Article:

Liu, J., Kang, J., Behm, H. et al. (1 more author) (2014) Landscape spatial pattern indices and soundscape perception in a multi-functional urban area, Germany. Journal of Environmental Engineering and Landscape Management, 22 (3). 208 - 218. ISSN 1648-6897

https://doi.org/10.3846/16486897.2014.911181

OURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 / eISSN 1822-4199
2014 Volume 22(03): 208–218
http://dx.doi.org/10.3846/16486897.2014.911181

LANDSCAPE SPATIAL PATTERN INDICES AND SOUNDSCAPE PERCEPTION IN A MULTI-FUNCTIONAL URBAN AREA, GERMANY

Jiang Liu[a, b], Jian Kang[a], Holger Behm[b], Tao Luo[c]

[a]*School of Architecture, University of Sheffield, Western Bank, Sheffield S10 2TN, UK*
[b]*Faculty of Agricultural and Environmental Sciences, University of Rostock,*
Justus-von-Liebig-weg-6, 18059 Rostock, Germany
[c]*Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences,*
1799 Jimei Road, 361021 Xiamen, China

Submitted 9 May 2013; accepted 31 Mar. 2014

Abstract. Soundscape research could provide more information about urban acoustic environment, which should be integrated into urban management. The aim of this study is to test how landscape spatial pattern could affect soundscape perception. Soundscape data on specifically defined spatial and temporal scales were observed and evaluated in a multi-functional urban area in Rostock, Germany. The results show that urban soundscapes were characterised by artificial sounds (human, mechanical and traffic sounds) overwhelming the natural ones (biological and geophysical sounds). Major sound categories were normally mutual exclusive and dynamic on temporal scale, and have different spatial distribution on spatial scale. However, biological and traffic sounds seem to be co-existing on both temporal and spatial scales. Significant relationships were found existing between perception of major sound categories and a number of landscape spatial pattern indices, among which vegetation density (NDVI), landscape shape index (LSI) and largest patch index (LPI) showed the most effective indicating ability. The research indicated that soundscape concepts could be applied into landscape and urban planning process through the quantitative landscape indices to achieve a better urban acoustic environment.

Keywords: landscape spatial pattern indices, multi-functional urban area, urban soundscape, human perception, landscape management.

Introduction

"Noise" has been considered as a global problem affecting the well-being of humans and organisms (André *et al.* 2011; Butkus, Januševičius 2011). The traditional approaches of noise control, such as noise mapping, noise zoning, noise monitoring and abatement have been pointed out by many researches as not effective enough (Paožalytė *et al.* 2012), as the physical parameters such as A-weighted sound pressure level (L_{Aeq}) ignore to a certain extent the physiological and psychological consequence on human (De Ruiter 2004; Raimbault, Dubois 2005).

The concept of soundscape, initiated by Schafer (1969), advocates treating "noise" in cities objectively and emphasises human experience. Thus it overcomes the limitations of quantitative approaches focusing only on the physical measurements of noise, and is advocated by many researches (Schulte-Fortkamp, Fiebig 2006; Kang 2007; Kang, Zhang 2010; Liu *et al.* 2013a, b). Soundscape research is also thought to be an integrated and multidisciplinary approach (Raimbault, Dubois 2005; Kull 2006; Brown *et al.* 2011), and concerted efforts have been made in this area (Genuit, Fiebig 2006; Schulte-Fortkamp, Fiebig 2006; Adams *et al.* 2006; Lavandier, Defreville 2006; Zhang, Kang 2007; Kang 2007; Brambilla, Maffei 2006, 2010; Joo *et al.* 2011; Pijanowski *et al.* 2011). Although using the same term "soundscape", the focuses of these researches mainly fall into two groups, i.e. one presented soundscape as the collection of all sounds that occur at a place (Schafer 1969), the other presented soundscapes as an ecological reflection of underlying ecological processes occurring in ecosystems (Pijanowski *et al.* 2011).

Corresponding author: Jian Kang
E-mail: j.kang@sheffield.ac.uk

www.tandfonline.com/teel

Taylor & Francis
Taylor & Francis Group

Particularly in the area of urban acoustics, combining soundscape concept into the planning process is thought to be the most effective and practical way to realise a better acoustic environment (Raimbault, Dubois 2005; Guastavino 2006; Adams *et al.* 2006; De Coensel *et al.* 2010). In terms of planning, urban planners thought that "how to conceive and design desirable soundscapes" was more important than "a simple decrease of noise level or the elimination of noises" (Raimbault, Dubois 2005). However, how could planners and decision makers easily apply the soundscape concept into practical urban planning management is still to be considered, where an inter-disciplinary approach could be helpful.

In the research area of landscape ecology, landscape spatial patterns are mainly analysed in terms of ecological processes (Turner 1989), and a series of spatial metrics that quantitatively measure landscape structures have been developed (Turner *et al.* 2001). Based on the area and spatial distribution of different landscape patches, these indices could be used to characterise landscapes in two main aspects, i.e. landscape composition, namely the variety and abundance of patch types within a landscape, and landscape configuration, namely the spatial distribution of patches within a landscape (McGarigal, Marks 1994; De la Fuente de Val *et al.* 2006). Recently, landscape metrics have been widely applied in indicating landscape changes and different landscape functions such as habitation, regulation and information (Uuemaa *et al.* 2012). In particular, for the information function, numerous studies have revealed the close relationship between landscape visual attributes and landscape patterns (Palmer 2004; Dramstad *et al.* 2006). The visual aspect of landscape has also been, up to now, paying more attention in urban planning process (Adams *et al.* 2006).

On the other hand, researches on the aural aspect of landscape have been drawing more attention, but mainly focusing on aural-visual interactions in landscape perception, treating sound as an important factor affecting landscape preference by human beings (Pheasant *et al.* 2008). As an auditory correspondent of landscape(Schafer 1969), soundscape and its quality are closely related to characteristics of the underlying landscape. For example, Matsinos *et al.* (2008) revealed that spatial sound variability in a coastal rural area in Greece was mainly shaped by landscape attributes. In the same rural area, Mazaris *et al.* (2009) pointed out later the interactions between soundscapes and several landscape features. Liu *et al.* (2013b) found that urban soundscape perception also showed a relationship with underlying landscape characteristics. Compared with visual perception, which is related only to the landscape characteristics in viewshed, sounds can propagate and be perceived by humans through the local landscapes even the sound sources are visually hidden. Although the previous studies revealed at an early stage how landscape spatial patterns could affect soundscape perception, their relationship needs to be explored in a more detailed way.

