were collected.

2.4. Theoretical Model

According to the theory of soundscape ecology and psychophysics [3,6,26,33,43,44], soundscape in urban forests is the sound energy produced by the superposition and mixing of geophony, biophony, and anthrophony sound sources [27]. We consider the soundscape in urban forests to also be affected by the uncertain occurrences of soundscape. Therefore, modeling the perceived occurrences of soundscape (POS) and the pleasantness of perceived soundscape in urban forests (PSUF) should consider both the weight-ratio of perceived occurrences of soundscape (WPOS) and the fitting equation of psychophysics law.

After the POS was obtained from the questionnaires, the POS of geophony, biophony, and anthrophony were summed and represented by n_{geo}, n_{bio}, and n_{ant}, respectively. The WPOS was

obtained to express the proportion of perceived occurrences of geophony, biophony, and anthrophony, represented by w_{geo}, w_{bio}, and w_{ant}:

$$w_{k,j} = \frac{n_{k,j}}{n_{geo,j} + n_{bio,j} + n_{ant,j}}, (k = geo, bio, ant; j = bf, cf) \tag{1}$$

where: n is the POS of geophony, biophony, and anthrophony, and j represents forest type, including broad-leaved forests (*bf*) and coniferous forests (*cf*).

Previous studies show Stevens' power law to be a suitable fitting equation of psychophysics for soundscape in urban forests [20]. The PSUF of geophony, biophony, anthrophony, and total soundscape was represented by s_{geo}, s_{bio}, and s_{t}, respectively. Therefore, the fitting equation is as follows:

$$s_{k,j}(I) = aI^p + b, (k = geo, bio, ant; j = bf, cf) \tag{2}$$

where: I is L_{Aeq} in each site, a and b are coefficients of the nonlinear curve, and p is determined by the type of sensation and the amount of stimulus.

We calculated the WPOS of geophony, biophony, and anthrophony in order to relate the PSUF of geophony, biophony, and anthrophony, reflecting how the uncertain occurrence of soundscape can influence the PSUF of the total soundscape. To test the applicability of the perceived occurrences of soundscape in psychophysical models, we can combine Equations (1) and (2) and a model can be expressed to construct the relationship between s_{geo}, s_{bio}, and s_{t} based on the WPOS as follows:

$$s_{t,j} = w_{geo,j} s_{geo,j} + w_{bio,j} s_{bio,j} + w_{ant,j} s_{ant,j} + c, (j = bf, cf) \tag{3}$$

where: c is a constant.

3. Results

3.1. Weight-Ratio of Perceived Occurrences of Soundscape in Urban Forests

The POS of each item obtained from questionnaires was summed and classified, including "leaves rustling", "branches swaying", "wind" and "water" for geophony; "birdsong", "footsteps", "speech", "insects" and "frogs" for biophony; and "music", "plant pruning", "traffic", and "plane" for anthrophony. The WPOS and the composition of sounds (a total of 13 sound elements which were perceived in this study) of geophony, biophony, and anthrophony are shown in Figure 2.
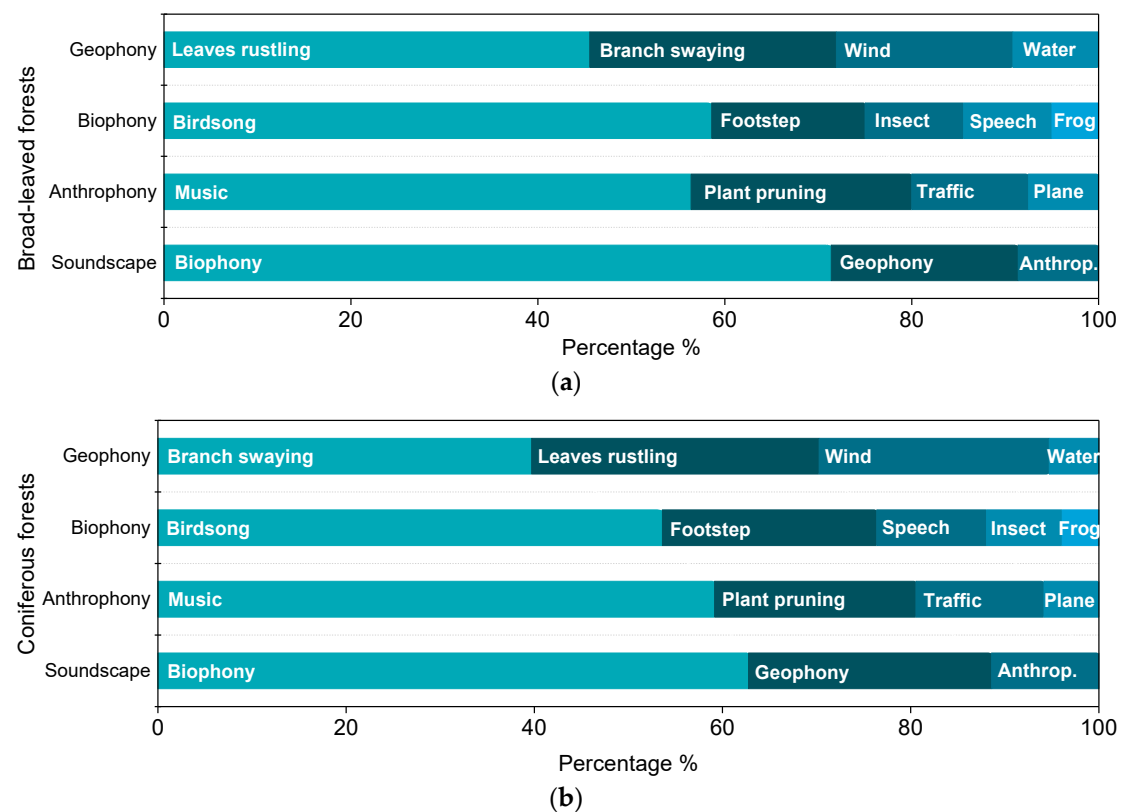
Figure 2. Weight-ratio of perceived occurrences of soundscape (WPOS) in broad-leaved urban forests (**a**) and coniferous urban forests (**b**).

