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Research on Urban Soundscapes in Relation to Landscape and Urban Planning: Case studies in Germany and China

Thesis

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Submitted by:
M. Sc. Jiang Liu
Hebei, China

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Gutachter:

1. Gutachter:
   Prof. Dr. Holger Behm
   Universität Rostock, AUF, Landschaftsplanung und Landschaftsgestaltung
2. Gutachter:
   Prof. Dr. Jian Kang
   University of Sheffield, Sheffield School of Architecture
3. Gutachter:
   Vice. Prof. Dr. Tao Luo
   Chinese Academy of Science, Institute of Urban Environment

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Abstract

The aim of this thesis is to explore the relationship between soundscape and underlying landscape in urban context, in order to improve the urban ecosystem service function of soundscapes through a landscape and urban planning approach. Soundscape-landscape relationship was studied on two scales, i.e. in a multi-functional urban area, and in typical functional areas—city parks, based on case studies in Germany and China, respectively.

Through reviewing research progress in urban acoustic environment, multiple disciplinary soundscape studies, and research on interaction between soundscape and landscape, a systematic methodology is set up for soundscape-landscape relationship study in urban context.

The core of this thesis is in two parts. Part I, "Soundscape and Landscape in a Multi-Functional Urban Area", focusing on soundscape characteristics and the soundscape-landscape relationship in a larger scale. The investigation was conducted by a group of 12 observers who took a special training process in advance to guarantee the "objectivity" of the soundscape dataset. With a specifically designed spatial and temporal scale (23 sampled sites and 8 sampled periods), a soundscape database with 3680 pieces of subjective soundscape recordings was established. Part II, "*Soundscape and Landscape in Typical Urban Open Spaces—City Parks*", focuses on the soundscape-landscape relationship in city parks, typical urban open spaces. Two investigations were conducted in five city parks in Xiamen, China to examine the landscape effects from visual, function, and physical aspects on soundscape experience or perception. The first investigation is based on the questionnaire information gathered from the general public, focusing on the visual and functional landscape effects on soundscape experience; and the second investigation is specifically designed soundwalks in the same city parks by a group of observers, focusing on physical landscape effect on soundscape perception. Major findings include:

(1) Urban soundscapes were dominated by anthrophony and showed a diverse spatiotemporal pattern because of the ever changing soundscape elements. Temporal variation of the three main-class sounds indicated a competitive relationship. It is also necessary to analyse the urban soundscapes with a more detailed classification of soundscape categories, i.e. on middle- and sub-class level. Thematic soundscape mapping is a useful method to reveal spatiotemporal characteristics of different soundscape elements.

(2) Significant relationships between landscape indices and soundscape elements were recognised on the three soundscape category levels. Influential landscape characteristics

on soundscape perception were extracted, including building (indicated by building density and distance to building), road (indicated by road density and distance to road), vegetation (indicated by NDVI), land use scale (indicated by largest patch index), land use shape (indicated by landscape shape index and fractal dimension), land use composition (indicated by patch density and Shannon diversity index), and land use distribution (indicated by contagion). Among these indices, building density, distance to building, vegetation density, largest patch index and landscape shape index show the most influential relationships with all the five middle-class sounds, making them the most powerful indicators for soundscape perception.

(3) An important and positive role of birdsong in urban soundscape perception was recognised. The analysis of the relationships between birdsong perception and other sounds suggests that, although birds could get used to the chronic urban traffic sounds, excessive sounds related to human appearance (adult voice, child voice and footstep) or human activities (construction sounds, music) could still frighten birds off. The spatiotemporal patterns of perceived loudness of birdsong suggest the adapted patterns of bird species in urban areas. A series of landscape indices were found in close relationships with loudness perception of birdsong, including construction density, vegetation density (NDVI), road density, distance to main road, patch density (PD), landscape shape index (LSI), fractal dimension (FRAC), largest patch index (LPI), and contagion (CONT).

(4) Effects of visual landscape on perception of individual sounds could be more reflected in natural sounds than artificial sounds and more in perceived occurrence of individual sounds than preference for individual sounds, while for functional landscape the effects are reversed. In general, landscape effects on perception of individual sounds are more significant in terms of perceived occurrence of individual sounds than preference for individual sounds. Landscape effects on overall soundscape preference are more reflected by artificial sounds than natural sounds, and are seen more in relation to preference for individual sounds. Taking effects of social, demographical and behavioural factors into consideration, landscape effects are still significant. Specifically, visual landscape shows significant effects on perceived occurrence of individual sounds, and is more effective than functional landscape. Both landscape factors show equal effects on preference for individual sounds, and they are highly related with the overall soundscape preference.

(5) Based on the specifically designed soundwalk approach, soundscape perception parameters including perceived loudness of individual sound (PLS), perceived occurrence of individual sound (POS), and soundscape diversity index (SDI) were introduced. Analyse of their relationships showed that the three parameters are correlated and should be used together to illustrate soundscape characteristics. Specifically, PLS and POS of biological and geophysical sounds could be affected by

PLS and POS of the other three kind of sounds, including human, traffic and mechanical sounds, indicating the disadvantage of natural sounds in the soundscape perception process. SDI is mainly related to human sounds, which shows their dominating position in the parks.

(6) Building, vegetation and sky are the three effective physical landscape elements in terms of on-site landscape composition on soundscape perception. In particular, building is only an effective variable for artificial sounds (human and mechanical sounds). Vegetation is an explanatory variable for mechanical and biological sounds in the study, and it is also the only variable related to the overall soundscape perception. Sky is an effective variable for both human and geophysical sounds, and it is also the only variable positively related to natural sound perception.

(7) Physical landscape effects on soundscape perception in terms of landscape spatial pattern showed that, the landscape shape index of building and water (LSI_B, LSI_W) and the patch cohesion index of water (COHESION_W) 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 road (PLAND_R) and the largest patch index of road (LPI_R). 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 (LPI_W) and the landscape shape index of building (LSI_B), respectively, whilst POS of biological sounds are positively related to the percentage of road (PLAND_R) and the landscape shape index of road (LSI_R). The patch cohesion index of road (COHESION_R) is the only index negatively related to both PLS and POS of geophysical sounds. The relationships with overall soundscape perception parameter shows that soundscape diversity index only shows positive relationship with water as indicated by PLAND_W.

It is expected that this thesis will be of practical value for the landscape and urban planning process.

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Chapter 1 Introduction

At a time when technological progress is bringing city sounds to the threshold of bedlam it is no longer sufficient to design environments that satisfy the eye alone.——Michael Southworth

1.1 Research background

Sound is one of the most important cues used by humans to perceive environmental condition and to communicate with other people (Yang and Kang, 2005a). In urban areas, people are usually exposed to excessive mechanical noise, which seriously affects our life quality and physical wellbeing (Chuengsatiansup, 1999; Öhrström et al., 2006; Skånberg and Öhrström, 2002). Plenty of efforts have been made by different disciplines especially urban environmental acoustics on problematic issues, such as traffic noise, noise propagation, vibrations, and noise annoyance, etc. EU directive on the Assessment and Management of Environmental Noise (EC 2002/49) also aims to introduce methods for assessing and controlling noise and reducing its effects particularly on human heal (Öhrström et al., 2006). However, most of studies focused only on the negative aspect of urban acoustic environment, using the term "noise". The positive sounds which could form a pleasant acoustic environment are usually overlooked.

The soundscape approach is advocated by more and more researchers, as it breaks the limitation of physical measurement of the acoustic environment, and considers more about physical, social, and psychological factors in human perception of the acoustic environment. Especially, in the area of urban acoustics, combining soundscape concept into planning process is thought to be a most effective and practical way to realise a better acoustic environment (Adams et al., 2006; De Coensel et al., 2010; Guastavino, 2006; Raimbault and Dubois, 2005). In terms of planning, urban planners think that "how to conceive and design desirable soundscapes" was more important than "a simple decrease of noise level or the elimination of noises" (Raimbault and Dubois, 2005). However, how could planners and decision makers easily apply the soundscape information into landscape and urban planning practice is still need to be considered, which is based on understanding the complex relationship between soundscape and landscape.

Therefore, in this thesis, the relationship between soundscape and landscape in urban contexts is studied on two scales from different approach. It is believed that this study will shorten the gap between soundscape and landscape, help planner create pleasant soundscapes in urban areas.

1.2 Aim of the study

The aim of this thesis is to explore the relationship between soundscape and underlying landscape in urban context, in order to improve the urban ecosystem service function of soundscapes through a landscape and urban planning approach. Soundscape-landscape relationship was studied on two scales, i.e. in a multi-functional urban area, and in typical functional areas—city parks. On-site soundscape information was collected with a similar method in all case studies, in order to acquire the "objective" and consistent data. Soundscape information from the general public was also collected from the city parks. Landscape physical, visual and functional characteristics are the three key factors considered affecting soundscape perception in this study. As the most concerned factor, landscape physical characteristics in terms of landscape spatial pattern are studied on both of the two scales. Based on these dataset, the detailed research objectives are:

(1) Reveal spatiotemporal characteristic of urban soundscape in a multi-function urban area at different levels of soundscape category;
(2) Generate thematic soundscape maps associated with Geographical Information Systems (GIS);
(3) Analyse the relationships between soundscape perception and landscape spatial pattern indicated by land use/cover data, and recognise potential landscape indices as indicators of soundscape information;
(4) Identify the role of birdsong played in urban soundscapes, its spatiotemporal characteristics, and the relationship birdsong perception and landscape patterns;
(5) Examine the visual and functional landscape effects on soundscape experience of the users in city parks, in comparison with the effects of social, demographical and behavioural factors;
(6) Introduce soundscape perception parameters based on a specific soundwalk approach and analyse their relationships;
(7) Reveal the effects of physical landscape on soundscape perception in city parks; and
(8) Explore the way to combine soundscape information into practical landscape management.

1.3 Thesis outline

Chapter 2, '*Research Progress'*, reviews the soundscape concept as a new approach in urban acoustic environment study; soundscape as a novel aspect of urban ecosystem services; previous soundscape studies, including the pioneering soundscape researches, recently multiple disciplinary approaches, and the up-to-date proposal of soundscape ecology concept; and research focuses on relationship between soundscape and landscape. Through the review, the methodology of soundscape study is set out, and a theoretical framework of soundscape-landscape relationship study is summarized. The thesis is then presented in two parts of cases studies on different scales.

Part I: Soundscape and Landscape in a Multi-functional Urban Area

In part I of the thesis, results of a project conducted in a multi-functional urban area in Rostock, Germany will be presented. Discussion is focused on three major aspects: spatiotemporal characteristic of urban soundscape, relationship between soundscape perception and landscape spatial pattern, and typical urban soundscape element birdsong.

Chapter 3, '*Methodology for the Field Survey in Germany*', describes the methodology used for the on-site investigation of urban soundscapes and the analysis methods used in the study.

Chapter 4, '*Spatiotemporal Characteristics of Urban Soundscapes*', focused on the spatiotemporal change of soundscapes in the studied multi-functional urban area in terms of three different levels' classification of soundscape composition. The discussion examines: classification of urban soundscape elements; spatiotemporal characteristics of main-calss, sub-class, and middle-class sounds; how the spatiotemporal characteristics could be reveal by thematic soundscape mapping; and the relationships between soundscape elements and soundscape preference.

Chapter 5, '*Soundscape Perception and Landscape Spatial Pattern*', focuses on the relationship between soundscape perception and landscape spatial pattern. The discussion falls into three parts: relationship between soundscape composition and underlying landscape based on the empirical data; the relationships between soundscape perception and several landscape indices based on statistical analysis on three different levels; and acquisition and application of soundscape information for planning purpose.

Chapter 6, '*Birdsong as a Typical Urban Soundscape Element*', pay special attention to birdsong. The discussion falls into four parts: the role of birdsong in urban soundscapes; the relationships between loudness perception of birdsong and other soundscape elements; spatiotemporal characteristics of birdsong perception combined with thematic mapping techniques; and the landscape characteristics that may affect birdsong perception.

PART Ⅱ: Soundscape and Landscape in Typical Urban Open Spaces—City Parks

In part Ⅱ of the thesis, results of a project conducted in five city parks in Xiamen, China will be presented. Two investigations were conducted to examine the landscape effects from visual, function, and physical aspects on soundscape experience or perception. The first investigation was based on the information gathered from the general public, and the second investigation was specifically designed soundwalks by a group of observers. Part II of the thesis contains three chapters:

Chapter 7, '*Methodology for the Field Survey in China*', describes the methodology used for questionnaire survey and soundwalks and the analysis methods used in the studies.

Chapter 8, '*Landscape Effects on Soundscape Experience in city parks*', presents the results of the first investigation in the five city parks. The discussion includes: soundscape characteristics in the city parks; the effects of landscape factors from visual and functional aspects on soundscape experience of the general public; effects of other social, demographical and behavioural factors on soundscape experience; and comparison of the effects from all the factors on soundscape experience.

Chapter 9, '*Landscape Effects on Soundscape Perception in city parks*', presents the results of the second investigation in the five city parks. Firstly, three soundscape perception parameters are extracted from the soundscape dataset from the specifically designed soundwalks in the five city parks, and the relationships among these soundscape perception parameters are analysed. Then the discussion falls into three parts: effects from physical landscape in term of on-site landscape composition and local landscape spatial pattern on soundscape perception; combination of soundscape information from the two sources, namely the general public and the soundwalks; and soundscape information for practical landscape management.

Finally, in Chapter 10, '*Conclusions and future work'*, the contributions of the study are summarised in terms of soundscape theory, study methodology, and soundscape information for practice. Suggestions for further studies are also made.

Chapter 2 Research Progress

This chapter aims to set up a systematic framework and methodology for soundscape-landscape relationship study in urban contexts. Section 2.1 reviews the soundscape concept as a new approach in urban acoustic environment study, and it is argued that soundscape should be considered as a novel aspect of urban ecosystem services. Section 2.2 reviews previous soundscape studies, including the pioneering soundscape researches, recently multiple disciplinary approaches, and the up-to-date proposal of soundscape ecology concept. The methodology of soundscape study is set out based on the review. To help understanding the relationship between soundscape and landscape, section 2.3 further reviews some researches focus on this topic. Finally, in section 2.4 a theoretical framework of soundscape-landscape relationship study is summarized.

2.1 Urban acoustic environment

2.1.1 Studies on urban acoustic environment

Urbanization is a pervasive and rapidly growing form of land use change from rural or natural landscape into urban and industrial ones, resulting the highly dynamic, complex and multifunctional landscapes (Antrop, 2004). Urban areas are generally characterized by intensive anthropogenic disturbance to the natural surroundings. Urban acoustic environments are thus pervaded with anthropogenic sounds, usually resulting in noise pollution which affects natural organisms as well as human wellbeing (André et al., 2011; Öhrström et al., 2006; Skånberg and Öhrström, 2002). A great and growing environmental problem in urbanized areas is noise from transport (Gidlöf-Gunnarsson and Öhrström, 2007).

Therefore, noise reduction has been the focus of most urban acoustic environment studies (Ouis, 2001). The overall sound level measured, for example, by the equivalent continuous sound level, L_{eq} has been widely used to analyse relationships between annoyance and noise exposure (Ali and Tamura, 2003; Arana and García, 1998; Kryter, 1982; Miedema and Vos, 1998; Schultz, 1978). A-weighted sound pressure level (L_{Aeq}) is also commonly used in regulations, such as guideline values from the World Health Organization for community noise in specific environments (Berglund et al., 1999; Kang, 2007). However, 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, as the physical parameters such as L_{Aeq} ignore to a certain extent the physiological and psychological consequence on human (Raimbault and Dubois, 2005). Besides, despite much effort in noise control, there is currently less knowledge on those sound elements that might contribute positively to an ideal urban acoustical environment (Botteldooren et al., 2009). These elements, such as bird song, have the potential to affect the overall acoustical impression of the environment and to reflect environmental condition, but their role in providing ecosystem services in noise management of urban areas has so far been neglected.

2.1.2 Soundscape as an objective approach of urban acoustics

The concept of the "soundscape" was firstly introduced by Schafer as the "auditory properties of a landscape", and defined as the total of the sounds from a particular environment that reaches the human ear (Schafer, 1969, 1977a). The soundscape concept focuses not only on the negative aspects of the sonic environment, noise, but also on the positive aspects, and considering about physical, social, and psychological factors in human perception of the acoustic environment. Thus it is thought of as an alternative approach to exclusively quantitative approaches, to overcome the limits of noise annoyance indicators, and to handle more general concepts of sound quality (Adams et al., 2006; Davies et al., 2013; Guastavino, 2006; Stockfelt, 1991). Although soundscape researches have been conducted by many researchers from different disciplines, the definition of the term soundscape is itself not yet standardised. Table 2.1 shows some of the definitions of soundscape by different researchers.

Table 2.1 Definitions of soundscape used in the literature c.f. (Pijanowski et al., 2011b)

Schafer: "the soundscape is any acoustic field of study…We can isolate an acoustic environment as a field of study just as we can study the characteristics of a given landscape. However, it is less easy to formulate an exact impression of a soundscape than of a landscape" (p.7). The soundscape can be any defined acoustic environment (Schafer, 1994).
Krause: all of the sounds (biophony, geophony and anthrophony) present in an environment at a given time, soundscape as a finite resource- competing for spectral space (niche hypothesis) (Krause, 1987, 2002).
Farina: the collection of sounds associated with a given landscape as perceived by organisms (eco-field hypothesis) (Farina, 2006).
Schulte-Fortkamp and Fiebig: Soundscapes can be described as environments of certain sound sources and the way people feel about those sounds contributing to the identity of those residential areas (Schulte-Fortkamp and Fiebig, 2006).
Brown et al.: The totality of all sounds within a location with an emphasis on the relationship between individual's or society's perception of, understanding of and interaction with the sonic environment (Brown et al., 2011).
Pijanowski, Farina et al.: The collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and which vary over space and time reflecting important ecosystem processes and human activities (Pijanowski et al., 2011b).

Combining the different understandings of the concept, soundscape could refer to 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. There are two important points in this definition. Firstly, soundscape is about human perception. Soundscapes are perceived by humans, and shaped by neural and psychological attributes rather than by physical parameters (Matsinos et al., 2008). Physical parameters such as A-weighted sound pressure level (L_{Aeq}) alone cannot sufficiently describe soundscapes that humans really perceive (Genuit and Fiebig, 2006). Thus, psychological methods have been widely used in soundscape studies, in which different sounds were usually perceived or recalled by human raters (Dubois et al., 2006; Jeon et al., 2010; Kang and Zhang, 2010; Lavandier and Defréville, 2006; Matsinos et al., 2008; Mazaris et al., 2009; Yang and Kang, 2005a, 2005b). Secondly, soundscape cannot be isolated from landscape. Soundscapes are always emanated in a place, where the landscape characteristics may have a decisive effect on the soundscape characteristics and human perception (Schafer, 1994). Soundscapes should always be studied in relation to specific locations and contexts.

2.1.3 Soundscape as a novel aspect of urban ecosystem services

Urban ecosystems are important in providing services with direct impact on health and security such as air purification, urban cooling, runoff mitigation and noise reduction (Bolund and Hunhammar, 1999). As a more objective concept than "noise", urban soundscape, rather than noise reduction, should more properly be recognised as a kind of ecosystem service. Several socially important values could also be ascribed to soundscapes, including creating a sense of place, providing cultural and historical heritage values, interacting with landscape perceptions, and connecting humans to the nature (Dumyahn and Pijanowski, 2011a). In this section, soundscape should be recognised as supplying urban ecosystem service is argued in its aesthetic, restorative and information functions, respectively.

Aesthetic

Although more than eighty percent of our sensory input is visual (Rock and Harris, 1967), other senses could not be overlooked, as they could also affect our emotion, and thus have aesthetic impacts. Aural aesthetics is proposed to be included into the whole aesthetic research system (Porteous, 2002; Yang, 2005). Aesthetic function of soundscape shows in two aspects. On one hand, soundscape itself is with aesthetic value. Noise is soundscape with low aesthetic value. It has been demonstrated by many researches that, noise could causes non-auditory stress effects such as changes in the physiological systems (e.g., elevated blood pressure), various cognitive deficits (e.g., poor sustained attention, memory/concentration problems), sleep disturbances, modifications of social behaviour, psychosocial stress-related symptoms, and emotional/motivational effects (e.g., annoyance, learned helplessness) (Babisch et al., 2005; Berglund et al., 1999; Bluhm et al., 2007; Gidlöf-Gunnarsson and Öhrström, 2007; Öhrström, 2004; Stansfeld et al., 2005), and thus affect human health (Chuengsatiansup, 1999; Öhrström et al., 2006; Skånberg and Öhrström, 2002), while soundscapes with natural sounds are usually preferred by people (Yang and Kang, 2005a, 2005b). On the other hand, soundscape could affect the aesthetic perception of landscape. Pleasant soundscape could have a positive effect on aesthetic perception of the landscape, thus the whole environment, and vice versa. A research conducted in national parks indicated that the presence of anthropogenic sounds–air traffic, ground traffic, or voices–negatively impacted environmental assessments, while the natural soundscape had little to no effect on assessments, and the effects were the most significant for landscapes that were high in scenic beauty (Benfield et al., 2010).

Restorative

People live in urban areas are usually in stressful situations everyday, because of responsibilities from work and family and harmful/adverse environmental conditions. Thus, restoration experiences are needed. The interaction between soundscape and landscape is important to achieve the restorative effect. It has been indicated by many empirical evidences that nature provides restorative experiences that directly affect people's psychological well-being and health in a positive way (Gidlöf-Gunnarsson and Öhrström, 2007; Hartig et al., 1996; Hartig et al., 2003; Herzog et al., 1997; Kaplan, 2001; Kaplan and Kaplan, 1989; Ulrich et al., 1991). As indicated previously, natural sounds are valued by people and are important aspects of natural area. Importance of protecting natural quite soundscapes is recognised both in European and USA. In urban areas, tranquil urban parks serve as important refuge from noisy daily life for residents.

Information

Sound is important signal people use in their daily life. It contains information that we need to decide how to response to the situations that may be enjoyable, emergency, and even danger. In urban areas, soundscape are usually degraded by traffic noise. The information function of urban soundscape is also not fully recognised for people. The initial purpose of soundscape concept was to arouse people’s awareness of their surrounding acoustic environment, and soundscapes have been recognised as an element of sense of place (Schafer, 1994). Sense of place is defined as a collection of symbols, values, feelings and meanings ascribed to a specific place (Williams and Stewart, 1998). Schafer used the term soundmark, like landmark, to describe the sound unique to a specific location. Soundmarks could give information about places that are different from the others, and help people form the sense of their living environment. Fisher also claimed that soundscapes are an acoustic manifestation of place, besides the visual environment (Fisher, 1998). Carles et al. recognised two main information functions of sound in the landscape, which complement visual data (Carles et al., 1999). One function is the interpretation of the sound identified, such as water, birdsong, voice and cars, and the other is the abstract structure of sound information (Kang, 2007).

Moreover, urban areas are not only habitats for human beings, but also many other organisms. Soundscapes are also important information resources for animals, such as prey location, predator avoidance and interspecies communication, and should be considered as an information medium that is transferable from signals from their surroundings into useful information (Pijanowski et al., 2011b). Urban organisms have been found negatively affected by degraded soundscapes (Slabbekoorn and Ripmeester, 2008). In conclusion, information function of urban soundscapes still needs to be highlighted.

2. 2 Progress in soundscape study

2.2.1 Pioneering soundscape researches

The pioneering researches in soundscape were carried out in 1960s by two representative researchers. Schafer as a musician and composer was concerned about noise pollution and people's awareness of acoustic environments (Schafer, 1969). Southworth as an urban planner tried to characterise the acoustic properties of certain spaces in cities (Southworth, 1969).

In the late 1960's and early 1970's, the World Soundscape Project (WSP) was carried out by Schafer, focusing on the way people perceive their environment consciously and the chance to change the orchestrating of the global soundscape (Truax, 1978). In 1975, Schafer led a group on a European tour to five villages in Sweden, Germany, Italy, France and Scotland, and made detailed investigations of their soundscapes (Schafer, 1977b). In 2000, the five villages were revisited to undertake comparative studies (Järviluoma, 2000). The research found that most rural soundscapes were radically changing and losing the complexity because of an increasing number of technological sounds. And the residents' response about the loss of certain sounds that they had previously used to gain information about their environment proved that soundscape is a definite element in the individual's perception of an environment.

In 1969, Southworth carried out an exploratory study on urban soundscapes (Southworth, 1969), involving a group of blind, deaf and normal subjects in a tour in Boston. Soundscape in terms of the identity and delightfulness of the sounds was one of his major concerns, with another one being the correlation between visual and auditory perception. It was suggested that sounds vary much depending upon the time of day and week and the weather. And also the pleasingness of sounds depended on much more than the physical qualities. Generally, sounds with low to middle frequency and intensity were preferred, but delight increased when sounds were novel, informative, responsive to personal action and culturally approved. It was concluded that the information contained in the sound, the context in which it is perceived and its level are three aspects which influence people's evaluation of a city's soundscape (Yang and Kang, 2005b) .

2.2.2 Multiple disciplinary researches

The soundscape concept has been explored by researchers from different disciplines (Karlsson, 2000), including acoustics, aesthetics, anthropology, architecture, ecology, ethnology, communication, design, human geography, information, landscape, law, linguistics, literature, media arts, medicine, musicology, noise control engineering, philosophy, pedagogics, psychology, political science, religious studies, sociology, technology and urban planning (Kang, 2007). Among these many researches, the Positive Soundscape Project tried to synthesise a shared perspective on soundscapes from a range of disciplines, including acoustics, manufacturing, sound art, social science, psychoacoustics, physiology, and neuroscience (Davies et al., 2013). In general, all the focuses could be generalized into four main aspects, namely soundscape perception, soundscape evaluation, soundscape simulation and soundscape design.

Soundscape perception

As stated earlier, soundscape concept breaks the limitation of physical measure of acoustic environment, and advocates human centered experience. However, in an outdoor environment, many factors could influence the experience. It is difficult to characterize all these factors and to explain how they interact with each other and how they affect human experience and behavior (Davies et al., 2013). However, some theoretical models of soundscape perception have been built to aid understanding of soundscape perception. For example, the model proposed by Zhang and Kang is based on four top-level elements of source, space, people and environment (Zhang and Kang, 2007). Each element has several variables attached, both physical/quantitative and perceptual/qualitative. Based on the investigation in a residential area, Schulte-Fortkamp and Fiebigmodeled the process of a person perceiving and responding to a soundscape, where the five elements or processes in the model, i.e., the acoustics of the sound (scape), the initial perception, a negotiation process internal to the listener, psychological reactions and behavioural response, can all occur in parallel (Schulte-Fortkamp and Fiebig, 2006).

It has been shown that a soundscape is often perceived as a collection of the individual sounds of which it is comprised (Kuwano et al., 2002); therefore, soundscape perception could be simplified into how people think about different sounds. There are many different ways to classify the soundscapes. As a musician, Schafer in his book *The Turning of the World*, revolutionarily defined sounds as '*keynotes*', '*signals*' sounds and '*soundmarks*' to describe background sounds, foreground sounds and location specific sounds, respectively, of landscapes (Schafer, 1977a). This classification was also the initial of equitably treating all the sounds in the universe. With an environment- or object-centred way, soundscapes could be classified into road traffic (car–truck–motorcycle), other transportation (railway, aircraft), working machines (street cleaning, working site), music, peoples presence (speech, walking), and nature (wind, animals) (Schafer, 1977a). Raimbault and Dubois proposed a more subject-centred way that classifies the soundscapes into two main categories, i.e., transportation or works (from road traffic, railway, building site) versus people presence (from departmental store, coffee shop terraces, traveling shoppers), and combined the objective/subjective ways by subcategorizing the soundscapes into four categories, namely transportation or works (with/without people presence), people presence (lively/relaxing+nature) (Raimbault and Dubois, 2005). Brown et al. proposed two major categories of urban acoustic environment, namely sounds generated by human activity/facility and sounds not generated by human activity (Brown et al., 2011). The most common category set is perhaps to classify the soundscape into three types in terms of their sources, i.e., biophony, geophony, and anthrophony (Krause, 2008; Pijanowski et al., 2011b). Rychtáriková and Vermeir proposed an automatic categorization method based on multi-parameter analysis by 13 acoustical parameters used as similarity measures, and classified the 370 binaurally recordings in urban public places into 20 different soundscape categories (Rychtáriková and Vermeir, 2013). This research stands for an objective approach of soundscape classification, which is different from other proposals.

Besides perception of different soundscape categories, another important aspect of soundscape perception is the emotional dimensions of the listener response (Davies et al., 2013). Semantic analysis method is usually used to identify the emotional dimensions (Osgood, 1957). Through analysis of 18 semantic differential scales with 223 subjects in two urban squares, Kang and Zhang extracted four perceptual factors which can be described as relaxation, communication, spatiality and dynamics (Kang and Zhang, 2010). By using a principal component analysis (PCA) to characterise the response of 100 listeners to 50 soundscapes on 116 semantic scales, Axelsson et al. produced a three-dimensional space with factors pleasantness, eventfulness and familiarity explaining 50%, 18% and 6% of the variance respectively (Axelsson et al., 2010). With a similar approach, Cain et al. proposed a 2-Dimensional perceptual space with factors of calmness and vibrancy (Cain et al., 2013).

Soundscape evaluation

Currently, standardized assessment methods of urban sound from EU directive on environmental noise are typically focusing on objective noise quantification defined through physical parameters such as $L_{A,eq}$, L_{day}, $L_{evening,}$, L_{night}, and L_{den}. These indicators provide a constant filter that is independent of sound source identification, because of which the information reflected by this indicator could be misleading for planners (Raimbault and Dubois, 2005). For example, even with the same A-weighted equivalent level, annoyance assessment of any single traffic sound over a period of time is not comparable with that of a city park. That means these physical indicators could reflect loudness, but they do not directly reflect annoyance. Leventhall suggested that a metric should take into account the variations in low-frequency sound energies that the A-weighted decibel does not, in order to properly assess soundscapes across differing sound sources (Leventhall, 2004). Accordingly, Raimbault and Dubois proposed to use deserved measurements related to specific locations of functions over the duration of characteristic events and other kinds of physical indicators to evaluate time variations of urban soundscape, such as the noise index over 90% of a period of time for characterizing the background noise pressure level, the duration of emergencies or specific events or the period between those emergencies (Raimbault and Dubois, 2005). Considering that the outline characteristics of all noted sound sources such as type, number, occurrences, location and distance are more meaningful for decision makers, urban planners and the general public, they also suggested that these indicators have to be linked to these characteristics.

Psychoacoustics is an important field of the different dimensions involved in the environmental noise evaluation process. Psychoacoustics parameters, such as loudness, sharpness, roughness, and fluctuation strength as well as further hearing-related parameters could describe sound perception mechanisms, which will advance soundscape evaluations (Genuit and Fiebig, 2006). However, soundscapes are usually consisted of a number of spatially distributed sound sources. Soundscape evaluation is also affected by human hearing characteristics such as binaural hearing and its consequential directional hearing and selectivity that could classify complex soundscapes into single sound events that are selected by human hearing and decisively influence the individual evaluation. Thus, these psychoacoustics parameters should be used in combination with physical, binaural signal processing as well as cognitive aspects affecting the soundscape evaluation (Genuit and Fiebig, 2006). Physiological response such as heart rate, respiratory rate and forehead electromyography levels were also used to indicate the effects of individual soundscape elements on the subjective assessment of pleasantness and arousal (Hume and Ahtamad, 2013).

