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Effects of landscape on soundscape perception: soundwalks in city parks

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ABSTRACT
The present study analyses the effects of the physical characteristics of the visual landscape on soundscape perception in city parks, based on information gathered in field surveys using a specifically designed soundwalk method in five city parks in China. Three soundscape parameters were conceived, including perceived loudness of individual sounds (PLS), perceived occurrence of individual sounds (POS) and soundscape diversity index (SDI), which were found to correlate and should thus be applied in concert. Physical characteristics of the visual landscape were analysed from two perspectives, i.e., by on-site landscape composition and local landscape spatial patterns. The results suggest that the percentage of buildings, vegetation and sky in panoramic views (here photos) were effective landscape elements influencing soundscape perception. The landscape shape index of buildings and water areas (LSI_B, LSI_W) and the patch cohesion index of water areas (COHESION_W) showed positive effects on the perception of human sounds. The percentage of roads (PLAND_R) and the largest patch index of roads (LPI_R) were related to traffic sounds. Both the PLS and POS of biological sounds were negatively related to LPI_W and LSI_B, respectively, whilst the POS of biological sounds was positively related to PLAND_R, and LSI_R. COHESION_R was the only index negatively related to both the PLS and POS of geophysical sounds. SDI only showed positive relationship with PLAND_W. Overall, the results reveal that local landscape spatial patterns could be more influential on soundscape perception than on-site landscape composition. The study proposed introducing soundscape information from different sources into landscape management.

KEY WORDS: soundwalk; soundscape parameter; visual landscape; landscape composition; landscape spatial pattern; city park

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1. Introduction

The soundscape concept is receiving increasing attention for addressing noise problems in urban areas. The pioneering work on soundscapes was carried out in 1960s. The musician R. M. Schafer was concerned about noise pollution and drew people's awareness to the acoustic environment (Schafer, 1969). The urban planner M. Southworth tried to characterise the acoustic properties of certain spaces in cities (Southworth, 1969).

Soundscape research has been conducted within different disciplines (Raimbault and Dubois, 2005). However, there is currently still no universal definition or common understanding of the term soundscape itself (Brown et al., 2011; Krause, 2002; Pijanowski et al., 2011a; Schafer, 1994; Schulte-Fortkamp and Fiebig, 2006). In the present study, the focus is on the relationship between soundscape and landscape, where soundscape is defined as the full range of perceptible sounds in a given landscape, at a given time, and the way humans respond to these acoustical cues that contribute significantly to the characteristics of a landscape (Liu et al., 2013a). Soundscape research has also been conducted with various approaches and can be divided into three groups according to soundscape characterization methods. One of the objective methods is to acquire soundscape information from analysing sound recordings in view of physical parameters (Barber et al., 2011; Farina et al., 2011) or in spectrograms (Pijanowski et al., 2011b). Subjective soundscape information can be derived from the human percipient on the basis of questionnaires or interviews (Liu et al., 2013b; Yang and Kang, 2005a, 2005b; Yu and Kang, 2008), and through on-site observation and evaluation, such as deployed in the soundwalk approach (Kang and Zhang, 2010; Liu et al., 2013a). The third method includes a combination of the objective and subjective soundscape-acquisition techniques, involving both objective analysis of sound recordings and subjective tests (Jeon et al., 2010).

Although more than 80 percent of our sensory input is visual (Rock and Harris, 1967), soundscape research highlights the auditory properties of a landscape and sets the visual dominance in landscape perception research into a new context. Research focuses have been on aural-visual interactions or soundscape-landscape relationships. Studies on mutual effects between landscape and soundscape perception have so far included two main aspects. Traditional landscape perception methods are usually conducted in a laboratory context by certain subjects using photography as a surrogate of the real landscape and visual stimuli to evaluate visual landscape attributes (Daniel, 2001; De la Fuente de Val et al., 2006; Dramstad et al., 2006; Dunn, 1976; Lange, 2001; Stamps, 1993; Steinitz, 1990; Trent et al., 1987), but introducing also sound recordings as the aural stimuli to the subjects (Carles et al., 1999; Pheasant et al., 2008; Viollon et al., 2002). Research has also been based on field investigations on the subjective experience of landscape aesthetic values and soundscapes in city parks (Liu et al., 2013b). Other approaches include landscape effects on soundscape perception at a larger scale, focusing on spatial patterns of landscapes. This kind of research was either carried by acoustic ecologists or urban planners.

For example, Matsinos et al. (2008) suggested that spatial sound variability in a costal rural area in Greece was mainly shaped by landscape attributes (Matsinos et al., 2008). Liu et al. (2013a) demonstrated that spatial patterns of urban land use may affect the perception of several sound categories in a multi-functional urban area in Germany (Liu et al., 2013a).

Despite these research efforts, the relationship between soundscape perception and landscape characteristics still requires to be analysed in greater detail. Soundscape perception itself is a highly subjective process and lacks general acceptance and effective illustration parameters. On the other hand, the physical characteristics of the visual landscape can vary strongly from place to place, and it needs frequent testing to substantiate the relationship between some specific landscape features and soundscape perception. In city parks, in particular, it is not clear to which degree the physical characteristics of visual landscapes affect soundscape perception, although landscape effects including aesthetic and functional aspects were revealed to be in close relationship with soundscape experience (Liu et al., 2013b).

In the present study, data on the soundscape perception collected by a group of observers following a specifically designed soundwalk method in five city parks in Xiamen, China, and information including visual landscape data with respect to on-site landscape composition and local landscape spatial pattern indices on class level, as well as questionnaire information from 580 park users, were combined to address the following research objectives: 1) characterisation of soundscape perception in city parks using various parameters; 2) analysis of the effects of the physical composition of the visual landscape on soundscape perception in city parks in view of on-site landscape composition and local landscape spatial pattern; 3) exploration of methods to combine soundscape information into applied landscape management.