This figure demonstrates that most of the WPOS was a result of biophony (especially birdsong and footsteps) and geophony (especially leaves rustling, branches swaying, and wind). The sum of these WPOS exceeded 85% in urban forests. We also found differences in the WPOS between broad-leaved and coniferous forests: For the WPOS of broad-leaved forests, $w_{geo,bf}$, $w_{bio,bf}$, and $w_{ant,bf}$ values were 0.713, 0.201, and 0.086, respectively; for the WPOS of coniferous forests, $w_{geo,cf}$, $w_{bio,cf}$, and $w_{ant,cf}$ values were 0.628, 0.258, and 0.114, respectively.

3.2. Relationship between Psychophysical Information of a Soundscape in Urban Forests

Figure 3 shows the distribution of PSUF and L_{Aeq} in the urban forests used in this study. This figure shows that the PSUF of the geophony and biophony in broad-leaved forests was distributed in the interval [−2, 2], and anthrophony was distributed in the interval [−2, 1]. As L_{Aeq} increases, the distribution of PSUF changes from the interval [0, 2] to [−2, 1], and that of anthrophony changes from the interval [−1, 1] to [−2, 1]. Moreover, the PSUF of geophony and biophony in coniferous forests was distributed in the interval [0, 2], and anthrophony was distributed in the interval [−2, 1]. The distribution of geophony and biophony rises from [0, 2] to the maximum of the interval as L_{Aeq} increases, and the distribution of anthrophony changes from the interval [−1, 1] to [−2, 1].
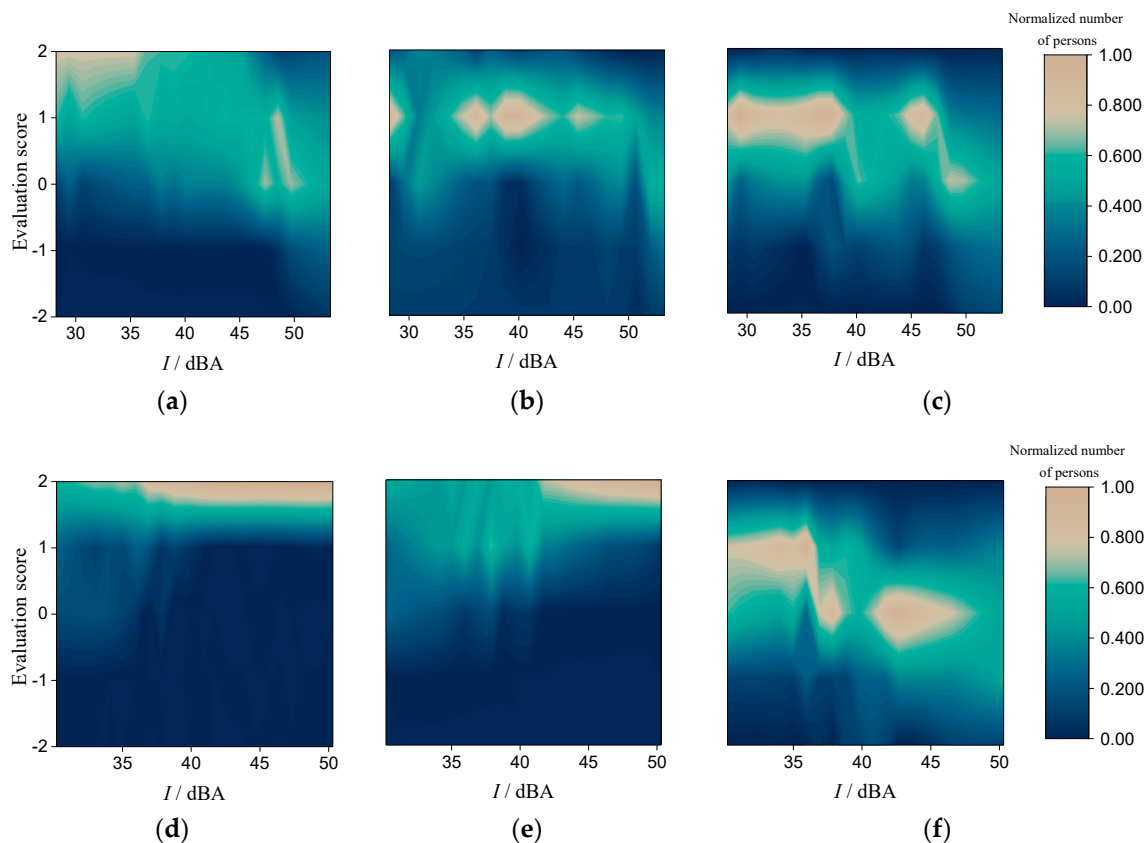