The semantic difference analysis has also been widely used to identify the most important factors in evaluating the overall soundscape and individual sound. Zeitler & Hellbrück found that for evaluation of general environmental sounds, evaluation, timber, power and temporal change were the four essential factors (Zeitler and Hellbrück, 2001).

In urban public open spaces, Kang and Zhang recognised four factor from 18 indices for soundscape evaluation, and the result showed that relaxation, including comfort-discomfort, quiet-noisy, pleasant-unpleasant, natural-artificial, like-dislike and gentle-harsh, is a main factor for people's soundscape evaluation, counting for 26% of the total variance (Kang and Zhang, 2010).

Soundscape simulation

Noise-mapping is an effective method to visualise and assess the acoustic environment. Based on macro-scale noise modelling techniques, noise-mapping is being used to create urban or even national scale noise maps, which could help develop noise policies/strategies to improve the acoustic environment. Especially all noise-mapping programs consist of geo-referenced, three-dimensional input data that are usually associated with Geographical Information Systems (GIS), which makes the mapping results easily adopted into planning and management practices. Cadna/A developed in Germany by DataKustik GmbH in 1998 and the CRTN model developed by the UK Department of Transport in 1988 are two typical noise-mapping programs. However, for urban designers and planners, the noise-mapping exercise is useful to visualise the sound level distributions of large areas. And apparently the information is not enough to characterise the complex soundscape.

With a different approach, Matsinos et al. visualised perceived intensity of the three major sound categories, namely anthropogenic, biological and geophysical sound with raster maps, using regularized spline with tension interpolation method (Matsinos et al., 2008; Mitasova et al., 2005). And with the powerful spatial analysis function of GIS, these raster maps were combined, generating a series of multi-sound raster maps, which could be recognised as soundscape maps with both spatial and temporal variation information. Although this study was conducted in a rural area, there is a great potential to adopt this technic into urban soundscape simulation.

Soundscape design

Soundscape design is the practical way to apply the research findings from the above mention three aspects of theoretical soundscape researches. In fact, at the very beginning of exploring the soundscape concept by Southworth (Southworth, 1969), he pointed out the necessity of soundscape design. He proposed that three aspects of hypothesized changes of the soundscape are needed, i.e., to increase the identity of the soundscape, the number of opportunities for delight in sounds and to provide responsive settings which contain novel sounds, and the correlation between sound and the visible spatial and activity form. He also proposed three types of form elements would seem to have strategic design potential in terms of the three hypothesized needs, namely large open spaces, small sonically responsive spaces, and sonic signs. The recent soundscape researches also provided rich knowledge for design purpose (Yang and Kang, 2005b), and soundscape oriented design approach was already adopted in urban planning (De Coensel et al., 2010), and urban park design (Gaetano et al., 2010). In 2010, the conference *Designing Soundscape for Sustainable Urban Development* was organised in Stockholm, with the purpose of introducing the soundscape approach to architects and urban planners who have little or no previous experience in this field. The conference report could possibly inspire and provoke new thoughts and challenge the visual dominance in architecture (Axelsson, 2011).

2.2.3 The concept of soundscape ecology

As one of the most recently progress in soundscape research, Pijanowski et al. proposed a new area of research called soundscape ecology (Pijanowski et al., 2011b; Pijanowski et al., 2011a). They argued that study of sound in landscapes is based on an understanding of how sound, from various sources—biological, geophysical and anthropogenic—can be used to understand coupled natural-human dynamics across different spatial and temporal scales. Though soundscape ecology uses the intellectual foundations of spatial ecology, bioacoustics, urban environmental acoustics and acoustic ecology, and especially rich vocabulary and conservation ethic from acoustic ecology, it focuses more than the only humanities driven focus of acoustic ecology. They also argued that soundscape ecology shares many parallels with landscape ecology, and it should therefore be considered a branch of this maturing field.

They summarized the foundational elements of soundscape ecology research, and introduced and defined several useful terms, such as soundscapes, biophony, geophony and anthrophony. By presenting an integrative framework based on the causes and consequences of biophony, geophony, and anthrophony, how climate, land transformations, biodiversity patterns, timing of life history events and human activities create the dynamic soundscape were described. By presenting several case studies, different approaches to understanding soundscape dynamics were illustrated, such as factors that control temporal soundscape dynamics and variability across spatial gradients, and several different phonic interactions (e.g., how anthrophony affects biophony). Necessary soundscape ecology tools are also discussed along with the several ways in which soundscapes need to be managed.

They suggested that, as the auditory link to nature of human beings, soundscape should be protected with the knowledge of how sounds are produced by the environment and humans. The theory of soundscape ecology could bring the idea of the soundscape—the collection of sounds that emanate from landscapes—into a research and application focus. They proposed the following six area as a research agenda for soundscape ecology, including: (1) measurement and analytical challenges, (2) spatial-temporal dynamics, (3) soundscape linkage to environmental covariates, (4) human impacts on the soundscape, (5) soundscape impacts on humans, and (6) soundscape impacts on ecosystems.

2.2.4 The methodology of the soundscape study

The multi-disciplinary research efforts bring various methodologies into soundscape research. They could be mainly divided into two groups, namely laboratory study and field study. In terms of laboratory studies, one of the methodologies is analysis of different sound recordings using traditional physical parameters in relation to the soundscape perception, for example, study on effects of natural sounds on the perception of road traffic noise (De Coensel et al., 2011), on acoustical characteristics of water sounds for soundscape enhancement in urban open spaces (Jeon et al., 2012). Another major methodology for laboratory soundscape studies is evaluation using landscape photos or videos combined with sound recordings, to study the interaction between soundscape and landscape (Carles et al., 1999; Pheasant et al., 2008; Viollon et al., 2002). These methodologies are borrowed from visual aesthetic research.

In terms of field studies, methodologies include questionnaires to specific people concerned (Raimbault, 2006; Yang and Kang, 2005a, 2005b; Yu and Kang, 2008), soundwalk combined with semantic differential analysis (Kang and Zhang, 2010), and in-depth interviews combined with ground theory (Schulte-Fortkamp and Fiebig, 2006), or sonic mind map (Marry and Defrance, 2013), and on-site observation with subjective evaluation (Matsinos et al., 2008), and so on. Field study and laboratory study are usually combined in soundscape research. For example, sound recordings collected from the field study could be analysed in laboratory, and the results could be compared with or as a complement of that of the field study (Jeon et al., 2010).

A successful soundscape study requires a comprehensive consideration of the environment, sound and people (Yang, 2005). For study on soundscape-landscape relationship in urban context, considering the difficulty of simulating complex sound sources and spatial landscape patterns, and the interaction among sound, landscape factors, and other social factors, it is more appropriate to carry out field studies in order to ensure the complex aural perception process.

2.3 Interaction between soundscape and landscape

Soundscape concept was coined in close relationship with landscape. On one aspect, the word soundscape is used as an analogy to “landscape”, to denote the overall sonic environment of a designated area. On the other aspect, soundscapes are always emanated in a place, where the landscape characteristics may have a decisive effect on the soundscape characteristics and human perception (Schafer 1994). As shown in the last section, the relationship between soundscape and landscape perception has been discussed in a number of studies, which could be classified into two groups. One is studies on aural-visual interaction in perception of soundscape or landscape or the environment, the other is on relationship between soundscape dynamics and underlying landscape.

2.3.1 Aural-visual interactions

The focus has been already on aural-visual interaction in one of earliest soundscape researches conducted by Southworth (Southworth, 1969). It was found that when aural and visual settings were coupled, attention to the visual form reduced the conscious perception of sound, and vice versa. The interactions between aural and visual perception, especially when the sounds are related to the scenes, give people a sense of involvement and lead to a more comfortable feeling. Several studies found that natural elements with more attractive visual appearance have a positive effect on perception of noise-exposed landscape (Gidlöf-Gunnarsson and Öhrström, 2007; Lercher, 1996). Maffiolo et al. pointed out, that "garden soundscape evaluations integrate subjective evaluation of the landscape visual contributions: a positive evaluation of the landscape reduces annoyance of the soundscapes whereas a negative evaluation of the landscape increases annoyance" (Maffiolo et al., 1999).

Aural-visual interactions were more tested in laboratory. In an early research conducted by Carles et al., 36 combinations of sound and image of natural/semi-natural settings and urban green spaces were presented to 75 subjects and the affective response of them was measured in terms of pleasure (Carles et al., 1999). The results showed a rank of preferences running from natural to man-made sounds, with the nuance of a potential alert or alarm-raising component of the sound. It is concluded that congruence or coherence between sound and image influences preferences. Viollon et al. conducted a similar laboratory research, and found that the impact of visual settings depended on the urban sound scenes involved in the aural-visual combinations. For all sound environments which did not involve any human sound, visual influence was significant and negative: the more urban the visual setting, the less pleasant and relaxing the perceived sound environment was (Viollon et al., 2002). Pheasant et al. tested the responses of 44 subjects to the video and audio stimuli from 11 locations in UK, and found that aural-visual interaction could affect tranquillity of the environments, with the maximum sound pressure level and the percentage of natural features present at a location being the key factors (Pheasant et al., 2008).

2.3.2 Soundscape dynamics and underlying landscape

Another approach of soundscape-landscape relationship study is soundscape dynamics and underlying landscape. As has been reviewed earlier, the concept of soundscape ecology stands for an important branch of this approach. Acoustic frequency patterns, phonic interactions, temporal pattern in and spatial dimension of soundscapes and the relation to underlying landscape and human activities are of special interest. This approach usually focuses on global and regional environmental change, a much larger scale than the perception oriented aural-visual interaction studies. Contributions from soundscape ecology approach have been increasing (Barber et al., 2011; Dumyahn and Pijanowski, 2011a, 2011b; Farina et al., 2011; Francis et al., 2011; Krause et al., 2011; Lynch et al., 2011; Truax and Barrett, 2011; Villanueva-Rivera et al., 2011).

Landscapes, as functional spaces, provide the basis for an integrated study of human and natural processes and patterns (Parker and Meretsky, 2004). Theories of landscape ecology have advanced sufficiently nowadays to support research on the ecological significance of soundscape in landscape (Farina, 2006; Forman and Godron, 1981; Turner, 1989; Turner et al., 2001; Urban, 2006). Especially, landscape features have been studied in relation to soundscape perception. Matsinos et al. revealed that spatial sound variability in a costal rural area in Greece was mainly shaped by landscape attributes (Matsinos et al., 2008). In the same rural area, Mazaris et al. pointed out later the interactions between soundscape and several landscape features (Mazaris et al., 2009). These researches indicated the necessity to explore the landscape features further, since the rich knowledge of landscape pattern and process in landscape ecology.

Landscape spatial patterns are mainly analysed in terms of ecological processes in research area of landscape ecology (Turner 1989), and a series of spatial metrics that quantitatively measure landscape structure 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 and Marks 1995; 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 (Dramstad et al., 2006; Palmer, 2004). Compared with visual perception which is related only to the landscape characteristics in viewshed, sound can propagate and be perceived by humans through the local landscapes even the sound sources are visually hidden. There is a great potential to discover the relationship between soundscape and landscape spatial pattern.

2.4 Summary—a theoretical framework of soundscape-landscape relationship study

In this chapter, the concept of soundscape has been introduced as an objective approach of urban acoustics, and a novel aspect of urban ecosystem service. A specific definition of soundscape is also given with the special concern of the study. From the review in this chapter, it is clearly shown that soundscape has been drawing increasing attention from different disciplines. In particular, soundscape and landscape are proved from different aspects in close relationship. The concept of soundscape ecology stands for a progress in studying on the soundscape-landscape relationship from a broader view, beyond perception issues about the aural-visual interaction. From a landscape and urban planning point of view, soundscape information related to underlying landscape in a larger scale could be more useful. However, most existing studies on urban soundscape were conducted in certain urban spaces, such as public parks or squares (Kang, 2007; Yang and Kang, 2005a, 2005b; Yu and Kang, 2009, 2010), residential areas (Berglund and Nilsson, 2006; Schulte-Fortkamp and Fiebig, 2006; Skånberg and Öhrström, 2002), and streets (Ge and Hokao, 2005). Although they provided useful information for urban planning and design, they are often not sufficient in terms of urban management that usually involves different land use forms in larger scales. Moreover, urban soundscape characteristic in a larger scale has been almost untouched. Of more concern to this study, soundscape information in multiple functional urban landscapes is essential to characterise typical urban soundscapes, and to examine the relationship between soundscape and landscape. For study on soundscape-landscape relationship in urban contexts, considering the difficulty of simulating complex sound sources and spatial landscape patterns, and the interaction among sound, landscape factors, and other social factors, it is more appropriate to carry out field studies in order to ensure the complex aural perception process. Besides, soundscape is also about human perception. Thus the scale of research may be still limited by human hearing ability. An approach combining different scales should be considered.

From the review, it is also found that there is a lake of general accepted and effective illustration parameters for soundscape, mainly because soundscape perception itself is a very subjective process. In order to make the soundscape information understandable for planners, it is vital to standardize the way to collect soundscape information, the parameters to illustrate soundscape information, and a method to show soundscape information.

Of more relevance to landscape and urban planning, to reveal the relationship between soundscape and landscape could help planners handle the acoustic problem using their own language. Therefore, feasible tools are needed to combine the soundscape information into landscape and urban planning. Landscape spatial pattern indices, as the potential tools to combine soundscape information into landscape characteristics, are of special interest in this study.

PART Ⅰ: Soundscape and Landscape in a Multi-functional Urban Area

Chapter 3 Methodology for the Field Survey in Germany

As the focus of the research is on soundscape-landscape relationships, field survey is inevitably the best method, given the difficulty of simulating complex sound sources, landscape components and structures, as well as the interactions between soundscape and landscape. The objectives of the field survey in Germany are, on one aspect, to reveal urban soundscape characteristics in a larger scale, an area involving multiple urban functions; on the other aspect, to identify major landscape characteristics affecting soundscape perception.

3.1 Study area

The study was conducted in the northern part of Rostock, a coastal area named Warnemünde in North Germany. Warnemünde was at the very beginning a small fishing village with minor importance for the economic and cultural development of the region, founded in about 1200. It was purchased by the city of Rostock in order to safeguard the city's access to the Baltic Sea in 1323. Being a centre of maritime traffic, the district of Warnemünde comprises numerous navigational aids, some of which become the landmark of this area. The oldest one is the lighthouse, built in 1897, and still currently in use. Warnemünde's large, sandy beaches are the broadest on the German Baltic Sea coast and stretch out over a length of 3 kilometers. Since the 19th century, Warnemünde began to develop into an important seaside resort. Tourism is also one of the mainstays of the local economy. There are approximately 8, 400 inhabitants in the area.

The study area extends 2,400 m along the East–West axis and 2,000 m along the North–South axis, as shown in Fig. 3.1, largely within flat terrain. The northern boundary of the study area is defined by the Baltic coast line with a beach extending from the East (about 240 m wide) to the West (about 50 m wide). The eastern boundary is defined by the "Warnow River" mouth with its harbour and adjacent railway station. The western part of the area comprises private gardens, with plantations and some domestic animal keeping (fowl, dogs). The southern part is mainly a residential area, with railways crossing this area. Based on the digital topographic-cartographic information system (ATKIS) 2010, provided by the Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV), as well as through actual on-site surveys, the landscape in the study area was classified into 17 types, including beach, commercial area, construction site, forest, garden, green space, industrial area, parking lot, residential & commercial mixed area, education and administration area, residential area, port, sea, sport area, road, urban park and wet land.

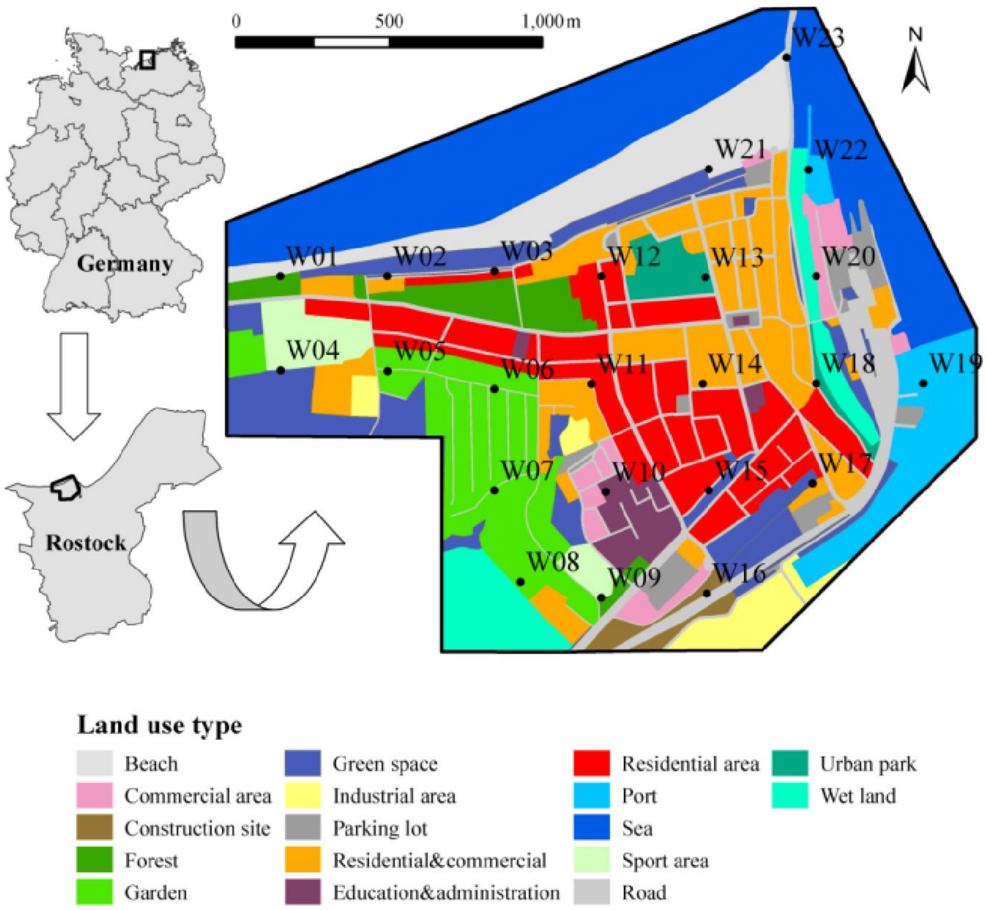


Fig. 3.1 Location of the study area and the 23 sampled sites (W01-W23), and land use structure of the study area

The multiple functions of landscape in this relatively small urban area generate diverse soundscapes, which are shaped from different human activities (transportation, construction, tourism, etc.), biological activities (birds, insects, domestic animals or pets, etc.) and geophysical activities (sea wave, wind, rain, etc.). The rich landscape and soundscape diversity is an important reason to choose this area as the study area, which could facilitate the analysis of the soundscape-landscape relationship.

3.2 Research methods

3.2.1 Soundscape data

It is essential in soundscape studies to capture sounds generated from both human activities and ambient natural sources. According to Krause (Krause, 2008) and Pijanowski, Farina et al. (Pijanowski et al., 2011b), a soundscape comprises three main-class active acoustic sources: *biophony* (Bio) –non-human biological sounds produced by all organisms in a given habitat; *geophony* (Geo) –non-biological natural sounds originating from the geophysical environment, which includes wind, water, thunder, geophysical activity, etc.; and *anthrophony* (Anthro) –anthropogenic sounds arising from stationary (e.g., air conditioner) and moving (e.g., vehicles) man-made objects. In this study, a list of commonly occurring sub-class sounds (27), with code names, was established in pilot studies to assist on-site investigation (Table 3.1). Traffic sounds are listed both as foreground and background sounds, depending on the situation.

Based on fishnet cells of 350*350 m created in ArcGIS 9.1 (Matsinos et al., 2008), 23 approachable sites were evenly sampled across the study area. Soundscape data on each sampled site during each sampled period were recorded into investigation tables on-site by a group of 12 observers without hearing deficiencies (10 students from the Agricultural and Environmental Faculty of the University of Rostock, 1 audio engineer and 1 musician; 7 male and 5 females; aged between 22 and 31, mean: 26, standard deviation: 2.8). One month before the on-site survey, the observers were trained in a series of trials 1) to make them familiar with the list of sound classes and the corresponding sounds through watching videos recorded on site and 2) to quantify inter-rater variability in order to control for observation bias. Results of this pilot study showed that average inter-rater reliability of loudness of major soundscape elements was 0.91 (Cronbach's Alpha, sample size 70). In order to increase recording efficiency, the observers were divided into 6 groups of 2 observers, each responsible for 3 or 4 sites, respectively. The sampling method refers to a similar soundscape perception investigation in a rural area in Greece (Matsinos et al., 2008; Mazaris et al., 2009), which could be named "objectively controlled subjective evaluation method". On one aspect, the 175 m radius distance around each sampled site is within the limitation of human hearing abilities, thus guarantee capturing most of the local soundscape information. On the other aspect, the evenly distributed sampled site could ensure a representative soundscape mapping of the whole area.

The investigation was carried out on 3rd and 4th August 2011. Data were collected in eight two-hour successively sampled periods at each site (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 10 min period of soundscape was randomly recorded. Each 10 min period was further divided into twenty sequential time-steps of 30 s. Within each time-step, the recognised sounds were recorded with code names and their perceived loudness was scored accordingly, by using a five-point linear scale (1=very quiet, 2=quiet, 3=normal, 4=loud, 5=very loud). For each sound, the score was given according to the highest one during the time-step. Any sound which did not appear in a given time-step was categorized as 0. In addition, at the end of each time-step, preference for the 30 seconds soundscape was evaluated with a five-point linear scale (1=*very pleasant*, 2=*pleasant*, 3=*normal*, 4=*unpleasant*, 5=*very unpleasant*).

Then, 3680 (20*8*23) pieces of soundscape recordings were collected, and the original soundscape dataset was built in Spss 16.0 for the later analysis from different aspects.

Table 3. 1 Classification of major sound categories in the study area

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

3.2.2 Landscape data

Although landscape metrics are usually used to indicate ecological functions in a large scale, in this research their quantification ability of landscape spatial patterns is more concerned (Corry and Nassauer, 2005; Uuemaa et al., 2012; Wu, 2000). 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. The digitalized land use map is shown in Fig. 3.1. Among the several quantitative landscape indices available, 11 potential landscape metrics that may affect the composition and/or perception of soundscapes were selected to test the possible relationships between landscape and soundscape perception. The indices include GIS based spatial analyst values: building density (BD), road density (RD), distance to building (DTB), and distance to road (DTR); remote sensing derived value: vegetation density (normalized difference vegetation index (NDVI)); and traditional landscape ecology metrics: patch density (PD), largest patch index (LPI), landscape shape index (LSI), fractal dimension (FRAC), Shannon diversity index (SHDI), and contagion (CONT). These indices could also characterise landscape spatial pattern from two aspects. On one aspect, landscape composition could be measured by construction density, road density, vegetation density, patch density, largest patch index, and Shannon diversity index. On the other aspect, landscape configuration could be measured by distance to construction, distance to main road, landscape shape index, fractal dimension, and contagion. Table 3.2 lists all the indices and their descriptions according to McGarigal and Marks and Wu (McGarigal and Marks, 1995; Wu, 2000).

All of the indices above were calculated based on the 175m radius buffer area of each sampled site in ArcGIS 9.1, except that the calculation of DTB and DTR was based on the whole study area by considering the shortest distances. The NDVI value was calculated for each site based on a Landsat TM image (30 m) on July 27, 2011 from the U.S. Geological Survey (USGS). Landscape metrics including PD, LSI, LPI, SIEI, SHDI, CONT, FRAC were calculated using Fragstats software (McGarigal and Marks, 1995).

3.2.3 Soundscape mapping

A soundscape map, which is comparable to a digital landscape map, is the visualisation of soundscape pattern information. While there are different kinds of soundscape maps (Kang, 2000, 2005, 2007), in this study, thematic soundscape maps were generated using a regularised spline with a tension interpolation method implemented in the GRASS GIS (Geographic Resources Analysis Support System)—a open source Geographic Information System (GIS) software (GRASS Development Team, 2008; Matsinos et al., 2008), since it can generate a smoother surface than ArcGIS.

Grid maps of each main-class sound were laid across the whole study area based on their overall accumulated loudness at each sampled site. Grid maps describing the accumulated loudness of each main-class sound were also created for each sampled period. The three main-class grid maps were then combined per-period in ArcGIS 9.1, generating a series of eight soundscape maps. Consequently, spatiotemporal variation of urban soundscape patterns and the spatial relationship between soundscape and underlying landscape could be visually reflected by these maps. Thematic soundscape mapping for a specific sub-class sounds, birdsong and middle-class sounds are also conducted using the same method.

Table 3.2 Indices used to characterise the landscape spatial patterns

Indices	Acronym	Description
Building density	BD	Density of buildings of different uses
Road density	RD	Density of main traffic roads
Distance to building	DTB	The shortest distance to the building around the sampled site
Distance to road	DTR	The shortest distance to main road (including railway and water way) around the sampled site
Vegetation density	NDVI	Normalized Difference Vegetation Index. A simple graphical indicator that assess whether the target being observed contains live green vegetation or not (Tucker, 1979).
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. It was used as an index for the diversity of sounds because of habitat richness (Kallimanis et al., 2008; Mazaris et al., 2009)
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
Landscape shape index	LSI	Landscape shape index can be interpreted as a measure of the total shape complexity of patches, indicating landscape fragmentation status
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
Shannon diversity index	SHDI	Shannon diversity index measures diversity of patch types, and is also an index of landscape fragmentation. SHDI value is 0 when only one type patch exists in the landscape.
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

3.3 Data analysis

Soundscape data were analysed on three different levels. Besides the main-class and sub-class levels, which are also used by other researchers, a middle-class level considering the major soundscape categories in urban areas was analysed too. The major difference between main-class and middle-class is that anthrophony in the main-class are broken into three different types of sounds in the middle-class, i.e., human sound, mechanical sound and traffic sound. Geophysical sound and biological sound correspond to geophony and biophony, respectively (Table 3.1).

Perceived loudness of each sub-class sound at a given site and in a given period was calculated by adding the scores from the twenty sequential time-steps (30s) of the period for it, respectively. Similarly, perceived loudness of each main-class sound or middle-class sound at a given site and in a given period was the sum of scores of all the corresponding sub-class sounds. The overall soundscape loudness at a given site and in a given period was calculated by adding the scores of all different sub-class sounds of the period.

Non-parametric (K independent samples) Kruskal-Wallis tests were used to examine possible differences on perceived loudness of each main-class sound and middle-class sound among 23 sampled sites and among 8 sampled periods, respectively. The relationship between perceived loudness of different sound categories and the overall soundscape loudness was studied at three levels. For the main-class sounds, per-site and per-period Spearman correlation analysis was conducted by time-step. For the middle-class sounds, regression analysis between the overall soundscape loudness and loudness of each of the five soundscape categories by time-step per-period was conducted to find out their relative contributions in different sampled periods. For the sub-class sounds, the percentage of the first five dominating sounds in the overall soundscape was calculated at each sampled site (spatial scale) as well as in each sampled period (temporal scale), and regression analysis between their respective loudness and the overall soundscape loudness per-period was conducted. Pearson correlation analysis between main soundscape elements and landscape indices was conducted by time-steps per-period. All the statistical analyses mentioned above were carried out in SPSS 16.0.

3.4 Summary

This chapter has described the large scale soundscape investigation in August, 2011 in a coastal area of Germany with multiple landscape functions. The investigation was conducted by a group of 12 observers who took a special training process in advance to guarantee the "objectivity" of the soundscape dataset. With a specifically designed spatial and temporal scale, a soundscape database with 3680 pieces of subjective soundscape recordings was established. Local landscape information was extracted using a series of landscape spatial pattern indices, considering both landscape composition and configuration characteristics, to establish the landscape database. Based on the databases, further analysis method was established for different purposes. Detailed soundscape characteristic analyses have been carried out in Chapter 4; relationships between soundscape perception and landscape characteristics have been analyzed in Chapter 5; and special attention is paid to birdsong as a typical urban soundscape element in Chapter 6.

Chapter 4 Spatiotemporal Characteristics of Urban Soundscapes

In an urban environment, there are usually different kinds of sound appearing at different places. At a certain place, there might be a dominating sound according to the specific function of this place. However, the soundscapes at this place are usually formed by different sounds that may come from nearby or far away activities happening in other functional spaces in the area. In other words, in urban areas where usually different functions assemble as a complex system, the soundscapes in a certain space are inevitable affected by the surrounding functions, and even the whole environmental background should be considered when examining the soundscape characteristics. However, former studies in urban areas were usually conducted on certain functional space, such as public parks or squares (Kang, 2007; Yang and Kang, 2005a, 2005b; Yu and Kang, 2009, 2010), residential areas (Berglund and Nilsson, 2006; Schulte-Fortkamp and Fiebig, 2006; Skånberg and Öhrström, 2002), and streets (Ge and Hokao, 2005). The focuses were mainly on finding out the factors affecting soundscape experience and preference. While the information from these studies is useful for improving soundscape quality in these specific locations, it may be not sufficient in terms of urban management that usually involves different land use forms in larger areas.

Soundscape characteristics in urban areas need to be analyzed in a large scale. Many questions need to be discussed in order to reveal more general and universal characteristics of urban soundscapes in terms of human perception. For example, how could the urban soundscape composition be classified? What are the relationships among different soundscape elements? How do different soundscape elements contribute to the overall soundscape? How do these soundscape elements affect the overall soundscape quality as perceived by human? Furthermore, how could the characteristics of urban soundscapes be observed in a more directly way or how could the soundscape information be visualized?

In this chapter, the discussion is focused on the spatiotemporal change of soundscapes in the studied multi-functional urban area in terms of three different levels' classification of soundscape composition. The discussion falls into four sections: the first section discusses the classification of urban soundscape elements; followed by examining spatiotemporal characteristics of main-class, middle-class and sub-class sounds in the second section; the third section further discusses how the spatiotemporal characteristics could be reveal by thematic soundscape mapping; the fourth section discusses the relationships between soundscape elements and soundscape preference.

4.1 Classification of the urban soundscape elements

As discussed in chapter 2, there are many different methods to classify the soundscapes according to the major concern. In this research, the soundscape investigation was supposed to collect as detailed and "objective" sound information as possible. Soundscape was treated as an assembly of perceptible sounds (Brown et al., 2011). Thus, as mentioned in chapter 3, a list of sub-class sounds, i.e., 28 different kinds of basic soundscape element regularly appearing in the study area was recognized in advance. The names and meanings of these sounds are easily understandable for common listeners. And all fall into the normally proposed three main soundscape classes, i.e., anthrophony, biophony, and geophony (Krause, 2008; Pijanowski et al., 2011b). The list was acting a reference and standardization of recording rule for the observers.

Soundscape characteristics could be revealed in a great detail on the sub-class level, but with a danger of too complex analysis of the relationships among these soundscape elements and generating excessive information with strong local characteristic. Soundscape classification on the main-class level, on the other hand, could characterize urban soundscapes in general, but some important information could be neglected because of the general classification. And also, the main-class soundscape elements could not really reflect the characteristic of some major soundscape elements in special concern in urban areas. Specifically, excessive human activities generate pervading traffic sounds and other mechanical sounds that have more fundamental influences on daily life of citizens. Thus, a middle-class soundscape classification is adopted in the research too. And the major difference between middle-class and main-class sounds is that the anthrophony is reclassified into three different classes in middle-class sound, i.e., human sound, traffic sound and mechanical sound. Therefore, the soundscape characteristics will be examined on the three different levels, in order to reveal possible relationships to a different degree.