2. Methodology

2.1. Field study

2.1.1. Case study sites

The survey was carried out in June 2012 in five public city parks in Xiamen, China, namely Bailuzhou (west), Huli, Haiwan, Nanhu and Zhongshan. These parks were chosen because of their similar characteristics in terms of location, scale, function and public importance (on the list of the Xiamen Construction and Administration Bureau). However, the landscape characteristics of these parks are not the same because of their terrain and specific design. There is no obvious difference in terms of fauna and flora composition among parks. Typical vegetation including *Ficus altissima, Delonix regia, Petiolus Trachycarpi Fortunei, Roystonea regia, Salix babylonica etc.,* and typical bird species including *Egretta garzetta*, *common magpie, Passer montanus saturatus, Lanius schach, Turdus merula, etc.* are commonly observed in the parks. The images from Google Earth for each park are shown in Fig. 1. In each park, six sampled sites were evenly chosen along the main visitor paths, and consecutively numbered as a sequence of the soundwalk route, as shown in Fig. 2.

Table 1 Recognised soundscape categories and corresponding sounds in the city parks

Soundscape category	Sound	Code
Human sound (Hum)	Surrounding speech	SS
	Children shouting	CS
	Footsteps	FS
	Exercising	EX
Traffic sound (Traf)	Traffic sound	TS
Mechanical sound (Mech)	Bicycle riding	BR
	Entertainment facilities	EF
	Aeroplanes	AF
	Lawn mowing	LM
	Road cleaning	RC
	Music	MS
	Indistinguishable sound	OS
Biological sound (Bio)	Birds	BS
	Dogs	DB
	Insects	IS
Geophysical sound (Geo)	Water sound	WS
	Leaves rustling	LR
	Wind	WB

Pilot investigations were carried out before the main survey by repeatedly visiting the parks, identifying and classifying 18 regularly appearing sounds into five sound categories, including human, traffic, mechanical, biological and geophysical sounds, as shown in Table 1.

2.1.2. Soundwalks

Soundwalks are frequently used in environmental acoustics research (Kang and Zhang, 2010). It is a method by which soundscape quality may be evaluated in places intended to be quiet and/or restorative, and is conducted by a group of people following a pre-defined walking route and using a structured protocol with a high level of sonic awareness (Schafer, 1969).

Soundwalks were conducted in five consecutive workdays in each of the five parks, respectively. The weather conditions during the investigation were stable, with light breeze, no rain and a temperature range of 24-31℃. Seven observers with normal hearing abilities (4 female and 3 male, average age 25±1.5 years) participated in the soundwalks. The sounds with their codes as shown in Table 1 were used as a reference for the observers. All of them went through a training process before performing the soundwalks. The training included (a) getting familiar with all the major sounds and their codes to ensure a fast recording; (b) performing pilot studies to learn the investigation process and minimise recording bias.

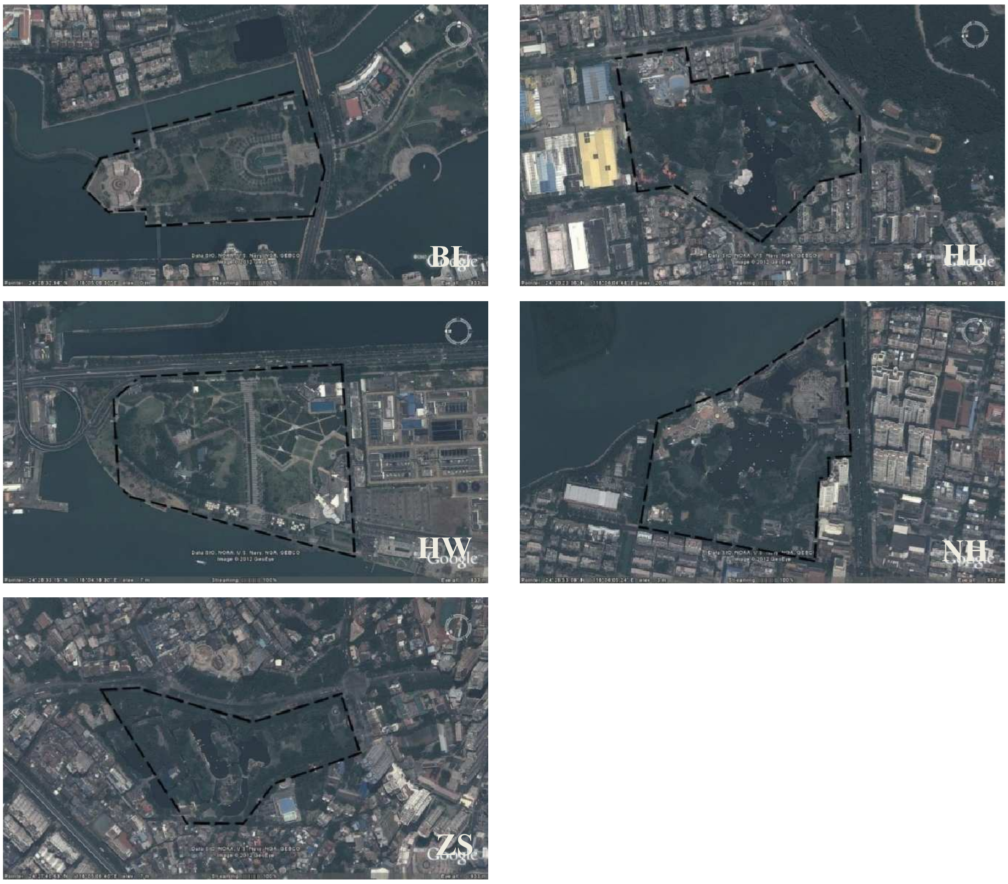

Fig. 1 Images of the five studied city parks from Google Earth, shown with the areas with broken line, BL: Bailuzhou (west), HL: Huli, HW: Haiwan, NH: Nanhu, ZS: Zhongshan

Soundscape data were recorded during the soundwalks in three periods of a day for each park, i.e., 1st period: morning (07:00-09:00), 2nd period: afternoon (12:00-14:00), and 3rd period: dusk (17:00-19:00). Within each period, all the six sampled sites were visited once following the same sequence. At each site, the codes of the heard sounds were entered into a table in 5 minute intervals which was further divided into ten sequential time-steps of 30 seconds each. Within each time-step, the perceived loudness of each individual sound was scored on a five-point linear scale (1=*very quiet*, 2=*quiet*, 3=*normal*, 4=*loud*, 5=*very loud*).