Figure 3. Distribution of pleasantness and L_{Aeq} of geophony (**a**), biophony (**b**) and anthrophony (**c**) in broad-leaved forests; distribution of pleasantness and L_{Aeq} of geophony (**d**), biophony (**e**) and anthrophony (**f**) in coniferous forests.

Table 1 shows the results of Pearson's correlation after we used a K-S test to examine the normal distribution of all parameters. Results show that for each soundscape element, there is a strong correlation between the PSUF, WPOS, L_{Aeq}, LO, and SH, suggesting that these parameters are related.

Table 1. Pearson's correlation coefficients between the pleasantness of perceived soundscape in urban forests (PSUF), the weight-ratio of perceived occurrences of soundscape (WPOS), and L_{Aeq} in urban forests.

	$s_{geo,bf}$	$s_{bio,bf}$	$s_{ant,bf}$	$s_{geo,cf}$	$s_{bio,cf}$	$s_{ant,cf}$
$w_{geo,bf}$	0.951 **	0.326 *	0.275 *	-	-	-
$w_{bio,bf}$	0.305 *	0.970 **	0.179	-	-	-
$w_{ant,bf}$	0.065	0.126	0.653 **	-	-	-
$w_{geo,cf}$	-	-	-	0.879 **	0.304 *	0.216
$w_{bio,cf}$	-	-	-	0.376 *	0.787 **	0.136
$w_{ant,cf}$	-	-	-	0.096	0.175	0.446 **
L_{Aeq}	−0.930 **	−0.950 **	−0.830 **	0.944 **	0.905 **	−0.930 **
LO	−0.917 **	−0.936 **	−0.776 **	0.896 **	0.857 **	−0.905 **
SH	0.537 **	0.633 **	0.449 **	−0.596 **	−0.558 **	0.616 **

* $p < 0.05$, ** $p < 0.01$. $s_{geo,bf}$, $s_{bio,bf}$, $s_{ant,bf}$, $s_{geo,cf}$, $s_{bio,cf}$, and $s_{ant,cf}$ represent the PSUF of geophony, biophony, and anthrophony in broad-leaved and coniferous forests. $w_{geo,bf}$, $w_{bio,bf}$, $w_{ant,bf}$, $w_{geo,cf}$, $w_{bio,cf}$, and $w_{ant,cf}$ represent the WPOS of geophony, biophony, and anthrophony in broad-leaved and coniferous forests. LO and SH represent loudness and sharpness of the psychoacoustics.