4.2 Spatiotemporal characteristics of urban soundscapes on different level

4.2.1 Main-class sound

Non-parametric (K independent samples) Kruskal-Wallis tests were used to examine possible differences on perceived loudness of each main-class sound among 23 sampled sites and among 8 sampled periods, respectively. The results show that, perceived loudness of the main-class sounds showed significant differences among sampled sites and among sampled periods, i.e., anthrophony (χ^2=52.539, p<0.001; χ^2= 58.624, p<0.001), biophony (χ^2=67.981, p<0.001; χ^2=20.93, p=0.005), and geophony (χ^2=78.555, p<0.001; χ^2=25.5, p=0.001), respectively, indicating a diverse spatiotemporal character of urban soundscape pattern.

Table 4.1 Per-site and per-period correlations among the perceived loudness of the main-class sounds and overall soundscape by time-step per-period, where at each cell the number of sites where significant positive or negative correlations existed is given. White areas: positive correlations; grey areas: negative correlations. * P<0.05, ** P<0.01

Period		Anthro	Bio	Geo	Sum
1st: 06:00–08:00	Anthro				1*, 22**
	Bio	2*, 2**			2*, 3**
	Geo	1*			1*, 3**
	Sum				
2nd: 08:00–10:00	Anthro				2*, 21**
	Bio	1*, 2**			2*, 4**
	Geo	4*, 2**	2*		2*
	Sum				
3rd: 10:00–12:00	Anthro				1*, 22**
	Bio	1*, 2**		1*	2*, 3**
	Geo	1*, 2**	2*		1*, 1**
	Sum			1**	
4th: 12:00–14:00	Anthro				1*, 22**
	Bio	1*, 1**		1*, 2**	3*, 2**
	Geo	1**			3*, 3**,
	Sum				
5th: 14:00–16:00	Anthro		1*		2*, 21**
	Bio	2*, 1**		2*	2*, 5**
	Geo	4*, 1**	3*		3*, 3**
	Sum				
6th: 16:00–18:00	Anthro				2*, 21**
	Bio	1*, 1**			4*, 1**
	Geo	1**	1*,1**		
	Sum				
7th: 18:00–20:00	Anthro			1**	23**
	Bio	3*		1*	7*, 3**
	Geo		1*, 3**		1*, 1**
	Sum				
8th: 20:00–22:00	Anthro		1*	1*	1*,19**
	Bio	1*, 1**			2*, 8**
	Geo		1**		4*, 3**
	Sum			1**	

Table 4.1 shows the per-site and per-period correlations between the loudness of each main-class sound and the overall soundscape loudness, which further reflects their spatiotemporal relationship. Significant positive correlations were found between

anthrophony and the overall soundscape loudness at nearly all sampled sites and during all sampled periods. It is obvious that anthrophony dominated daily urban soundscapes across the study area, which is the typical urban acoustic environment characteristic (Truax, 1978).

The contribution of biophony to the overall soundscape loudness was only significant in a limited number of sampled sites, but almost during all sampled periods. At sites W04 and W05, biophony showed the most stable relationship with overall soundscape loudness in five and six sampled periods, respectively. This can be explained by the underlying landscape characteristics, as those two sites are ecologically suitable habitats for birds and insects. During the last two sampled periods, biophony showed a significant correlation with overall soundscape loudness at most sampled sites, which may relate to the chorus of songbirds at dusk (Leopold and Eynon, 1961).

Geophony contributed the least to overall soundscape loudness, both spatially and temporally, and no consistent relationship was detected. One explanation may be masking through anthrophony. As indicated in Table 4.1, the two kinds of sound were mainly negatively correlated.

Among the main-class sounds, anthrophony was mainly negatively correlated with biophony and geophony at limited sites, while biophony and geophony were more negatively (14 times in six sampling periods) than positively correlated (7 times in four sampling periods) (Table 4.1). Results indicated that, the three kinds of soundscape elements could all be perceived in the study area, showing a coexisting but competing model among them. Especially, perception of biological sounds was impaired by the other two.

Figure 4.1 shows the temporal change of the sum of the perceived loudness scores of each main-class sound over the study area during all sampled periods. It is obvious that anthrophony increased from the 1st period onwards and peaked in the 6th period, after which a rapid decrease occurred in the last two periods, which reflects exactly the diurnal pattern of human activities (e.g., travel, construction, leisure activities). Biophony showed almost a reverse temporal trend compared with anthrophony. As bird song was the most important biophony source. The higher values during the first and last periods could be explained by the dawn and dusk choruses of songbirds (Leopold and Eynon, 1961). Though geophony was unstable, it corresponded to natural phenomena, e.g., the high value in the 8th period was a result of rainfall. There was also a daily temporal trend in geophony, as indicated in Fig. 4.1, which was mostly reverse to that of biophony, suggesting a possible counter-gradient relationship.

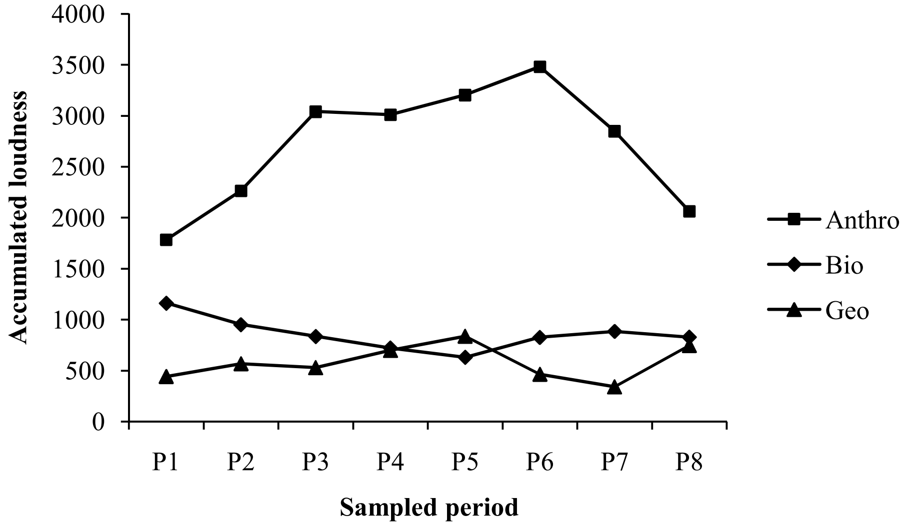


Fig. 4.1 Temporal change of accumulated perceived loudness of each main-class sound during all sampled periods

In summary, urban soundscapes showed a diverse spatiotemporal pattern because of the ever changing soundscape elements. They were spatiotemporally dominated by anthrophony, and this could impair the perception of biophony and geophony. Temporal variation of the three main-class sounds indicated a competitive relationship, resulting in diurnally varying soundscape patterns, which were mostly driven by the time course of urban activities.

4.2.2 Middle-class sound

Table 4.2 shows the results of non-parametric analysis of each middle-class sound by sampled period and sampled site. It can be seen that perceived loudness of all five 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. It indicates, on one aspect, the dynamic characteristic of urban soundscape patterns, and on the other aspect, the traffic sound was acting as the background sound of the urban area.

Fig. 4.2 shows the contributions of the five middle-class sound to the overall soundscape loudness during all sampled periods. In general, artificial sounds (anthrophony), namely human, mechanical and traffic sounds dominated the urban soundscape, while contributions from natural sounds, i.e., geophysical (geophony) and biological sounds (biophony) were less to the overall soundscape loudness. It could also be seen from Fig. 4.2 that, contributions of each sound categories to the overall soundscape loudness were changing in different sampled periods, indicating the dynamic temporal pattern of urban soundscape again. After the second sampled period, three kinds of artificial sounds were showing similar changing patterns, reflecting that human activities were generating a relatively stable composition of anthrophony. Though the perceived loudness of traffic sound did not show a significant difference among all the sampled periods, its contribution to the overall soundscape loudness were changing, and ranking at a higher position among all the five main-class sounds during most sampled periods, especially during the first and second ones. Human sound showed a rapid increase from the first period to the third period, corresponding to the normal temporal pattern of human activities, and contributing the most to the overall soundscape loudness during five periods except the first two. Contribution of mechanical sound to the overall soundscape loudness showed almost a level pattern among all sampled periods, though the perceived loudness of this kind of sound was changing significantly.

Table 4.2 Kruskal-Wallis independent samples non-parametric analysis for each middle-class sound 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

During the first five sampled period, geophysical and biological sounds were also showing similar changing pattern, and geophysical sound was contributing more to the overall soundscape loudness than biological sound. Both of them have a relatively higher contribution to the overall soundscape loudness during the first two and last two periods. Comparing the relationship between them revealed on main-class level and middle-class level, it is found that, though accumulated perceived geophony were usually lower than that of biophony during most of the periods (Fig. 4.1), the contribution of it to the overall soundscape loudness was usually higher than biophony (Fig. 4.2). That means the existence of geophony could lead to a louder soundscape than biophony.

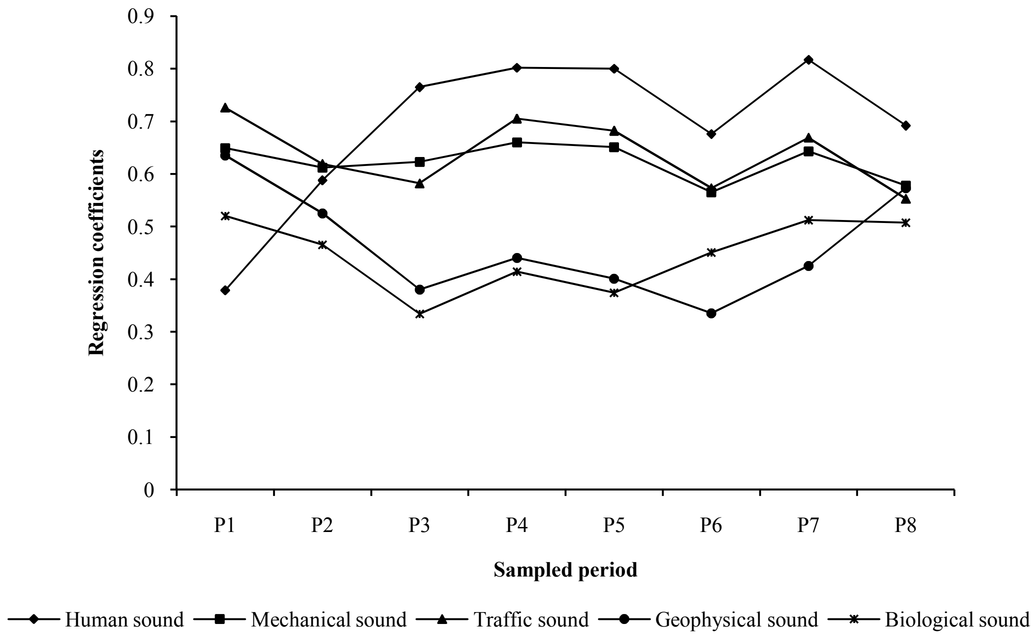


Fig. 4.2 Contributions of the five middle-class sounds to the perceived overall soundscape loudness during all sampled periods (P1-P8)

Table 4.3 shows correlation results among different middle-class sounds 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.

In summary, soundscape composition on the middle-class level confirmed dominance of anthrophony again. With a more detailed classification of anthrophony into three categories, more information about the urban soundscape characteristics were revealed, such as human sound contributed the most to the urban soundscape loudness; traffic sound was dominating all the time without so much changing. Relationships among different soundscape elements were also more revealed, such as the differences or similarities of their temporal patterns. And it is interesting to find out that biological sounds are not impaired by all anthrophony. As an exception, traffic sound and biological sound are positively related.

Table 4.3 Spearman' rho correlation among different middle-class sounds 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**

4.2.3 Sub-class sound

Analysis on the most detailed soundscape data reflected on the sub-class level could indicate specifically which kinds of sound were actually leading the characters of urban soundscapes. Thus, supply also detailed and concrete information for local soundscape management.

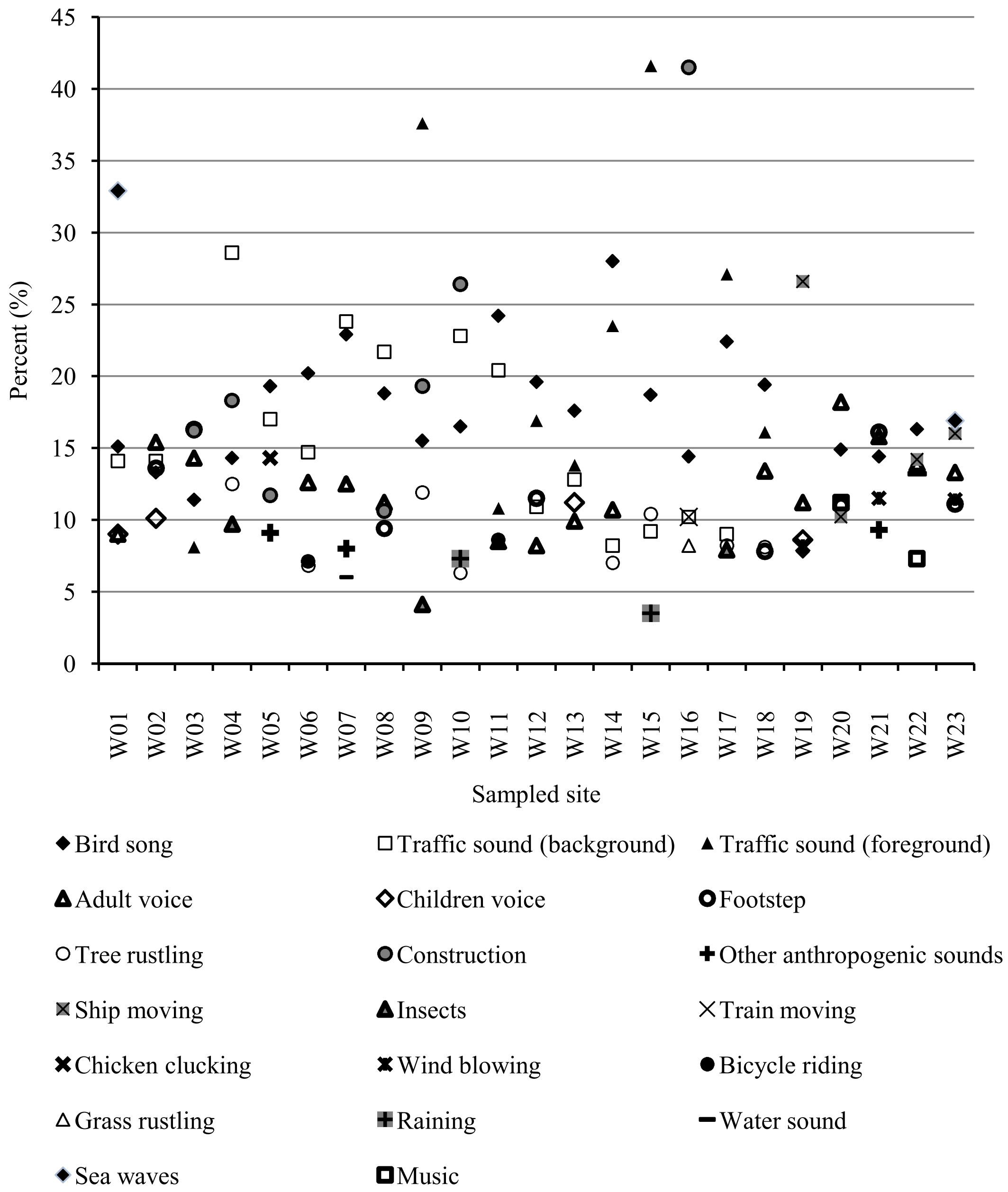


Fig. 4.3 Percentage (%) of the first five dominating sub-class sounds in terms of accumulated soundscape loudness during all sampled periods at different sampled sites (W01-W23)

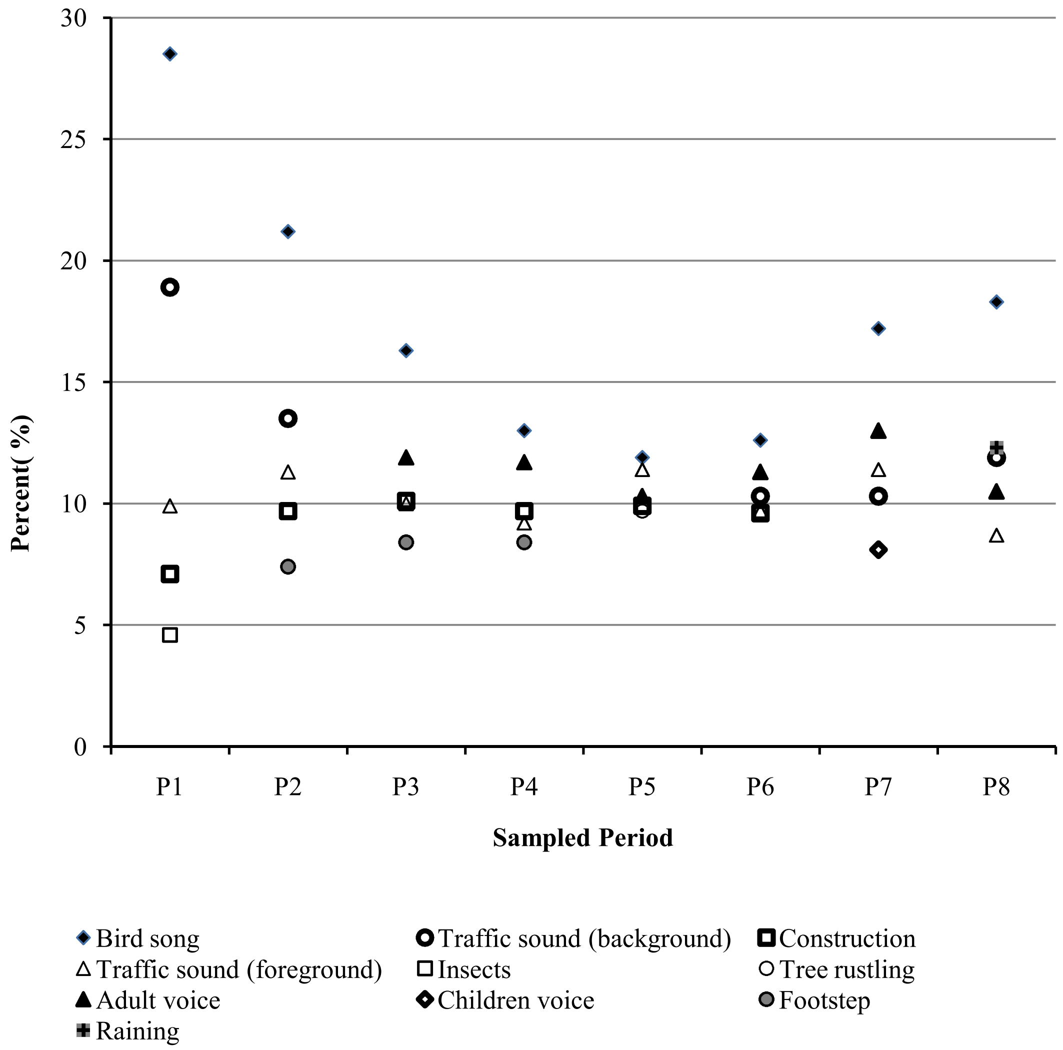


Fig. 4.4 Percentage (%) of the first five dominating sub-class sounds in accumulated soundscape loudness across the area during different sampled periods (P1-P8)

Figure 4.3 shows the spatial distribution of major sub-class sounds, according to the percentage of recording scores of each sound during all sampled periods at each of the 23 sites in accumulated overall soundscape loudness of this site. The dominating sounds heard at each sampled site (with the total number of sites shown in brackets) were bird song (22), adult voice (16), traffic sound (background) (15), traffic sound (foreground) (9), footsteps (9), tree rustling (8), and construction sound (7). The five most dominant sounds contributed over 60% to overall soundscape loudness at all sites. Figure 4.4 shows the temporal distribution of sub-class sounds, according to the percentage of recording scores of each sound at all 23 sites during each period in accumulated overall soundscape loudness of relevant period. It can be seen that bird song and traffic sound (foreground) dominated in all sampled periods; construction sound dominated in six periods except in the last two periods (18:00-22:00), while adult voices also dominated in six periods except in the first two periods (6:00-10:00); traffic sound (background) dominated in the first two periods (6:00-10:00) and the last three periods (16:00-22:00). Overall, the five most dominating sounds contributed more than 50% to overall soundscape loudness in all sampled periods. The temporal pattern of bird song was parallel to that of biophony (Fig. 4.1), which indicates the strong contribution of bird song to the urban biophony.

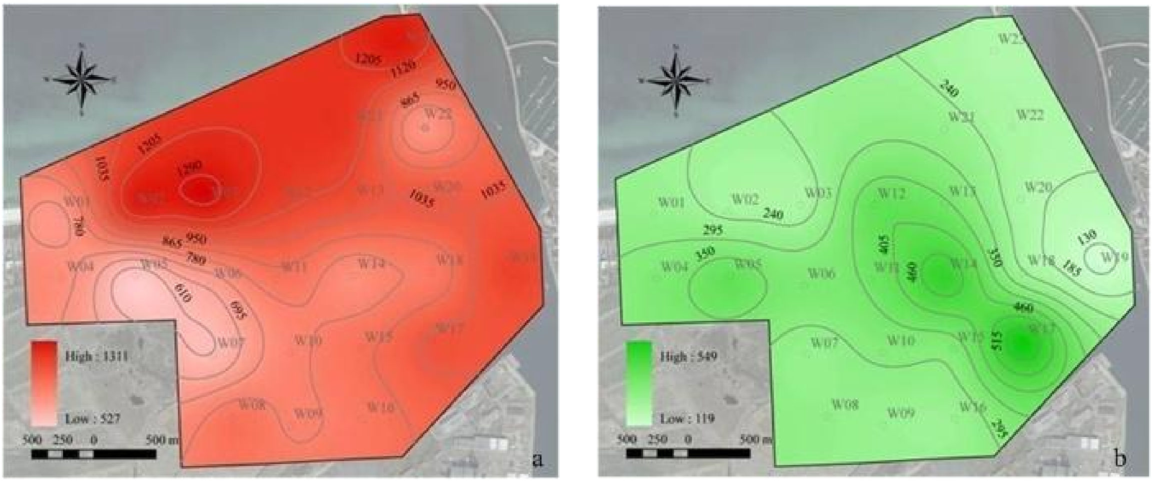
The regression model between the loudness of sub-class sounds and overall soundscape loudness delineated 15 different sounds (with standardised coefficients shown in brackets), including construction sound (0.442), traffic sound (foreground) (0.417), child voice (0.353), adult voice (0.314), wind (0.287), sea waves (0.278), tree rustling (0.238), traffic sound (background) (0.238), bird song (0.236), other anthropogenic sounds (0.224), footsteps (0.196), music (0.182), rain (0.172), bell ringing (0.163), and insects (0.149), explaining 90.7% of the overall soundscape loudness. The results show that the overall soundscape loudness tends to be rated higher when anthrophony was classified louder by the observers. Moreover, the occurrence of geophony is more likely to result in a higher overall soundscape loudness than the occurrence of biophony, as also indicated in section 4.2.2.

In summary, soundscape composition on the sub-class level confirmed dominance of anthrophony, but the contribution of biophony and geophony could only be detected at this level. The results indicate that perceived loudness of bird song could also contribute with a high percentage to overall soundscape loudness as an integral part of the biophony. Many geophony such as wind, sea waves, and tree rustling is among the most contributing sounds to the overall soundscape loudness.

4.3 Thematic soundscape mapping

4.3.1 Soundscape maps of main-class sounds

Soundscape maps of anthrophony, biophony and geophony are presented in Fig. 4.5 a-c, respectively. Anthrophony was perceived mostly in areas near the beach and main roads, and the least in garden areas (Fig. 4.5a). Biophony of the central and south-eastern parts of the study area, which mostly consisted of residential areas and parks, was more than in the boundary areas (Fig. 4.5b). As shown in Fig. 4.5c, geophony prevailed in the north-western and north-eastern corner of the study area, while far less was perceived in central areas. From these thematic maps, it is possible to pin-point quieter or more naturally sounding areas.



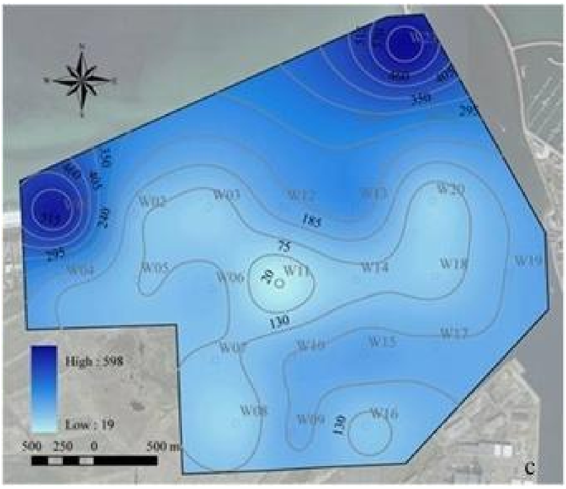


Fig. 4.5 Accumulated perceived loudness of each main-class sound during all sampled periods: anthrophony (a), biophony (b), and geophony (c)

Fig. 4.6 shows soundscape maps combining anthrophony, biophony, and geophony at different sampled periods coded by red, green, and blue, respectively. In all of the eight maps, a large percentage of the study area show intermediate colours. This suggests that the three kinds of sound occurred simultaneously at most sites. The maps again confirm that spatiotemporal patterns of urban soundscapes were dominated by anthrophony. The strongly varying colours seen in all maps of each sampled period indicate complex spatiotemporal patterns of urban soundscapes. However, some temporal trends of the three main-class sounds could be detected. For example, in the early morning, i.e., the first period (6:00-8:00), the soundscape pattern near the beach was mainly affected by geophony (Fig. 4.6a). During the following four periods (8:00-16:00), anthrophony became the major component of the soundscape due to increasing human activities (Fig. 4.6b-e). During periods 6 to 8 (16:00-22:00) the contribution of anthrophony decreased in this area (Fig. 4.6f-h). In core areas, biophony contributed most to the soundscape during the first two periods (6:00-10:00) and the last two periods (18:00-22:00) (Fig. 4.6a-h). Biophony and geophony were more prominent during the last period (20:00-22:00) in the southern part of the study area (Fig. 4.6h). These maps highlight combined effects of the three main-class sounds and the extent of soundscape dynamics.

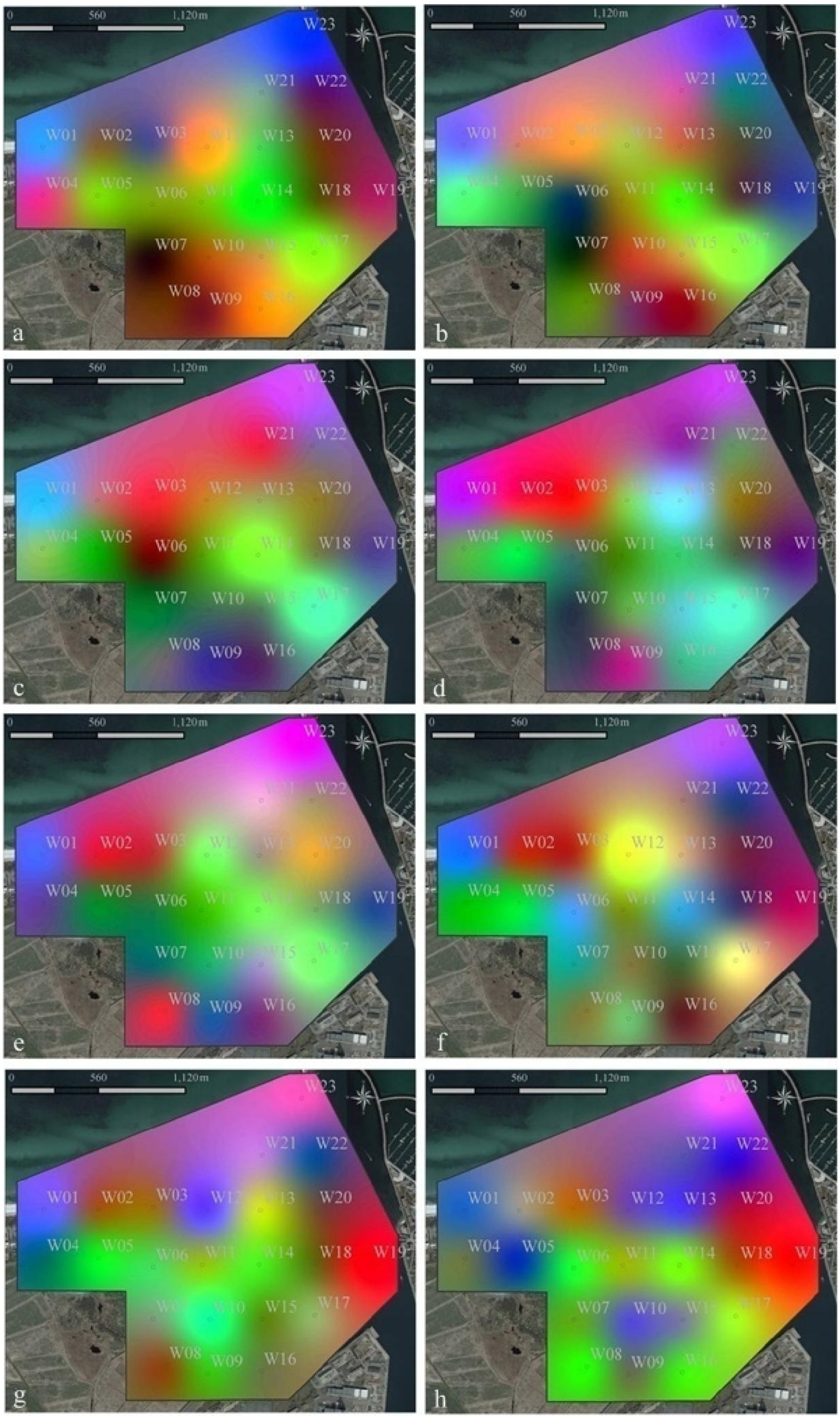


Fig. 4.6 Soundscape composition at each sampled period, where anthrophony, biophony, and geophony are originally described in red, green and blue respectively, and the intermediate colours stands for area that received combined sounds. Map a-h describes the soundscape composition in the 1st- 8th sampled period respectively.

4.3.2 Soundscape maps of middle-class sounds

Soundscape mapping on the middle-class sound level could provide more information, concerning the special issue of traffic sounds in urban areas. Figure 4.7 (a-e) shows the interpolation results of human, mechanical, traffic, geophysical and biological sounds, respectively. These maps are presented with the same scale (0-1000) to make them easily comparable by the darkness of the colour. 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 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 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 categories have 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.

In conclusion, thematic soundscape mapping using regularised spline with a tension interpolation is an effective method to illustrate spatial pattern of specific soundscape element. A combination of the thematic soundscape maps on main-class level could show vividly the spatiotemporal changes of overall soundscape composition in the study area.