The soundscape data sets were then processed from all protocols by the seven observers. Before processing the soundscape data sets, inter-rater reliability of the seven observers for perceived loudness of five major sound categories was analysed (mean inter-rater reliability: 0.96

±0.02, Cronbach's alpha). Thus, only one set of soundscape data was generated for each period on each sampled site from the recordings by the seven observers, and in each soundscape recording, only the sounds recorded by more than 3 participants in the same time-steps were regarded as effective recordings, in order to get a more reliable data set. Subsequently, three soundscape indices were calculated from the soundscape data set for each sampled site in each period, including

(1) Perceived loudness of individual sound (PLS), i.e. the mean of all the perceived loudness scores of a sound provided by the seven observers.

(2) Perceived occurrence of individual sound (POS), i.e. the occurrences of a sound recorded in each period divided by 10 (time-steps).

(3) Soundscape diversity index (SDI), based on Simpson's Diversity Index, which is often used to quantify the biodiversity of a habitat in ecology (McGarigal and Marks, 1995). SDI denotes the probability that two individual sounds randomly selected from a soundscape sample will belong to different types of sound. The formula for calculating SDI is:

$$\mathrm{SDI} = 1 - \sum_{i=1}^{S} \left(\frac{n}{N}\right)^2 \tag{1}$$

where n and N are the total number of perceived occurrences of a particular sound i and all sounds S in the soundscape sample, respectively. SDI ranges between 0 and 1, the greater the value, the more diverse the soundscape.

All the three parameters are based on the matrix crossed by observation time-steps and perceived loudness of different sound sources. Each matrix stands for a soundscape piece, and it is made-up of all the matrices provided by the observers during the same period. As POS is based on the occurrence matrices of the seven observers, a mean inter-rater reliability of 0.94±0.03 (Cronbach's alpha) of the seven observers supports the objectivity of this parameter. SDI is also based on the occurrence matrices. Thus, all three soundscape perception parameters could “objectively” reflect soundscape characteristics, in which PLS and POS indicate the perception characteristics of individual sound, and SDI illustrates the overall soundscape perception characteristics.

2.2. Landscape data

The physical characteristics of visual landscapes can be viewed from two perspectives. Firstly, from a human perspective—a horizontal perspective of view reflecting the entire on-site landscape composition; secondly, from a bird’s eye view—a vertical perspective of view reflecting landscape spatial patterns. Landscape indices derived from these two perspectives should in conjunction objectively reflect the physical characteristics of the local visual landscape. Thus, landscape effects on soundscape perception as indicated by these indices could be of general relevance.

2.2.1. On-site landscape composition

Since the 1970s and 1980s, photography has been used as a surrogate of the real landscape in landscape perception research (Lange, 2001). It has been demonstrated that artificial geometric alterations of up to 15% produced through digital photomontage techniques were not distinguishable for human subjects (Watzek and Ellsworth, 1994). The use of landscape photos for subjectively evaluating landscape characteristics such as the scenic value and preference of visual landscape has been empirically established as a valid method (Daniel, 2001; De la Fuente de Val et al., 2006; Dramstad et al., 2006; Dunn, 1976; Shafer and Brush, 1977; Stamps III, 1997; Steinitz, 1990; Strumse, 1994). In aural-visual interaction research, landscape photos have also been combined with sounds and evaluated by subjects in terms of a series of psychological parameters and cultural values, e.g., naturalness, freedom, annoyance, solitude, scenic beauty and tranquillity (Benfield et al., 2010; Carles et al., 1999; Pheasant et al., 2008; Viollon et al., 2002). In addition, landscape photos have been used to quantitatively measure the landscape composition by calculating the percentage of different landscape elements captured in photographs (Pheasant et al., 2008).

In this study, landscape photos are also used as a surrogate of the real landscape. Panoramic landscape photos were shot horizontally in each park, using a Canon ESO 5D Mark II (Canon EF 35mm f/1.4L USM lens) with a tripod at a height of 1.2 m, on the same day the soundwalks took place. Panorama photos were used because the full set of landscape elements surrounding the recipient could affect sound composition and propagation (Shum and Szeliski, 1997). The panorama photos were made-up of 8-10 photos of each sampled site using the software MGI Photovista 2.0. Subsequently, six kinds of landscape elements were extracted from these panorama photos, i.e. *vegetation*, *water*, *buildings*, *pavement*, *furniture*, and *sky*. Their percentages were calculated in each photo by overlaying 5*5 mm grids on printed panorama photos (about 4 cm × 25 cm) (Pheasant et al., 2008). People appearing on the photos were disregarded. Since the observers were requested to focus on detecting sounds during the soundwalks and did not perceive the surrounding landscape at the same time, aural-visual interactions could be biased, and thus, landscape aesthetic effects on soundscape perception were not considered in this study.

2.2.2. Local landscape spatial patterns

Although landscape indices are commonly used to characterise ecological processes in large scale landscapes (Gustafson, 1998; Turner, 1989; Turner and Gardner, 1991), they have been more widely used due to their quantitative explanatory power (Corry and Nassauer, 2005). They have also been used in studies on small-scale visual landscapes (Dramstad et al., 2006).

Moreover, it has been suggested that spatial patterns of local landscapes could affect on-site soundscape perception on a small scale, i.e. < 175 m radius (Liu et al., 2013a; Matsinos et al., 2008). The effects were explained by two aspects, (a) by landscape composition—related to sound sources, thus affecting soundscape composition; (b) by landscape configuration—related to sound transmission route, thus affecting soundscape perception. In this previous study, land-use data were used to test whether the spatial landscape pattern of a multi-functional urban area effected soundscape perception. In the present study, all the sampled sites were located in five different city parks with the same type of land use. Thus, land cover data were more suitable to compare local landscape effects.