3.3. Psychophysical Models and the Perceived Occurrences of Soundscape in Urban Forests

In order to determine the relationships between soundscape parameters in urban forests, Stevens' power law Equation (2) was used to fit the PSUF and L_{Aeq} of urban forests.

When the PSUF and L_{Aeq} of broad-leaved forests were fitted, results showed that the coefficients of determination (R^2) of geophony, biophony, and anthrophony were 0.927, 0.951, and 0.788, respectively. The relationship between $s_{geo,bf}$, $s_{bio,bf}$, $s_{ant,bf}$, and I in a broad-leaved forest could be expressed as follows:

$$s_{geo,bf}(I) = -8.065 \times 10^{-14} I^{7.741} + 1.920 \tag{4}$$

$$s_{bio,bf}(I) = -5.391 \times 10^{-11} I^{6.125} + 1.923 \tag{5}$$

$$s_{ant,bf}(I) = -1.214 \times 10^{-14} I^{8.127} + 0.870 \tag{6}$$

When the PSUF and L_{Aeq} of coniferous forests were fitted, results showed that the coefficients of determination (R^2) of geophony, biophony, and anthrophony were 0.894, 0.924, and 0.821, respectively. The relationship between $s_{geo,cf}$, $s_{bio,cf}$, $s_{ant,cf}$, and I in a coniferous forest could be expressed as follows:

$$s_{geo,cf}(I) = 0.199 I^{0.567} - 0.668 \tag{7}$$

$$s_{bio,cf}(I) = 2.711 \times 10^{-15} I^{8.517} + 0.652 \tag{8}$$

$$s_{ant,cf}(I) = -2.920 \times 10^{-3} I^{1.853} + 2.781 \tag{9}$$

Based on Equations (1–9), and WPOS, two psychophysical models influenced by the perceived occurrences of soundscape were expressed as follows:

$$\begin{aligned} s_{t,bf} = \; & w_{geo,bf} s_{geo,bf} + w_{bio,bf} s_{bio,bf} + w_{ant,bf} s_{ant,bf} + c_{bf} \\ = \; & -10^{-14} \times (5.750 I^{7.741} + 1084 I^{6.125} + 0.104 I^{8.127}) + 1.424 \end{aligned} \tag{10}$$

$$\begin{aligned} s_{t,cf} = \; & w_{geo,cf} s_{geo,cf} + w_{bio,cf} s_{bio,cf} + w_{ant,cf} s_{ant,cf} + c_{cf} \\ = \; & 10^{-3} \times \left(124 I^{0.567} + 6.994 \times 10^{-13} I^{8.517} - 0.333 I^{1.853}\right) + 0.307 \end{aligned} \tag{11}$$

where: w is the WPOS of geophony, biophony, and anthrophony, s is the PSUF of geophony, biophony, and anthrophony, and I is the L_{Aeq}.

To test the applicability of these models, $s_{t,bf}$, $s_{t,cf}$, and I were run through Equations (10) and (11). Results showed that the coefficients of determination (R^2) of Equations (10) and (11) were 0.860 and 0.686, respectively (See Figure 4), suggesting that WPOS is related to the PSUF of the total soundscape in the urban forests. Results indicate two opposite trends, including negative trends in broad-leaves forests and positive trends in coniferous forests. This suggests that the perceived occurrences of soundscape play a role in psychophysical models of soundscape.
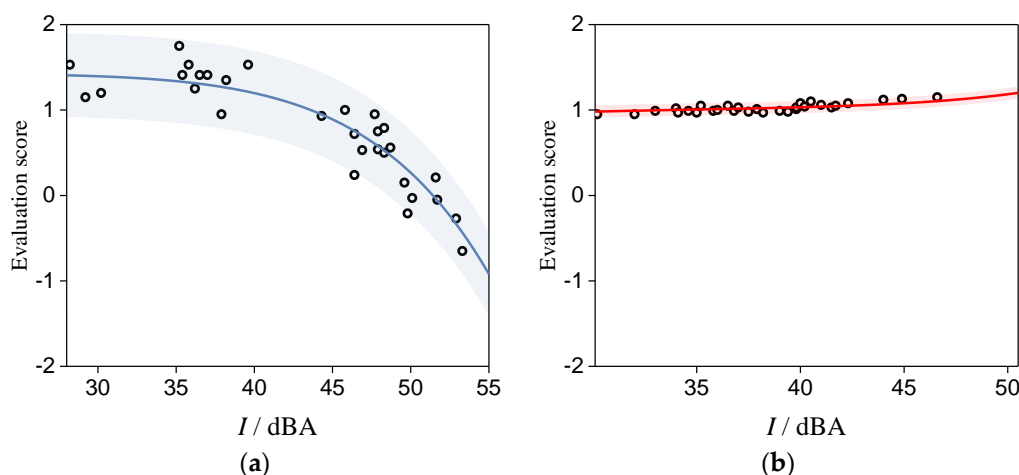
Figure 4. Fitting of pleasantness of total soundscape and L$_{Aeq}$ in broad-leaves forests (**a**) and coniferous forests (**b**).