The key aim of this research is therefore trying to do so by examining the soundscape-landscape relationship at a relatively large scale. Concepts from landscape ecology were applied into the soundscape approach, attempting to combine soundscape perception with urban ecological processes, aiming to reveal the relationships: 1) among the perceptual sound categories; 2) between each of the perceptual sound categories and landscape spatial pattern. Urban soundscapes in a multi-functional urban area were subjectively observed and evaluated on specifically defined spatial and temporal scales, in which soundscape was treated as an assembly of different sounds that were perceived by humans (Brown *et al.* 2011). Then based on the characteristics of the urban soundscapes, relationships between the major sound categories and the landscape spatial pattern indices were analysed. If landscape spatial indices could be indicators of soundscape perception, they could be an effective tool for planners and decision makers in creating a better acoustic environment.

1. Methods

1.1. Study area

The study was conducted in a coastal area of the Baltic Sea named Warnemünde, in Rostock, Germany, as shown in Figure 1. The area was chosen because of its rich landscape diversity and multiple land use types. As indicated in Figure 1, the local landscape includes 17

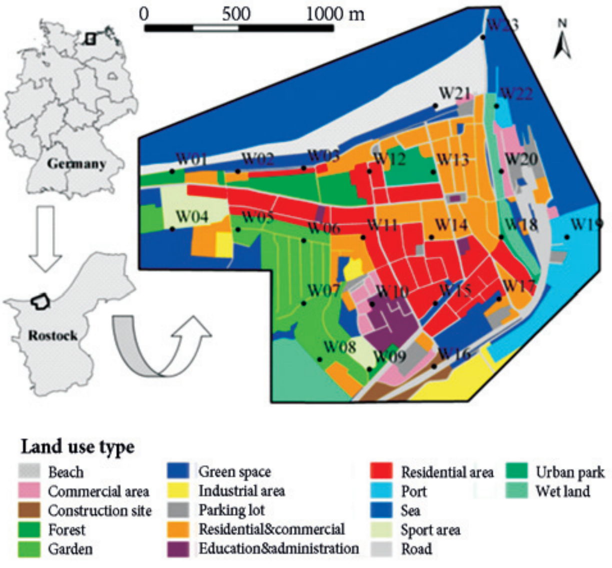

Fig. 1. Location of the study area and the 23 sampled sites (W01–W23), and land use structure of the study area

different types of land use according to the digital topographic-cartographic information system (ATKIS) 2010 from the Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV), and actual on-site situation. Moreover, as a tourist resort, this area is subject to high leisure activity demands especially in summer time. As a result, on the one hand, different urban functions and human activities here generate diverse soundscapes; and on the other hand, different types of landscape appearing in this relatively small area can facilitate the analysis between soundscape perception and landscape spatial patterns on a human scale.

1.2. Soundscape observation and evaluation

Understanding the characteristics of urban soundscapes is the prerequisite of a soundscape-landscape relationship research. Urban sounds that form the urban soundscapes are rich and diverse. In soundscape researches, sounds were usually classified into different categories (Brown *et al.* 2011). In this research, according to the sources and nature of major sounds, urban sounds were decomposed into five major categories, i.e. human, mechanical, traffic, geophysical and biological sound (Table 1). Traffic sound was chosen to be independent from other mechanical sounds mainly because it is more concerned in urban areas.

Table 1. Classification of major sound categories in the study area

Sound category	Major sound	Code
Human sound (Hum)	Children voice	CS
	Adult voice	AS
	Footstep	FS
Mechanical sound (Mech)	Airplane flying	AF
	Bicycle riding	BC
	Bell ringing	BR
	Construction	CT
	Emergency	ES
	Grass mowing	GM
	Music	MS
	Ship moving	SM
	Other mechanical sounds	OA
Traffic sound (Traf)	Train moving	TM
	Traffic sound (foreground)	TSF
	Traffic sound (background)	TSB
	Motorcycle rumbling	MR
Geophysical sound (Geo)	Grass rustling	GR
	Raining	RS
	Sea wave	SW
	Tree rustling	TR
	Wind blowing	WF
	Water sound	WS
Biological sound (Bio)	Bird song	BS
	Chicken clucking	CC
	Dog barking	DB
	Frog	FR
	Insects	IS

Soundscape data was collected by a group of observers in terms of on-site perception and evaluation. Firstly, based on 350*350 m fishnet cells created in ArcGIS 9.1, 23 sites were randomly sampled in the study area (Fig. 1). During a pilot study, major sounds that frequently appear in this area were recognised and coded, as shown in Table 1, as a reference for the observers. A team of 12 people, including 10 students, one audio engineer and one musician conducted the investigation (7 male and 5 females; average age: 26 ± 2.8). All of them went through a training process one month before on-site investigation, to ensure a good inter-user reliability. The training included (a) getting familiar with all the major sounds on the list by presenting videos shot recorded on site; (b) remembering the code names to ensure a fast recording; and (c) performing pilot studies to test the investigation procedure and to minimise observation bias. After the training process, the observers could achieve an average inter-user reliability of 0.91 for loudness evaluation of the five major sound categories. Thus, in order to promote the observation efficiency, the observers were divided into 6 small groups of 2 to work together in responsible for 3 or 4 of the sampled sites (Matsinos *et al.* 2008; Mazaris *et al.* 2009).