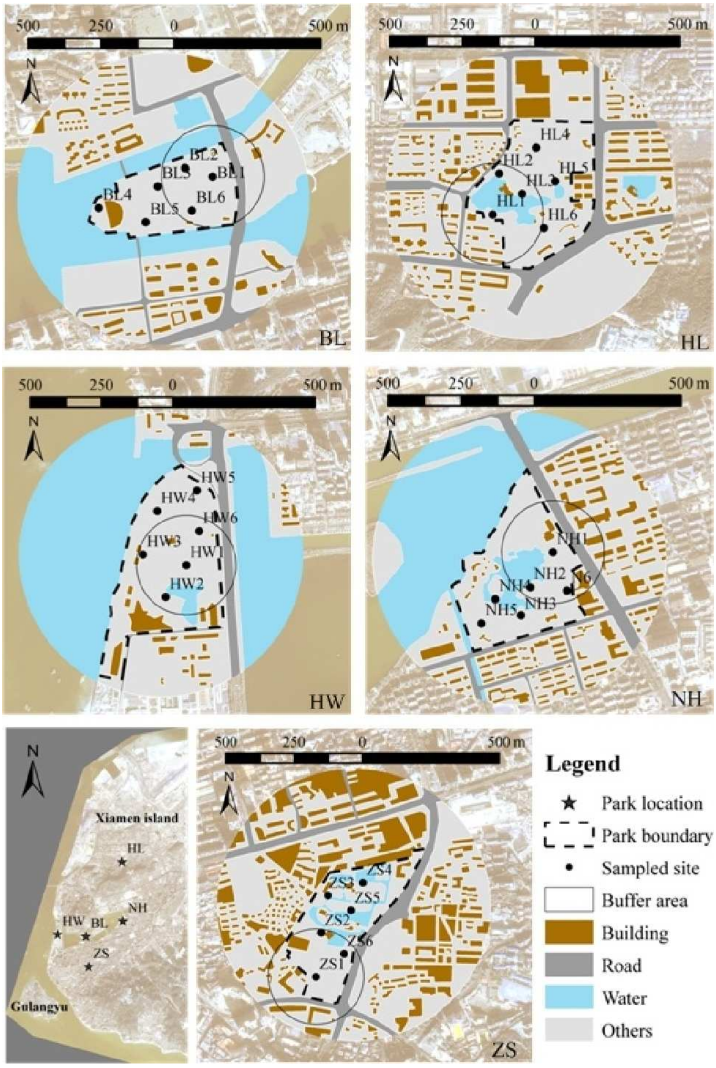

Fig. 2 Location of the five city parks and sampled sites, showing the local land cover and example of the buffer areas (circles around the 1st sampled sites for each park). BL: Bailuzhou (west), HL: Huli, HW: Haiwan, NH: Nanhu, ZS: Zhongshan

Based on IKONOS satellite images (resolution 3 m in 2009) and Google Earth data, land cover types including buildings, roads, and water areas were digitalized in ArcMap 9.3. Landscape composition indices including the percentage of landscape (PLAND), and landscape configuration indices including largest patch index (LPI), landscape shape index (LSI) and patch cohesion index (COHESION) for each of the three main land-cover types were chosen. Based on the digitalized maps, and following similar previous studies (Liu et al., 2013a; Matsinos et al., 2008), these landscape-composition and -configuration indices were calculated based on the 175 m radius buffer area centred on each of the sampled sites, using the software Fragstats (McGarigal and Marks, 1995). Vegetation density was calculated on the basis of SPOT satellite images (resolution 10 m in 2012), using normalized difference vegetation index (NDVI) values to reflect the status of landscape composition (Liu et al., 2013a). The value of vegetation density in the same 175 m buffer area of each sampled site was the sum of positive values of NDVI in each grid (Tucker, 1979). In total, 13 landscape indices, which are commonly implemented in landscape monitoring and relatively simple to interpret, were selected to indicate spatial landscape characteristics.

2.3. Citizen science

Although the soundwalk methods can provide "objective" soundscape information, and on-site landscape composition and spatial patterns of local landscapes could objectively reflect physical characteristics of visual landscapes, they are insufficient when applying soundscape information to landscape management. Soundscapes deal more with human perception (Schafer, 1969). There are major differences between soundscape information derived from soundwalks and from the experience of the general public. While soundscape perception during soundwalk is confined to certain sites and time periods and limited to a small group of observers, the public park users' soundscape experiences are shaped randomly among different sites and during a wider time window, and cover a wider demographic range. The levels of sonic awareness are different, too. Thus, subjective opinions especially about the preference for different sound categories should be based on public park users' experiences, rather than on a selected soundwalk group alone. Moreover, effects of visual landscape effects on soundscape perception of the general public could be reflected more directly by aesthetic and functional aspects, according to the park users' motivation to visit city parks. A supplementary questionnaire survey was, therefore, carried out in the five parks involving 580 park users.

The interviewees were asked to indicate their preference for a similar set of individual sounds as shown in Table 1, using a three-point linear scale: 1, annoying; 2, neither annoying nor favourable; and 3, favourable. The overall soundscape preference in terms of tranquillity, the satisfaction degree of landscape in terms of scenic beauty (visual aesthetics) and the status of the infrastructure and facilities (function) in the parks were all scored by the interviewees on a five-point linear scale (1=*very unsatisfied*, 2=*unsatisfied*, 3=*neither satisfied nor unsatisfied*, 4=*satisfied*, and 5=*very satisfied*).

2.4. Statistical analysis

Pearson correlations were conducted to analyse the relationships between soundscape perceptual parameters. Stepwise multiple regressions were performed in order to identify landscape elements as well as landscape spatial pattern indices that significantly affect soundscape perception. Pearson correlation analysis was also deployed to test the collinearity between different landscape indices, as well as the relationship among overall soundscape preference, the preference for individual sound categories, and the degree of satisfaction concerning visual aesthetics and the landscape function among the general public. All statistical analyses were carried out in SPSS 16.0.

3. Results

3.1. Relationships among soundscape perception parameters

3.1.1. Perceived loudness and occurrences of individual sound categories

In order to simplify the analysis, perceived loudness and occurrences of individual sounds (PLS and POS) were analysed by sound category. PLS and POS of individual sound category is the sum of PLS and POS of corresponding sounds in Table 1.