4. Discussion

Birds are one of the most commonly recognized source of biophonies in broad-leaved and coniferous forests, as the dense forest provides sufficiently safe altitude and concealment, allowing birds to inhabit and reproduce [45–47]. The WPOS of birds (58.6% of biophony) in broad-leaved forests was more than that (53.6% of biophony) in coniferous forests, indicating that there were more species of birds in broad-leaved forests. This is due to broad-leaved forests providing more resources, including food and nesting sites, than coniferous forests [48]. Since multiple potential drivers, including wind, topography, species composition, spatial location, etc., conduct geophony in high-density forests, the soundscape of leaves rustling, branches swaying, and wind usually occur at the same time [10,49]. However, the WPOS of leaves rustling (45.6% of geophony) in broad-leaved forests was higher than that (30.6% of geophony) in coniferous forests. Furthermore, the WPOS of branches swaying (26.4% of geophony) in broad-leaved forests was less than that (39.7% of geophony) in coniferous forests. This suggests that geophony may be affected by the difference in size and weight between leaves in broad-leaved and coniferous forests, as suggested by a previous study [50]. If under the same wind conditions, the leaves of broad-leaved forests would be more prone to make sounds, while the branches of coniferous forests would be more likely to sway to make sound [51].

Since there is less human commuting and vegetation care in urban forests than in urban parks, anthrophony made up the smallest portion of WPOS (less than 15% of the soundscape) in the broad-leaved forests and coniferous forests, which contradicts the findings of previous research in urban parks because there is a closer distance and higher probability of exposure to urban noise in urban parks [23]. Anthrophony is the result of "music" (56.4% and 59.1% of anthrophony) and "plant pruning" (23.6% and 21.4% of anthrophony). We found a strong variation in PSUF in both forest types (as shown in Figure 3), and this is consistent with many previous studies in urban areas [51,52].

The distribution of PSUF for geophony and biophony in coniferous forests was more concentrated than that in broad-leaved forests (Figure 3). Results show opposite trends of geophony and biophony in different urban forests, including a decreasing trend in broad-leaved forests and an increasing trend in coniferous forests. These trends were more obvious when L$_{Aeq}$ was higher than 46.4 dBA for geophony and 47.6 dBA for biophony in broad-leaved forests, and 35.2 dBA for geophony and 40.2 dBA for biophony in coniferous forests. This difference may be caused by the difference between the leaves and woods of broad-leaved and coniferous forests, especially the leaf characteristics. More specifically, the leaves of *Castanopsis carlesii* with 6–9 cm long and 3–4.5 cm wide in the broad-leaved forest are larger than the leaves of *Pinus massoniana* with 12–20 cm long and 0.8–1 mm wide and *P. Cunninghamia* with 2–6 cm long and 3–5 mm wide in the coniferous forest.

Table 1 shows higher correlations between WPOS and PSUF for broad-leaved forests. Results also show a correlation between WPOS of geophony and PSUF of geophony and biophony, which may reflect that geophony is a key background sound to perceived soundscape in urban forests [25]. In addition, there was a positive correlation between the WPOS and PSUF of geophony and biophony in the urban forests, suggesting that perceived occurrences and the composition of natural sounds inspire feelings of pleasure in green spaces [23,53].

Based on application of Stevens' power law Equation (2), used to fit PSUF and L_{Aeq}, results of Equations (4–9), psychophysical models are applicable to determine the pleasantness of the perceived soundscape in urban forests, demonstrating a relationship between physical and cognitive stimulation of a soundscape [20,27]. These equations show that some trends, especially Equations (4) and (7) for geophony, and Equations (5) and (8) for biophony, are opposite in broad-leaved forests and coniferous forests, suggesting different absorption and radiation of the leaves and woods between these forest types [15]. This indicates that there is a potential difference between the reverberation of broad-leaved forests and coniferous forests [54,55]. Furthermore, Equation (3) conducts psychophysical models related by perceived occurrences of soundscape in urban forests, obtaining Equations (10) and (11). More specifically, through combining the WPOS, PSUF, and L_{Aeq} in these equations, the models can link the PSUF of geophony, biophony, anthrophony, and total soundscape in urban forests. The applicability of these models is demonstrated by the high fitting coefficients of Equations (10) and (11). Thus, uncertain occurrences of soundscape could be reflected by WPOS in the psychophysical model, which may be further considered to relate the potential parameter of soundscape and optimize the soundscape model.