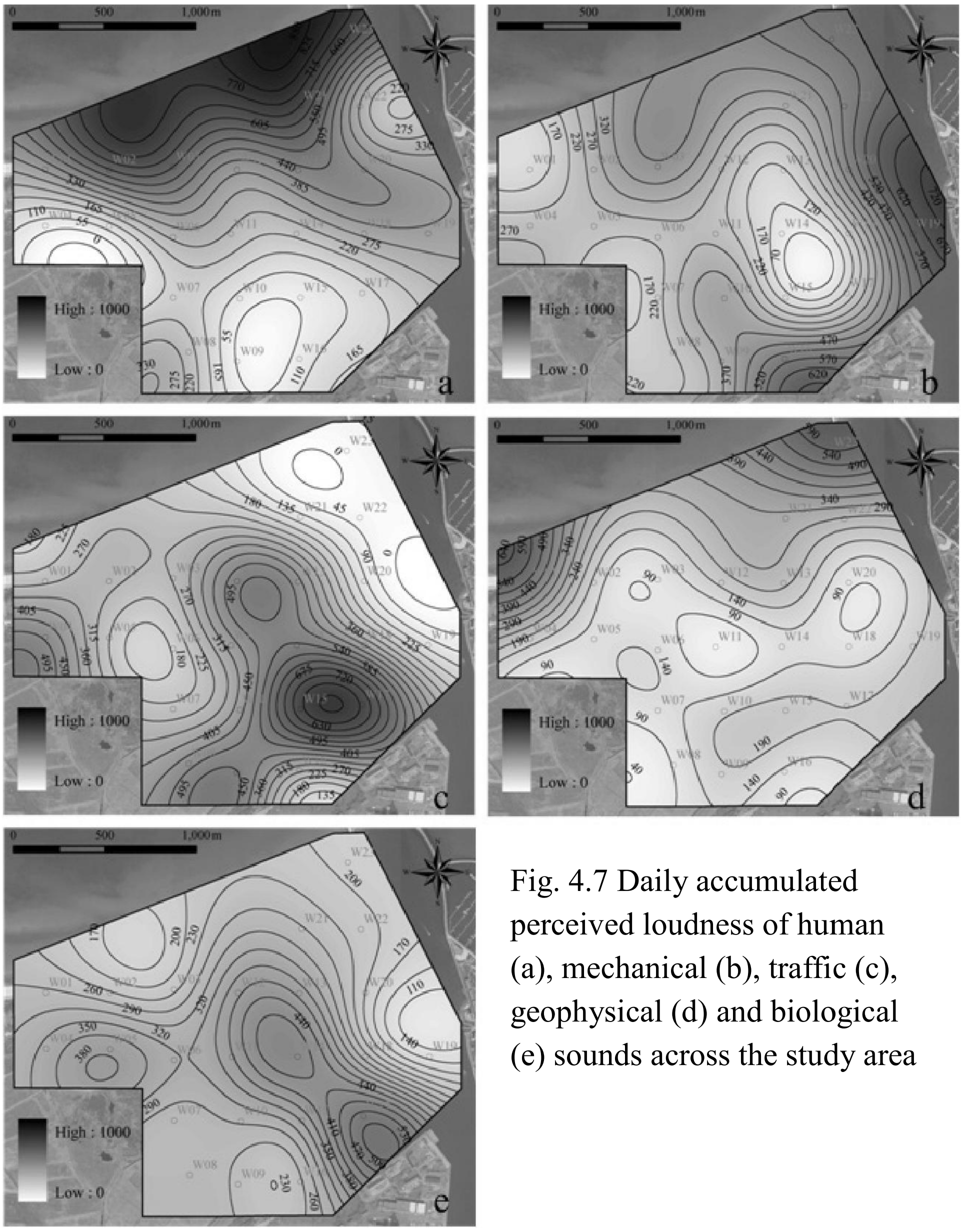


Fig. 4.7 Daily accumulated perceived loudness of human (a), mechanical (b), traffic (c), geophysical (d) and biological (e) sounds across the study area

4.4 Preference for soundscapes and soundscape elements

The relationship between soundscape preference and certain soundscape elements have been discussed by many researches in different types of urban spaces (Nilsson and Berglund, 2006; Yang and Kang, 2005a, 2005b). This is important information for soundscape design, as it is directly related to whether the designed soundscape in a certain place will be liked by the potential users. Positive soundscape element should be recognized and paid special focus during soundscape designing process.

In this investigation, though the focus is on revealing the characteristics of urban soundscapes and the relationships between soundscape and landscape, soundscape preference is still evaluated by the small group observers. Thus, the preference data does not stand for the broad opinions of the users, especially from the local citizens. But it is supposed that there could be still some clue be revealed, which could reflect a general relationship between soundscape preference and certain soundscape elements of a group of common listeners. The analysis was only conducted on the middle-class level.

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 (Nilsson and Berglund, 2006; Yang and Kang, 2005a, 2005b), 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. Though human sound is dominating the urban soundscapes during the day, it seems that it is not the decisive element that deteriorates the urban soundscape.

4.5 Summary

In this chapter, spatiotemporal characteristics of urban soundscapes were analysed based on three different levels of soundscape categories, i.e., main-class, middle-class, sub-class. The results show that it is necessary to do so, because the information generated from different levels could reflect both the common characteristics of the soundscape and special information that could only be revealed on the specific level. To be specific, urban soundscapes were dominated by anthrophony and showed a diverse spatiotemporal pattern because of the ever changing soundscape elements. Temporal variation of the three main-class sounds indicated a competitive relationship, but on the middle-class level, biological sound and traffic sound was showing positive relationship. Analysis on the relationships among different soundscape elements on the middle-class level revealed more information about the three kinds of anthrophony in terms of the dominance and temporal patterns. Analysis on the sub-class level recognised some specific sounds that were decisive for the urban soundscape characteristics. Especially, the contribution of biophony and geophony to overall soundscape loudness was more detected on this level. Bird song as an integral part of the biophony and many geophony such as wind, sea waves, and tree rustling are among the most contributing sounds to the overall soundscape loudness.

Several soundscape maps exhibited in this chapter show that thematic soundscape mapping could reveal spatiotemporal characteristics of different soundscape elements. The dynamic characteristic of urban soundscapes was also shown vividly by overlaying the thematic soundscape maps of main-class sounds. Thematic soundscape maps on the sub-class level could supply definitely more information, but considering the limited length of the thesis, not all of them could be mapped. Only thematic mapping of bird song as a special concern of this thesis was conducted in chapter 6.

Relationship between soundscape preference and certain soundscape elements was also analysed in this chapter. Though the preference data could not reflect the local users' opinion, it was collected as a necessary part of soundscape information which could combine the research results with practical management. Interestingly, the results from this research are in consistence with that of many previous researches. About soundscape preference, there will be more discussion in Part Ⅱ.

Chapter 5 Soundscape Perception and Landscape Spatial Pattern

The relationship between soundscape and landscape perception has been discussed in a number of studies in terms of aural-visual interaction as illustrated in chapter 2. However, the physical landscapes could affect soundscapes in a more directly way, i.e. sound generation and propagation. Sound generation is more related to the activities in a certain area with particular functions that are related to land use. Sound as transmission of energy through solid, liquid, or gaseous media in the form of vibration (Kang, 2007), the propagation through underlying landscape could be definitely affected by the physical landscape elements, such as reflection and absorption by building facades, street ground, water surfaces and vegetation. In a broader view, the landscape structure or the spatial pattern could have a combined effect on soundscape composition.

In this chapter, discussions are focused on the relationship between soundscape perception and landscape spatial pattern. The discussion falls into three parts: the first part discusses the relationship between soundscape composition and underlying landscape based on the empirical data; the second part examines statistically the relationships between soundscape perception data and several landscape indices on three different levels and the influential landscape characteristics are extracted; the third part discusses acquisition and application of soundscape information for planning purpose.

5.1 Soundscape composition and underlying landscape

In chapter 4, the spatiotemporal characteristics of urban soundscapes were analysed. Especially, the spatial patterns of different soundscape elements showed already some clue about the relationship with underlying landscape. Among the 15 sub-class sounds that explain 90.7% of the overall soundscape loudness, it is further found that soundscape composition differed significantly among sampling sites according to the contribution of the first five dominating sounds. For example, bird song dominated nearly at all sites except for W23, and it contributed the most at site W14 (28%). Other relatively high values were found at W11 (24.2%), W07 (22.9%), W17 (22.4%), W06 (20.2%), and W12 (19.6%). An analysis of the locations of these sites showed that all of them are in residential or garden areas, where have a relative quiet acoustic environment isolated by dense buildings or vegetation. The domination of bird song (17.6%) in park areas, as indicated at site W13, where with good ecological conditions, was not that obvious as supposed. The busy traffic on the nearby road and park visitors' appearance and activities may result in a relatively low proportion of bird song in overall soundscape loudness here. Sounds that related with human appearance, i.e., adult voice, children voice, and footstep dominated on the beach (W01, W02, W03, W21, W22 and W23), in gardens (W06, W07, and W08), residential areas (W11, W12, and W14), urban parks (W13), commercial areas (W20), the city square (W18), and the harbor area (W19). These areas provide basic urban functions, i.e., recreation, communication, shopping, and transportation for citizens and tourists, introducing frequent human activities, thus possess more human sounds. Traffic sounds including both foreground traffic sound (TSF) and background traffic sound (TSB) are a major sound source forming the urban soundscapes. TSF was extremely loud as compared with the other dominating sounds at sites W09 and W15, due to their proximity to main roads. But, at sampling sites W14 and W17, which are both close to roads, though TSF were the most dominating sound, too, the contribution to overall soundscape was not extremely more than other soundscape elements. The reason is possibly that they are located in residential areas and close to buildings, which could block some traffic sounds from outside. TSB was perceived as a dominating sound source at 15 sites out of 23. It was much obvious at sites that were far from main roads, and relatively closed by trees or buildings (W04, W07, W08, W10, and W11). Moreover, SW dominated at sites W01 and W23 due to their close proximity to the sea. Site W16 is located in a construction yard and was full of construction sound (41.6%), and because it is the site closest to the railway, it is also the only one where train moving sound (TM) was perceived predominantly.

From the thematic soundscape maps, the relationship between soundscape and landscape is also quite obvious. The spatial patterns of the three main-class sounds and five mid-class sounds in the study area showed clearly their dominating areas respectively.

All of the facts mentioned above show that different land use types possess different kinds of sounds, and difference in soundscapes of certain location depends on the local landscape spatial arrangement. The relationship between soundscape and landscape will be further revealed statistically in the next section, other than in empirical data.

5.2 Landscape characteristics affecting soundscape perception on different levels

Pearson correlation analysis was conducted to test the relationships between the 11 landscape indices, i.e., building density (BD), road density (RD), distance to building (DTB), distance to road (DTR), vegetation density (NDVI), patch density (PD), largest patch index (LPI), landscape shape index (LSI), fractal dimension (FRAC), Shannon diversity index (SHDI), and contagion (CONT), and different soundscape elements on the three level, namely main-class, middle-class and sub-class. Given the dynamic temporal characteristic of the urban soundscape, 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 results are shown in Table 5.1, 5.2 and 5.3, respectively. Though the relationship between the same landscape index and soundscape element 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.

Although the landscape indices chosen all have their specific intention, Pearson correlation coefficients among all the indices were calculated too, in order to detect colinearity in landscape indices. The correlation results are shown in Table 5.4.

5.2.1 Main-class sound

Pearson correlation results between each of the landscape indices and main-class sounds by time-step per-period are shown in Table 5.1. The results show that perceived loudness of anthrophony is mainly positively related to road density, and distance to building, and mainly negatively related to distance to road, vegetation density, largest patch index, landscape shape index, fractal dimension, and contagion. It is obvious that most of the landscape indices are related with perception of anthrophony. Generally, more anthrophony could be perceived in areas with or close to busy roads, which possibly because traffic sounds are a major source of anthrophony in urban areas. The result shows that anthrophony were more in locations where are away from building. On the other hand, dense vegetation could significantly reduce perceived loudness of anthrophony, as indicated by NDVI. Landscape metrics show complex relationships with anthrophony. Considering the largest patch index and contagion are positively related, and they are both negatively related to landscape shape index and fractal dimension which are also positively related, the relationships between each of the four indices and anthrophony show this contradiction during the first two and last two periods. That means anthrophony during this periods could be more perceived in areas with small dispersed landscape patches with complex shape. However, their relationships with anthrophony were the same during the 3rd and 4th period. The possible reason could be attributed to the complex sources of anthrophony in the study area changed significantly in different periods.

Perceived loudness of biophony is mainly positively related to building density, vegetation density, patch density and landscape shape index, and mainly negatively related to distance to building, largest patch index and contagion. That means, biophony could be more perceived in areas with dense buildings and vegetation. Possible reasons are that dense buildings can prevent sound propagation and form an area of high acoustic quality, which was named “hi-fi” environment by Schafer (Schafer, 1994), while areas with dense vegetation usually represent high-quality habitats for vocalising organisms, such as birds and insects. Landscape fragmentation resulting from dispersed (CONT) of land use patches with complex shape (LSI) and small size (LPI) could facilitate perception of biophony, too, possibly because fragmented landscapes may also provide a wider range of ecological niches for a wider range of diverse bird species (Andren, 1994).

Perceived loudness of geophony could be affected by a multitude of different landscape features, mainly positively with distance to building, distance to road and largest patch index, mainly negatively with building density, road density, vegetation density, patch density, landscape shape index and fractal dimension. Geophony could be more perceived in areas with less buildings and roads, the possible reasons could be that buildings may block the transmission of geophony like wind flowing and sea wave, while low frequency geophony could be masked by traffic sounds generated from roads that are also low frequency. Complex landscape configuration could also impair geophony perception. The negative relationship with vegetation is hard to explain, and the reason could be revealed on the sub-class level.

Table 5.1 Pearson correlation between each of the landscape indices and main-class sounds by time-step per-period (*p<0.05, **p<0.01). See Table 3.2 for full names of the acronyms

Main-class sound	Period	BD	RD	DTB	DTR	NDVI	PD	LPI	LSI	FRAC	SHDI	CONT
Anthrophony	1	-0.015	.149**	-.168**	-.114*	.096*	0.077	-.112*	.094*	0.045	.156**	-.183**
	2	0.044	.139**	-0.033	-.254**	-0.02	.171**	-.176**	.142**	0.04	.206**	-.227**
	3	0.043	-0.075	.256**	0.011	-.347**	0.027	-.117*	-.154**	-.314**	0.05	-.117*
	4	-.220**	-0.081	.222**	-0.046	-.204**	-0.072	-.098*	-.094*	-.149**	.220**	-.158**
	5	0.03	0.009	.266**	0.056	-.257**	0.034	-0.061	-.105*	-.148**	0.017	-0.044
	6	0.072	.172**	0.069	-.175**	-.260**	0.077	-0.07	0.06	0.066	0.03	-0.055
	7	-0.083	.108*	.216**	0.01	-.318**	-.180**	.283**	-.225**	-0.065	-.279**	.313**
	8	-0.031	.220**	.224**	0.043	-.429**	-.231**	.207**	-.175**	-0.025	-.241**	.222**
Biophony	1	.437**	.204**	-.179**	-.246**	0.035	.230**	-.393**	.263**	0.051	0.088	-.299**
	2	.146**	-0.041	-.171**	0.003	.175**	-0.082	-.201**	-0.022	-.119*	0.021	-.264**
	3	.242**	0.019	-.095*	-0.017	0.054	-0.042	-.107*	0.036	0.024	0.002	-.138**
	4	.324**	.181**	-.114*	-0.043	0.086	.157**	-.241**	.228**	.118*	0.051	-.191**
	5	.416**	.212**	-.238**	-.277**	-0.043	.337**	-.190**	.323**	.254**	0.078	-.176**
	6	.135**	-.102*	-.128**	0.047	.330**	0.02	-.148**	0.08	0.039	-0.015	-.122**
	7	.221**	0.03	-.143**	-0.07	.253**	.280**	-.210**	.341**	.203**	0.055	-.105*
	8	0.036	-0.055	-.150**	0.041	.352**	-0.059	-0.082	0.077	0.064	-.211**	.097*
Geophony	1	-.446**	-.276**	.755**	.499**	-.349**	-.422**	.234**	-.557**	-.541**	-.126**	.121**
	2	-.435**	-.226**	.652**	.431**	-.366**	-.324**	.150**	-.462**	-.469**	-0.015	0.032
	3	-.339**	-.106*	.569**	.341**	-.261**	-.337**	.104*	-.335**	-.276**	0.033	-0.002
	4	0.027	.166**	.328**	.140**	-.120**	-0.064	0.036	-0.081	-.108*	-0.068	0.007
	5	-.240**	0.029	.568**	.353**	-.245**	-.184**	.226**	-.264**	-.215**	-.131**	.123**
	6	-0.072	-.122**	.470**	.347**	-.226**	-.156**	.126**	-.169**	-.150**	-.245**	.250**

	7	-.167**	-.244**	.343**	.202**	-.229**	0.013	.118*	-.150**	-.127**	0.048	-0.024
	8	-0.089	-0.051	.514**	.235**	-.278**	.122**	-0.088	-0.028	-.169**	.167**	-.123**

Table 5.2 Pearson correlation between each of the landscape indices and middle-class sounds by time-step per-period (*p<0.05, **p<0.01)

Middle-class sound	Period	BD	RD	DTB	DTR	NDVI	PD	LPI	LSI	FRAC	SHDI	CONT
Human sound	1	0.085	0.011	-.137**	-0.072	0.046	.165**	-.203**	.165**	0.045	-0.004	0.003
Human sound	2	-0.005	-.100*	.178**	-0.072	-.212**	0.082	.099*	-.118*	-.125**	-0.039	0.064
Human sound	3	0.06	-.160**	.353**	0.051	-.492**	0.072	0.023	-.163**	-.259**	-.098*	0.089
Human sound	4	-.155**	-.276**	.294**	0.034	-.386**	-0.04	0.09	-.252**	-.252**	0.025	0.06
Human sound	5	-.150**	-.242**	.403**	0.086	-.450**	0.024	.129**	-.210**	-.209**	-0.023	.098*
Human sound	6	-0.066	-.129**	.219**	0.029	-.350**	-0.054	.101*	-.263**	-.265**	-0.063	0.051
Human sound	7	-.178**	-.205**	.370**	.171**	-.416**	-.154**	.309**	-.363**	-.248**	-.223**	.277**
Human sound	8	-.119*	-0.007	.424**	.102*	-.626**	-.194**	.150**	-.285**	-.225**	-.122**	.166**
Mechanical sound	1	-.117*	0.027	.213**	.111*	-.321**	0.081	.151**	-0.06	-0.034	0.058	0.024
Mechanical sound	2	-.098*	0.048	-0.025	-0.083	-.140**	0.064	-0.072	.102*	0.072	.238**	-.135**
Mechanical sound	3	-.235**	-.133**	.200**	0.056	-.332**	-0.07	0.061	-.214**	-.235**	.193**	-0.067
Mechanical sound	4	-.329**	-.189**	.234**	.200**	-.189**	-.242**	0.068	-.238**	-.237**	.175**	-0.073
Mechanical sound	5	-.124**	0	.216**	.222**	-.247**	-0.056	.102*	-.156**	-.103*	0.075	-0.003
Mechanical sound	6	-.143**	0.064	.176**	-0.052	-.370**	0.033	-0.043	0.065	.113*	.132**	-0.038
Mechanical sound	7	-.105*	0.079	.195**	0.059	-.421**	-.119*	.326**	-.179**	-0.03	-.175**	.299**
Mechanical sound	8	-0.03	.123**	.173**	.134**	-.457**	-.233**	.389**	-.267**	-0.044	-.278**	.334**
Traffic sound	1	0.043	.138**	-.309**	-.191**	.371**	-0.071	-.156**	0.073	0.058	.126**	-.229**
Traffic sound	2	.161**	.235**	-.189**	-.192**	.312**	0.089	-.261**	.201**	.101*	0.08	-.233**
Traffic sound	3	.244**	.234**	-.262**	-.114*	.433**	0.029	-.288**	.196**	0.086	0.006	-.234**
Traffic sound	4	.198**	.386**	-.266**	-.286**	.351**	.179**	-.293**	.388**	.315**	.094*	-.206**

Traffic sound	5	.334**	.296**	-.322**	-.238**	.419**	0.072	-.332**	.254**	.145**	-0.022	-.171**
Traffic sound	6	.329**	.351**	-.326**	-.251**	.381**	.150**	-.184**	.338**	.302**	-0.011	-.108*
Traffic sound	7	.194**	.329**	-.316**	-.244**	.448**	0.037	-.278**	.284**	.233**	0.032	-.168**
Traffic sound	8	.124**	.283**	-.301**	-.189**	.478**	0.065	-.216**	.317**	.282**	0.004	-.150**

Table 5.3 Pearson correlation between each of the landscape indices and sub-class sounds by time-step per-period (*p<0.05, **p<0.01)

Sub-class sound	Period	BD	RD	DTB	DTR	NDVI	PD	LPI	LSI	FRAC	SHDI	CONT
Adult voice	1	.109*	0.04	-0.075	-.128**	-0.05	0.064	-.132**	0.06	0.041	.105*	-0.071
Adult voice	2	-0.064	-.122**	.175**	0.029	-.139**	0.026	.139**	-.139**	-.102*	-0.075	.108*
Adult voice	3	.138**	-.161**	.170**	0	-.393**	0.068	-0.029	-0.087	-.192**	-0.056	0.034
Adult voice	4	-.120*	-.258**	.245**	.102*	-.356**	-0.062	.160**	-.235**	-.199**	-0.068	.144**
Adult voice	5	-0.076	-.150**	.255**	0.066	-.326**	0.057	.138**	-0.086	-0.051	-.109*	.181**
Adult voice	6	-0.031	-.150**	.156**	.098*	-.258**	-0.003	0.046	-.180**	-.186**	-0.003	-0.027
Adult voice	7	-.127**	-.208**	.270**	.196**	-.319**	-.160**	.350**	-.301**	-.166**	-.282**	.367**
Adult voice	8	0.084	.125**	.238**	-0.059	-.616**	-0.025	0.051	-.106*	-0.058	-0.028	0.074
Child voice	1	-0.07	-0.059	-.110*	.112*	.175**	.135**	-.129**	.150**	-0.007	-.180**	.134**
Child voice	2	.117*	0.041	-0.022	-.120**	-0.014	0.048	-0.073	0.028	-0.007	0.015	-0.006
Child voice	3	0.091	-0.04	.382**	.102*	-.416**	-0.003	.119*	-.190**	-.216**	-.103*	0.089
Child voice	4	-.093*	-.149**	.339**	0.039	-.345**	-0.02	-0.013	-.174**	-.231**	0.077	-0.035
Child voice	5	-.133**	-.183**	.377**	0.035	-.348**	-0.053	0.064	-.239**	-.295**	0.064	-0.041
Child voice	6	-0.049	-0.014	.213**	-0.021	-.351**	-0.055	.094*	-.186**	-.177**	-0.079	0.048
Child voice	7	-.161**	-.097*	.251**	.109*	-.301**	-.135**	.202**	-.284**	-.179**	-.158**	.133**
Child voice	8	-.210**	-0.045	.513**	.283**	-.450**	-.326**	.254**	-.392**	-.298**	-.253**	.288**
Footstep	1	.131**	0.047	-0.05	-.132**	-0.062	.098*	-0.09	0.083	0.054	0.082	-0.073

Footstep	2	-0.003	-0.072	.143**	-0.089	-.212**	0.089	0.07	-0.08	-.108*	-0.004	0.012
Footstep	3	-0.091	-.159**	.279**	0.023	-.330**	.096*	-0.026	-.106*	-.192**	-0.072	0.086
Footstep	4	-.158**	-.249**	.112*	-0.069	-.212**	-0.01	0.059	-.187**	-.171**	0.058	0.027
Footstep	5	-.150**	-.247**	.333**	.104*	-.402**	0.052	.106*	-.178**	-.158**	-0.008	.092*
Footstep	6	-0.07	-.132**	.126**	-0.01	-.181**	-0.065	0.089	-.234**	-.241**	-0.06	.098*
Footstep	7	-.108*	-.148**	.306**	0.069	-.307**	-0.041	.123**	-.219**	-.210**	-0.044	.101*
Footstep	8	-.227**	-.140**	.331**	0.081	-.433**	-.175**	.092*	-.249**	-.240**	-0.048	0.073
TSB	1	-.131**	-.351**	-.278**	0.014	.458**	-.169**	-0.056	-.106*	-0.083	0.082	-.153**
TSB	2	-.269**	-.508**	-0.071	.232**	.347**	-.169**	0.021	-.207**	-.234**	-0.063	-0.054
TSB	3	-0.076	-.198**	-.190**	.156**	.480**	-.108*	-0.019	-0.073	-.121**	-.154**	0.008
TSB	4	.108*	-0.007	-.204**	0.028	.408**	.112*	-0.037	.151**	.103*	-0.041	-0.042
TSB	5	.241**	.120*	-.208**	-0.02	.352**	0.045	-.120*	.147**	0.027	-.120**	-0.08
TSB	6	0.006	-.302**	-.245**	.132**	.458**	0.026	.200**	-0.002	0.071	-.231**	.195**
TSB	7	-.237**	-.269**	-.174**	.137**	.441**	-.171**	0.016	-0.083	-0.066	-0.027	0.029
TSB	8	-0.022	-.269**	-.229**	.119*	.466**	-0.086	.101*	-0.01	0.041	-.163**	.092*
TSF	1	.141**	.417**	-.134**	-.227**	.096*	0.037	-.131**	.147**	.095*	0.053	-.120**
TSF	2	.309**	.512**	-.135**	-.329**	.118*	.173**	-.256**	.299**	.213**	.105*	-.169**
TSF	3	.350**	.426**	-.197**	-.242**	.202**	.120*	-.325**	.295**	.190**	0.071	-.261**
TSF	4	.204**	.473**	-.203**	-.341**	.168**	.144**	-.311**	.362**	.308**	0.07	-.181**
TSF	5	.251**	.277**	-.266**	-.284**	.295**	0.061	-.305**	.210**	.152**	-0.007	-.096*
TSF	6	.394**	.546**	-.209**	-.344**	.154**	.124**	-.304**	.335**	.253**	0.064	-.186**
TSF	7	.367**	.490**	-.215**	-.327**	.196**	.145**	-.287**	.333**	.266**	0.018	-.158**
TSF	8	.143**	.490**	-.171**	-.286**	.207**	.126**	-.288**	.340**	.263**	0.069	-.181**
Construction	1	-.102*	0.035	-0.084	0.01	0.055	-0.013	0.065	0.007	0.012	.205**	-.150**
Construction	2	-.100*	-0.002	-0.068	-.154**	0.001	.107*	-.125**	.173**	.096*	.343**	-.247**

Construction	3	-0.032	-0.05	-.154**	-.115*	.166**	0	-.233**	.113*	0.002	.380**	-.369**
Construction	4	-.303**	-.191**	-.120**	0.079	.396**	-.159**	-.181**	-0.036	-.157**	.350**	-.331**
Construction	5	-.176**	-0.079	-.121**	.150**	.501**	-.165**	-.112*	-0.041	-0.035	.163**	-.203**
Construction	6	-0.076	.116*	-.110*	-.231**	-0.031	.184**	-.230**	.307**	.232**	.446**	-.389**
Construction	7	-0.091	0.056	-0.003	-0.071	0.059	0.002	-0.082	0.075	0.052	.277**	-.201**
Construction	8	-0.035	-.138**	-0.022	.149**	.131**	-0.009	0.019	-0.021	-0.076	0.059	-.107*
Other anthrophony	1	.193**	.271**	-0.088	-.170**	-0.047	.151**	-.172**	.194**	.176**	0.077	-0.083
Other anthrophony	2	0.088	0.016	-.103*	-0.02	0.014	.162**	-.187**	.146**	.098*	.190**	-.191**
Other anthrophony	3	-0.055	0.008	.138**	-0.06	-.412**	.287**	.273**	-.094*	-0.074	0.012	0.039
Other anthrophony	4	.153**	.210**	-.110*	-.135**	-.198**	-0.044	0.047	-0.015	0.038	-0.02	0.029
Other anthrophony	5	0.011	0.03	.101*	-0.063	-.386**	.180**	.263**	-.126**	-0.087	-0.049	0.063
Other anthrophony	6	0.065	-0.059	-0.091	-0.068	-0.06	.163**	.135**	0.023	.106*	-.118*	.135**
Other anthrophony	7	0	-0.055	-0.085	.097*	0.051	-0.083	.288**	-0.012	.217**	-.332**	.370**
Other anthrophony	8	-0.03	-0.084	.226**	.240**	-0.071	-.154**	.120**	-.109*	-0.006	-.245**	.210**
Sea wave	1	-.346**	-.257**	.592**	.356**	-.191**	-.362**	0.069	-.387**	-.364**	0.006	0.05
Sea wave	2	-.348**	-.258**	.608**	.361**	-.214**	-.338**	0.089	-.390**	-.366**	-0.007	0.06
Sea wave	3	-.349**	-.257**	.607**	.368**	-.198**	-.367**	0.072	-.391**	-.366**	-0.004	0.058
Sea wave	4	-.329**	-.243**	.577**	.351**	-.189**	-.347**	0.069	-.370**	-.346**	-0.007	0.058
Sea wave	5	-.365**	-.264**	.667**	.415**	-.225**	-.390**	0.082	-.409**	-.381**	-0.042	.092*
Sea wave	6	-.351**	-.253**	.668**	.423**	-.227**	-.382**	0.084	-.402**	-.371**	-0.052	.099*
Sea wave	7	-.345**	-.264**	.596**	.322**	-.254**	-.250**	.137**	-.388**	-.366**	-0.002	0.052
Sea wave	8	-.383**	-.284**	.687**	.373**	-.357**	-.238**	.132**	-.395**	-.379**	-0.035	0.079
Tree rustling	1	-0.001	0.021	-0.033	.169**	.273**	-.181**	-0.027	-.128**	-.198**	-0.04	-.138**
Tree rustling	2	-0.091	-0.073	-.151**	0.014	.312**	-0.036	-.292**	0.06	-.112*	.209**	-.321**
Tree rustling	3	.102*	.165**	-.189**	-.152**	.210**	.098*	-.197**	.255**	.200**	.158**	-.276**

Tree rustling	4	.282**	.300**	-.275**	-.162**	.411**	.154**	-.330**	.324**	.159**	0.032	-.188**
Tree rustling	5	.200**	.113*	-.315**	-0.061	.509**	0.085	-.196**	.266**	.174**	-0.011	-.148**
Tree rustling	6	.412**	.162**	-.223**	-.193**	.162**	.106*	-.103*	.254**	.246**	-0.033	-0.033
Tree rustling	7	0.05	0	-0.039	0.039	0.04	-0.01	-0.041	0.02	0.003	-0.025	-0.063
Tree rustling	8	-0.06	-0.051	-.102*	-0.07	-0.022	0.027	-.165**	0.081	0.031	.139**	-.203**
Wind flowing	1	-.316**	-.125**	.688**	.388**	-.597**	-.127**	.442**	-.452**	-.354**	-.279**	.315**
Wind flowing	2	-.314**	-.110*	.710**	.417**	-.640**	-.155**	.452**	-.462**	-.356**	-.302**	.347**
Wind flowing	3	-.311**	-.155**	.808**	.528**	-.504**	-.266**	.284**	-.428**	-.347**	-.280**	.309**
Wind flowing	4	-.325**	-0.059	.605**	.354**	-.594**	-.225**	.494**	-.491**	-.353**	-.319**	.364**
Wind flowing	5	-.279**	-0.085	.653**	.344**	-.607**	-.097*	.364**	-.389**	-.296**	-.173**	.248**
Wind flowing	6	-.298**	-.100*	.616**	.394**	-.531**	-.179**	.471**	-.418**	-.269**	-.344**	.387**
Wind flowing	7	-0.064	-0.074	.154**	-0.018	-.259**	.288**	.232**	-0.082	-0.083	-0.034	0.028
Wind flowing	8	-.265**	-.159**	.852**	.618**	-.367**	-.307**	.164**	-.353**	-.296**	-.334**	.323**
Bird song	1	.413**	.106*	-0.068	-.252**	-.126**	.111*	-.270**	0.063	-.093*	0.087	-.253**
Bird song	2	.142**	0.042	-.121**	-.129**	0.042	0.019	-.147**	0.031	-0.014	0.003	-.149**
Bird song	3	.337**	.150**	-0.048	-.194**	-0.079	0.077	-0.091	.146**	.159**	-0.047	0.021
Bird song	4	.401**	.349**	-0.078	-.179**	-0.076	.222**	-.225**	.291**	.231**	0.015	-.113*
Bird song	5	.436**	.263**	-.275**	-.337**	-0.049	.377**	-.190**	.376**	.325**	0.055	-.125**
Bird song	6	.185**	-0.064	-0.06	0.018	.232**	.093*	-.121**	0.082	0.016	-0.078	-0.029
Bird song	7	.221**	-0.085	-0.071	-0.018	.164**	.254**	-.130**	.249**	.142**	0.002	-0.053
Bird song	8	-0.048	-.108*	-0.078	0.073	.347**	-.114*	-0.031	0	0.008	-.229**	.110*

Table 5.4 Pearson correlation among landscape indices (*p<0.05, **p<0.01)

	BD	RD	DTB	DTR	NDVI	PD	LPI	LSI	FRAC	SHDI
RD	.521**									
DTC	-.357**	-.244**								
DTR	-.525**	-.547**	.675**							
NDVI	-.194**	-.176**	-.446**	0.089						
PD	.482**	.447**	-.333**	-.562**	-.136**					
LPI	-.402**	-.274**	.187**	.390**	-.096*	-.370**				
LSI	.536**	.617**	-.478**	-.611**	0.087	.849**	-.516**			
FRAC	.365**	.546**	-.452**	-.482**	.092*	.656**	-0.053	.837**		
SHDI	.153**	0.063	-.207**	-.493**	-.123**	.339**	-.675**	.318**	0.011	
CONT	-.263**	-.099*	.224**	.391**	0.039	-.318**	.776**	-.323**	0.059	-.903**

5.2.2 Middle-class sound

As stated in Chapter 3, the major difference between middle-class sounds and main-class sounds is that, anthrophony in the main-class are broken into three different types of sounds in the middle-class, i.e., human sound, mechanical sound and traffic sound. Geophysical sound and biological sound correspond to geophony and biophony, respectively. Thus the focus of the relationships between perception of middle-class sounds and landscape indices are only on the three different kind of anthrophony.