Correlations between perception parameters of the five sound categories are shown in Table 2. The results show that, in the case of PLS, biological sounds could be significantly impaired by human and mechanical sounds, while geophysical and mechanical sounds were negatively correlated. Mechanical sounds may not only impair the perception of natural sounds, but also override traffic sounds as well. For POS, both biological and geophysical sounds showed negative relationships with human and mechanical sounds. POS of mechanical sounds were closely negatively related to traffic sounds, while geophysical sounds were positively associated with traffic sounds of low coefficient value. Overall, the results suggest that the perception of natural sounds (biological and geophysical) could be profoundly affected by the prevalence of artificial sounds (human, traffic and mechanical) in urban parks.

In terms of the relationships between PLS and POS, the results in Table 2 show that within the same sound category, the two parameters were positively correlated in all five sound categories. PLS of human and mechanical sounds may significantly minimize POS of biological and geophysical sounds. POS of human and mechanical sounds could also significantly impair PLS of biological and geophysical sounds. These suggest that artificial sounds may dominate over natural sounds in soundscape perception process. PLS and POS of traffic sounds were negatively correlated with POS and PLS of mechanical sounds, respectively. As music was commonly recorded in the parks, the results indicate potential masking effects of this anthropogenic sound source on traffic noise. Interestingly, PLS and POS of traffic sounds were positively correlated to POS and PLS of biological sounds, respectively, which is consistent with some previous studies (Brumm, 2004; Liu et al., 2013a).

Table 2 Relationships between perception parameters of individual sound categories (PLS, POS), as well as between perception parameters of individual sound categories and the overall soundscapes (SDI), where Pearson correlation coefficients are shown in each cell, * $p<0.05$, ** $p<0.01$

		PLS					POS				
		Hum	Traf	Mech	Bio	Geo	Hum	Traf	Mech	Bio	Geo
PLS	Hum	1									
	Traf	-0.158	1								
	Mech	0.073	-0.437**	1							
	Bio	-0.344**	0.176	-0.420**	1						
	Geo	-0.146	-0.011	-0.244*	-0.109	1					
POS	Hum	0.885**	-0.103	0.040	-0.307**	-0.229*	1				
	Traf	-0.153	0.654**	-0.596**	0.220*	0.147	-0.110	1			
	Mech	0.073	-0.437**	1.000**	-0.420**	-0.244*	0.040	-0.596**	1		
	Bio	-0.360**	0.300**	-0.346**	0.704**	-0.045	-0.353**	0.122	-0.346**	1	
	Geo	-0.257*	0.048	-0.309**	-0.032	0.828**	-0.330**	0.217*	-0.309**	0.048	1
SDI		0.504**	-0.118	0.123	-0.220*	0.072	0.612**	-0.059	0.123	-0.023	0.128

3.1.2. Soundscape diversity indices and perception of individual sound categories

Correlations between overall soundscape perception as reflected by the soundscape diversity index (SDI) and the perception of the five individual sound categories are presented in Table 2. SDI is positively related to PLS and POS of human sounds, and negatively related to PLS of biological sounds. This suggests that soundscape elements in city parks are dominated by human sounds. With this situation, a higher SDI value could impair the perception of biological sounds.

3.2. Effects of on-site landscape composition

Given the dynamic nature of soundscapes, on-site landscape composition were analysed in relation to soundscape perception parameters for each period. Stepwise multiple regression analysis between each of the soundscape parameters and the percentage of different landscape elements calculated from panorama photos on each site in all three periods are shown in Table 3.

Table 3 Effects of landscape elements on soundscape perception in each sampled period, where no effect was shown are marked with "—"; 1: morning, 2: afternoon, 3: dusk; * p<0.05, ** p<0.01

Dependent variable		Period	Variables	β	t	Adjusted R^2	F
PLS	Hum	1	Sky	-0.503	-3.264**	0.313	7.599**
			Building	0.335	2.176*		
		2	Sky	-0.461	-2.915**	0.275	6.490**
			Building	0.341	2.157*		
		3	—	—	—	—	—
	Traf	1, 2, 3	—	—	—	—	—
	Mech	1	Vegetation	0.363	2.065*	0.101	4.262*
		2	—	—	—	—	—
		3	Building	0.390	2.240*	0.122	5.018*
	Bio	1, 2, 3	—	—	—	—	—
	Geo	1,2	—	—	—	—	—
		3	Sky	0.518	3.201**	0.242	10.244**
POS	Hum	1	Sky	-0.417	-2.428*	0.144	5.897*
		2	Sky	-0.454	-2.940**	0.309	7.470**
			Building	0.394	2.548*		
		3	—	—	—	—	—
	Traf	1, 2, 3	—	—	—	—	—
	Mech	1	Vegetation	0.363	2.065*	0.101	4.262*
		2	—	—	—	—	—
		3	Building	0.390	2.240*	0.122	5.018*
	Bio	1	Vegetation	-0.399	-2.302*	0.129	5.300*
		2, 3	—	—	—	—	—
	Geo	1	Sky	0.381	2.179*	0.114	4.748*
		2	—	—	—	—	—
		3	Sky	0.526	3.271**	0.251	10.701**
SDI		1, 2	—	—	—	—	—
		3	Vegetation	-0.438	-2.575*	0.163	6.629*

3.2.1. Perception of individual sound categories

It can be seen in Table 3 that, in terms of perceived loudness of the five sound categories, PLS of human sounds are negatively associated with factor *sky*, and positively associated with factor *buildings* in the first and second period (morning and afternoon). Assuming that the percentage of *sky* in the photos is a measure of landscape openness, one explanation for these relationships could be that the park users avoid staying in places without shade due to the hot climate in Xiamen. More buildings (shade) could lead to increased human activities, thus more human sounds may be heard. The positive relationship between mechanical sounds and *buildings* in the third period could be explained similarly. In the first period, mechanical sounds also showed a positive relationship with *vegetation*. This may be explained by the fact that in the parks of Xiamen, music is a major component of the anthropogenic soundscape, which is produced by loudspeakers that are usually hidden in the vegetation, or because some park users dance in the tree-shaded areas while playing music. Lawn mowing activities only take place in the first period, too, which may be another possible explanation for the correlation between vegetation and mechanical sounds. Geophysical sounds were only correlated to factor *sky* in the third period (dusk). It is possible that more geophysical sounds, especially wind, are perceived in more open or exposed places. PLS of traffic and biological sounds show no relationship with any landscape element.