Some limitations may be present in this research. Although the fitting coefficient of the total soundscape model in broad-leaved forests was similar or higher than that of each soundscape element in broad-leaved forests, the fitting coefficient of the total soundscape model in coniferous forests was slightly lower than that of each soundscape element in coniferous forests. This suggests that other potential factors in urban forests, such as the size and weight of leaves, should be considered in future studies.

5. Conclusions

This study demonstrates the composition of perceived soundscapes and the relationship between perceived occurrences and perceived pleasantness of soundscapes in urban forests. In terms of soundscape parameters, findings show that: 1) The uncertain occurrence of soundscape can be expressed as a probability based on the WPOS; 2) there are positive correlations between the WPOS and the PSUF of natural sounds in urban forests; 3) the WPOS is beneficial to link the PSUF of geophony, biophony, anthrophony, and total soundscape in urban forests. These findings suggest that soundscape occurrence could be considered in landscape planning, such as to increase occurrence of birdsong through arrangement of vegetation, inspiring a feeling of pleasure in urban forests. Various planning options could be used to contribute a variety of compositions of geophony, biophony, and anthrophony in urban forests. Results suggest that plant morphology may be a potential driver of perceived soundscape in urban forests, and this should be considered in future research to further explore soundscape patterns in urban forests.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kuehler, E.; Hathaway, J.; Tirpak, A. Quantifying the benefits of urban forest systems as a component of the green infrastructure stormwater treatment network. *Ecohydrology* **2017**, *10*, e1813. [CrossRef]
2. Oldfield, E.E.; Felson, A.J.; Auyeung, D.S.N.; Crowther, T.W.; Sonti, N.F.; Harada, Y. Growing the urban forest: Tree performance in response to biotic and abiotic land management. *Restor. Ecol.* **2015**, *23*, 707–718. [CrossRef]
3. Albert, D.G. *Past Research on Sound Propagation through Forests*; US Army Corps of Engineers: Hanover, Germany, 2004.
4. Schafer, R.M. *The New Soundscape: A Handbook for the Modern Music Teacher*; BMI: New York, NY, USA, 1969.
5. Carles, J.L.; Barrio, I.L.; Lucio, J.V. Sound influence on landscape values. *Landsc. Urban Plan.* **1999**, *43*, 191–200. [CrossRef]
6. Farina, A.; Gage, S.H.; Rankin, L.; Axel, A.C. *Biodiversity Assessment in Tropical Biomes using Ecoacoustics: Linking Soundscape to Forest Structure in a Human-Dominated Tropical Dry Forest in Southern Madagascar*; John Wiley & Sons: Hoboken, NJ, USA, 2017.
7. Payne, S.R. Are Perceived Soundscapes within Urban Parks Restorative. *J. Acoust. Soc. Am.* **2008**, *123*, 3809. [CrossRef]
8. Coensel, D.B.; Botteldooren, D. The quiet rural soundscape and how to characterize it. *Acta Acust. United Acust.* **2006**, *92*, 887–897.
9. Luitel, B.; Murthy, Y.V.S.; Koolagudi, S.G. *Sound Event Detection in urban Soundscape using Two-Level Classification. Distributed Computing, Vlsi, Electrical Circuits and Robotics*; IEEE: Piscatway, NJ, USA, 2017.
10. Yamada, Y.; Nilsson, K. Soundscape-based Forest Planning for Recreational and Therapeutic Activities. *Urban For. Urban Green.* **2006**, *5*, 131–139. [CrossRef]
11. Richards, D.G.; Wiley, R.H. Reverberations and amplitude fluctuations in the propagation of sound in a forest: Implications for animal communication. *Am. Nat.* **1980**, *115*, 381–399. [CrossRef]
12. Aylor, D. Sound Transmission through Vegetation in Relation to Leaf Area Density, Leaf Width, and Breadth of Canopy. *J. Acoust. Soc. Am.* **1971**, *51*, 411. [CrossRef]
13. Jeon, J.Y.; Lee, P.J.; You, J.; Kang, J. Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. *J. Acoust. Soc. Am.* **2010**, *127*, 1357–1366. [CrossRef]
14. Ware, H.E.; McClure, C.J.; Carlisle, J.D.; Barber, J.R. A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 12105–12109. [CrossRef]
15. Embleton, T.F.W. Sound propagation in homogeneous deciduous and evergreen woods. *J. Acoust. Soc. Am.* **1963**, *35*, 1119. [CrossRef]
16. Jeon, J.Y.; Lee, P.J.; Hong, J.Y.; Cabrera, D. Non-auditory factors affecting urban soundscape evaluation. *J. Acoust. Soc. Am.* **2011**, *130*, 3761–3770. [CrossRef] [PubMed]
17. Krause, B. Bioacoustics, habitat ambience in ecological balance. *Whole Earth Rev.* **1987**, *57*, 14–18.
18. Kull, R.C. Natural and urban soundscapes: The need for a multi-disciplinary approach. *Acta Acust. United Acust.* **2006**, *92*, 898–902.
19. Pijanowski, B.C.; Villanueva-Rivera, L.J.; Dumyahn, S.L.; Farina, A.; Krause, B.L.; Napoletano, B.M. Soundscape ecology: The science of sound in the landscape. *BioScience* **2011**, *61*, 203–216. [CrossRef]
20. Hong, X.C.; Liu, J.; Wang, G.Y.; Jiang, Y.; Wu, S.; Lan, S.R. Factors influencing the harmonious degree of soundscapes in urban forests: A comparison of broad-leaved and coniferous forests. *Urban For. Urban Green.* **2019**, *39*, 18–25. [CrossRef]
21. Payne, S.R. The Production of a Perceived Restorativeness Soundscape Scale. *Appl. Acoust.* **2013**, *74*, 255–263. [CrossRef]
22. Jeon, J.Y.; Hong, J.Y.; Lee, P.J. Soundwalk approach to identify urban soundscapes individually. *J. Acoust. Soc. Am.* **2013**, *134*, 803. [CrossRef]
23. Liu, J.; Kang, J.; Luo, T.; Behm, H. Landscape effects on soundscape experience in city parks. *Sci. Total. Environ.* **2013**, *454–455*, 474–481. [CrossRef]
24. Fastl, H. Neutralizing the Meaning of Sound for Sound Quality Evaluations. In Proceedings of the 19th ICA 2013 Congress, Montreal, QC, Canada, 9 June 2013.