Soundscape data were recorded in eight two-hour successive sampled periods in two days, covering main daily active periods in summer time (1st period: 06:00–08:00, 2nd period: 08:00–10:00, 3rd period: 10:00–12:00, 4th period: 12:00–14:00, 5th period: 14:00–16:00, 6th period: 16:00–18:00, 7th period: 18:00–20:00, 8th period: 20:00–22:00). Within each sampled period, a random 10 min sub-set was chosen to carry out the on-site observation-evaluation, which was further divided into twenty sequential time-steps, each of 30 s. The observers filled in a form with recognised sounds, evaluated their perceived loudness by using a five-point linear scale (1 = *very quiet,* 2 = *quiet,* 3 = *normal,* 4 = *loud,* 5 = *very loud*), respectively, and at the end of each time-step, evaluated soundscape preference by using a five-point linear scale (1 = *very pleasant,* 2 = *pleasant,* 3 = *normal,* 4 = *unpleasant,* 5 = *very unpleasant*). Overall 3680 samplings (8*20*23) of urban soundscapes and corresponding preference data were obtained. All the recognised major sounds were reclassified into five sound categories to simplify the analysis process, according to Table 1. The perceived loudness of each sound category and overall soundscape loudness were calculated by accumulating scores.

1.3. Landscape spatial pattern indices

Although landscape metrics are usually used to indicate ecological functions on a large scale, this research is more concerned with their ability to quantify landscape spatial patterns (Corry, Nassauer 2005). Considering that sound generation is more related to the activities in a certain area with particular functions, raster land use map (resolution 1 m) of the study area was used to calculate landscape metrics (Fig. 1). Among the several landscape metrics available, the following landscape metrics that may affect the composition and/or perception of soundscapes were selected. For the landscape composition, metrics used include largest patch index (LPI), patch density (PD) and evenness (SIEI). Landscape configuration was measured according to landscape shape index (LSI), contagion (CONT), and fractal dimension (FRAC). All the metrics mentioned above were calculated in Fragstats software (McGarigal, Marks 1994), based on a 175 m radius buffer area centred on each sampled site, according to some previous studies (Mazaris *et al.* 2009; Liu *et al.* 2013b).

Considering the land cover factors that may influence soundscape generation and/or propagation, another three indices reflecting landscape composition status were introduced, including construction density (CD), road density (RD) and vegetation density. For vegetation density, normalised difference vegetation index (NDVI) was chosen to be the indicator (Liu *et al.* 2013b), and the calculation was based on the Landsat TM image (30 m) on July 27, 2011 from U.S. Geological Survey (USGS). The three indices were also calculated based on the 175 m radius buffer area of each sampled site in ArcGIS 9.1. Table 2 lists all the indices and their descriptions according to McGarigal and Marks (1994).

1.4. Statistical analysis

Based on the daily accumulated perceived loudness of each sound category on each sampled site, interpolation method (regularised spline with tension in GRASS) was used to show the spatial patterns of them across the study area (GRASS Development Team 2008). Kruskal-Wallis independent samples non-parametric test was used to examine the possible differences on perceived loudness of each sound category among 23 sampled sites and among 8 sampled periods. Regression analysis between overall soundscape loudness and loudness of each of the five sound categories by time-step per-period was conducted to find out their relative contributions in different sampled periods. Spearman's roh correlation analysis between perceived loudness of different sound categories and corresponding soundscape preference, among perceived loudness of different sound categories, as well as between perceived loudness of different sound categories and each of the landscape indices were conducted by time-step per-period. Although the landscape indices chosen all have their specific intention, Pearson correlation coefficients among all the landscape pattern indices were calculated too, in order to detect colinearity in landscape indices (Turner, Ruscher 1988). All the statistical analyses were conducted in SPSS 16.0.

Table 2. Indices used to describe the landscape spatial patterns (McGarigal, Marks 1994)

Indices	Acronym	Description
Construction density	CD	Density of buildings of different uses
Road density	RD	Density of main traffic roads
Vegetation density	NDVI	Normalized Difference Vegetation Index. A simple graphical indicator that assess whether the target being observed contains live green vegetation or not
Patch density	PD	Patch density has the same basic utility as number of patches as an index, but facilitates comparisons among landscapes of varying size. It is used as a measure of landscape fragmentation
Landscape shape index	LSI	Landscape shape index can be interpreted as a measure of the total shape complexity of patches, indicating landscape fragmentation status
Largest patch index	LPI	Largest patch index quantifies the percentage of total landscape area comprised by the largest patch. It is a simple measure of dominance
Fractal dimension	FRAC	Area-weighted mean fractal dimension for all patches. It reflects shape complexity of patches. As polygons become more complex, the fractal dimension changes from 1 to 2
Contagion	CONT	It measures the aggregation extent of landscape patches. Higher values may characterise landscapes with a few large, contiguous patches. Lower values might be resulted by many small and dispersed patches formed landscapes
Evenness	SIEI	Simpson's evenness index indicates a structural component of diversity. An even distribution among landscape types results in maximum evenness, and low evenness indicates that either one or just a few elements are dominant

Table 3. Kruskal-Wallis independent samples non-parametric analysis for each sound category by sampled period and sampled site

Sound category	Sampled period		Sampled site	
	χ^2	p	χ^2	p
Hum	43.917	<0.001	85.859	<0.001
Mech	27.929	<0.001	77.525	<0.001
Traf	5.439	0.607	137.55	<0.001
Geo	25.5	0.001	78.555	<0.001
Bio	20.093	0.005	67.981	<0.001

Table 4. Spearman' rho correlation among different sound categories by time-step per-period (*p < 0.05, **p < 0.01)