The results on the occurrences of the five perceived sound categories are rather similar to those on PLS. Human sounds show similar relationships among POS and factors *buildings* and *sky*, but in the first period, factor *buildings* did not contribute significantly. Traffic sounds again showed no relationship with landscape elements. In the first and third period, mechanical sounds were positively related with the factors *vegetation* and *buildings*. However, biological sounds were negatively correlated with *vegetation*, perhaps because the perception of biological sounds, especially bird song, were overridden by anthropogenic sounds (music) which were positively related to *vegetation* during dawn. Geophysical sounds were positively related to *sky* in the first and third period.

3.2.2. Perception of overall soundscape

As for the perception of the overall soundscape, SDI showed a negative relationship with *vegetation* only during the third period. This indicates that places with more vegetation show less sound diversity. Since SDI is closely related to human sounds, this may suggest that during the third period, park users were engaged in diverse activities at various places, not only at places with vegetation.

3.3. Effects of landscape spatial patterns

Indices of landscape spatial patterns were also analysed in relation to soundscape perception parameters for each period. Stepwise multiple regressions between each of the soundscape perception parameters and landscape spatial pattern indices are shown for the three study periods in Table 4. Correlations between landscape indices as shown in Table 5 are also considered when explaining the results of the regression.

Table 4 Effects of landscape spatial pattern on soundscape perception parameters in each sampled period, where no effect was shown are marked with "—"; 1: morning, 2: afternoon, 3: dusk; _B: Building, _R: Road, _W: Water; * p<0.05, ** p<0.01.

Dependent variable		Period	Variables	β	t	Adjusted R^2	F
PLS	Hum	1	LSI_B	0.459	2.851**	0.399	9.977**
			LSI_W	0.340	2.113*		
		2	LSI_B	0.599	3.814**	0.334	14.547**
		3	LSI_B	0.453	2.434*	0.174	6.697*
	Traf	1	PLAND_R	0.615	3.980**	0.355	15.837**
		2	PLAND_R	0.558	3.427**	0.285	11.744**
		3	LPI_R	0.674	4.646**	0.433	21.585**
	Mech	1, 2, 3	—	—	—	—	—
	Bio	1, 2	—	—	—	—	—
		3	LPI_W	-0.400	-2.229*	0.128	4.967*
	Geo	1, 2	—	—	—	—	—
		3	COHESION_R	-0.530	-3.185**	0.253	10.145**
POS	Hum	1	LSI_B	0.485	3.851**	0.469	8.943**
			LPI_B	-0.361	-2.534*		
			LSI_W	0.349	2.296*		
		2	LSI_B	0.655	4.417**	0.407	19.531**
		3	COHESION_W	0.403	2.245*	0.130	5.041**
	Traf	1, 2	—	—	—	—	—
		3	COHESION_R	0.534	3.224**	0.258	10.394**
	Mech	1, 2, 3	—	—	—	—	—
	Bio	1	LSI_B	-0.497	-3.310**	0.394	9.774**
			PLAND_R	0.478	3.178**		
		2	—	—	—	—	—
		3	LSI_R	0.480	2.860**	0.275	6.113**
			LSI_B	-0.434	-2.586*		
	Geo	1, 2	—	—	—	—	—
		3	COHESION_R	-0.495	-2.908**	0.216	8.458**
SDI		1, 2	—	—	—	—	—
		3	PLAND_W	0.492	2.879**	0.213	6.895**

3.3.1. Perceived loudness of individual sound categories

PLS of human sounds was positively correlated with the landscape shape index of buildings (LSI_B) in all three periods. The more complex the buildings' shapes, the more human sounds were perceived. As LSI_B showed a significant positive relationship with the percentage of buildings (PLAND_B), and most of the buildings are for residential purpose, one explanation may be that the sampled sites which were near residential buildings could have attracted more people, thus introducing more human sounds. The landscape shape index of water areas (LSI_W) was also positively correlated with human sounds in the first period, but the explanatory power was lower than LSI_B. The reason for this could be that water areas with complex shapes attract more park users.

PLS of traffic sounds were positively correlated with the percentage of roads (PLAND_R) during the first and second period and with the largest patch index of roads (LPI_R) in the third period. As PLAND_R and LPI_R values in this study were the same, it seems that traffic sounds are only explained by the area of roads. As expected, larger roads have higher traffic loads and thus more traffic sounds.

There was no predictable landscape index for PLS of mechanical sounds in all three periods. The main reason for this could be that there was no stable sound source for this kind of sound in the parks, and most of the mechanical sounds were occasional events. Therefore, the relationship with spatial landscape patterns is week.

PLS of biological sounds showed a negative relationship with the largest patch index of water areas (LPI_W) in the third period only. Thus, large water areas did not introduce more biological sounds. That is obvious, since the predominant biological sounds are produced by terrestrial song birds singing from trees.

PLS of geophysical sounds was negatively related to the patch cohesion index of roads (COHESION_R) in the third period. As COHESION_R is positively correlated with both PLAND_R (0.749) and LPI_R (0.751), a possible reason is that more traffic sounds could affect the perception of wind, especially as they both show low frequency components.

3.3.2. Perceived occurrences of individual sound categories

In terms of perceived occurrences of different sound categories, there were three variables related to human sounds in the first period. The most effective one is the landscape shape index of buildings (LSI_B, 0.485), and the other two are the largest patch index of buildings (LPI_B, -0.361) and the landscape shape index of water areas (LSI_W, 0.349). LSI_B and patch cohesion index of water areas (COHESION_W) were the only explanatory variable for human sounds in the second and third period, respectively. The cause for the associations between LSI_B and LSI_W could be the same as suggested for the PLS of human sounds, and the relationship with COHESION_W may be explained by park users' preference towards places with large bodies of water, as COHESION_W is highly correlated with both PLAND_W (0.483) and LPI_W (0.435).