25. Bahalı, S.; Tamer-Bayazıt, N. Soundscape research on the Gezi Park–Tunel Square route. *Appl. Acoust.* **2017**, *116*, 260–270. [CrossRef]

26. Davies, W.J.; Adams, M.D.; Bruce, N.S.; Cain, R.; Carlyle, A.; Cusack, P. Perception of soundscapes: An interdisciplinary approach. *Appl. Acoust.* **2013**, *74*, 224–231. [CrossRef]

27. Hong, X.C.; Jiang, Y.; Wu, S.T.; Zhang, H.; Lan, S.R. A study on the difference of forest soundscape evaluation models based on geophonies. In Proceedings of the 25th ICSV 2018 Congress, Hiroshima, Japan, 8–12 July 2018.

28. Liu, J.; Kang, J. Soundscape design in city parks: Exploring the relationships between soundscape composition parameters and physical and psychoacoustic parameters. *J. Environ. Eng. Landsc. Manag.* **2015**, *23*, 102–112. [CrossRef]

29. Ou, D.; Mak, C.M.; Pan, S. A method for assessing soundscape in urban parks based on the service quality measurement models. *Appl. Acoust.* **2017**, *127*, 184–193. [CrossRef]

30. Song, X.; Lv, X.; Yu, D.; Wu, Q. Spatial-temporal change analysis of plant soundscapes and their design methods. *Urban For. Urban Green.* **2017**, *29*, 96–105. [CrossRef]

31. Farina, A. *Soundscape Ecology: Principles, Patterns, Methods and Applications*; Springer: Berlin, Germany, 2014.

32. Kogan, P.; Turra, B.; Arenas, J.P.; Hinalaf, M. A comprehensive methodology for the multidimensional and synchronic data collecting in soundscape. *Sci. Total Environ.* **2017**, *580*, 1068–1077. [CrossRef] [PubMed]