Pearson correlation results between each of the landscape indices and middle-class sounds by time-step per-period are shown in Table 5.2. The results indicate that, perceived loudness of human sound is mainly positively related to distance to building and largest patch index, and mainly negatively related to building density, road density, vegetation density, landscape shape index and fractal dimension. It suggested that human sound could be more easily perceived in open spaces that are not enclosed too much by buildings and even dense vegetations. Especially, in the study area, the beach area is the most popular places. People usually do not like to stay at places with too much traffic sound, as revealed by the negative relationship between human sound and traffic sound, thus dense roads could impair perception of human sounds. Areas that are with small size and complex shape land use patches could also affect human sound perception, which could indirectly from the effect of these indices on other kind of soundscape elements like traffic sound.

Perceived loudness of mechanical sound is mainly positively related to distance to building, distance to road and largest patch index, and mainly negatively related to building density, vegetation density, and landscape shape index. It shows that dense buildings and vegetation could all impair the perception of mechanical sound. Because mechanical sound is negatively related with traffic sound, thus places far from main road could perceive more mechanical sound. Areas with large size and simple shape land use patches could reserve more mechanical sound too, which may also because of less traffic sound there.

Perceived loudness of traffic sound is mainly positively related to building density, road density, vegetation density, landscape shape index and fractal dimension, and mainly negatively related to distance to building, distance to road, largest patch index and contagion. Positive relationship between traffic sound and road density was not hard to understand, as more road means more traffic load could exist. The positive relations with building density and vegetation density may be explained by the fact that main traffic roads do always combine with dense constructions and/or vegetations on both sides in the study area. The results suggest that dispersed smaller land use patches with irregular contours could reserve more traffic sound. That is mainly because this kind of landscape characteristic could have more boundaries that are usually defined by traffic roads. The results also verify the possible indirect effects of these indices on human and mechanical sounds.

The results also indicate that landscape effects on traffic sound are nearly reversed with that on human and mechanical sounds. Thus, it is necessary to conduct detailed analysis of the three kind of anthrophony on middle-class level.

5.2.3 Sub-class sound

Because there are as many as 27 different kinds of sub-class sound appeared in the study area, there will be too much work to examine the relationships between landscape indices and each of them. Thus, only relatively important ones are analysed, including these either dominating ones (either spatially or temporally) and influential ones to the overall soundscape loudness, according to the results in Chapter 4, namely adult sound, children sound, footstep, traffic sound (background) (TSB), traffic sound (foreground) (TSF), construction, other anthrophony, sea wave, tree rustling, wind flowing and bird song.

Pearson correlation results between each of the landscape indices and sub-class sounds by time-step per-period are shown in Table 5.3. The results show that road density, distance to building, vegetation density, landscape shape index and fractal dimension have nearly the same effects on the three kinds of human sound, i.e., adult voice, child voice and footstep, and only distance to building shows positive relationships with them. The reasons could be also explained by those of human sounds. However, it is noticed that largest patch index which is effective on the middle-class level for human sound, shows no obvious relationships with all the three sub-class human sounds.

Effects of landscape characteristics on the two kinds of traffic sounds are interestingly found different. Landscape effects on perception of traffic sound (foreground) are highly consistent with that on traffic sound on middle-class level, except that patch density also shows positive effect on traffic sound (foreground). However, landscape effects on traffic sound (background) are quite different. Similar effects with those on traffic sound (foreground) only come from distance to building and vegetation density. Road density and distance to road show reversed effects on the two kinds of traffic sounds. It makes sense that background traffic sound could be more perceived when the foreground traffic sound is not so intensive. Besides, Shannon diversity index only shows negative relationship with traffic sound (background).

For the two kinds of mechanical sounds, landscape effects on them show no highly consistence with that on the full range mechanical sound on middle-class level. While several landscape indices show relatively stable relationships with perception of construction sound, landscape effects on other anthrophony are really not predictable.

That is mainly because most unrecognisable mechanical sounds were occasional and regardless of locations. Because of this, it is concluded that though landscape affects perception of mechanical sounds, landscape indices may not be effective as indicators for them.

For the three kinds of geophony, landscape effects on perception of sea wave and wind flowing are quite similar with that of the geophony on main-class level. And the effects on wind flowing are even more from all the landscape indices. Largest patch index does not show significant effect on sea wave, though it is effect for the full range geophony. However, for tree rustling, landscape effects are quite different with that of on main-class level. With three same effective indices, all of them show reversed effects on tree rustling, i.e., distance to building, vegetation density and largest patch index. Contagion also shows negative effect on tree rustling. Especially for vegetation density, it is positively related to tree rustling, which is quite understandable. But it is negatively related to sea wave and wind flowing, which may because with the mild weather condition during most of the investigation time, most of the sea wave and wind flowing were perceived in the coastal area, where vegetation density is relatively lower.

Birdsong is the only sub-class sound analysed as biophony. Landscape effects on perception of birdsong are quite similar as those on biophony, mainly because birdsong is at a dominating position in biophony in the study area. The relationships between birdsong perception and landscape indices will be discussed in more detail in Chapter 6.

5.2.4 Extraction of influential landscape characteristics

In this research, 11 landscape indices are tested in relation to soundscape perception. As shown in the last three sections, several landscape indices show obvious relationships with soundscape elements on different classification levels. These indices all reflect landscape composition and configuration status from different aspects. Specifically, 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), heterogeneous status (PD, SHDI), and distribution (CONT) (McGarigal and Marks, 1995). In order to get more instructive results, influential landscape characteristics are extracted in this section, based on the relationships between soundscape perception and landscape indices shown mainly on middle-class levels.

Building. There are two indices used to characterise buildings in the local landscape, building density and distance to building. These two indices all show significant relationships with all the five middle-class sounds, making buildings one of the most important and influential landscape elements on soundscape perception. Building density is usually high in urban areas, which may form a kind of acoustic space termed "hi-fi area" (Schafer, 1994), a relatively quiet area formed by preventing a large part of sounds from outside, which makes it easier for human to recognise more sounds such as biological sounds. As most of the buildings are near traffic roads and form another kind of acoustic space termed "street canyons" to some extent (Kang, 2007), this may explain the positive correlation between dense buildings and traffic sound. Dense buildings 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. Buildings also show significant effect on the overall urban landscape characteristics, as indices for buildings show significant relationships with all the other landscape indices (Table 5.4).

Road. There are also two indices for characterising roads in the urban area, road density and distance to road. As the artery of urban areas, traffic roads are one of the main sound sources of urban acoustic environment, traffic sounds, which is also obviously suggested in the result that higher road density associates with more traffic sound. Traffic roads also show significant effect on perception of geophysical sound (geophony). The possible negative effects on geophysical sound could be indirectly from masking by traffic sound, as they both contain low frequency components. For the other sound elements, traffic roads have no obvious positive or negative trend, except for the negative effect of building density on human sound and positive effect of distance to building on mechanical sounds. It is important to note that, traffic roads in urban areas are also influencing the other aspects of landscape characteristic, which could be detected in the close relationships between the two road indices and other landscape indices (Table 5.4).

Vegetation. Vegetation density is indicated by NDVI value, and show relationships with all the five middle-class sounds. Vegetation could act in two aspects in relationship to soundscape perception. On the one hand as sound 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.

Land use scale. Largest patch index (LPI) is selected to characterise land use scale, and high value means existing of certain large scale and dominating land use patch in the landscape. LPI could affect the perception of all the five middle-class sounds. As land use is related to certain activities happening in this area and further determine 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 5.4), so that high LPI value is related to less traffic sound.

Land use shape. Landscape shape index and fractal dimension are used to characterise land use shape. Both LSI and FRAC could reflect shape complexity of land use patches. Although they are highly correlated, as shown in Table 5.4, LSI showed more indicating ability than FRAC on different soundscape elements, as it shows significant relationships with all the five middle-class sounds. 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 5.4). 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 sounds that from far distance (e.g. sea wave, or wind blowing), high LSI and FRAC means more "boundaries" during propagation before they are perceived, thus negative relationships between them were shown. However, the same type of landscape characteristic may favour the perception of gentle geophysical sounds, like tree rustling.

Land use composition. Patch density (PD) and Shannon diversity index (SHDI) could characterise landscape composition, and reflect landscape heterogeneous status. However, these two indices do not show significant indicating ability for soundscape perception. PD is mainly related to perception of geophony and biophony on the middle-class (also main-class) level and SHDI only show effects on the sub-class level, with child voice, traffic sound (background), construction and wind flowing. The reason may be due to the diversity of the landscape limited by the small scale of the 175 m buffer area.

Land use distribution. Contagion (CONT) indicates the spatial distribution of land use patches. It is positively correlated with LPI (see Table 5.4). 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 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 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. Though collinearity exists among the landscape indices chosen, they could not really replace each other without further evidence, when considering the effects on soundscape perception, as illustrated above they characterise different aspects of the landscape. 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 (De Coensel et al., 2010; Yu and Kang, 2008, 2010).

5.3 Soundscape information for planning purpose

5.3.1 Acquisition of soundscape information

As soundscapes in urban environments are spatially and temporally highly dynamic and depend essentially upon human activity and perception, several aspects should be considered when acquiring soundscape information with the method outlined in the present study. Firstly, the way to record soundscape information should be easily understood and easy to conduct by human raters. In this study, soundscape in the project is treated as an "objective" reflection of the urban acoustic environment, but the data collected still follows the central principle of soundscape concept, namely through human perception. Soundscape information was collected descriptively by a group of pre-trained non-local observers (Raimbault, 2006). Soundscape was treated as an assembly of different sounds with a standard loudness value appearing in a certain period perceived by the observers. The category of different sounds was based on the common understanding of sound sources. Pre-trained observers are important factors in the research design, in order to guarantee the "objectivity" of the whole soundscape dataset, which is crucial for revealing the relationships among different soundscape elements in soundscape perception, as well as solid and universal soundscape-landscape relationships. In future studies, the sound categorisation could also be used to analyse cognitive aspects of soundscape categorisation (De Coensel et al., 2010; Dubois et al., 2006), and preference for each category should also be considered and not only perceived loudness. Moreover, an appropriate spatial scale based on observers' perception would be helpful for a better understanding of relationships between soundscape perception and spatial landscape patterns, as well as the factors influencing soundscape. The scope of this study was confined to a multiple functional urban area, assuming that soundscapes are composed mainly by sounds from local activities. Future considerations should include a larger spatiotemporal scale and acoustical band-width beyond the scope of this study. In the present study, the temporal variability of the soundscape was analysed on a daily basis. While interesting patterns were found, it will be important to consider a longer time span covering a wider range of seasonal variation or phenophases. A detailed long-term survey of soundscape information involving local citizens is a promising direction to follow.

5.3.2 Application of soundscape information

Urban ecosystems are important in providing services with direct impact on health and security such as air purification, urban cooling, runoff mitigation and noise reduction (Bolund and Hunhammar, 1999). As a more objective concept than "noise", urban soundscape should also be recognised as a kind of ecosystem service, as argued in chapter 2. The EU' s strategies to stop the progress of environmental degradation and the concomitant loss of biodiversity, for example through, establishing green infrastructure that enhances ecosystem services, could significantly benefit from including aspects of urban acoustic ecology. In fact, soundscape information could be influential when combined with landscape management. The problem, however, is how this information can be combined in practice. Landscape indices are recognised as effective tools in current landscape assessment and management procedures, as they 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 and Ahern, 2002; Corry and Nassauer, 2005; Turner and Gardner, 1991). Hitherto, applications of indices of acoustical aspects of landscapes have been neglected. In our study, we assumed that landscape affects soundscape perception in two ways, i.e., landscape composition determines which kind of sounds are generated (soundscape composition); and spatial landscape configuration affects sound propagation and thus soundscape patterns. Therefore, landscape indices were tested as the link combining soundscape information with landscape features. The close relationships between soundscape perception and several spatial landscape indices show a great potential for implementing soundscape information into landscape management practice. Especially, vegetation density as reflected in NDVI proved to be positively related to biophony, which indicates the need to establish green infrastructure in urban areas to improve perceived soundscape quality. However, soundscape perception and assessment involves a range of facets in addition to perceived loudness, so that the relationship between soundscape perception and landscape indices should be explicitly tested in future studies that should also involving more landscape types at different spatial scales and over longer seasonal periods.

5.4 Summary

In this chapter, relationships between soundscape perception and landscape spatial pattern indices were discussed on the three different levels of soundscape categories. 11 landscape indices were selected to characterize the landscape spatial patterns from different aspects. Significant relationships between landscape indices and soundscape elements were recognised on the three levels. Relationships on different levels were not always consistent. Generally speaking, relationships on the sub-class level could reveal more information with stronger local characteristics, and on the middle-class level the information could be more universal for urban areas, also not too general as on the main-class level.

Then, influential landscape characteristics on soundscape perception were extracted, including building (indicated by building density and distance to building), road (indicated by road density and distance to road), vegetation (indicated by NDVI), land use scale (indicated by largest patch index), land use shape (indicated by landscape shape index and fractal dimension), land use composition (indicated by patch density and Shannon diversity index), and land use distribution (indicated by contagion). Among these indices, building density, distance to building, vegetation density, largest patch index and landscape shape index show the most influential relationships with all the five middle-class sounds, making them the most powerful indicators for soundscape perception. However, the relationships between landscape indices and soundscape perception need to be further discussed and proved.

Therefore, in the last section acquisition and application of soundscape information for planning purpose through examining the relationships between soundscape and landscape was discussed in terms of future research necessities.

Chapter 6 Birdsong as a Typical Urban Soundscape Element

Birds habitat in urban areas where are generally characterized by intensive anthropogenic disturbance to the natural surroundings may have to adjust their behaviours. Especially for birds that use song (i.e. Oscines) for communicating territorial claims and mate attraction, they could be more sensitive to the urban acoustic environment (Naguib and Riebel, 2006; Slabbekoorn and Ripmeester, 2008). At the same time, it is found that birdsong can enhance landscape visual enjoyment and be a positive element in urban acoustic environment (Carles et al., 1999; Yang and Kang, 2005a, 2005b; Yu and Kang, 2010). Thus, desirable sounds like birdsong and water sound are given more research attention (De Coensel et al., 2011; Jeon et al., 2010; Nilsson and Berglund, 2006). While previous work has been carried out using laboratory tests and public questionnaires, birdsong as it relates to the underlying landscape in actual urban context has not been paid enough attention. Such information would be useful for mapping of birdsong in a specific area and providing more information to the public and the urban planners.

In chapter 4 and chapter 5, birdsong has been recognised as an important element of many urban soundscapes. In this chapter, based on the consideration above, it seems necessary to pay special attention to birdsong. Based on the same soundscape dataset in Warnemünde, the discussion falls into four parts: in the first section, the role of birdsong as a significant element in urban soundscapes is recognised in a more detailed way; in the second section, the relationships between loudness perception of birdsong and other soundscape elements are revealed; in the third section, spatiotemporal characteristics of birdsong perception are analysed combined with thematic mapping techniques; and in the last section, the landscape characteristics that may affect birdsong perception are identified.

6.1 Role of birdsong in urban soundscapes

Many bird species are commonly appearing in the study area in summer time, such as *Passer domesticus*, *Turdus merula*, *Parus major, Parus caeruleus, Carduelis chloris, Pica pica, Larus argentatus, Larus canus,* etc., bringing rich birdsongs to the study area. Contribution of birdsong to the overall soundscape loudness was examined on both spatial and temporal scales. On the spatial scale, Fig. 6.1 shows contributions of perceived loudness of birdsong to overall soundscape loudness during all sampled periods at each sampled site. It can be seen that contributions were over 20% at seven of the 23 sampled sites (W14, W07, W11, W17, W08, W06 and W18), with the highest percentage of 29.4% at site W14. Smaller contributions were recorded at sites W19, W23, W03, W02, and W16, with the lowest contribution of 9.1% at site W19. At the other 11 sampled sites the contributions were over 15%. On the temporal scale, Fig.

6.2 shows the contribution of birdsong to the overall soundscape loudness at all sampled sites during each sampled period. It shows that average contributions were over 15% in five of the eight sampled periods, with the highest percentage of 28.8% in the 1st period, and the lowest contribution of 12.4% in the 5th period.

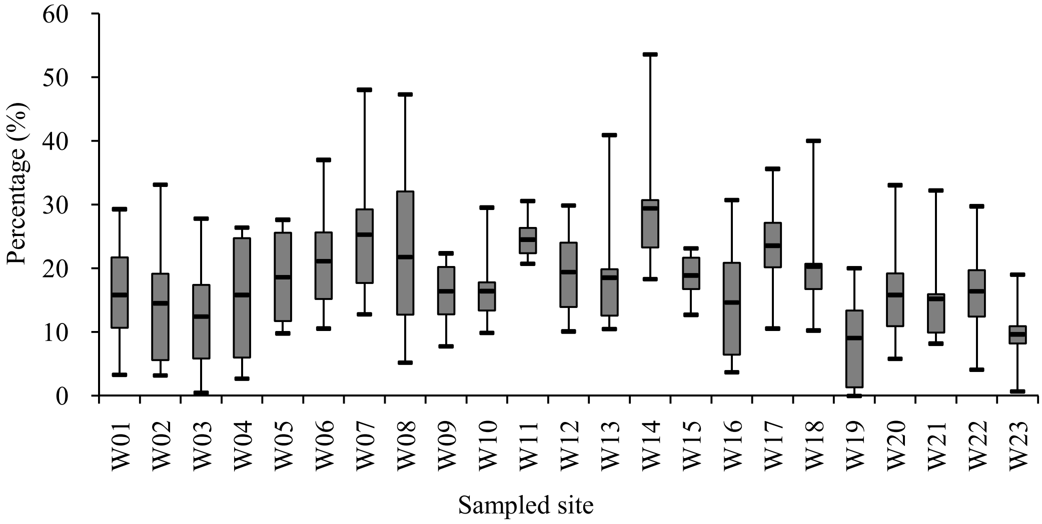


Fig. 6.1Contribution of birdsong to the overall soundscape loudness (%) during all sampled periods at each sampled site

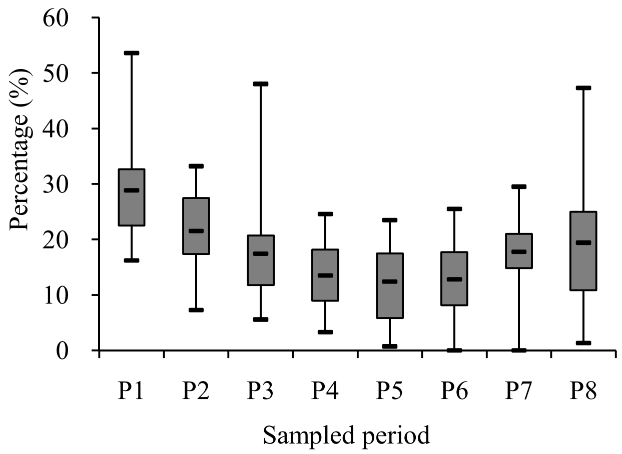


Fig. 6.2 Contribution of birdsong to the overall soundscape loudness (%) at all sampled sites during each sampled period

Spearman's rho correlation analysis between perceived loudness of birdsong and soundscape preference indicated a positive relationship (*C*=-0.162, p<0.001). The result is in line with several former studies (Yang and Kang, 2005a, 2005b; Yu and Kang, 2010).

In conclusion, the results indicate that in an urban area with intensive human activities and disturbance, the contribution of birdsong to the overall soundscape loudness is still significant spatiotemporally, which makes birdsong worth investigation as an important positive urban soundscape element.

6.2 Relationships with other sound sources

Relationships between perceived loudness of birdsong and the other main soundscape elements based on Spearman's rho correlation analysis are shown in Table 6.1. It shows that, human sounds seem to impair birdsong perception, indicated by the negative correlations with *adult voices* (-0.276), *child voices* (-0.209) and *footstep* (-0.175). Sounds from human activities such as *construction* and *music* were also negatively correlated with perceived loudness of birdsong, with correlation coefficients of -0.217 and -0.288, respectively. The reason may be that too much human appearance or activities could deter the birds (Fernandez-Juricic and Jokimäki, 2001). It is also reported by other researchers that noise from pervasive human disturbance in cities could promote nestedness of songbirds (González-Oreja et al., 2012). The relationships between birdsong and different kinds of anthropogenic sounds indicate the limited plasticity of birdsong, and need to be further studied in terms of soundscape perception.

However, the relationships between perceived loudness of birdsong and traffic sounds, the most dominating sounds in urban areas, are positive. Especially at sites W13 and W15, which were next to busy traffic roads and with dense vegetation, birdsong still contributed a lot to the overall soundscapes. The result suggested that birds in urban areas may have elevated the frequency and volume of their songs to avoid being masked by traffic sounds, which is in line with former studies that have found that behavioural flexibility of songbirds, such as adjusting their songs by changing frequency, amplitude, or singing time to adapt to the environmental noise (Brumm, 2004; Slabbekoorn and Ripmeester, 2008), is an important factor for surviving in urban areas. It seems that how noticeable this response depends on the extent to which birds can adjust their songs. For example, at sites W02 and W03, located near a traffic road, birdsong was much less perceived. Overall, the relationships between birdsong perception and anthropogenic sounds suggest that, although birds might adapt somewhat to persistent urban traffic sounds, excessive sounds related with human appearance (*adult voice*, *child voice*, *footstep*) or human activities (*construction activity*, *music*) could still frighten birds off.

Birdsong perception also showed a close relationship with some natural sounds (*insects*, *tree rustling* and *rain*). Because *insects* were usually perceived in quiet and ecologically good places in the area, which are also preferred by some bird species, and the predator-prey relationship exists between some bird species and insects, it is reasonable that birdsong and *insects* showed a positive relationship (0.233). Birdsong perception is also positively related with *tree rustling*, although only with a low coefficient of 0.146, which is perhaps because many birds are active in dense trees. With the mild weather conditions during most of the investigation time, there are more chances to perceive birdsong and *tree rustling* at the same time, whereas as reported by some researchers, birds often stop singing when the weather condition is harsh such as windy or raining heavily (Feng and Schul, 2006). This point was verified in this research by the negative relationship between birdsong and *rain* (-0.155) too, when it was raining heavily during the last period.

These relationships indicate the possibilities to enhance the contribution of birdsong to urban soundscape through controlling the volume of other sounds. For example, human activities in birds' sensitive habitat areas could be limited and controlled by careful land use arrangement in urban planning process. Thus, how the underlying landscape could affect birdsong perception is an important issue. This point will be discussed in the next sections.

Table 6.1 Soundscape elements showing significant correlations with birdsong based on Spearman's rho correlation analysis (2-tailed, * p<0.05, ** p<0.01)

Sound	Coefficient	Sig.
Adult voice	-0.276**	<0.001
Child voice	-0.209**	0.004
Footsteps	-0.175*	0.018
Traffic (background)	0.318**	<0.001
Traffic (foreground)	0.334**	<0.001
Music	-0.288**	<0.001
Construction	-0.217**	0.003
Other anthropogenic sounds	0.183*	0.013
Insects	0.233**	0.001
Tree rustling	0.146*	0.048
Rain	-0.155*	0.036

6.3 Spatiotemporal patterns

Mapping results of spatial distribution of perceived loudness of birdsong in each sampled period are shown in Fig. 6,3. All the maps are presented using the same scale (0-100), in order to make them easily comparable by the colour. It can be seen that the distributions of birdsong across the study area showed an ever changing characteristic along with different sampled periods. However, a clear spatial pattern was shown in each period, i.e., there was always relatively more birdsong perceived at certain sampled sites than others. Higher perceived loudness of birdsong was normally concentrated in residential areas (W14, W17, W11 and W12), garden areas (W05, W06, W07, W08), and urban park (W13). Daily accumulated birdsong across the study area, as shown in Fig. 6.4, indicated more clearly that birdsong concentrated in these areas. The reasons could be that, the residential areas are usually quiet areas because of the limited traffic inside these areas, and the dense buildings in residential areas blocking and dissipating much of the outside sounds especially traffic sounds, thus forming high acoustic quality areas (Schafer, 1994), where birdsong could be more easily perceived. Urban park in the study area is with dense vegetation, and could be an ecologically good place for birds, although occasional human activities existing at the same time. Garden areas are to some extent the combination of park and residential areas, as they are well cultivated by the owners, with a lot of greenery, and they are private, without excessive human activities. As a result, the green and quiet garden areas could be good choice for birds to forage and communicate. However, not so much birdsong as supposed was perceived near the water area (W19, W23) and the beach area (W01, W02, W03 and W21), which should be a foraging place especially for sea birds. One of the reasons is that organisms have to colonize, adapt to or abandon urban areas, which is highly artificial and novel ecosystem with altered habitat conditions (Katti and Warren, 2004). The beach and river mouth areas with intensive human activities form noisy environments with traffic sounds, human sounds, and other human made sounds are no longer suitable as bird habitats. For example, many *Larus argentatus* were found at site W14, where is a residential area. From these thematic maps in Fig. 6.3, it is also suggested that, the survived bird species in this area have found other suitable habitats and get used to the urban environments.

The temporal pattern of perceived loudness of birdsong could also be reflected in Fig. 6.3 when comparing all the maps in different sampled periods. It is obvious that perceived loudness of birdsong in the first two periods and the last three periods of the day were higher. This trend is also revealed in Fig. 6.2, where daily temporal pattern of birdsong loudness showed a “V” changing trend, and similar trend appeared also at most of the sampled sites. It indicates that bird species in urban area still show the circadian rhythms of dawn and dusk chorus as reported in natural bird species (Katti and Warren, 2004; Leopold and Eynon, 1961; Pijanowski et al., 2011b).