POS of traffic sounds showed a positive relationship with COHESION_R in the third period only. Considering the positive relationships between COHESION_R, PLAND_R and LPI_R, the explanation could again be linked to more roads causing more traffic sound. POS of mechanical sounds also showed no relationship with any of the landscape indices in all three periods.

POS of biological sounds were negatively correlated to LSI_B in the first and third period, respectively. Since LSI_B is positively related to human sounds and biological sounds are rather sensitive towards disturbance or distortion through human sounds, the negative relationship between LSI_B and biological sounds can be explained. PLAND_R and LSI_R were the other two variables associated with POS of biological sounds in the first and third period, respectively. Positive relationships between each of them and with biological sounds suggest that vocal organisms like birds have to increase song frequency or amplitude to compensate masking effects of traffic sound.

Similar to PLS of geophysical sounds, COHESION_R was the only variable of geophysical sounds related to POS during the third period.

3.3.3. Soundscape diversity index

The soundscape diversity index showed significant relationships with the percentage of water areas (PLAND_W) during the third period only. This result indicates that water areas could potentially increase soundscape diversity. Considering that soundscape diversity in the parks was to a large extent composed by anthropogenic sounds, most park users seem to prefer water features.

3.4. Soundscape perception of the general public and landscape effects

Table 6 shows the preference of the general public for different sound categories. It can be seen that humans have a clear preference for biological and geophysical sounds and experience traffic sounds as mostly annoying. It is also shown that humans have a higher level of tolerance or acceptance towards natural anthropogenic sounds (from human) than towards mechanical sounds. Correlations between overall soundscape preference of the general public and both the preference for an individual sound category and the degree of satisfaction towards the visual aesthetic and functional landscape were significant, with correlation coefficients of 0.371 and 0.278, respectively. As for the five major sound categories, overall soundscape preference was positively correlated with four of them, except for biological sounds. This suggests that acceptance of existing artificial sounds and more natural sounds could improve overall soundscape preference. Visual aesthetic and functional landscape effects could affect overall soundscape perception to a large extent, and the effects could be stronger than the preference for individual sound categories.

As for the effects of visual aesthetic and functional landscape on the preference for individual sound categories, both of them were significantly positively correlated with human sounds, although the correlation coefficients were rather low. The visual aesthetic and functional landscape was also strongly positively correlated with the preference for geophysical and mechanical sounds.

Table 5 Correlations between each of the landscape indices, where * $p<0.05$, ** $p<0.01$

Landscape indices		Building				Road				Water				NDVI
		PLAND	LPI	LSI	COHESION	PLAND	LPI	LSI	COHESION	PLAND	LPI	LSI	COHESION	
Building	PLAND	1												
	LPI	.683**	1											
	LSI	.732**	0.18	1										
	COHESION	.587**	.723**	0.05	1									
Road	PLAND	0.044	-0.201	0.059	0.064	1								
	LPI	0.044	-0.202	0.06	0.062	1.000**	1							
	LSI	0.213	0.158	0.221	0.181	0.27	0.27	1						
	COHESION	0.214	-0.154	.408*	-0.25	.749**	.751**	0.204	1					
Water	PLAND	-0.334	-0.249	-0.278	-0.072	-.457*	-.460*	-0.143	-.702**	1				
	LPI	-.377*	-0.256	-0.317	-0.12	-.472*	-.474*	-0.127	-.702**	.922**	1			
	LSI	.437*	0.215	.465*	0.078	-0.075	-0.074	-0.194	0.161	-0.003	-0.284	1		
	COHESION	-0.351	-.712**	-0.009	-.389*	0.121	0.12	-0.178	-0.025	.483**	.435*	-0.066	1	
NDVI		-.657**	-.472**	-.399*	-.528**	-0.218	-0.217	-0.079	-0.133	-0.009	0.026	-0.315	0.282	1

Table 6 Preference for different sound categories of the general public

	N	Mean	Std. Deviation
Hum	551	2.2666	0.45845
Traf	429	1.7133	0.64803
Mech	539	2.0729	0.48388
Bio	558	2.7154	0.44098
Geo	499	2.7365	0.42639

4. Discussion

4.1. Soundscape information related to on-site landscape composition

Of all six landscape elements, *water*, *pavement* and *furniture* showed no relationship with any of the soundscape parameters regarded in this study. *Buildings* was only an explanatory variable of artificial sounds, namely human and mechanical sounds. *Sky* was an explanatory variable of human sounds and also the only variable positively related to natural sound perception (geophysical sounds). The percentage of sky area appearing in the landscape photo may be related to perceived landscape openness. *Vegetation* as the explanatory variable of mechanical and biological sounds in this study may reflect specific qualities of the parks and sheds light on the relationship between humans and birds in their differential exploitation of the park vegetation. *Vegetation* was also the only variable related to the perception of the overall soundscape. However, although the regression models were all significant, adjusted R^2 values were rather low. This means that, although the chosen landscape elements had significant effects on certain soundscape perception parameters, other variables could have been more effective upon soundscape perception.

Generally speaking, soundscape information reflected by the relationships between the six landscape elements and soundscape perception parameters are not to be expected. One of the reasons could be the limitations of photographic techniques. A picture is a conical projection and therefore lens zoom, number of pictures per 360º panoramic views, camera vertical angle, etc. are all important factors affecting the measurement of landscape composition. In this study, the landscape photos were taken with a fixed focus wide-angle lens, so that the zoom distance was also fixed. But the projection of all landscape elements on a two-dimensional photo is directly affected by the distance from the lens. The image of a landscape element closer to the lens on a photo will be larger than a landscape element with the same size. Moreover, because of the visual thresholds of the camera, the whole landscape composition of the surrounding landscapes cannot be captured completely by using photographic methods as adopted in this study. Furthermore, distortion of perspective while making the panorama photos was not considered when measuring the landscape composition. Thus, a better surrogate of landscape could reveal more between on-site landscape composition and soundscape perception, for example, by using three-dimensional visualization technology (Bishop and Lange, 1998; Shang, 1992). On the other hand, on-site landscape composition may interact in a more complex way in terms of the effects on soundscape perception, for example, through visual aesthetic preferences and via specific functions of the landscape (Liu et al., 2013b). However, the perceived effective landscape elements, i.e., *buildings*, *vegetation*, and *sky* should be considered as key factors in future studies, especially *sky* which is usually neglected (Pheasant et al., 2008).