Period	Sound	Hum	Mech	Traf	Geo
1	Mech	−0.003			
	Traf	−0.212**	−0.340**		
	Geo	−0.242**	0.102*	−0.128**	
	Bio	0.081	−0.245**	0.081	−0.125**
2	Mech	−0.098*			
	Traf	−0.051	−0.394**		
	Geo	0.033	−0.121**	−0.087	
	Bio	−0.05	−0.193**	0.269**	−0.067
3	Mech	0.099*			
	Traf	−0.283**	−0.419**		
	Geo	−0.104*	0.025	−0.069	
	Bio	−0.087	−0.316**	0.194**	0.05
4	Mech	0.043			
	Traf	−0.488**	−0.364**		
	Geo	0.002	−0.116*	−0.004	
	Bio	−0.335**	−0.269**	0.219**	0.086
5	Mech	−0.064			
	Traf	−0.340**	−0.354**		
	Geo	0.106*	0	−0.176**	
	Bio	−0.166**	−0.191**	0.163**	−0.132**
6	Mech	0.06			
	Traf	−0.266**	−0.347**		
	Geo	−0.011	−0.113*	−0.072	
	Bio	−0.201**	−0.261**	0.431**	0.003
7	Mech	0.102*			
	Traf	−0.397**	−0.430**		
	Geo	0.058	−0.031	−0.205**	
	Bio	−0.312**	−0.078	0.157**	−0.139**
8	Mech	0.403**			
	Traf	−0.441**	−0.333**		
	Geo	−0.041	−0.026	−0.269**	
	Bio	−0.293**	−0.332**	0.373**	−0.397**

2. Results

2.1. Urban soundscape characteristics

Correlation analysis showed that soundscape preference was significantly and positively correlated with geophysical sound (correlation coefficient: −0.155) and biological sound (correlation coefficient: −0.106), and negatively correlated with mechanical sound (correlation coefficient: 0.267) and traffic sound (correlation coefficient: 0.238), but there was no significant relationship with human sound. This, corresponding to previous research (Yang, Kang 2005a, b; Nilsson, Berglund 2006), suggests that soundscapes with more natural sounds (biological and geophysical sounds) are more preferable, while too much artificial sounds (mechanical and traffic sounds) could reduce soundscape quality.

Table 3 shows the results of non-parametric analysis of each sound category by sampled period and sampled site. It can be seen that perceived loudness of all five major sound categories had significant differences among both different sampled sites and different sampled periods, except that traffic sound had no significant difference across all sampled periods, indicating a dynamic characteristic of urban soundscape patterns.

Table 4 shows the correlation results among different sound categories by time-step per-period. It can be seen that human sound was negatively correlated with traffic sound and biological sound in seven and five periods, respectively. Mechanical sound was negatively correlated with traffic sound and biological sound in all and seven periods, respectively. Biological sound was positively correlated with traffic sound in seven periods except the first one. Geophysical sound was negatively correlated with biological sound and traffic sound both in four periods, but showed no consistent relationships with other sound categories. It seems that different sound categories were almost mutually exclusive, except that biological sound was not lessened by traffic sound.

Figure 2 shows the contributions of the five sound categories to the overall soundscape loudness during all sampled periods. In general, artificial sounds, namely human, mechanical and traffic sounds dominated the urban soundscapes, while contributions from natural sounds, i.e. geophysical and biological sounds were less to the overall soundscape loudness. It could also be seen from Figure 2 that, contributions of each sound categories to the overall soundscape loudness were changing in different sampled periods, indicating the dynamic temporal pattern of urban soundscapes again.

Figure 3 (map a–e) shows the interpolation results of human, mechanical, traffic, geophysical and biological sounds, respectively. It can be seen that, more human sounds appeared across the beach area, as many local people and tourist concentrated in this area. More mechanical sounds concentrated along the south-eastern and

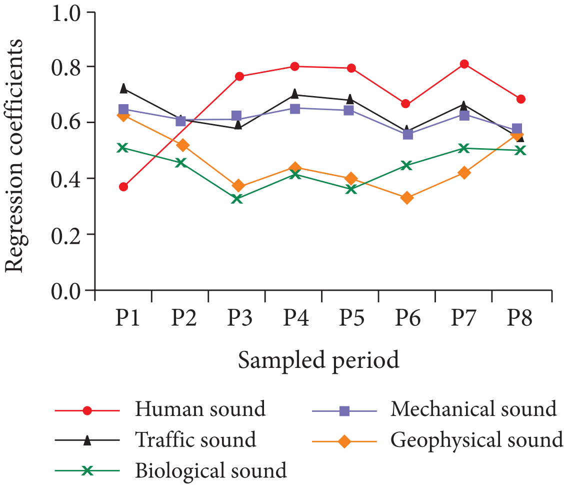

Fig. 2. Contributions of major sound categories to the perceived overall soundscape loudness during all sampled periods (P1–P8)

eastern boundary of the study area, where the rail way passes through and construction work was carried out at site W16. It is clear that traffic sounds concentrated almost along the direction of W09–W15, where the widest traffic road in the study area is located. Geophysical sounds were mainly perceived along the beach area, especially on the two ends, where the sea wave and wind were stronger. More biological sounds appeared in the central and south-eastern parts of the study area, mainly because dense constructions of the residential area form a quiet environment thus prevent fragile biological sounds from masking by other sounds, and dense vegetation of the urban park is ecologically good habitats for vocalising organisms such as birds and insects.

These maps indicate that artificial sounds, i.e. human, mechanical and traffic sounds permeated a larger part of