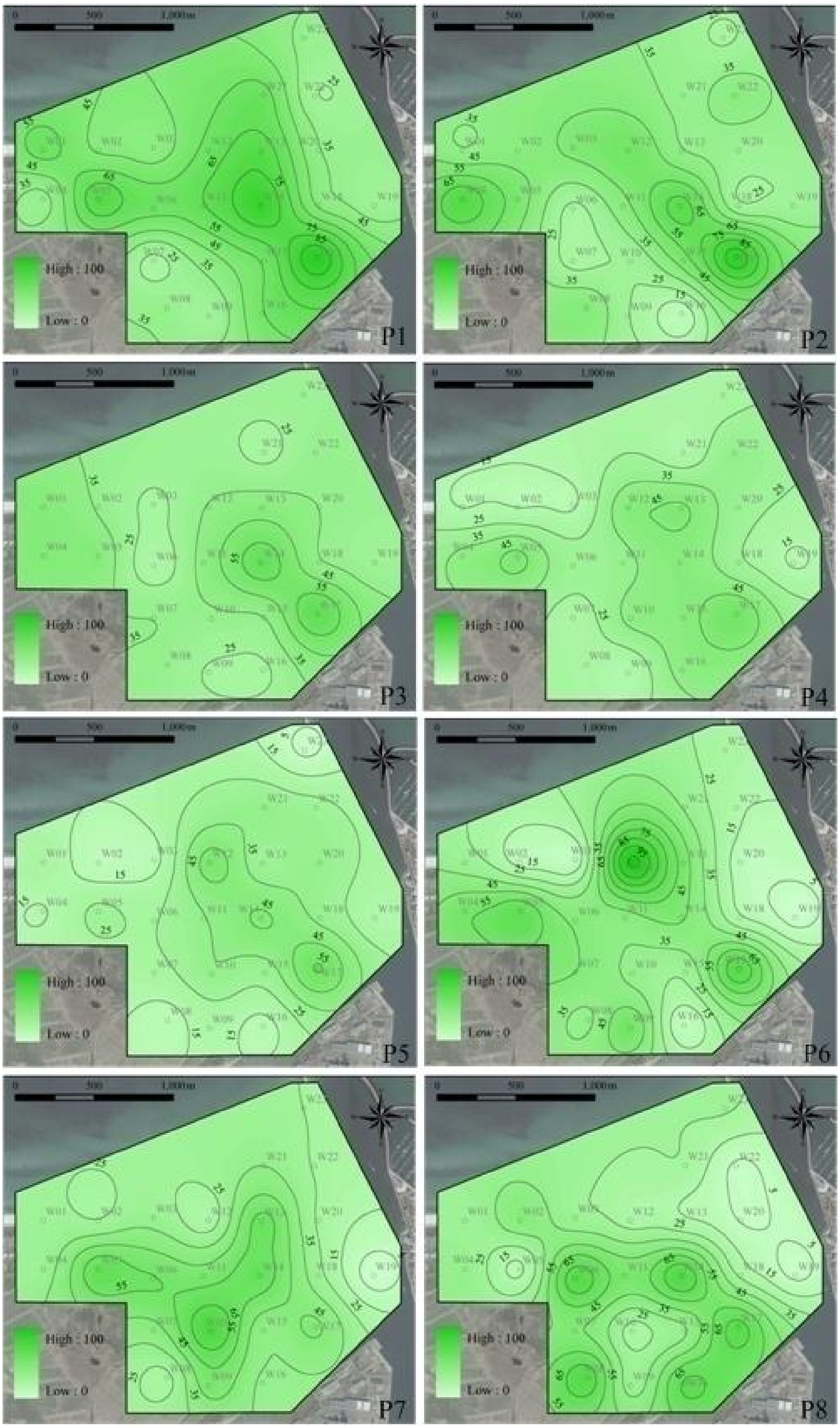


Fig. 6.3 Perceived loudness of birdsong across the study area during the 1st to 8th sampled periods, respectively (map P1-P8)

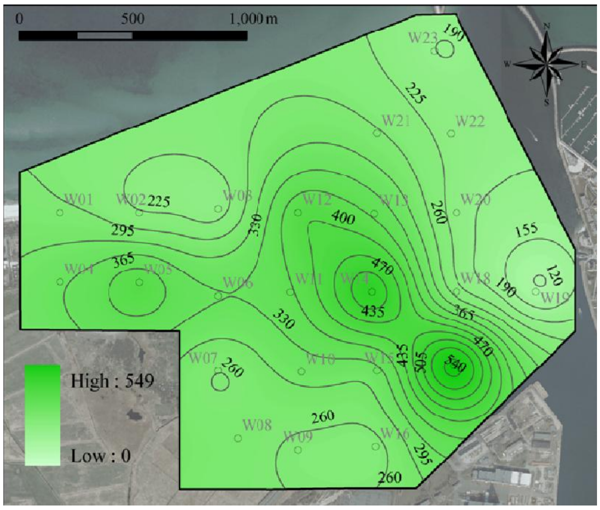


Fig. 6.4 Daily accumulated perceived loudness of birdsong across the study area

6.4 Landscape characteristics affecting bird song perception

Although it was reported in previous studies that bird species in urban areas have a close relationship with landscape features (Bolger et al., 1997; Melles et al., 2003; Odell and Knight, 2001), these studies were seldom carried out from the perspective of urban soundscapes, or related to landscape spatial patterns. Given the dynamic nature of birdsongs, in this study the landscape indices were tested in relation to the perceived loudness of birdsong by time-step per-period, using Pearson correlation analysis in SPSS 16.0. The results are shown in Table 3, where only landscape indices showing significant and relatively stable correlations with perceived loudness of birdsong can be regarded to be potential influential landscape characteristics. It can be seen that, construction density (CD), road density (RD), vegetation density (NDVI), patch density (PD), landscape shape index (LSI) and fractal dimension (FRAC) are mainly positively correlated with perceived loudness of birdsong. Largest patch index (LPI), distance to main road (DTR), and contagion (CONT) are almost negatively correlated with perceived loudness of birdsong.

Dense constructions could block much of the external sounds and thus form inside spaces of high acoustic quality, which makes both bird communication and human perception of birdsong easier. This point could also be reflected by the fact that more birdsongs were perceived in residential areas with dense constructions. The positive correlation between birdsong and road density corresponds to the positive correlations between birdsong and traffic sounds, as more roads usually mean more traffic sounds. The negative relationship between birdsong and distance to main road is consequently expected. Dense vegetation usually provides ecologically good habitats for birds, so it is reasonable that more birdsong could be heard in areas with more vegetation, namely high NDVI value. All the landscape metrics, namely patch density, landscape shape index, fractal dimension, largest patch index and contagion could reflect landscape fragmentation status from different aspects. Their relationships with birdsong perception indicate that more birdsong could be perceived in areas with highly fragmented landscape. The result is in line with the previous research finding that biological organisms like birds could have more chance to find suitable habitats in a fragmented landscape (Andren, 1994). In other words, although birds may not be highly evolved for urban living, there are still opportunities to find suitable habitats in these areas which are usually characterised by a fragmented landscape (Antrop, 2004).

Table 6.2 Pearson correlation between each of the landscape indices and birdsong by time-step per-period (*p<0.05, **p<0.01)

Period	BD	RD	DTB	DTR	NDVI	PD	LPI	LSI	FRAC	SHDI	CONT
1	.413**	.106*	-0.068	-.252**	-.126**	.111*	-.270**	0.063	-.093*	0.087	-.253**
2	.142**	0.042	-.121**	-.129**	0.042	0.019	-.147**	0.031	-0.014	0.003	-.149**
3	.337**	.150**	-0.048	-.194**	-0.079	0.077	-0.091	.146**	.159**	-0.047	0.021
4	.401**	.349**	-0.078	-.179**	-0.076	.222**	-.225**	.291**	.231**	0.015	-.113*
5	.436**	.263**	-.275**	-.337**	-0.049	.377**	-.190**	.376**	.325**	0.055	-.125**
6	.185**	-0.064	-0.06	0.018	.232**	.093*	-.121**	0.082	0.016	-0.078	-0.029
7	.221**	-0.085	-0.071	-0.018	.164**	.254**	-.130**	.249**	.142**	0.002	-0.053
8	-0.048	-.108*	-0.078	0.073	.347**	-.114*	-0.031	0	0.008	-.229**	.110*

6.5 Summary

In this chapter, through a soundscape approach, characteristics of birdsong as an integral element of the urban sound environment in the context of landscape. An important and positive role of birdsong in urban soundscape perception was recognised. The analysis of the relationships between birdsong perception and other sounds suggests that, although birds could get used to the chronic urban traffic sounds, excessive sounds related to human appearance (adult voice, child voice and footstep) or human activities (construction sounds, music) could still frighten birds off. The spatiotemporal patterns of perceived loudness of birdsong suggest the adapted patterns of bird species in urban areas.

A series of landscape indices were found in close relationships with loudness perception of birdsong, which could be generalised as follows: a) landscapes with dense arrangements of buildings serve as shelters from urban noise and showed positive relationship with loudness perception of birdsong (CD); b) landscapes with dense vegetation provide usually ecologically good habits and could possess more birdsong (NDVI); c) landscapes with or close to dense traffic roads birdsong perception was not impaired (RD, DTR), which was also verified by the positive relationships between birdsong and traffic sounds; d) there might be more chance to perceive birdsong in fragmented landscapes characterised by small dispersed land use patches with complex shape (LPI, CONT, LSI, FRAC); e) loudness perception of birdsong showed also positively relationship with heterogeneous landscapes resulted from high patch density (PD).

PART Ⅱ: Soundscape and Landscape in Typical Urban Open Spaces —City Parks

Chapter 7 Methodology for the Field Survey in China

Soundscape is usually interpreted by means of identifying and describing different sound sources in a certain place (Brown et al., 2011). In the process of soundscape perception, how sensitive people are to specific sounds in the place and their preferences for these sounds are expected to affect their overall opinion of soundscape quality. And this process could be affected by many factors as studied previously (Kang et al., 2012; Zhang and Kang, 2007). Specifically, in urban open spaces the effects of social, demographical and behavioural factors on soundscape perception have been widely analysed in terms of preference for sounds, subjective sound level evaluation and acoustic comfort evaluation (Szeremeta and Zannin, 2009; Yang and Kang, 2005a, 2005b; Yu and Kang, 2010). However, it seems that these factors are not universally effective in explaining differences in soundscape perception (Fields, 1993; Miedema and Vos, 1999; Rylander et al., 1972; Yang and Kang, 2005b; Yu and Kang, 2010). The reason may be that people in different types of urban open spaces may have different expectations and sensitivities of soundscapes, and use correspondingly different evaluation standards.

Furthermore, though the relationship between soundscape perception and landscape characteristics is discussed in the first part of the thesis, it still need to be explored in more aspects. On the one hand, soundscape perception itself is a very subjective process, and lake of general accepted and effective illustration parameters. On the other hand, physical landscape characteristics could be very different from place to place, and it needs more test studies to consolidate the relationship between some specific landscape features and soundscape perception.

From this respect, specific and intensive studies are needed to examine the effects of more landscape factors that to some extent are intrinsic to soundscape quality on soundscape perception, i.e., in the same type of urban open spaces with similar cultural background.

Therefore, two investigations were conducted in five city parks in Xiamen, China to examine the landscape effects from visual, function, and physical aspects on soundscape experience or perception. The first investigation is based on the information gathered from the general public in a most understandable way, the aim of this study is to analyse the effect of landscape factors from visual and functional aspects on soundscape experience in terms of experienced occurrence of individual sounds, preference for individual sounds and overall soundscape preference in city parks. Effects of social, demographical and behavioural factors are also considered at the same time.

The second investigation is specifically designed soundwalks in the same city parks by a group of observers. Combined with the physical landscape data in respect to on-site landscape composition and local landscape spatial pattern indices on class level, the aim of the investigation is: 1) to characterise soundscape perception in city parks using a series of parameters; 2) to reveal the effects of physical landscape on soundscape perception in city parks, in terms of on-site landscape composition and local landscape spatial pattern.

These two studies are both aiming to reveal the relationships between soundscape and landscape. The concept "soundscape experience" is used in the first investigation because of the responses of the interviewees could based on their former experience of soundscape perception in the parks, while "soundscape perception" in the second investigation means on-site perception of the soundscapes at certain places during certain time periods. The two studies are related to each other by discussing the way to combine soundscape information into practical landscape management in chapter 9.

7.1 Field survey sites

The survey was carried out in five public city parks during summer time in Xiamen, China, namely Bailuzhou (west), Huli, Haiwan, Nanhuand Zhongshan. All these parks are located in the Xiamen island (the central area of Xiamen city), of similar size, and considered as important (on the list of Xiamen Construction and Administration Bureau), popular, and freely accessible. Fig. 7.1 shows the images from Google Earth for each park. Fig. 7.2 shows some photos taken in the five city parks.

Bailuzhou (west) park is a European style park, built in 1997, with an area of more than one hundred thousand square meter. There are three parts in the park, with a sinking music fountain square on the eastern part, green space in the middle part and a sinking stage on the western part. The large open space in the park makes it popular for large public cultural activities in Xiamen, and there are more than one hundred cultural activities local hosted here. Besides, with three sides surrounded by the Yuandang lake, tree-lined paths, and large green space, it is loved by many citizens.

Haiwan park is opened in 2006. It is a city comprehensive park with tourism, leisure and entertainment functions. The park has seven major sceneries, including "heaven garden", "earth garden", "forest garden", "grass garden", "water flower garden", the coastal scenic and the "Star Boulevard", and it is divided by the "Star Boulevard" into south park and north park.

Huli park is opened in 1996. It is a city comprehensive park, combining entertainment with garden, modern attractions with natural landscape, with a total area of 11.26 hectares. And the green area is 7 hectares, with more than 100 kinds of tropical and subtropical plants. There are seven major parts, including pre-function area, children's play area, youth activity area, senior sitting area, administrative zone, recreation and scenic enjoying area, and lake area.

Name: Bailuzhou (west)

Location: 24° 28′ 32.94″ N, 118° 05′ 06.30″E

Scale: E-W: 530m, S-N: 250m

Name: Haiwan

Location: 24° 28′ 33.15″ N, 118° 04′18.30″E

Scale: E-W: 320m, S-N: 570m

Name: Huli

Location: 24° 30′ 23.36″ N, 118° 06′ 04.48″E

Scale: E-W: 400m, S-N: 500m

Name: Nanhu

Location: 24° 28′ 53.09″ N, 118° 06′ 05.24″E

Scale: E-W: 450m, S-N: 550m

Name: Zhongshan

Location: 24° 27′ 40.63″ N, 118° 05′ 06.40″E

Scale: E-W: 250m, S-N: 550m

Fig. 7.1 The five studied city parks from Google Earth, shown with the areas with broken line, and general information of the parks


a
b
c
d
e
f
g
h

Fig. 7.2 Landscape photos taken in the five city parks, Bailuzhou (west) (a, b), Haiwan (c, d), Huli (e, f), Nanhu (g, h), Zhongshan (i, j)

Nanhu park is opened in 1995, near the Yuandang lake, with an area of 16.1 hectares. There are four major sceneries in this park, “YuandangYuhuo”, “Zuo Shi Lin Liu”, “Yuandang Chunxiao” and “Qu Shui He Xiang”. “YuandangYuhuo” is one of the eight most famous scenic areas in Xiamen.

Zhongshan park is a garden-style park with notable characteristics of main gates, bridges, pavilions and still water features, with an area of 11.07 hectares. It is one of the oldest city park in Xiamen, and was built in 1927, for commemorating the “public” spirit advocated by Sun Yat-sen. The open and extroverted characteristics of this park are different from the traditional Chinese gardens that are close and introverted, which makes it internationally famous.

7.2 Questionnaire survey

Before the survey, pilot investigations were conducted, and 17 different sounds regularly appearing in the parks were recognised, including natural sounds (biological and geophysical sounds) and artificial sounds (human sounds, human made sounds and mechanical sounds). They were introduced into the questionnaire later to represent the general soundscapes in the parks. The English version of the questionnaire (originally in Chinese) is shown in Appendix 2.

The survey was introduced not as a soundscape survey, but as a general satisfaction survey of city parks, in order to avoid possible bias. In total, 580 interviews with a similar numbers of males and females were made. The number of interviews in each park was also similar, ranging from 111 to 119, following the suggested sample size for soundscape evaluation in urban open public spaces (Kang and Zhang, 2010). The interviewees were selected randomly among the users of the city parks during the daytime. A database was then established in SPSS for further analysis, where the interviewees were assigned into six categories in terms of age: ≤24, 25-30, 31-40, 41-50, 51-59, and ≥60 years; three categories in terms of education level: primary, secondary, and higher; three categories in terms of occupation: students, working persons, and others (including retired, unemployed， and full-time homemaker); and three categories in terms of residential status: local resident, city resident, and tourist. The user behaviour characteristics of the park were observed in terms of frequency of visit, categorised as low (once in one or several months), medium (once a week), and high (several times a week); and length of stay, categorised as short (less than one hour), medium (1-3 hour), and long (more than 3 hours).

7.2.1 Soundscape data

Soundscape data includes evaluation of the experienced occurrences of and preferences for the 17 different sounds identified during the pilot study, as well as the overall soundscape preference. Based on the hypothesises that 1) only limited sounds might appear during the short time interview; 2) inevitable disturbance from the interviewers could affect the judgments of interviewees against actual stimuli; and 3) soundscape experience (memory and preference) could reflect soundscape perception, the sounds evaluated by the interviewees were not necessarily heard at the time of interview (Yang and Kang, 2005b), and answers could be based on their previous experience in the investigated parks. The interviewees were asked to indicate the experienced occurrences of the sounds listed in the questionnaire using a three-point rating scale: 1, never; 2, occasionally; 3, frequently, and their preference for each sound using: 1, annoying; 2, neither annoying nor favourable; 3, favourable. Overall soundscape preference could be judged from different perspectives, such as peaceful, tranquil, enhancing well-being, conveying information, or promoting unique cultural or natural characteristics, etc. (Brown et al., 2011). In this study the overall soundscape preference was evaluated in terms of tranquillity using a five-point scale: 1, very unsatisfied; 2, unsatisfied; 3, neither satisfied nor unsatisfied; 4, satisfied; 5, very satisfied.

The main focus of this study is to examine the general effects of landscape and other factors on soundscape experience, rather than to examine the differences among individual case study sites. This point was considered in the selection of the case study sites, and similarities were sought in their topography, location, size, function and cultural background characteristics. Fig. 7.3 shows the ratio between the standard deviations (SDT) of social, demographical and behavioural characteristics of the interviewees and the respective SDT averages among the five city parks. It is shown that, for each factor, the range of the ratio is no more than 0.2. Thus a holistic analysis could be carried out based on the database.

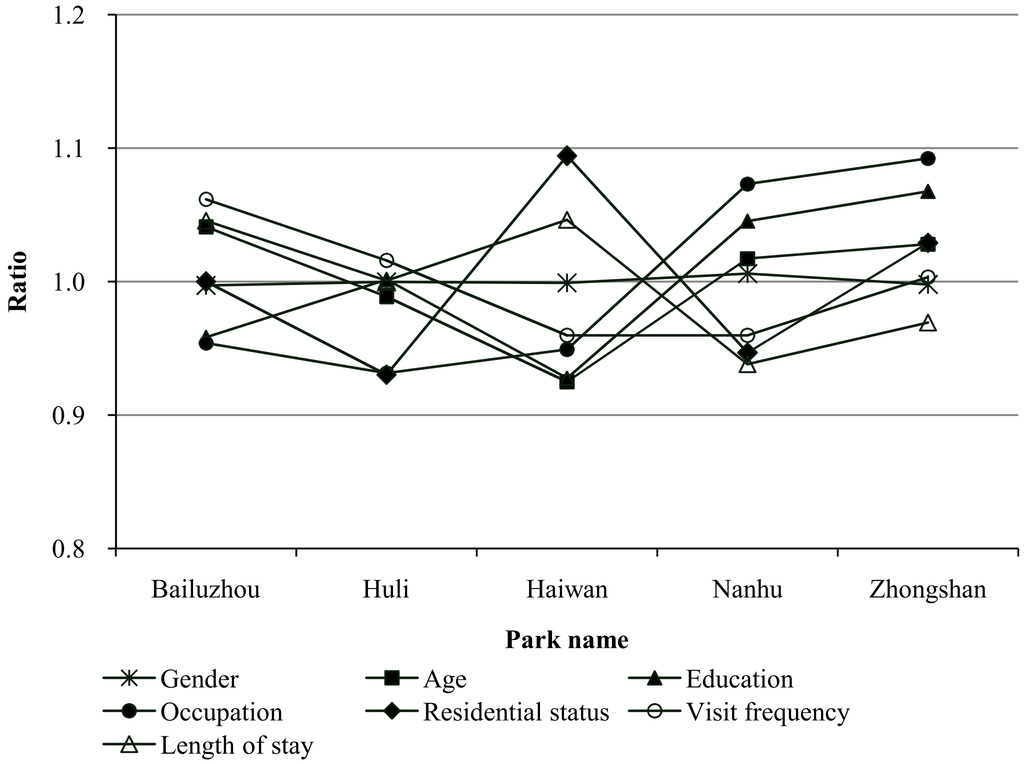


Fig. 7.3 Ratio between the standard deviation (SDT) of social, demographical and behavioural characteristics of the interviewees and the respective STD average among the five city parks

7.2.2 Landscape data

Landscape factors are studied in two aspects, i.e., visual landscape and functional landscape, which in this study specifically refer to scenic beauty and the status of infrastructures and facilities in the parks, respectively. Their satisfaction levels were both evaluated by the interviewees using a five-point rating scale: 1, very unsatisfied; 2, unsatisfied; 3, neither satisfied nor unsatisfied; 4, satisfied; 5, very satisfied. It is acknowledged that other attributes could influence the perceptions measured, such as coherence, legibility, complexity, mystery, and diversity, in the case of visual landscape (Kaplan and Kaplan, 1982; Kaplan, 1987; De la Fuente de Val et al., 2006); culture, space for activities, and safety, in the case of functional landscape. In addition, the interviewees were asked to evaluate the satisfaction level of the overall visiting experience using the same rating scale as the landscape factors.

7.2.3 Data analysis

Kruskal-Wallis independent samples non-parametric test was conducted for examining difference in experienced occurrence of and preference for individual sounds in terms of differences in visual and functional landscape satisfaction as well as the overall soundscape preference.

Spearman's rho correlation analysis was used to detect the relationships between perception of individual sounds (experienced occurrence of and preference for individual sounds) and both landscape (visual and functional) satisfaction degree and the overall soundscape preference; the relationships between each of the social, demographical and behavioural factors, i.e., age, education, occupation, residential, visit frequency and length of stay (2-tailed), and experienced occurrence of individual sounds, preference for individual sounds, the overall soundscape preference as well as visual and functional landscape satisfaction degree; and relationships between each of the social, demographical and behavioural factors (2-tailed). Mean differences in these soundscape and landscape perception variables between males and females were tested with independent sample t test (2-tailed).

Stepwise multiple regression analysis was used to detect the relationship between the interviewees' overall satisfaction of the visiting experience and the three categories of satisfaction level, i.e., the visual and functional landscape satisfaction levels and the overall soundscape preference; and the relationships between each of the landscape and social/demographical/behavioural variables and perceived occurrence of individual sounds, preference for individual sounds, as well as the overall soundscape preference.

7.3 Soundwalks

The second investigation was carried out in the same five public city parks in June, 2012 in Xiamen, China, namely Bailuzhou (west), Huli, Haiwan, Nanhu and Zhongshan. In each park, six sampled sites were evenly chosen along the main visiting paths, and consecutively numbered as the sequence of soundwalk route, as shown in Fig. 7.4. Through pilot investigations before the main survey by repeatedly visiting the parks, and also the on-site soundwalk results, 18 different sounds regularly appearing in the parks were identified and classified into five sound categories including human, traffic, mechanical, biological and geophysical sounds, as shown in Table 7.1.

7.3.1 Specific soundwalk design

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

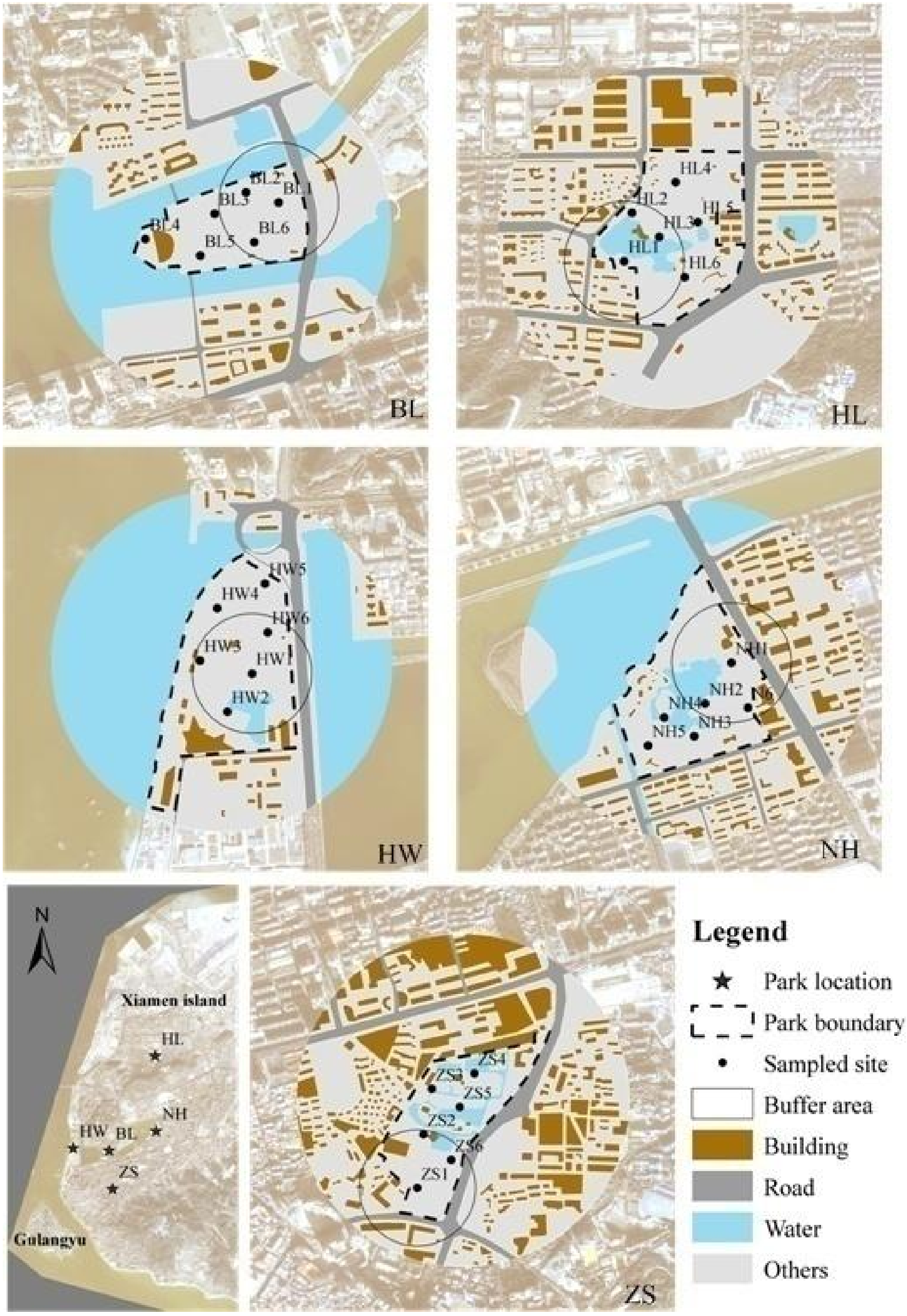


Fig. 7.4 Location of the five city parks and sampled sites, showing the local land cover and example of the buffer areas (circles around the 1st sampled sites for each park). BL: Bailuzhou (west), HL: Huli, HW: Haiwan, NH: Nanhu, ZS: Zhongshan

Soundwalks were conducted in five consecutive workdays in each of the five parks, respectively. The weather conditions were stable and sunny during the investigation. Seven observers without any hearing problems, 4 female and 3 male, average age 25±1.5 years, participated in the soundwalks. The sounds with their codes in Table 1 were used as a reference for the observers. All of them went through a training process before 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 know the investigation process and minimise recording bias.

Table 7.1 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

Soundscape data were recorded during the soundwalks in three periods of a day for each park, i.e., 1st: morning (07:00-09:00), 2nd: afternoon (12:00-2:00) and 3rd: dusk (17:00-19:00). Within each period, all the six sampled sites were visited once following the same sequence. At each site codes of heard sounds were recorded into a table in a 5 minute slot, which was further divided into ten sequential time-steps, each of 30 seconds. In each time-step, the perceived loudness of each individual sound was evaluated with a five-point linear scale (1=*very quiet*, 2=*quiet*, 3=*normal*, 4=*loud*, 5=*very loud*). The recording table for the investigation is attached as Appendix 3. The soundscape datasets were then processed from all the recording tables by the seven observers. Fig. 7.5 shows some on-site working photos of the soundwalk group.

Fig. 7.5 On-site working photos of the soundwalk group

7.3.2 Physical landscape data

Physical landscape could be observed from two perspectives. One is from a human view—a horizontal perspective of view reflecting all on-site landscape composition; the other is from a bird view—a vertical perspective of view reflecting landscape spatial patterns. Landscape indices from these two perspectives could objectively characterise the whole local physical landscape. Thus landscape effects on soundscape perception indicated by these indices could have universal significance.

Visual landscapes have been the research focus for a long time because of the affective and aesthetic properties (Daniel, 2001; De la Fuente de Val et al., 2006), and recently also because of the visual-aural interaction in soundscape perception (Carles et al., 1999; Pheasant et al., 2008). In many studies conducted in laboratory context, landscape photos are usually used as testing media to the subjects (Benfield et al., 2010; Carles et al., 1999; De la Fuente de Val et al., 2006; Dramstad et al., 2006; Pheasant et al., 2008). Landscape photos or videos were either combined with sounds and evaluated by the subjects in terms of a series of parameters, such as pleasant, naturalness, freedom, preference, annoyance, solitude, scenic beauty and tranquillity, or the landscape elements in the photos were measured to reflect landscape composition characteristic, for example, such as the naturalness.

However, in this study, the landscape photos were not used in laboratory test. Instead, only landscape elements in panorama photos were measured objectively as a reflection of on-site landscape compositions. Panorama photos were used because landscape composition around the observers from all directions may affect sound composition and propagation. Since the observers were requested to focus on sounds during the soundwalks and could not totally observe the surrounding landscape at the same time, aural-visual interaction could be biased during the soundwalks, and thus, landscape effects from aesthetic aspects on soundscape perception were not considered in this study. Landscape photos at each sampled sites were shot using a Canon ESO 5D Mark II with a tripod at a high of 1.2 m from four directions on the same day of the soundwalk in each park. These photos were then made into panorama photos of each sampled site using MGI Photovista 2.0 software. Six kind of landscape elements were extracted from these panorama photos, i.e. *vegetation*, *water*, *building*, *pavement*, *furniture*, and *sky*. Their percentages in each photo were calculated respectively by overlaying 5*5 mm grids on the printed panorama photos (about 4 cm × 25 cm) (Pheasant et al., 2008). People appeared in the photos were not counted. Fig.7.6 shows several samples of the panorama photos of some sampled sites.

Fig. 7.6 Samples of the panorama photos from sampled sites BL3, HL2 and HW2

Local landscape spatial patterns have been shown affecting on-site soundscape perception in the first part of the thesis. The effects were explained in two aspects, one is landscape composition—related to sound sources, thus affecting soundscape composition; the other is landscape configuration—related to sound transmission route, thus affecting soundscape perception. As the previous study was done in a multi-functional urban area, land use data was used to test the landscape spatial pattern effects on soundscape perception. In this study, all the sampled sites are located in five different city parks, namely the same type of land use. Thus, land cover data were more suitable to study the local landscape effects.

Based on the IKONOS satellite image (in 2009, resolution 3 m) and Google Earth data, land cover types including building, road, and water area 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, these landscape composition and configuration indices were calculated on the 175 m radius buffer area centred on each of the sampled sites in all parks in Fragstats software (McGarigal and Marks, 1995), following some previous similar studies (Matsinos et al., 2008). For another important land cover type vegetation, vegetation density was calculated based on the SPOT satellite image (in 2012, resolution 10 m), using normalized difference vegetation index (NDVI) value to reflect landscape composition status. 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). Totally, 13 landscape indices were selected to indicate the landscape spatial pattern characteristics.

7.3.3 Data analysis

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

The results of these two investigations will be discussed in chapter 8 and chapter 9, respectively.

Chapter 8 Landscape Effects on Soundscape Experience in city parks

In this chapter, results of the first investigation in the five city parks will be discussed. Firstly, soundscape characteristics in the city parks are analysed. Then in the second section, the focuses are on the effects of landscape factors from visual and functional aspects on soundscape experience of the general public. Soundscape experience in the study includes experienced occurrence of individual sounds, preference for individual sounds and the overall soundscape preference. In the third section, effects of other social, demographical and behavioural factors on soundscape experience are also considered. At last, the effects from all the factors on soundscape experience are compared.

8.1 Soundscape characteristics of the city parks

The experienced occurrences of and preferences for 17 different sounds are shown in Fig. 8.1 and Fig. 8.2, respectively. Together they reflect how the park soundscapes were perceived by the interviewees. From Fig. 8.1 it can be seen that most of the frequently perceived sounds were from natural sources (birds, leaves rustling and wind), human sources (surrounding speech, footsteps and children shouting) and from road traffic outside the parks (traffic sound). According to Schafer's classification of sounds (Schafer, 1994), these could be defined as keynotes of the city parks. Music could be the most obviously recognised sounds for all these parks, such as music played by the dancers in Zhongshan Park and Huli Park, broadcast music in Nanhu Park, music with water sound from the music fountains in Bailuzhou Park and Haiwan Park (though the fountains only operate at certain times). As most of the water features in the parks are still, water sound was not frequently perceived. Sounds including road cleaning, lawn mowing, aeroplanes, bicycle riding and insects also show a high level of awareness from the interviewees, whereas sounds such as roller skating, construction sound and frogs were seldom heard. The results indicate that, soundscape composition in city parks is closely related with their particular functions, typical landscape elements, and even the spatial relationship with other urban functional areas, especially roads (Szeremeta and Zannin, 2009).