4.2. Soundscape information related to landscape spatial patterns

The results show that most of the adjusted R^2 values of the regression models using landscape spatial pattern indices are higher than those using percentage of landscape elements in panorama photos, suggesting that soundscape perception is affected more by local spatial landscape patterns. Also, certain sound categories could be affected by different land cover types and their spatial characteristics. For the perception of human sounds, two types of land cover, namely buildings and water, show close relationships. Traffic as a remote sound source from outside the parks could reflect more the effects of local landscape on soundscape perception within the parks. As expected, roads are the only land cover type related to traffic sounds. Effects of the physical composition of the visual landscape on the perception of these two sound categories are associated more with sound sources. Biological sounds could be affected by several land cover types, namely buildings, roads and water, while geophysical sounds only showed negative relationships with roads. Perception of these two sounds could be indirectly affected by the physical composition of the visual landscape mediated through effects on other sound sources, for example, landscape shape index of buildings affecting human sounds, and both percentage of roads and landscape shape index of roads affecting traffic sounds. In terms of overall soundscape perception, soundscape diversity only showed a positive correlation with water area, as indicated by percentage of water areas during the dusk period. This suggests that introducing water features into parks could improve their attractiveness to park users.

However, the landscape indices may not be predictive for all sound categories. For example, no index is related to mechanical sounds in this study, mainly because of their unstable nature. Moreover, not all landscape indices are effective on soundscape perception. In this study, 13 indices were selected as potential explanatory variables, but 8 different indices were introduced into the regression models. This may be partly due to the collinearity between most the landscape indices (Turner and Ruscher, 1988). For example, normalized difference vegetation index was found to be an effective indicator for soundscape perception in a previous study (Liu et al., 2013a), but in this study, it was not introduced into any regression model. The strong correlations with the four road indices could be an explanation. Another important reason may be attributed to the scale of the study. Following the human hearing ability, in this study the scale was limited to a radius of 175m. Thus, the sounds beyond the scale may not be well related to the local landscape. Although similar previous studies were conducted on the same scale (Liu et al., 2013a; Matsinos et al., 2008), it is necessary to consider the scaling effect in future studies. Moreover, while many landscape indices have been developed (McGarigal and Marks, 1995), more of them should be tested as suitable soundscape indicators.

4.3. Necessary soundscape information in practical landscape management

While in this study the relationships between the relatively objective soundscape parameters and physical characteristics of the visual landscape were mainly explored, it is also useful to consider the soundscape experiences and opinions of the park users from the general public, as they cover a wider temporal period and demographic range.

The results from the questionnaires showed that the park users clearly preferred natural sounds over artificial sounds (except for music), and in between, a relatively high acceptance for human sounds. Thus, natural sounds should be introduced more into city parks to improve soundscape quality. The results from the investigation including the general public could be a bridge to connect the information reflected by the relationships between "objective" parameters (PLS, POS, SDI) and visual landscape indices with practical management. According to the results, the physical composition of the visual landscape in favour of natural sounds should be considered with priority in urban landscape management, and could be managed according to the positive or negative relationships of different landscape indices with perception parameters of different sounds.

The visual aesthetic and functional landscape was found also to be closely related to both the preference for certain individual sound categories and overall soundscape preference. As the effects of both visual aesthetic and functional landscape could only function through physical composition of the visual landscape, these would provide important supplemental information to landscape design. Especially, when the "objective" soundscape information provided by physical composition of visual landscape and soundwalks is not enough or difficult to apply to existing landscapes, considering the enhancement of aesthetic or functional aspects of the visual landscape could be a promising approach.

In general, soundscape information derived randomly from the general public may be necessary to better understand to the "objective" soundscape information derived from non-random by soundwalks.

5. Conclusions

In this study, which was based on information gathered in a field survey with a specifically designed soundwalk method in five city parks in Xiamen, China, visual landscape effects in terms of physical composition on soundscape perception were examined. In terms of soundscape perception parameters, it was shown that, PLS and

POS of biological and geophysical sounds could be affected by PLS and POS of the other three kinds of sound, including human, traffic and mechanical sounds, indicating that natural sounds are often overridden in the soundscape perception process. SDI is mainly related to human sounds, which demonstrates their dominant role in the urban parks. Overall, the three parameters are correlated and should be used together to illustrate soundscape characteristics.

The relationships between the soundscape perception parameters and physical characteristics of the visual landscape were analysed, and the results suggest that in terms of on-site landscape composition, *buildings*, *vegetation* and *sky* are the three effective landscape elements. In particular, *buildings* is only an effective variable of artificial sounds (human and mechanical sounds). *Vegetation* is an explanatory variable of mechanical and biological sounds in the study, and it is also the only variable related to overall soundscape perception. *Sky* is an effective variable of both human and geophysical sounds, and it is also the only variable positively related to natural sound perception. In terms of landscape spatial patterns, the landscape shape index of buildings and water areas and the patch cohesion index of water areas have positive effects on human sounds perception. Traffic road is the only land cover type which is related to traffic sounds, indicated by the percentage of roads and the largest patch index of roads. There is no landscape index that is effective in explaining perception of mechanical sounds. PLS and POS of biological sounds are negatively related to the largest patch index of water areas and the landscape shape index of buildings, respectively, whilst POS of biological sounds are positively related to the percentage of roads and the landscape shape index of roads. The patch cohesion index of roads is the only index negatively related to both PLS and POS of geophysical sounds. The relationships with overall soundscape perception parameter, the soundscape diversity index, shows that it shows positive relationship with water as indicated by percentage of water areas. In general, soundscape perception could be affected more by local landscape spatial patterns than on-site landscape composition. Thus, in landscape and urban planning and designing practice, the spatial arrangement of different landscape elements should be considered in terms of improving the quality of soundscapes. At the same time, soundscape information derived from the general public should always be considered as an important supplement.

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