33. Southworth, M. The Sonic Environment of Cities. *Environ. Behav.* **1967**, *1*, 49–70.

34. Zhang, D.; Zhang, M.; Liu, D.; Kang, J. Soundscape evaluation in Han Chinese Buddhist temples. *Appl. Acoust.* **2016**, *111*, 188–197. [CrossRef]

35. Liu, J.; Kang, J.; Behm, H.; Luo, T. Effects of landscape on soundscape perception: Soundwalks in city parks. *Landsc. Urban Plan.* **2014**, *123*, 30–40. [CrossRef]

36. Ge, J.; Hokao, K. Research on the sound environment of urban open space from the viewpoint of soundscape-a case study of saga forest park, japan. *Acta Acust. United Acust.* **2004**, *90*, 555–563.

37. Chapin, F.; Stuart, J. Urban time allocation. (book reviews: Human activity patterns in the city. things people do in time and space). *Science* **1975**, *187*, 1072.

38. International Organization for Standardization. *ISO/TS 12913-2:2018 Acoustics—Soundscape—Part 2: Data Collection and Reporting Requirements*; ISO: Geneva, Switzerland, 2018.

39. Osgood, C.E. Semantic Differential Technique in the Comparative Study of Cultures 1. *Am. Anthropol.* **1964**, *66*, 171–200. [CrossRef]

40. Yang, J.; Yu, Y.; You, L. Segmentation by Visitor Motivation in Fuzhou National Forest Park: A Factor-Cluster Approach. *Sci. Silvae Sin.* **2015**, *51*, 106–116.

41. Xu, X.; Zhu, Z.; Chen, Z.; Zheng, X.; Dong, J. Comprehensive evaluation of urban forest trails. *J. Northwest Norm. Univ. (Nat. Sci.)* **2018**, *54*, 109–115.

42. Gygi, B.; Kidd, G.R.; Watson, C.S. Similarity and Categorization of Environmental Sounds. *Percept. Psychophys.* **2018**, *69*, 839–855. [CrossRef] [PubMed]

43. Smith, J.W.; Pijanowski, B.C. Human and policy dimensions of soundscape ecology. *Glob. Environ. Chang.* **2014**, *28*, 63–74. [CrossRef]

44. Stevens, S.S. To Honor Fechner and Repeal His Law: A power function, not a log function, describes the operating characteristic of a sensory system. *Science* **1961**, *133*, 80–86. [CrossRef] [PubMed]

45. Forman, R.T.T. *Urban Ecology: Science of Cities*; Cambridge University Press: Cambridge, UK, 2014.

46. DeGraaf, R.M. *Trees, Shrubs, and Vines for Attracting Birds*; University Press of New England: Hanover, Germany, 2002.

47. Dawson, K.J. Flight, fancy, and the garden's song. *Landsc. J.* **1988**, *7*, 170–175. [CrossRef]

48. Hayes, F.E.; Ishmaelangelo, S. Diversity, abundance and seasonality of birds in a caribbean pine plantation and native broad-leaved forest at trinidad, west indies. *Bird Conserv. Int.* **1998**, *8*, 67–87. [CrossRef]

49. Cerwén, G.; Pedersen, E.; Pálsdóttir, A.M. The role of soundscape in nature-based rehabilitation: A patient perspective. *Int. J. Environ. Res. Public Health* **2016**, *13*, 1229. [CrossRef]

50. Sneddon, M.; Fidell, S.; Silvati, L.; Pearsons, K.; Harrison, R. Predicting sound levels from wind speed in a coniferous forest. *J. Acoust. Soc. Am.* **1990**, *88*, 74. [CrossRef]

51. Yang, W.; Kang, J. Acoustic comfort evaluation in urban open public spaces. *Appl. Acoust.* **2005**, *66*, 211–229. [CrossRef]

52. Yang, W.; Kang, J. Soundscape and sound preferences in urban squares. *J. Urban Des.* **2005**, *10*, 69–88. [CrossRef]
53. Hong, X.C.; Wang, G.Y.; Liu, J.; Lan, S.R. Cognitive persistence of soundscape in urban parks. *Sustain. Cities Soc.* **2019**, *51*, 101706. [CrossRef]
54. Padgham, M. Reverberation and frequency attenuation in forests–implications for acoustic communication in animals. *J. Acoust. Soc. Am.* **2004**, *115*, 402. [CrossRef] [PubMed]
55. Huisman, H.T.W. Reverberation and attenuation in a pine forest. *J. Acoust. Soc. Am.* **1991**, *90*, 2664. [CrossRef]