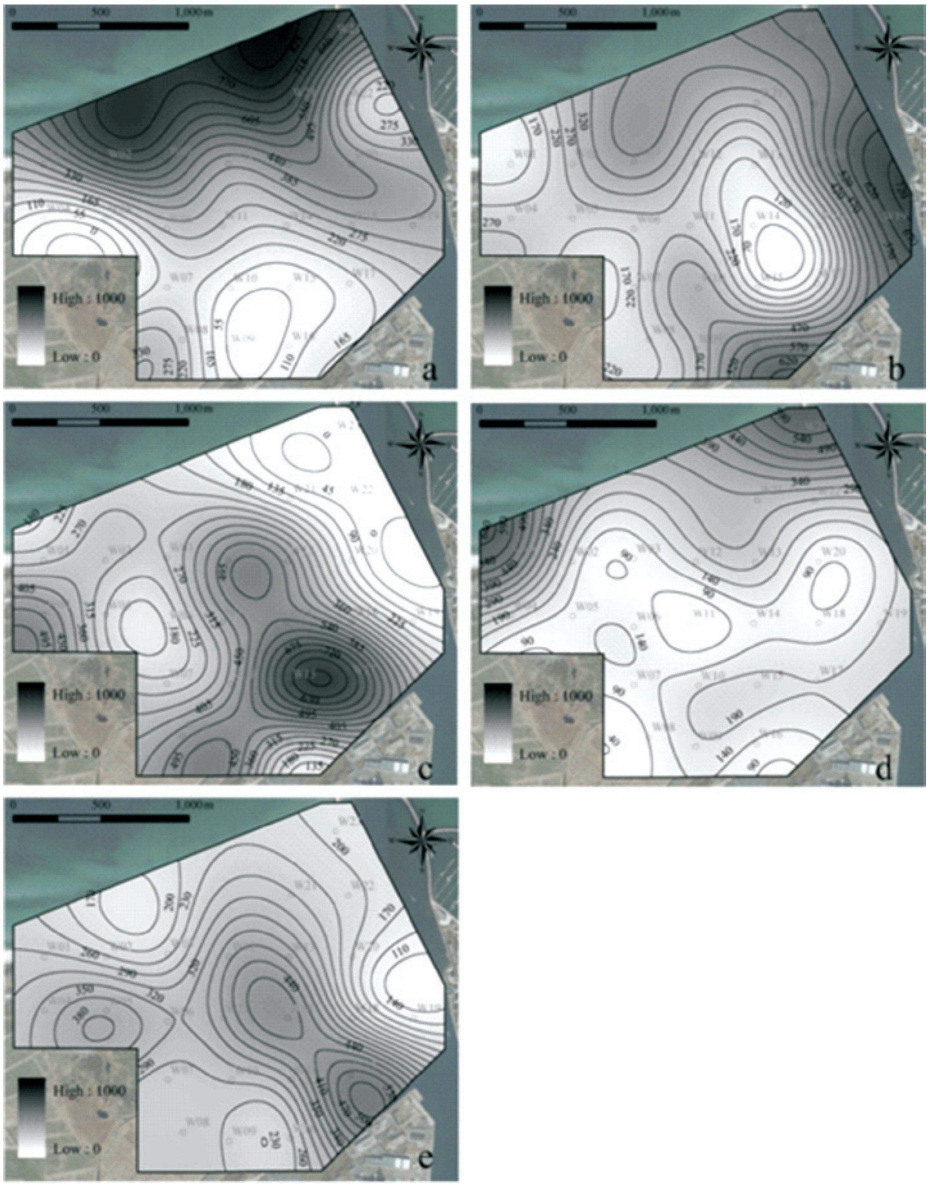

Fig. 3. Daily accumulated perceived loudness of human (a), mechanical (b), traffic (c), geophysical (d) and biological (e) sounds across the study area

the study area and were louder than natural sounds, i.e. geophysical and biological sounds, which show the dominating reality of artificial sounds in urban areas. Dominating areas of each sound category were usually not overlapping, or in other words, different sound category has different spatial arrangement, with an exception of biological and traffic sound, which indicates that biological organisms survived in urban areas may get used to the chronic traffic sound (Brumm 2004). From these maps, the underlying landscape characteristics show obvious relationships with soundscape perception.

2.2. Relationship between soundscape perception and landscape indices

Given the dynamic temporal characteristic of the urban soundscapes, and the stable characteristic of the landscape spatial patterns in the study area in a daily temporal period, the relationships between them were studied in each sampled period. The correlation results between landscape indices and each sound category were shown in Table 5. Though the relationship between the same landscape index and sound category may change in different period as supposed, some relatively stable significant relationships could still be found, i.e. mainly positively or negatively related with certain sound categories in most periods. The results showed that all the landscape indices correlated with at least one of the sound categories, except for patch density. Specifically, CD showed positive relationships with traffic and biological sounds, and negative relationship with geophysical sounds. RD only had stronger positive relationship with traffic sound, and possible negative relationship with geophysical sounds. FRAC showed similar effects with LSI, but stronger relationships were shown with human, traffic, and geophysical sounds. CONT and SIEI showed reverse effects on the same sound categories, namely human, traffic and biological sounds. In particular, NDVI, LSI and LPI showed the most significant relationships with all the five sound categories, making them the most potential "predictors" for soundscape characteristics.

3. Discussion

Landscape indices have several attributes, such as efficient, accessible, easily acquired, fully documented, and applicable to digital data, which make them attractive for planners and designers to apply to several alternative plans (Botequilha-Leitão, Ahern 2002; Corry, Nassauer 2005). Considering that landscape fragmentation is a common result of urbanisation process (Antrop 2004), all the landscape metrics used in this research could to some extent indicate landscape fragmentation pattern from different aspects, i.e. patch size (LPI), shape (LSI, FRAC), distribution (CONT), and heterogeneous status (PD, SIEI) (McGarigal, Marks 1994). The relationships between these indices and perception of different sound categories could be explained as following.

Construction density. Construction density is usually high in urban areas, which may form a kind of acoustic space termed "hi-fi area", a relatively quiet area formed by preventing a large part of sounds from outside (Schafer 1969), which makes it easier for human to recognise more sounds such as biological sounds. As most of the constructions are near traffic roads and form another kind of acoustic space termed "street canyons" to some extent (Table 6) (Kang 2007), this may explain the positive correlation between dense constructions and traffic sound (Table 5). Dense constructions also mean more barriers for geophysical sounds (e.g. tree rustling, grass rustling and wind blowing) before they are perceived, thus may impede the perceived loudness of this kind of sound.

Table 5. Spearman' rho correlation between each of the landscape indices and different sound categories by time-step per-period, where at each cell the number of periods when significant positive or negative correlations existed is given (*p < 0.05, **p < 0.01). See Table 1 and Table 2 for full names of the acronyms

Landscape indices	Positive/Negative				
	Hum	Mech	Traf	Geo	Bio
CD	1**/ 3**, 1*	—/3**	7**/—	—/5**	7**/—
RD	1**/ 3**, 1*	1**, 1*/1**	7**/—	1**/4**	3**/1**, 1*
NDVI	—/7**	—/8**	8**/—	—/8**	4**/—
PD	1**/1**	1*/1**	2*/1*	1**/ 3**, 1*	4**/2*
LPI	5**, 1*/1**	5**,1*/—	—/8**	7**/—	—/6**, 2*
LSI	1**/7**	—/ 4**, 1*	7**,1*/—	—/ 5**, 1*	4**,1*/1*
FRAC	1**/7**	1**/ 2**, 1*	6**/—	—/8**	3**/1**
CONT	7**/—	2**/1*	—/ 7**, 1*	2**/ 1**, 1*	—/ 5**, 1*
SIEI	—/ 2**, 4*	1**, 1*/2**	6**/—	2*/ 2**, 1*	3**, 2*/—

Road density. As the artery of urban areas, traffic roads are one of the main sound sources of urban acoustic environment. The result suggests that higher road density associates with more traffic sound. The possible negative effects on geophysical sound could be indirectly from masking by traffic sound, as they both contain low frequency components. Road effects on other sound categories have no obvious positive or negative trend.