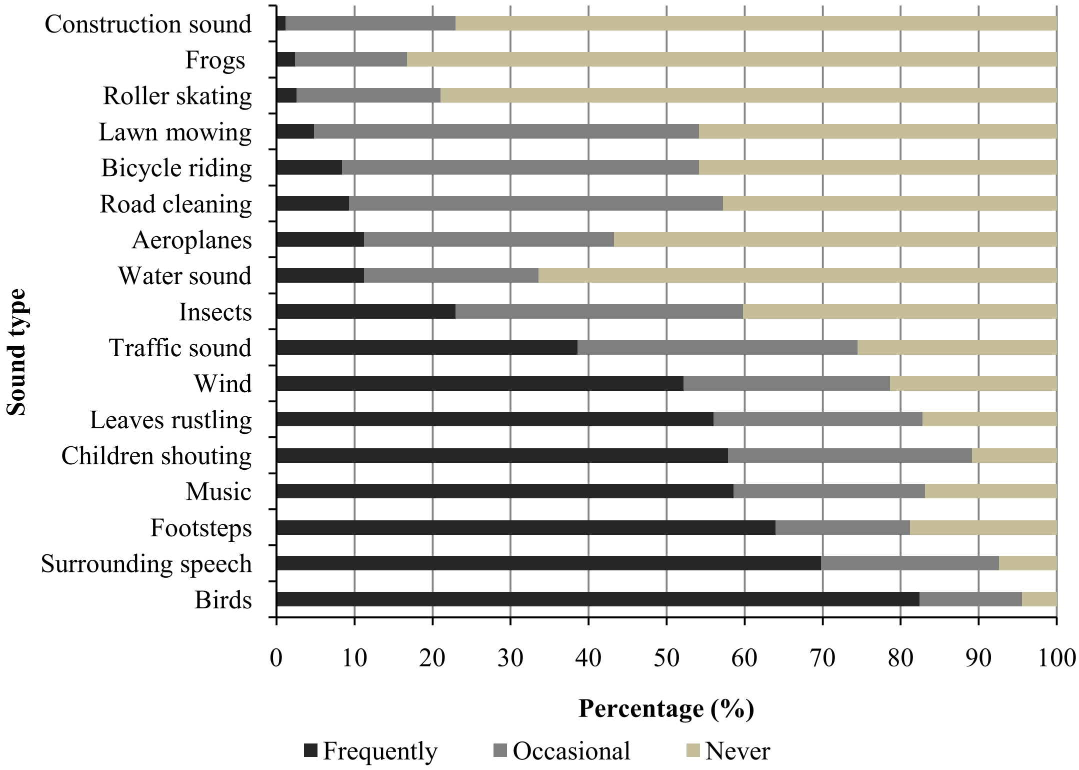


Fig. 8.1 Distribution of the interviewees' experienced occurrence of different sounds

From Fig. 8.2 a clear tendency for preference for natural sounds (birds, leaves rustling, wind, water sound, insects and frogs) can be seen over human sounds (children shouting, surrounding speech and footsteps) and other artificial sounds (human made or mechanical sounds). This result is consistent with many other studies (Carles et al., 1999; Kariel, 1980; Porteous and Mastin, 1985; Yang and Kang, 2005a, 2005b). Among human sounds, children shouting was more preferred than surrounding speech and footsteps. Music as a kind of culturally approved sound was perceived as favourable for more than 63% of the interviewees. But 10% of them thought it was annoying, mainly because it was played repeatedly or not to their tastes. The interviewees also showed great tolerance to most of the artificial sounds, as most of them thought they were neither favourable nor annoying. For example, for lawn mowing, most of the interviewees commented that it is inevitable and reasonable as part of park management activities and only happens occasionally, so it is acceptable, which explains its relatively lower annoying degree than expected. Human sounds and sounds from other users' activities were also thought inevitable, reasonable and acceptable for most of the interviewees. For traffic sound, almost half of the interviewees thought it was neither favourable nor annoying, possibly because of the long term exposure to traffic sound in urban areas. However, there were still quite a lot of people (39%) who thought it was annoying, especially when they intended to enjoy a quiet environment (44%). More than 65% of interviewees thought construction sound was annoying, making it the most annoying sound.

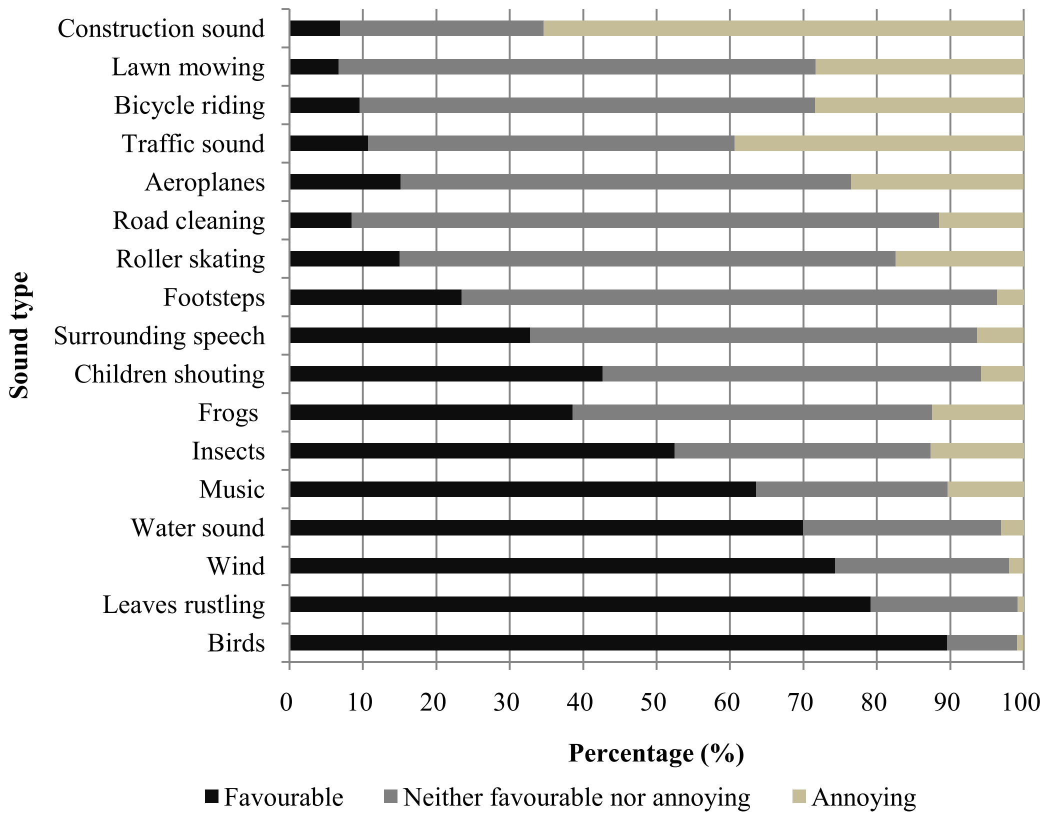


Fig. 8.2 Distribution of the interviewees' preference for different sounds

Combining the results from Fig. 8.1 and Fig. 8.2, it can be seen that many favourable sounds like birds, music, leaves rustling and wind could be more frequently perceived by the interviewees. At the same time, the most annoying construction sound did not appear frequently. As a result of such soundscape characteristics of the studied city parks, more than 76% of the interviewees indicated that they were satisfied or very satisfied with the soundscape. The results may reflect the experienced soundscape quality in these parks, but to which degree soundscape experience is related to landscape quality will be discussed in the next sections.

8.2 Effects of landscape factors on soundscape experience

8.2.1 Soundscape, landscape and overall satisfaction of visit experience

Fig. 8.3 shows the percentages of the interviewees' different motivations to come to each park. It can be seen that the interviewees' motivations to come to different parks are diverse and slightly different according to each park. However, the motivations could be generalised into three categories in terms of expectation, i.e. visual, aural and functional (in terms of infrastructures and facilities). The result of the stepwise multiple regression analysis between the interviewees' overall satisfaction of the visiting experience and the three categories of satisfaction level, i.e., the visual and functional landscape satisfaction levels and the overall soundscape preference, showed their relative importance in achieving a satisfactory visit experience. The regression coefficients indicate that visual aspect is the most important factor, with standardized coefficient of 0.478, followed by aural and functional aspects with standardized coefficients of 0.264 and 0.115, respectively. However, usually the visual and functional aspects are highlighted in the park design and management process and the aural aspect is neglected. Their mutual influence is also seldom studied based on the users' experience. In this study, visual and functional aspects are treated as intrinsic landscape characteristics, while the aural aspect corresponds to soundscape quality. Among the three main aspects of general satisfaction of park experience, visual and functional landscape satisfaction levels are both significantly correlated with overall soundscape preference. From the Spearman's rho correlation analysis results, the coefficient values are 0.383 ($p<0.01$) and 0.262 ($p<0.01$), respectively. Thus, landscape effects on perception of individual sounds and the overall soundscape preference should be examined in detail in terms of effects from the visual and functional aspects, respectively.

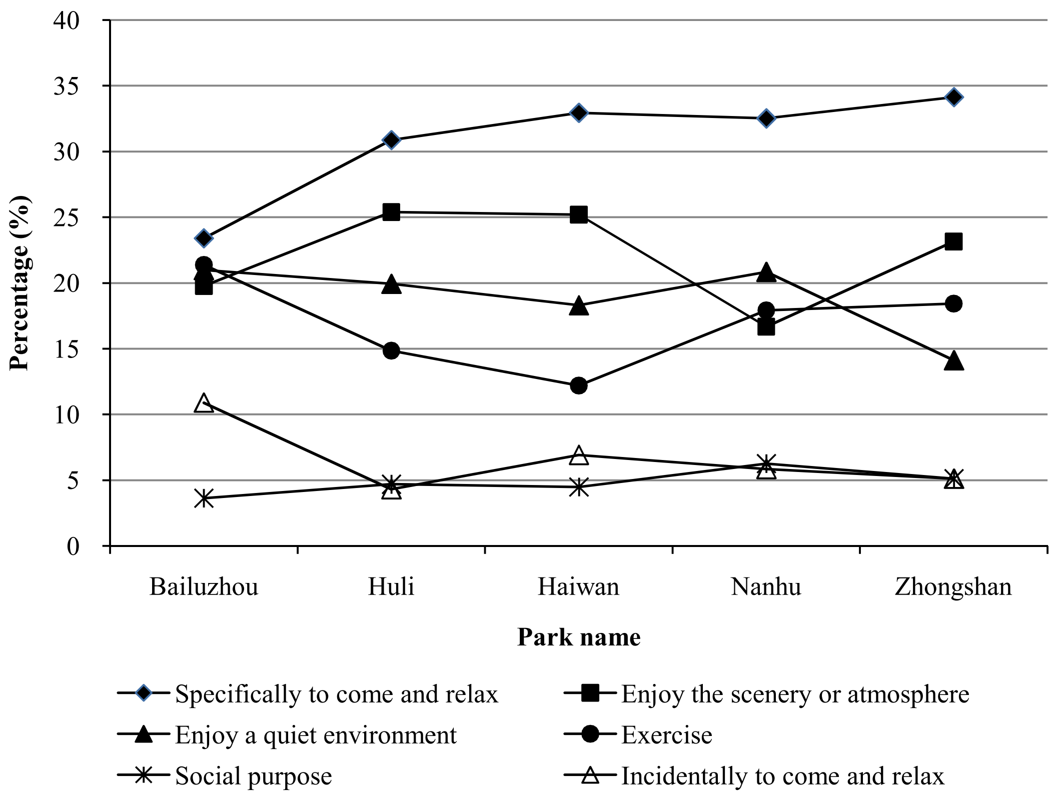


Fig. 8.3 Percentages of the interviewees' different motivations to come to each park

8.2.2 Effects of visual landscape on perception of individual sounds

Kruskal-Wallis independent samples non-parametric analysis was used to test the significance of differences in individual sound perception among the five levels of visual landscape satisfaction, as shown in Table 8.1. It can be seen that visual landscape could significantly affect the experienced occurrences of most natural sounds (5 out of 6 sounds, i.e., wind, leaves rustling, water sound, birds and insects). This may be because better visual landscape usually contains more natural elements, such as trees, bushes, grasses, flowers and water, thus more natural sounds may be introduced. On the other hand, as also reported by other researches, natural sounds may promote the enjoyment of visual perception (Carles et al., 1999). However, visual landscape seems to have no considerable effect on preference for sounds, with only four sounds (music, road cleaning, wind and frogs) showing significant differences. This is perhaps because people's preference for certain sounds is formed in their life experience, and could not be changed just by short term visual satisfaction.

Spearman's rho correlation analysis between perceptions of individual sounds and features of the visual landscape could further indicate their relationships, as shown in Table 8.2. It can be seen that the 5 natural sounds whose experienced occurrences change significantly between different visual landscape satisfaction levels are also highly correlated with visual landscape (Table 8.1). Besides, 6 out of 11 artificial sounds also show close relationships with visual landscape, though the coefficient values are rather low, around 0.1. It seems that people in a high visual quality landscape may be more sensitive to intrusive or disturbing sounds. As for preference for individual sounds, 3 out of 4 sounds whose preferences change significantly between different visual landscape satisfaction levels show high correlation with visual landscape. Highly valued visual landscape seems to be closely related to natural especially geophysical sounds (wind and water sound), and also with road cleaning, an activity which has a positive effect on the visual landscape.

In conclusion, effects of visual landscape on perception of individual sounds are more reflected in natural sounds than artificial sounds, more in experienced occurrence of individual sounds than preference for individual sounds.

Table 8.1 Kruskal-Wallis tests for difference in perceived occurrence of and preference for individual sounds in terms of differences in visual and functional landscape satisfaction as well as overall soundscape preference. Significant differences are marked with* ($p<0.05$) and ** ($p<0.01$)

	Perceived occurrence (χ^2/Sig.)			Preference (χ^2/Sig.)		
Sound type	Visual	Functional	Soundscape	Visual	Functional	Soundscape
Traffic sound	7.227/0.124	8.290/0.082	10.522/0.032*	7.397/0.060	12.937/0.012*	15.884/0.003**
Surrounding speech	9.033/0.060	3.633/0.458	3.105/0.54	6.197/0.102	5.652/0.227	22.562/0.000**
Children shouting	7.856/0.097	1.145/0.887	4.231/0.376	1.298/0.730	4.782/0.310	8.371/0.079
Footsteps	9.235/0.055	5.405/0.248	3.093/0.542	2.478/0.479	6.702/0.153	12.779/0.012**
Music	6.035/0.197	6.614/0.158	4.771/0.312	8.650/0.034*	16.015/0.003**	27.407/0.000**
Bicycle riding	8.210/0.084	13.544/ 0.009**	9.876/0.043*	1.919/0.589	24.513/0.000**	11.087/0.026*
Roller skating	4.523/0.340	7.186/0.126	5.597/0.231	7.436/0.059	13.719/0.008**	4.578/0.205
Lawn mowing	9.858/0.043*	12.866/0.012*	8.053/0.09	0.743/0.863	2.554/0.635	6.369/0.173
Road cleaning	6.790/0.147	12.4864/0.014*	8.709/0.069	9.329/0.025*	3.028/0.553	9.604/0.048*
Construction sound	2.557/0.634	5.157/0.272	10.983/0.027*	2.822/0.420	3.314/0.346	5.666/0.225
Aeroplanes	3.829/0.430	1.525/0.822	5.294/0.258	6.192/0.103	7.207/0.125	19.042/0.001**
Wind	22.50/0.000**	17.213/0.002**	19.893/0.001**	11.249/0.010**	5.906/0.206	11.495/0.022*
Leaves rustling	18.239/0.001**	10.812/0.029*	19.248/0.001**	7.132/0.068	4.845/0.304	13.679/0.008**
Water sound	10.608/0.031*	5.870/0.209	1.554/0.817	8.938/0.030*	3.857/0.426	3.237/0.519
Birds	13.773/0.008**	1.534/0.821	8.167/0.086	5.437/0.142	3.310/0.507	3.093/0.542
Frogs	6.560/0.161	15.784/0.003**	5.901/0.207	0.877/0.831	3.673/0.452	4.152/0.386
Insects	15.370/0.004 **	5.270/0.261	11.124/0.025*	2.118/0.548	2.679/0.613	5.543/0.236

Table 8.2 Spearman's rho correlation coefficients for the relationship between perception of individual sounds (perceived occurrence of and preference for individual sounds) and both landscape (visual and functional) satisfaction and overall soundscape preference (2-tailed). Significant correlations are marked with* (p<0.05) and ** (p<0.01)

	Perceived occurrence			Preference		
Sound type	Visual	Functional	Soundscape	Visual	Functional	Soundscape
Traffic sound	0.087*	0.013	**-0.027**	0.081	**0.123***	***0.155****
Surrounding speech	0.098*	0.041	-0.032	0.097*	0.069	**0.120****
Children shouting	0.092*	-0.006	-0.063	0.048	0.052	0.100*
Footsteps	0.108**	0.041	0.036	0.067	0.029	**0.159****
Music	0.073	-0.008	-0.03	**0.083**	**0.171****	***0.197****
Bicycle riding	0.100*	**0.014**	**0.067**	0.078	**0.237****	***0.148****
Roller skating	0.084*	-0.08	0.086*	0.244**	**0.337****	0.146
Lawn mowing	**0.031**[a]	**-0.092***	0.042	0.035	0.067	0.106
Road cleaning	0.077	**-0.029**	0.066	**0.162****	0.027	***0.138****
Construction sound	0.055	-0.067	**0.041**	-0.024	0.058	0.142
Aeroplanes	0.054	0.027	0.092*	0.116	0.113	**0.233****
Wind	**0.182****	**0.127****	***0.176****[b]	**0.148****	0.111*	***0.131****
Leaves rustling	**0.169****	**0.086***	***0.165****	0.118**	0.078	**0.149****
Water sound	**0.114****	0.049	0.051	**0.216****	0.063	0.096
Birds	**0.105***	0.005	0.092*	0.071	0.045	0.012
Frogs	0.063	**-0.026**	0.048	0.063	-0.142	0.147
Insects	**0.148****	0.016	**0.072**	0.037	0.051	0.120*

[a] The bold numbers for visual and functional correspond to the sounds with significant difference in terms of landscape effects and overall soundscape preference in Table 1; [b] Italic numbers for soundscape indicate significant correlations existing either in visual or functional at the same time.

8.2.3 Effects of functional landscape on perception of individual sounds

Table 8.1 also shows the significance of differences in perception of individual sounds among different levels of functional landscape satisfaction. Functional landscape seems to be equally influential on natural and artificial sounds in terms of experienced occurrence (each with 3 sounds). As for the effects on preference for individual sounds, functional landscape only show close relationships with artificial sounds, though significant differences are only seen in 4 out of 11 (traffic sound, music, bicycle riding and roller skating).

The correlation results (Spearman's rho) between perception of individual sounds and functional landscape can be seen in Table 8.2. It indicates that functional landscape shows limited correlations with experienced occurrences, with only 3 (also the total number) out of the 6 kinds of sound with significant difference in terms of functional landscape satisfaction difference (wind, leaves rustling and lawn mowing), much less than the visual landscape. Effects of functional landscape are more significantly related to preference for the four artificial sounds, all of which show significant difference in terms of functional landscape satisfaction difference (Table 8.1). A possible reason is that people who are more satisfied with the facilities and/or infrastructures could also tolerate more artificial sounds even though they are annoying to most people. In other words, improving the condition of infrastructure and facilities could offset the adverse influence of annoying sounds. Sounds, whose experienced occurrences or preferences show significant difference among different visual or functional satisfaction levels but no significant correlation relationships with visual or functional landscape, may not be related with landscape factors.

In conclusion, effects of functional landscape on perception of individual sounds are more reflected in artificial sounds than natural sounds, more in preference for individual sounds than experienced occurrence of individual sounds.

8.2.4 Landscape effects on the overall soundscape preference

The significance of differences in the perception of individual sounds among different levels of the overall soundscape preference can be seen in Table 8.1. The overall soundscape preference seems to be equally related to natural and artificial sounds in terms of experienced occurrence (each with 3 sounds). As for relationships with preference for individual sounds, the overall soundscape preference shows close relationships with 9 different sounds, including 7 (out of 11) artificial sounds and 2 (out of 6) natural sounds.

The relationships between perception of individual sounds and the overall soundscape preference can be seen in Table 8.2. It is seen that, only two sounds whose experienced occurrences change significantly between different overall soundscape preference levels are also highly correlated with the overall soundscape preference (wind and leaves rustling). However, preference for all the 9 individual sounds that show significant difference among different overall soundscape preference levels are also highly correlated with the overall soundscape preference. It is obvious that preference for or tolerance of artificial sounds is decisive in the overall soundscape experience. As natural sounds usually contribute positively to soundscape preference, the more tolerant the user to artificial sounds, the more satisfied they are with soundscapes in the parks.

Thus, landscape could affect the overall soundscape preference via effects on perception of individual sounds. From Table 8.2, it can be seen that in terms of experienced occurrence of individual sounds, only wind and leaves rustling show significant relationships with both visual and functional landscapes, while in terms of preference for individual sounds, the rate is 5 out of 9, with either visual or functional landscape or both. It indicates that landscape has limited effects on overall soundscape preference, but the effects could be more related to preference for individual sounds. A possible reason is that the overall soundscape preference involves more aspects than a simple accumulation effect of experienced occurrence of and preference for individual sounds.

In summary, the overall soundscape preference is more related to preference for individual sounds than experienced occurrences of individual sounds, and more related to artificial sounds than natural sounds. Thus, landscape effects on overall soundscape preference are more reflected by artificial sounds than natural sounds, and more related to preference for individual sounds than experienced occurrence of individual sounds.

Table 8.3 Spearman's rho correlation coefficient between each of the social, demographical and behavioural factors (2-tailed). Significant correlations are marked with * ($p<0.05$) and ** ($p<0.01$).

	Age	Education	Occupation	Residential status	Visit frequency
Education	-0.208**				
Occupation	0.779**	-0.23**			
Residential status	-0.367**	0.084*	-0.346**		
Visit frequency	0.452**	-0.08	0.404**	-0.552**	
Length of stay	0.337**	-0.094*	0.288**	-0.108**	0.24**

8.3 Personal variables in soundscape and landscape experience

Strong correlations (Spearman's rho) between social, demographical and behavioural factors, i.e., age, education, occupation, residential status, visit frequency and length of stay exist in this study as shown in Table 8.3, as also pointed out in some other researches (Yu and Kang, 2008), and the effects are considered below in the analysis of their influence on soundscape experience.

The relationships between experienced occurrence of and preference for individual sounds and each of the social/demographical/behavioural factors in terms of correlation coefficients based on Spearman's rho correlation analysis, as well as the mean differences in experienced occurrence of and preference for individual sounds between males and females based on independent samples t test, are shown in Table 8.4 and Table 8.5, respectively.

From Table 8.4 it can be seen that age, visit frequency and length of stay are the most significant three factors affecting experienced occurrence of individual sounds. With increasing age, people tend to perceive most of the sounds as being more frequent; one reason may be that they tend to visit the parks more frequently and stay a longer time, thus have more chance to hear different sounds. However, with water sound and aeroplanes, they tend to show less sensitivity, indicated by the negative coefficient values. Visit frequency and length of stay are both peoples' behaviour characteristics. They are significantly related with 9 and 12 out of the 17 sounds, respectively. It is reasonable that the more frequently people come to the parks and the longer they stay there, the greater are the chances of hearing different sounds. However, length of stay seems to be more influential on experienced occurrence than visit frequency. It may indicate that peoples' sound sensitivity could be lowered by long term exposure to similar acoustic environment at a certain location. The relatively few and weak correlations between experienced occurrence of individual sounds and factors including education, occupation and residential status indicate that these three factors do not have much effect on people's sound sensitivity. There is generally no significant difference between males and females in terms of experienced occurrence of individual sounds, which is in agreement with former results in previous studies, where it was indicated that gender was not important in perception of individual sounds (Fields, 1993; Miedema and Vos, 1999; Rylander et al., 1972; Yang and Kang, 2005a; Yu and Kang, 2008).

It can be seen in Table 8.5 that age is the most influential factor on preference for individual sounds. With increasing age, people tend to prefer more natural sounds (birds, wind, leaves rustling) and cultural-related sound (music), which is consistent with previous research findings (Yang and Kang, 2005a). They also tend to be more tolerant of human sounds (children shouting and footsteps), but may feel annoyed with sounds from young people's activities like roller skating which seems disturbing to them. Occupation could be another influential factor, or at least because of the significant correlation with age. The other factors have an influence on relatively fewer sounds. Residential status and length of stay are the only two factors correlated with overall soundscape preference. In terms of effects of social, demographical and behavioural factors on landscape preference, as also shown in Table 8.5, visit frequency and length of stay are the only two factors significantly correlated with visual landscape satisfaction, while functional landscape satisfaction is only influenced by residential status.

In summary, social/demographical/behavioural factors show more effects on the experienced occurrence of different sounds than preference for individual sounds. The effect of age is significant on both experienced occurrence of and preference for individual sounds, and could reflect the difference in sound sensitivity. Length of stay and visit frequency are two related factors and could have more influence on experienced occurrence of individual sounds as well as visual landscape perception than other factors, but their effects on preference for individual sounds is much less.

8.4 Importance of landscape factors in soundscape experience

As shown above, all landscape, social, demographical and behavioural factors considered show effects on soundscape perception to some extent. There is a concern about which factors matter more in this process. Results of stepwise multiple regressions between soundscape perception and landscape and each of the social, demographical and behavioural variables in terms of perceived occurrence of and preference for individual sounds (as well as the overall soundscape preference), as shown in Table 8.6 and Table 8.7 respectively, could further reveal this point. In the two tables, selected explanatory variables as recognised for each sound are presented with standardized coefficient values.

It can be seen in Table 8.6, that length of stay is the dominating factor in the explanation of the perceived occurrences of 12 out of the 17 sounds. Visual landscape is the second important factor, especially for natural sounds (5 out of 6 natural sounds). Age could be another factor influencing perceived occurrence of different sounds, and could indicate sound sensitivity difference of different age groups. The other factors including functional landscape show relatively less explanatory ability and could not be key factors.

As shown in Table 8.7, several factors show similar explanatory ability in preference for individual sounds, including visual landscape, functional landscape, age and education, but with only five to six kinds of sound. It indicates that preference for individual sounds is a complex process which may involve more factors, besides the tested ones. As for the overall soundscape preference, both visual and functional landscape show significant explanatory ability, and are the only two variables selected, indicating the importance of landscape effects on soundscape perception. It is noted that, although the regression models in Table 8.6 and Table 8.7 show the ability to explain the variations in soundscape perception, the strength of their relationships are rather weak. Thus more factors should be considered in relation to soundscape perception.

In summary, considering the effects from social, demographical and behavioural factors, landscape effects on soundscape perception are still considerable. In particular, visual landscape shows significant effects on perceived occurrence of individual sounds, and this is more effective than functional landscape. The two landscape factors show equal effects on preference for individual sounds, and are also considerable compared with other factors. Their effects on the overall soundscape preference are more significant, as the only two variables which entered into the regression model.

8.5 Summary

This study focuses on the effects of landscape factors on soundscape experience, at the same time considering other social, demographical and behavioural factors, based on field surveys in five city parks in China. The results suggest that effects of visual landscape on perception of individual sounds could be more reflected in natural sounds than artificial sounds and more in perceived occurrence of individual sounds than preference for individual sounds, while for functional landscape the effects are reversed. In general, landscape effects on perception of individual sounds are more significant in terms of perceived occurrence of individual sounds than preference for individual sounds. Landscape effects on overall soundscape preference are more reflected by artificial sounds than natural sounds, and are seen more in relation to preference for individual sounds.

Social, demographical and behavioural factors show more effects on perceived occurrence of individual sounds than preference for individual sounds. Age is a factor showing close relationship with both perceived occurrence of and preference for individual sounds, and could reflect the difference in sound sensitivity. Length of stay and visit frequency are two related factors and could have more influence on perceived occurrence of individual sounds and visual landscape perception than other factors. Taking their effects into consideration, landscape effects are still significant. Specifically, visual landscape shows significant effects on perceived occurrence of individual sounds, and is more effective than functional landscape. Both landscape factors show equal effects on preference for individual sounds, and they are highly related with the overall soundscape preference.