Vegetation density. Vegetation density is indicated by NDVI value, and could act in two aspects in relationship to soundscape perception. On the one hand as sound

Table 6. Pearson correlation among landscape indices (*p < 0.05, **p < 0.01)

Indices	CD	RD	NDVI	PD	LPI	LSI	FRAC	CONTAG
RD	0.521*	1						
NDVI	–0.194	–0.176	1					
PD	0.482*	0.447*	–0.136	1				
LPI	–0.402	–0.274	–0.096	–0.37	1			
LSI	0.536**	0.617**	0.087	0.849**	–0.516*	1		
FRAC	0.365	0.546**	0.092	0.656**	–0.053	0.837**	1	
CONTAG	–0.263	–0.099	0.039	–0.318	0.776**	–0.323	0.059	1
SIEI	0.29	0.083	–0.059	0.271	–0.776**	0.242	–0.152	–0.972**

sources, areas with dense vegetation are usually ecologically good habitats for organisms such as birds and insects, so that dense vegetation may possess rich biological sounds (Gasc *et al.* 2013). As in urban areas traffic roads are usually planned with roadside trees, dense vegetation may also be related to traffic sound, as indicated in this study. On the other hand, dense vegetation could also act as barriers, thus affect sound propagation and perception. As revealed in this study, dense vegetation could minimise the perception of human sound, mechanical sound and geophysical sound.

Largest patch index. LPI indicates land use scale, and high value means existing of certain large scale and dominating land use patch in the landscape. As land use is related to certain activities happening in this area and further determines main sound sources, high LPI values may indicate more perception of certain sounds in the local landscape. In this study, the LPI values were mainly related to land use patches such as residential and commercial mixed area, beach, garden and urban park. As these areas are usually where human outdoor activities concentrate, e.g. chatting, shopping, relaxing and entertainment, it is reasonable that the positive relationships exist between LPI and the perception of human and mechanical sounds. The negative relationship between LPI and biological sound indicated that large areas with too many human activities may frighten off singing birds, for example. High LPI value could also mean less penetration by other land use types, such as traffic roads (Table 6), so that high LPI value is related to less traffic sound.

Landscape shape index and fractal dimension. Both LSI and FRAC could reflect shape complexity of land use patches. Although they are highly correlated, as shown in Table 6, LSI showed more indicating ability than FRAC. As indicated by both of them, complex land use shape may result in more traffic sound and less human and geophysical sounds. A possible reason of this pattern is that, in urban areas roads are usually the boundaries and/or connections of different functional areas, so that land use patches with complex shapes may be surrounded by more traffic roads, and a landscape penetrated by more roads could result in high landscape shape complexity. This point could also be verified by the positive relationships between road density and both LSI and FRAC (Table 6). As for human sound, since LSI (also FRAC) and LPI are negatively correlated and human sound was perceived more in certain large functional areas as indicated by LPI, it was reasonable in this case that less human sound was perceived in landscapes with high LSI and FRAC values and relatively small scale land use patches. For geophysical sound, either from far distance (e.g. sea wave) or sound caused by wind (e.g. tree or grass rustling), high LSI and FRAC means more “boundaries” during propagation before they are perceived, thus negative relationships between them were shown.

Contagion and Simpson’s evenness index. CONT indicates the spatial distribution of land use patches, while SIEI indicates the distribution of diverse land use types in terms of structural component. They are highly negatively correlated, and both correlated with LPI (Table 6). It is suggested again that landscape with one large functional area could reduce the perception of traffic sound, and if there are a few large patches, they should be better contiguously and evenly distributed. This way of land use arrangement in planning could largely reduce the length of traffic roads as boundaries and/or connections among land use patches. However, biological sound require a total different pattern if more of them to be perceived, i.e. landscape with diverse and scattered land use types, since in this case biological organisms like birds could have more chance to find suitable habitats in a heterogeneous landscape (Andren 1994). Of course, landscapes with a large area of contiguous green areas would be definitely better for biological organisms, but at the scale of this research, this point could not be revealed.

It needs to be noted that, the relationships between the landscape spatial pattern indices and perceptual sound categories in this study were analysed at a relatively small scale. Thus, the effectiveness of certain landscape indices as soundscape indicators at larger scales still needs to be testified. Moreover, more landscape indices are available in the field of landscape ecology, and they could be further explored for soundscape evaluation. On the other hand, because parameters of soundscape quality have not yet come to a general accepted standard, the method of treating soundscape as an assembly of different meaningful sounds perceived by a certain user group as in this study could be adjusted in practical planning process by considering a more detailed user profile (Yu, Kang 2008, 2010; De Coensel *et al.* 2010).

Conclusions

The work shows how soundscape perception might be related to landscape spatial pattern. Based on the assumption that sound categories play a decisive role in soundscape perception, urban soundscapes were analysed in terms of five major sound categories. It has been found that:

1. Urban soundscapes were characterised by artificial sounds (human, mechanical and traffic sounds), overwhelming the natural ones (biological and geophysical sounds) which were more preferred by the observers.

2. Major sound categories were normally mutually exclusive and dynamic on a temporal scale, and have different spatial arrangement on a spatial scale. However, biological and traffic sounds seem to be co-existing on both temporal and spatial scales.

3. Significant correlations have been revealed between perception of major sound categories and a number of landscape spatial pattern indices, including vegetation density (NDVI), construction density (CD), road density (RD) and fragmentation status resulted from scale (LPI), shape (LSI, FRAC), composition (SIEI) and distribution (CONT) characteristics of different land use patches. Especially, NDVI, LSI, and LPI showed the most effective indicating ability.

4. As landscape spatial pattern indices are all quantitative, they could be adopted to compare different plans in terms of creating a better soundscape.

Acknowledgments

The authors would like to thank all the participants who were involved in the field work. The PhD research of the first author is supported by the German Academic Exchange Service (DAAD) and COST Action TD0804 (Short Term Scientific Mission). This project was also financed by Foundations in China (40971111; 51378139; 20112302110045; 2013BAJ12B02).

References

Adams, M.; Cox, T.; Moore, G.; Croxford, B.; Refaee, M.; Sharples, S. 2006. Sustainable soundscapes: noise policy and urban experience, *Urban Studies* 43(13): 2385–2398. http://dx.doi.org/10.1080/00420980600972504

André, M.; Solé, M.; Lenoir, M.; Durfort, M.; Quero, C.; Mas, A.; Lombarte, A.; van der Schaar, M.; López-Bejar, M.; Morell, M.; Zaugg, S.; Houégnigan, L. 2011. Low-frequency sounds induce acoustic trauma in cephalopods, *Frontiers in Ecology and the Environment* 9(9): 489–493. http://dx.doi.org/10.1890/100124

Andren, H. 1994. Effects of habits fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review, *OIKOS* 71: 355–366.

Antrop, M. 2004. Landscape change and the urbanization process in Europe, *Landscape and Urban Planning* 67(1–4): 9–26. http://dx.doi.org/10.1016/S0169-2046(03)00026-4

Botequilha-Leitão, A.; Ahern, J. 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning, *Landscape and Urban Planning* 59(2): 65–93. http://dx.doi.org/10.1016/S0169-2046(02)00005-1

Brambilla, G.; Maffei, L. 2006. Responses to noise in urban parks and in rural quiet areas, *Acta Acustica united with Acustica* 92(6): 881–886.

Brambilla, G.; Maffei, L. 2010. Perspective of the soundscape approach as a tool for urban space design, *Noise Control Engineering Journal* 58(5): 532–539. http://dx.doi.org/10.3397/1.3484180

Brown, A. L.; Kang, J.; Gjestland, T. 2011.Towards standardising methods in soundscape preference assessment, *Applied Acoustic* 72: 387–392. http://dx.doi.org/10.1016/j.apacoust.2011.01.001

Brumm, H. 2004. The impact of environmental noise on song amplitude in a territorial bird, *Journal of Animal Ecology* 73: 434–440. http://dx.doi.org/10.1111/j.0021-8790.2004.00814.x

Butkus, D.; Januševičius, T. 2011. Acoustic investigations of the exterior and interior wall of a log house, *Journal of Environmental Engineering and Landscape Management* 19(2): 140–147. http://dx.doi.org/10.3846/16486897.2011.580919

Corry, R. C.; Nassauer, J. I. 2005. Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs, *Landscape and Urban Planning* 72: 265–280. http://dx.doi.org/10.1016/j.landurbplan.2004.04.003

De Coensel, B.; Bockstael, A.; Dekoninck, L.; Botteldooren, D.; Schulte-Fortkamp, B.; Kang, J.; Nilson, M. E. 2010. The soundscape approach for early stage urban planning: a case study, in *Internoise 2010*, 13–16 June 2010, Lisbon, Portugal.

De la Fuente de Val, G.; Atauri, J. A.; de Lucio, J. V. 2006. Relationship between landscape visual attributes and spatial pattern indices: a test study in Mediterranean-climate landscapes, *Landscape and Urban Planning* 77: 393–407. http://dx.doi.org/10.1016/j.landurbplan.2005.05.003

De Ruiter, E. 2004. *Reclaiming land from urban traffic noise impact zones – the great canyon*: Dissertation. Technical University of Delft.

Dramstad, W. E.; Tveit, M. S.; Fjellstad, W. J.; Fry, G. L. A. 2006. Relationships between visual landscape preferences and map-based indicators of landscape structure, *Landscape and Urban Planning* 78: 465–474. http://dx.doi.org/10.1016/j.landurbplan.2005.12.006

Gasc, A.; Sueur, J.; Jiguet, F.; Devictor, V.; Grandcolas, P.; Burrow, C.; Depraetere, M.; Pavoine, S. 2013. Assessing biodiversity with sound: do acoustic diversity indices reflect phylogenetic and functional diversities of bird communities?, *Ecological Indicators* 25: 279–287. http://dx.doi.org/10.1016/j.ecolind.2012.10.009

Genuit, K.; Fiebig, A. 2006. Psychoacoustics and its benefit for the soundscape approach, *Acta Acustica united with Acustica* 92(6): 952–958.

GRASS Development Team. 2008. *Open Source Geospatial Foundation Project: Geographic Resources Analysis Support System (GRASS) Software* [online], [cited on 20 November 2011]. Available from Internet: http://grass.osgeo.org.

Guastavino, C. 2006. The ideal urban soundscape: investigating the sound quality of French cities, *Acta Acustica United Acustica* 92: 945–951.

Joo, W.; Gage, S. H.; Kasten, E. P. 2011. Analysis and interpretation of variability in soundscape along an urban-rural gradient, *Landscape and Urban Planning* 103: 259–276. http://dx.doi.org/10.1016/j.landurbplan.2011.08.001

Kang, J. 2007. *Urban sound environment*. London: Taylor & Francis incorporating Spon. 304 p.

Kang, J.; Zhang, M. 2010.Semantic differential analysis of the soundscape in urban open public spaces, *Building Environment* 45(1): 150–157. http://dx.doi.org/10.1016/j.buildenv.2009.05.014

Kull, R. C. 2006. Natural and urban soundscapes: the need for a multi-disciplinary approach, *Acta Acustica United with Acustica* 92(6): 898–902.

Lavandier, C.; Defreville, B. 2006. The contribution of sound characteristics in the assessment of urban soundscapes, *Acta Acustica United with Acustica* 92(6): 912–921.

Liu, J.; Kang, J.; Luo, T.; Behm, H. 2013a. Landscape effects on soundscape experience in city parks, *Science of the Total Environment* 454–455: 474–481. http://dx.doi.org/10.1016/j.scitotenv.2013.03.038

Liu, J.; Kang, J.; Luo, T.; Behm, H.; Coppack, T. 2013b. Spatiotemporal variability of soundscapes in a multiple functional urban area, *Landscape and Urban Planning* 115: 1–9. http://dx.doi.org/10.1016/j.landurbplan.2013.03.008

Matsinos, Y. G.; Mazaris, A. D.; Papadimitriou, K. D.; Mniestris, A.; Hatzigiannidis, G.; Maioglou, D.; Pantis, J. D. 2008. Spatio-temporal variability in human and natural sounds in a rural landscape, *Landscape Ecology* 23: 945–959. http://dx.doi.org/10.1007/s10980-008-9250-7

Mazaris, A. D.; Kallimanis, A. S.; Chatzigianidis, G.; Papadimitriou, K. D.; Pantis, J. D. 2009. Spatiotemporal analysis of an acoustic environment: interactions between landscape features and sounds, *Landscape Ecology* 24: 817–831. http://dx.doi.org/10.1007/s10980-009-9360-x

McGarigal, K.; Marks, B. J. 1994. *Fragstats– spatial analysis program for quantifying landscape structure*. USDA Forest Service, General Technical Report PNW-GTR-351, Corvallis, OR.

Nilsson, M. E.; Berglund, B. 2006.Soundscape quality in suburban green areas and city parks, *Acta Acustica United with Acustica* 92(6): 903–911.

Palmer, J. F. 2004. Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts, *Landscape and Urban Planning* 69: 201–218. http://dx.doi.org/10.1016/j.landurbplan.2003.08.010

Paožalytė, I.; Grubliauskas, R.; Vaitiekūnas, P. 2012. Modelling the noise generated by railway transport: statistical analysis of modelling results applying CADNAA and IMMI programs, *Journal of Environmental Engineering and Landscape Management* 20(3): 206–212. http://dx.doi.org/10.3846/16486897.2012.663090

Pheasant, R.; Horoshenkov, K.; Watts, G. 2008. The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments tranquil spaces-quiet places?, J*ournal of the Acoustical Society of America* 123(3): 1446–1457. http://dx.doi.org/10.1121/1.2831735

Pijanowski, B. C.; Farina, A.; Gage, S. H.; Dumyahn, S. L.; Krause, B. L. 2011. What is soundscape ecology? An introduction and overview of an emerging new science, *Landscape Ecology* 26: 1213–1232. http://dx.doi.org/10.1007/s10980-011-9600-8

Raimbault, M.; Dubois, D. 2005.Urban soundscapes: experiences and knowledge, *Cities* 22(5): 339–350. http://dx.doi.org/10.1016/j.cities.2005.05.003

Schafer, R. M. 1969. *The new soundscape: a handbook for the modern music teacher*. BMI, Don Mills, Canada.

Schulte-Fortkamp, B.; Fiebig, A. 2006. Soundscape analysis in a residential area: an evaluation of noise and people's mind, *Acta Acustica United with Acustica* 92(6): 875–880.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process, *Annual Review of Ecology and Systematics* 20: 171–197.

Turner, M. G.; Gardner, R. H.; O'Neill, R. V. 2001. *Landscape ecology in theory and practice: pattern and process*. NY, Berlin, Heidelberg: Springer-Verlag. 406 p.

Turner, M. G.; Ruscher, C. L. 1988. Changes in landscape patterns in Georgia, USA, *Landscape Ecology* 1(4): 241–251. http://dx.doi.org/10.1007/BF00157696

Uuemaa, E.; Mander, Ü.; Marja, R. 2012. Trends in the use of landscape spatial metrics as landscape indicators: a review, *Ecological Indicators* 28: 100–106. http://dx.doi.org/10.1016/j.ecolind.2012.07.018

Yang, W.; Kang, J. 2005a. Soundscape and sound preferences in urban squares: a case study in Sheffield, *Journal of Urban Design* 10(1): 61–80. http://dx.doi.org/10.1080/13574800500062395

Yang, W.; Kang, J. 2005b. Acoustic comfort evaluation in urban open public spaces, *Applied Acoustic* 66(2): 211–229. http://dx.doi.org/10.1016/j.apacoust.2004.07.011

Yu, L.; Kang, J. 2008. Effects of social, demographic and behavioral factors on sound level evaluation in urban open spaces, *Journal of the Acoustical Society of America* 123(2): 772–783. http://dx.doi.org/10.1121/1.2821955

Yu, L.; Kang, J. 2010. Factors influencing the sound preference in urban open spaces, *Applied Acoustic* 71(7): 622–633. http://dx.doi.org/10.1016/j.apacoust.2010.02.005

Zhang, M.; Kang, J. 2007. Towards the evaluation, description and creation of soundscape in urban open spaces, *Environment and Planning B: Planning and Design* 34(1): 68–86. http://dx.doi.org/10.1068/b31162

Jiang LIU finished his PhD at the faculty of Agricultural and Environmental Sciences, University of Rostock, Germany, and is recently a guest research at the School of Architecture, University of Sheffield. He has published 8 refereed journal papers. His research interest is on soundscapes in relation to landscape planning and design.

Jian KANG has been Professor of Acoustics at the University of Sheffield, School of Architecture since 2003. He obtained his PhD from the University of Cambridge. He has published 3 books, over 200 refereed journal papers and book chapters, and over 600 conference papers and technical reports.

Holger BEHM is an Apl. Professor at the Faculty of Agricultural and Environmental Sciences, University of Rostock, Germany. He has published more than 70 refereed journal papers. His research interest is in landscape planning and historical landscape management.

Tao LUO is an Associate Professor at the Institute of Urban Environment, Chinese Academy of Sciences. He obtained his PhD from the University of Rostock. His research interest is in regional sustainable development planning and landscape planning, landscape and environmental evaluation.