Table 8.4 Spearman's rho correlation coefficient for the relationship between perceived occurrence of individual sounds and each of the social, demographical and behavioural factors, i.e., age, education, occupation, residential, visit frequency and length of stay (2-tailed), as well as mean differences in perceived occurrence of individual sounds between males and females (t test, 2-tailed). Significant correlations are marked with * (p<0.05) and ** (p<0.01)

	Perceived occurrence (correlation coefficient)						Mean difference
Sound type	Age	Education	Occupation	Residential status	Visit frequency	Length of stay	Gender
Traffic sound	-0.005	-0.051	-0.039	0.043	0.011	0.058	0.023
Surrounding speech	0.172**	-0.083*	0.118**	-0.069	0.136**	0.184**	-0.059
Children shouting	0.143**	0.015	0.084*	-0.092*	0.084*	0.156**	-0.081
Footsteps	0.143**	-0.021	0.089*	-0.064	0.132**	0.167**	-0.067
Music	0.214**	-0.085*	0.112**	-0.134**	0.242**	0.238**	-0.088
Bicycle riding	0.120**	0	0.015	-0.058	0.095*	0.109**	-0.056
Roller skating	-0.007	0.083*	-0.038	-0.084*	0.067	0.07	-0.029
Lawn mowing	0.186**	0.008	0.069	-0.164**	0.165**	0.157**	0.038
Road cleaning	0.188**	0.006	0.107**	-0.164**	0.140**	0.164**	-0.039
Construction sound	0.109**	-0.023	0.054	-0.055	0.077	0.121**	-0.033
Aeroplanes	-0.120**	0.098*	-0.133**	0.054	-0.017	-0.03	0.019
Wind	0.024	0.064	-0.021	0.021	0.066	0.115**	0.013
Leaves rustling	0.014	0.117**	-0.049	0.01	0.082*	0.109**	0.039
Water sound	-0.103*	0.025	-0.076	0.043	-0.068	0.053	-0.011
Birds	0.087*	0.069	0.047	-0.052	0.117**	0.099*	-0.054
Frogs	0.072	-0.054	0.04	-0.039	0.024	0.073	0.008
Insects	0.054	0.072	-0.017	0.019	0.029	0.145**	0.02

Table 8.5 Spearman's rho correlation coefficient for the relationship between preference for individual sounds, the overall soundscape preference as well as visual and functional landscape satisfaction and each of the social/demographical/behavioural factors, i.e., age, education, occupation, residential status, visit frequency and length of stay (2-tailed), as well as mean differences in preference for individual sounds between males and females (t test, 2-tailed). Significant correlations are marked with * (p<0.05) and ** (p<0.01)

		Preference (correlation coefficient)						Mean difference
		Age	Education	Occupation	Residential status	Visit frequency	Length of stay	Gender
Individual sounds	Traffic sound	-0.012	-0.051	0.004	0.052	0.017	0.053	0.035
	Surrounding speech	0.162**	-0.086*	0.165**	-0.056	0.082	0.116**	0.098*
	Children shouting	0.161**	-0.064	0.209**	-0.104*	0.068	0.075	0.01
	Footsteps	0.128**	-0.032	0.112*	-0.012	0.045	0.097*	0.041
	Music	0.156**	-0.122**	0.140**	-0.066	0.170**	0.076	-0.107
	Bicycle riding	-0.031	-0.144*	-0.064	0.114*	-0.02	0.006	0.063
	Roller skating	-0.211*	0.024	-0.179	-0.017	0.018	-0.142	0.048
	Lawn mowing	0.09	-0.096	0.08	-0.009	0.041	0.016	0.141*
	Road cleaning	0.188**	-0.058	0.195**	0.019	0.048	0.055	0.102*
	Construction sound	0.025	-0.166	0.033	0.052	-0.155	-0.113	0.098
	Aeroplanes	0.116	-0.036	0.077	0.022	0.098	0.085	0.091
	Wind	0.123**	0.082	0.075	0.036	-0.035	0.067	-0.023
	Leaves rustling	0.142**	0.095*	0.074	0.02	-0.004	0.069	-0.063
	Water sound	0.105	0.105	-0.003	0.046	-0.03	0.088	-0.122
	Birds	0.107*	-0.023	0.123**	-0.06	0.08	0.063	-0.012
	Frogs	0.012	0.114	0.156	0.066	-0.026	0.087	0.093
	Insects	0.066	0.004	0.092	0.073	-0.065	-0.008	-0.051
	Soundscape	0.041	0.025	0.045	0.112**	0.037	0.086*	0.001

Visual landscape	0.05	0.03	0.039	0.022	0.108**	0.119**	0.013
Functional landscape	-0.03	-0.064	-0.029	0.117**	-0.03	0.049	0.041

Table 8.6 Results of stepwise multiple regressions between perceived occurrence of individual sounds and each of the landscape and social/demographical/behavioural variables. Standardized coefficient values are given in the cells, with significance levels marked with * ($p<0.05$) and ** ($p<0.01$). Blank cells show cases where variables were not satisfied with criteria for statistical model entry

Sound type	Age	Education	Occupation	Residential status	Visit frequency	Length of stay	Gender	Visual	Functional
Traffic sound								0.088*	
Surrounding speech	0.129**					0.139**			
Children shouting				-0.095*		0.151**			
Footsteps					0.038*	0.056**		0.055*	
Music					0.203**	0.185**			
Bicycle riding	0.286**		-0.226**						
Roller skating								0.121**	-0.108*
Lawn mowing	0.270**		-0.220**	-0.122**		0.094*			-0.093*
Road cleaning	0.202**		-0.130*	-0.135**		0.090*			
Construction sound						0.127**			
Aeroplanes	-0.129**								
Wind						0.092*		0.179**	
Leaves rustling		0.131**				0.099*		0.156**	
Water sound	-0.147**					0.090*		0.126**	
Birds						0.092*		0.110**	
Frogs									
Insects						0.121**		0.125**	

Table 8.7 Results of stepwise multiple regressions between preference for individual sounds, the overall soundscape preference and each of the landscape and social/demographical/behavioural variables, standardized coefficient values are given in the cells, with significance levels marked with * (p<0.05) and ** (p<0.01). Blank cells show cases where variables were not satisfied with criteria for statistical model entry

Sound type	Age	Education	Occupation	Residential status	Visit frequency	Length of stay	Gender	Visual	Functional
Traffic sound									
Surrounding speech	0.171**								
Children shouting			0.214**						
Footsteps	0.144**								
Music		-0.105*			0.159**				0.156**
Bicycle riding		-0.146**		0.127*					0.199**
Roller skating	-0.237**							0.209*	0.272**
Lawn mowing		-0.112*					-0.130*		
Road cleaning			0.180**					0.135*	
Construction sound									
Aeroplanes	0.134*								0.131*
Wind	0.184**	0.130**			-0.113*			0.141**	
Leaves rustling	0.184**	0.145**					0.093*		0.092*
Water sound								0.190**	
Birds			0.123**						
Frogs									
Insects									
Soundscape								0.325**	0.204**

Chapter 9 Landscape Effects on Soundscape Perception in city parks

In this chapter, the results from the second investigation as introduced in chapter 7 will be discussed. In the first section, three soundscape perception parameters are extracted from the soundscape dataset from the specifically designed soundwalks in the five city parks, and the relationships among these soundscape perception parameters are analysed. In the second and third sections, combined with the physical landscape data in respect to on-site landscape composition and local landscape spatial pattern indices on class level, respectively, physical landscape effects on soundscape perception are examined. In the fourth section, soundscape information from the general public as stated in chapter 8 was further analysed in relation to the soundscape information reflected by the physical landscape. At last, the soundscape information from the investigations in the city parks is discussed in terms of meaning in practical landscape management.

9.1 Relationships among soundscape perception parameters

9.1.1 Extraction of the three soundscape perception parameters

The soundscape datasets were processed from all the recording tables from the soundwalks by the seven observers, as illustrated in chapter 7. Before the process of the soundscape datasets, reliability analysis was made and the results show that, the mean inter-rater reliability of the seven observers for perceived loudness of five major sound categories was 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 “objective” dataset. Then, three soundscape perception parameters were calculated from the soundscape data set for each sampled site in each period, including

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

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

(3) Soundscape diversity index (SDI), the calculation refers to 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:

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

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 from all the matrixes given by the observers at the same period. As POS is based on the occurrence matrixes of the seven observers, a mean inter-rater reliability of 0.94±0.03 (Cronbach's Alpha) of the seven observers could guarantee the objectivity of this parameter. SDI is also based on the occurrence matrixes. Thus, the three soundscape perception parameters are all relatively "objectively" reflect the soundscape characteristics, where PLS and POS indicate the perception characteristics of individual sound, and SDI illustrate the overall soundscape perception characteristics.

9.1.2 Perceived loudness and occurrences of individual sound categories

In order to simplify the analysis process, perceived loudness and occurrences of individual sounds (PLS and POS) were analysed by sound categories. PLS and POS of individual sound category is the sum of PLS and POS of corresponding sounds in Table 7.1, respectively.

Correlations between perception parameters of the five sound categories are shown in Table 9.1. The results show that, in terms of PLS, biological sounds could be significantly impaired by human and mechanical sounds, whilst geophysical and mechanical sounds show negative relationship. Mechanical sounds could not only impair perception of natural sounds, but also minimize traffic sounds as well. For POS, both biological and geophysical sounds showed negative relationships with human and mechanical sounds. POS of mechanical sounds are highly negatively related to traffic sounds, whilst geophysical sounds show positive relationships with traffic sounds, but the coefficient value is rather low. Overall, the results suggested that the perception of natural sounds (biological and geophysical) could be easily affected by the appearance of artificial sounds (human, traffic and mechanical) in the parks.

Table 9.1 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

In terms of the relationships between PLS and POS, the results in Table 9.1 show that within the same sound category, the two parameters have positive relationships in all five sound categories. PLS of human and mechanical sounds could 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 are in a dominating position over natural sounds in soundscape perception process. PLS and POS of traffic sounds are negatively correlated to POS and PLS of mechanical sounds, respectively. As music is recorded as a kind of common mechanical sound in the parks, the results indicate the masking effects of music on traffic sounds. It is interesting to find that, PLS and POS of traffic sounds are positively correlated to POS and PLS of biological sounds, respectively. Considering that bird songs are the major biological sound sources, it may indicate that birds in the parks have to sing more frequently and louder with a background of traffic noise. Similar results were reported in some previous studies (Brumm, 2004).

9.1.3 Soundscape diversity index and perception of individual sound categories

Correlations between the overall soundscape perception in terms of soundscape diversity index (SDI) and the perception of the five individual sound categories are shown in Table 9.1 as well. It can be seen that SDI is positively related to PLS and POS of human sounds, and negatively related to PLS of biological sounds. It suggests that soundscape elements in the city parks are dominated by human sounds. With this situation, a higher SDI value could impair the perception of biological sounds.

9.2 Effects of on-site landscape composition

Given the dynamic nature of soundscapes, on-site landscape composition were analysed in relation to the soundscape perception parameters for each periods. Stepwise multiple regression analysis results between each of the soundscape parameters and the percentage of different landscape elements calculated from the panorama photo on each site in all three periods are shown in Table 9.2.

9.2.1 Perception of individual sound categories

It can be seen in Table 9.2 that, in terms of perceived loudness of the five sound categories, PLS of human sounds are negatively correlated to *sky*, and positively correlated to *building* in the first and second periods (morning and afternoon). As the percentage of *sky* in the photos may reflect the degree of openness of the sites, the reason could be that the park users do not prefer to stay at places without shade because of the hot weather in Xiamen. More buildings means that more people and human activities could occur, thus more human sounds could be heard. The positive relationship between mechanical sounds and *building* in the third period could be explained similarly. Mechanical sounds also show positive relationship with *vegetation* in the first period. As music is the major source of mechanical sound in this period, it is perhaps because loudspeakers in the parks are usually hidden in vegetations, or because some park users dance in the tree-shading areas while playing music. Lawn mowing activities, happened only in the first period could be another possible reason too. Geophysical sounds are only correlated to *sky* in the third period (dusk). It is possible that more geophysical sounds especially wind could be more perceived at places with more openness and less barriers. PLS of traffic and biological sounds show no relationship with any landscape elements.

In terms of perceived occurrences of the five sound categories, the results are rather similar with those of PLS. Human sounds show similar relationships as for POS with *building* and *sky*, but in the first period, *building* is not an effective variable. Traffic sounds still do not show any relationships with the landscape elements. Mechanical sounds show positive relationships with *vegetation* and *building* in the first and third period, respectively. However, biological sounds show negative relationship with *vegetation*, where the reason could be that the perception of biological sounds especially bird song were impaired by mechanical sounds which are positively related to *vegetation* in this period. Geophysical sounds are positively related to *sky* in the first and third periods.

9.2.2 Perception of overall soundscapes

As for perception of overall soundscapes, SDI only showed negative relationship with vegetation in the third period. That means places with more vegetation have less sound diversity. Since SDI is closely related to human sounds, this is perhaps because in the third period, park users were doing activities at different types of place, not only at places with vegetation.

9.3 Effects of landscape spatial pattern

Landscape spatial pattern indices were also analysed in relation to the soundscape perception parameters for each periods. Stepwise multiple regression analysis results between each of the soundscape perception parameters and local landscape spatial pattern indices in three periods are shown in Table 9.3. Correlations between the landscape indices, as shown in Table 9.4, are also considered when explaining the regression results.

Table 9.2 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*

9.3.1 Perceived loudness of individual sound categories

PLS of human sounds is positively correlated to the landscape shape index of building (LSI_B) in all three periods. The more complex the buildings' shapes in the area, the more human sounds could be perceived. As LSI_B has significant positive relationship with the percentage of building (PLAND_B) in the studied park areas, and most of the buildings are for residential purpose, it is easy to understand that sampled sites near residential buildings could attract more people, thus introduce more human sounds. The landscape shape index of water (LSI_W) is also positively correlated to human sounds in the first period, but the explanatory ability is less than LSI_B. The reason could be that water area with a complex shape could attract more park users.

Table 9.3 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**

PLS of traffic sounds are positively correlated to the percentage of road (PLAND_R) in the first and second periods, while showing positive relationship with the largest patch index of road (LPI_R) in the third period. As PLAND_R and LPI_R values in this study are the same, it seems that traffic sounds are only explained by the area of roads. This is expected, as more roads have more traffic load, thus more traffic sounds.

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

PLS of biological sounds only show negative relationship with the largest patch index of water (LPI_W) in the third period. It seems that large water areas are not helpful in introducing more biological sounds. That is also because the most important biological sounds are bird songs from trees.

PLS of geophysical sounds negatively related to the patch cohesion index of road (COHESION_R) in the third period. As COHESION_R is positively correlated to 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 have low frequency components.

Table 9.4 Correlations between each of the landscape indices, where * p<0.05, ** p<0.01

Landscape indices		Building				Road				Water			
		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

9.3.2 Perceived occurrences of individual sound categories

In terms of perceived occurrences of different sound categories, there are three variables related to human sounds in the first period. The most effective one is the landscape shape index of building (LSI_B, 0.485), and the other two are the largest patch index of building (LPI_B, -0.361) and the landscape shape index of water (LSI_W, 0.349). LSI_B and patch cohesion index of water (COHESION_W) are the only explanatory variable for human sounds in the second and third period, respectively. The reason for the relationships with LSI_B and LSI_W could be the same as that of PLS of human sounds, and the relationship with COHESION_W is likely because park users prefer places with large water areas, as COHESION_W is highly correlated to both PLAND_W (0.483) and LPI_W (0.435).

POS of traffic sounds only show positive relationship with COHESION_R in the third period. Considering the positive relationships between COHESION_R, PLAND_R and LPI_R, the reason could again be more traffic sounds associated with more roads. POS of mechanical sounds also show no relationship with any landscape indices in all three periods.

POS of biological sounds are 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 to human sounds, it is reasonable to see the negative relationship between LSI_B and biological sounds. PLAND_R and LSI_R are the other two variables for the first and third periods, respectively. The positive relationships between each of them and biological sounds suggest that vocal organisms like birds have to sing more times to reduce the effects from traffic sounds.

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

9.3.3 Soundscape diversity index

Soundscape diversity index only has significant relationship with the percentage of water (PLAND_W) in the third period. The results indicate that more water area could improve soundscape diversity. Considering that soundscape diversities in the parks are to a large extent resulted from perceived occurrences of human sounds, the reason could be that many park users prefer doing activities near water features.

9.4 Soundscape perception of the general public and landscape effects

Table 9.5 shows the preference for different sound categories of the general public. It can be seen that, people have a clear preference for biological and geophysical sounds, and think traffic sounds are slightly annoying. It is also shown that people have a higher level of tolerance or acceptance for human sounds than mechanical sounds. Correlation analysis results between the overall soundscape preference and both the preference for individual sound category and the satisfaction degree of visual and function landscape of the general public show that, the overall soundscape preference is positively correlated with the satisfaction degree of visual and function landscape, with correlation coefficients of 0.371 and 0.278, respectively. As for the five major sound categories, the overall soundscape preference is positively correlated with four of them, except biological sounds. It suggests that acceptance of existing artificial sounds and more natural sounds could improve the overall soundscape preference. Visual and function landscape effects could affect the overall soundscape perception to a large extent, and the effects could be higher than that on the preference for individual sound categories.

As for the effects of visual and function landscape on the preference for individual sound categories, both of them show significant positive relationships with human sounds, although the correlation coefficients are rather low. Visual and function landscape is also highly positively correlated with the preference for geophysical and mechanical sounds, respectively.

Table 9.5 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

9.5 Soundscape information for practical landscape management

9.5.1 Soundscape information related to on-site landscape composition

Among all the six landscape elements, *water*, *pavement* and *furniture* did not show any relationship with all the soundscape parameters in this study. *Building* is only an effective variable for artificial sounds, namely human and mechanical sounds. *Sky* is an effective variable for 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 the feeling of openness of the site. *Vegetation* as the explanatory variable for mechanical and biological sounds in the study may only reflect some reality in the parks, but it sheds a light on the relationship between human and organisms in terms of usage of vegetation areas. *Vegetation* is also the only variable related to perception of overall soundscapes. It is worth noting that, although the regression models are all significant, adjusted R^2 values of them are rather low. This means that, although the chosen landscape elements have significant effects on certain soundscape perception parameters, other variables could be more effective on soundscape perception.

Generally speaking, soundscape information reflected by the relationships between the six landscape elements and soundscape perception parameters are not much as expected. It suggests that the spatial arrangements and the specific functions of the surrounding landscapes could not be fully reflected by using photo measurements. In other words, on-site landscape composition may function in a more complex way in terms of the effects on soundscape perception, for example, through visual preference of the landscape. However, the recognised effective landscape elements, i.e., *building*, *vegetation*, and *sky* should be considered as key factors in future studies, especially *sky* which is usually neglected (Pheasant et al., 2008).

9.5.2 Soundscape information related to landscape spatial pattern

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 more affected by local landscape spatial pattern. Also, certain sound category could be affected by different land cover types and their spatial pattern characteristics. For the perception of human sounds, two types of land cover, namely building and water, show close relationships. Traffic sounds as the sound sources from totally outside of the parks, could reflect more the effects from local landscape to the soundscape perception in the parks. As expected, traffic roads are the only land cover type related to traffic sounds. Effects of physical landscape on perception of these two sound categories are more associated with sound sources. Biological sounds could be affected by several land cover types, namely building, road and water. And geophysical sounds only have negative relationships with roads (COHESION_R). Perception of these two sounds could be indirectly affected by physical landscape through the effects on other sound sources, for example, buildings (LSI_B) affecting human sounds, traffic roads (PLAND_R, LSI_R) affecting traffic sounds. In terms of overall soundscape perception, soundscape diversity only shows positive relationship with water as indicated by PLAND_W in the third period, which means introducing water features in the parks could improve attraction of the parks to park users.

However, the landscape indices may be not predictive for all sound categories. For example, no index is related to mechanical sounds in this study, mainly because of their unstable nature. Besides, not all landscape indices are effective for 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 partly because of the collinearity between many of the landscape indices. For example, NDVI was found an effective indicator for soundscape perception in the previous study, but in this study, it could not enter into any regression models. The strong correlations with the four road indices could be an important reason.

9.5.3 Other necessary soundscape information

While in this study the relationships between the relatively objective soundscape parameters and physical landscape characteristics could have been mainly explored. It is also useful to consider the soundscape experiences and opinions of the users from the general public, as they cover a wider range of time periods and demographic factors.

The results from the questionnaires showed that the park users have a clear tendency of preferring natural sounds over artificial sounds (except music), and in the meantime, a relatively high acceptance for human sounds. Thus, natural sounds should be more introduced into city parks to achieve better soundscapes. The results from the investigation with the general public could be a bridge to connect the information reflected by the relationship between “objective” parameters (PLS, POS, SDI) and physical landscape indices with the practical management. According to the results, physical landscape in favour of natural sounds should be considered in priority in the case of city park landscape management, and could be managed according to the positive or negative relationships of different landscape indices with perception parameters of different sounds.

Visual and function landscape was found also to be closely related to both the preference for certain individual sound categories and the overall soundscape preference. As the effects of both visual and function landscape could only function through physical landscape, these would be important supplement information to physical landscape design. Especially, when the “objective” soundscape information provided by physical landscape and soundwalks is not enough or difficult to apply into existing landscapes, considering enhancing aesthetic or function aspects of the physical landscape could be an easier approach.

In general, soundscape information from the general public could be a necessary supplement to the objective soundscape information collected by soundwalks.

9.6 Summary

In this study, based on information gathered in a field survey with a specifically designed soundwalk method in five city parks in Xiamen, China, physical landscape effects on soundscape perception are examined. In terms of soundscape perception parameters, it has been shown that, PLS and POS of biological and geophysical sounds could be affected by PLS and POS of the other three kind of sounds, including human, traffic and mechanical sounds, indicating the disadvantage of natural sounds in the soundscape perception process. SDI is mainly related to human sounds, which shows their dominating position in the 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 landscape characteristics were analysed, and the results suggest that in terms of on-site landscape composition, *building*, *vegetation* and *sky* are the three effective landscape elements. In particular, building is only an effective variable for artificial sounds (human and mechanical sounds). Vegetation is an explanatory variable for mechanical and biological sounds in the study, and it is also the only variable related to the overall soundscape perception. Sky is an effective variable for both human and geophysical sounds, and it is also the only variable positively related to natural sound perception. In terms of landscape spatial pattern, the landscape shape index of building and water (LSI_B, LSI_W) and the patch cohesion index of water (COHESION_W) 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 road (PLAND_R) and the largest patch index of road (LPI_R). 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 (LPI_W) and the landscape shape index of building (LSI_B), respectively, whilst POS of biological sounds are positively related to the percentage of road (PLAND_R) and the landscape shape index of road (LSI_R). The patch cohesion index of road (COHESION_R) is the only index negatively related to both PLS and POS of geophysical sounds. The relationships with overall soundscape perception parameter shows that soundscape diversity index only shows positive relationship with water as indicated by PLAND_W. In general, soundscape perception could be more affected by local landscape spatial pattern than on-site landscape composition. Thus, in landscape and urban planning and designing practices, the spatial arrangement of different landscape elements should be more considered in terms of better soundscapes. At the same time, soundscape information from the general public should always be considered as an important supplement.

Chapter 10 Conclusions and future work

The main aim of this thesis is to explore the relationship between soundscape and underlying landscape in urban context, in order to improve the urban ecosystem service function of soundscapes through a landscape and urban planning approach. Landscape characteristic in terms of the spatial pattern is therefore the major focus of the thesis. Under the theoretical framework of soundscape-landscape relationship study, the thesis could contribute in the following aspects, namely soundscape theory, study methodology, and soundscape information for practice. Part of the research findings have been published in peer-reviewed international journals (Liu et al., 2013a; Liu et al., 2013b), and the other three articles are in review.

10.1 Contributions of the study

10.1.1 Soundscape theory

At the beginning of the thesis, soundscape has been argued as a kind of urban ecosystem service, which could help people better understand and accept the soundscape concept. This also extend to theoretical meaning of soundscape to a larger scope, thus may attract more attention from different disciplines. The theoretical basis of this thesis stands for a novel combination of theories from different disciplines, especially landscape ecology. And this generated now knowledge to enrich the soundscape theory. Moreover, the thesis has also tried to introduce soundscape perception parameters into soundscape research, namely perceived loudness of individual sounds (PLS), perceived occurrence of individual sounds (POS) and soundscape diversity index (SDI). They have a great potential to be used as standardised parameters in future.

Major findings of the thesis which could contribute to the soundscape theory include: in the multi-functional urban area, based on three different levels of soundscape categories, i.e., main-class, middle-class, sub-class, spatiotemporal characteristics of urban soundscapes were analysed. The results show that, urban soundscapes showed a diverse spatiotemporal pattern because of the ever changing soundscape elements and dominated by anthrophony. Temporal variation of the three main-class sounds indicated a competitive relationship, but on the middle-class level, biological sound and traffic sound was showing positive relationship. Analysis on the relationships among different soundscape elements on the middle-class level revealed more information about the three kinds of anthrophony in terms of the dominance and temporal patterns. Analysis on the sub-class level recognised some specific sounds that were leading the urban soundscape characteristics. Especially, the contribution of biophony and geophony to overall soundscape loudness was more detected on this level. Bird song as an integral part of the biophony and many geophony such as wind, sea waves, and tree rustling are among the most contributing sounds to the overall soundscape loudness. Specifically for birdsong perception, an important and positive role of birdsong in urban soundscape perception was recognised. The results also show that, although birds could get used to the chronic urban traffic sounds, excessive sounds related to human appearance (adult voice, child voice and footstep) or human activities (construction sounds, music) could still frighten birds off. The spatiotemporal patterns of perceived loudness of birdsong suggest the adapted patterns of bird species in urban areas.

In terms of soundscape perception parameters, it has been shown in the city parks that, PLS and POS of biological and geophysical sounds could be affected by PLS and POS of the other three kind of sounds, including human, traffic and mechanical sounds, indicating the disadvantage of natural sounds in the soundscape perception process. SDI is mainly related to human sounds, which shows their dominating position in the parks. Overall, the three parameters are correlated and should be used together to illustrate soundscape characteristics.

10.1.2 Study methodology

The thesis has used different approaches to study the relationship between soundscape and landscape. These also include specifically designed methods. On-site soundscape investigations in the case studies were conducted using a similar method—"objectively controlled subjective evaluation method", to guarantee the "objectivity" of soundscape information and build the solid relationship with landscape. And the method could be used as a standardised method for collecting soundscape information for planning purpose in future. Specifically designed soundwalk method in the thesis shows also great potential to collect more "objective" soundscape information, other than the usual focus on semantic differential analysis.

The thesis also introduces an open source Geographic Information System (GIS) software—GRASS (Geographic Resources Analysis Support System). Combined with ArcGIS, different thematic soundscape maps could be generated to visualise the soundscape information, and the soundscape spatiotemporal dynamics could be easily shown by these maps. This method could be used to supply more soundscape information to planners or decision makers than just sound pressure level distribution from traditional noise mapping.

10.1.3 Soundscape information for practice

As the major focus of the thesis, landscape characteristic in terms of the spatial pattern was illustrated by different landscape indicators. The relationships between soundscape perception and landscape indicators revealed in different urban areas have both theoretical and practical meanings. Landscape indices are recognised as effective tools in current landscape assessment and management procedures, as they 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. Thus, landscape indices combined with soundscape information could be very useful for planners to design the soundscape in planning process.

In the multi-function urban area, influential landscape characteristics on soundscape perception are extracted, including building (indicated by building density and distance to building), road (indicated by road density and distance to road), vegetation (indicated by NDVI), land use scale (indicated by largest patch index), land use shape (indicated by landscape shape index and fractal dimension), land use composition (indicated by patch density and Shannon diversity index), and land use distribution (indicated by contagion). Among these indices, building density, distance to building, vegetation density, largest patch index and landscape shape index show the most influential relationships with all the five middle-class sounds, making them the most powerful indicators for soundscape perception. A series of landscape indices were found in close relationships with loudness perception of birdsong, which could be generalised as follows: a) landscapes with dense arrangements of buildings serve as shelters from urban noise and showed positive relationship with loudness perception of birdsong (CD); b) landscapes with dense vegetation provide usually ecologically good habits and could possess more birdsong (NDVI); c) landscapes with or close to dense traffic roads birdsong perception was not impaired (RD, DTR), which was also verified by the positive relationships between birdsong and traffic sounds; d) there might be more chance to perceive birdsong in fragmented landscapes characterised by small dispersed land use patches with complex shape (LPI, CONT, LSI, FRAC); e) loudness perception of birdsong showed also positively relationship with heterogeneous landscapes resulted from high patch density (PD).

In the city parks, analysis of the effects of visual and functional landscape factors on soundscape experience suggests that effects of visual landscape on perception of individual sounds could be more reflected in natural sounds than artificial sounds and more in perceived occurrence of individual sounds than preference for individual sounds, while for functional landscape the effects are reversed. In general, landscape effects on perception of individual sounds are more significant in terms of perceived occurrence of individual sounds than preference for individual sounds. Landscape effects on overall soundscape preference are more reflected by artificial sounds than natural sounds, and are seen more in relation to preference for individual sounds. Social, demographical and behavioural factors show more effects on perceived occurrence of individual sounds than preference for individual sounds. Age is a factor showing close relationship with both perceived occurrence of and preference for individual sounds, and could reflect the difference in sound sensitivity. Length of stay and visit frequency are two related factors and could have more influence on perceived occurrence of individual sounds and visual landscape perception than other factors. Taking their effects into consideration, landscape effects are still significant. Specifically, visual landscape shows significant effects on perceived occurrence of individual sounds, and is more effective than functional landscape. Both landscape factors show equal effects on preference for individual sounds, and they are highly related with the overall soundscape preference.

The relationships between the soundscape perception parameters and physical landscape characteristics were also analysed, and the results suggest that in terms of on-site landscape composition, building, vegetation and sky are the three effective landscape elements. In particular, building is only an effective variable for artificial sounds (human and mechanical sounds). Vegetation is an explanatory variable for mechanical and biological sounds in the study, and it is also the only variable related to the overall soundscape perception. Sky is an effective variable for both human and geophysical sounds, and it is also the only variable positively related to natural sound perception. In terms of landscape spatial pattern, the landscape shape index of building and water (LSI_B, LSI_W) and the patch cohesion index of water (COHESION_W) 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 road (PLAND_R) and the largest patch index of road (LPI_R). 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 (LPI_W) and the landscape shape index of building (LSI_B), respectively, whilst POS of biological sounds are positively related to the percentage of road (PLAND_R) and the landscape shape index of road (LSI_R). The patch cohesion index of road (COHESION_R) is the only index negatively related to both PLS and POS of geophysical sounds. The relationships with overall soundscape perception parameter shows that soundscape diversity index only shows positive relationship with water as indicated by PLAND_W. In general, soundscape perception could be more affected by local landscape spatial pattern than on-site landscape composition.

In order to promote the ecosystem service function of urban soundscape through planning approach, the thesis also highlights the necessity to combine soundscape information from different sources in practice, i.e., objective soundscape information related to physical landscape from images and soundscape information related to soundscape experience of the general public.

10.2 Future work

The thesis has been tried to reveal the relationship between soundscape and landscape at an early stage. There still a long way to go to build the concrete and universal principles about their relationship. Efforts should still be made on the following aspects:

Find out general accepted soundscape perception parameters. Soundscape perception itself is a very subjective and complex process, which could be affected by many factors. Although there are different parameters from physical, psychoacoustics and cognitive aspects used for soundscape evaluation, there is still a lake of general accepted and effective illustration parameters, as has been achieved in landscape evaluation area. Parameters with subjective connotation and universal applicable are still needed. The three soundscape perception parameters proposed in the thesis also need to be tested for the suitability.

More landscape indices should be tested. Besides the landscape indices tested in the thesis, there are much more landscape indices available in landscape ecology research, and they could be further explored for soundscape evaluation. In the thesis, landscape indices are used in consideration of their quantification ability of landscape spatial pattern (pattern). Another important ability of landscape indices to measure the landscape dynamics (process) should also be considered in landscape-soundscape relationship study.

Different spatial scale research is needed. An appropriate spatial scale based on observers' perception would be helpful for a better understanding of relationships between soundscape perception and spatial landscape patterns, as well as the factors influencing soundscape. The scope of this study was confined to a multiple functional urban area, assuming that soundscapes are composed mainly by sounds from local activities. Future considerations should include a larger spatiotemporal scale and acoustical band-width beyond the scope of this study.

Longer temporal scale research is also needed. In the present study, the temporal variability of the soundscape was analysed on a daily basis. While interesting patterns were found, it will be important to consider a longer time span covering a wider range of seasonal variation or phenophases. A detailed long-term survey of soundscape information involving local citizens is a promising direction to follow.

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Appendix 1

Urban Soundscape Investigation

Site NO.:___________ Observation Time period: ______________

Time-step	Sound source	Loudness	Preference
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Time-step	Sound source	Loudness	Preference	Time-step	Sound source	Loudness	Preference
11				16			
12				17			
13				18			
14				19			
15				20			

Note:

Appendix 2

Investigation on public satisfaction of city parks in Xiamen, China

Personal information：

① Gender (male, female)
② Age (≤24，25-30，31-40，41-50，51-59，≥60)
③ Education (Primary, secondary, higher)
④ Occupation (Student, working person, other)
⑤ Residential status (nearby resident, local resident, tourist)

Questions：

1、 **How often do you come to this park？ _____**
A low frequency (once in one or several months), B normal (once a week), C high frequency (almost everyday)

2、 **How long do you usually stay in this park？**
A short time (less than one hour), B normal (1-3 hour), C long time (more than 3 hours)

3、 **What is your purpose to visit this park? (Multiple reply) __________**
A Specifically to come and relax, B Enjoy the beautiful scenery or special atmosphere, C Enjoy a quiet environment, D Exercise, E Social purpose, F By the way to come and relax

4、 **Where do you usually do your activities in this park?**
A Small square, B Entertainment facilities, C Fitness facilities, D Walking and jogging tracks,
E Lawn, F Waterside, G Tree shade

5、 **What is your most satisfied aspect (s) with the park? (Multiple reply) __________**
A Beautiful and pleasant scenery, B Quiet, C Tidy and clean, D Enough space for activities, E Cultural and artistic atmosphere, F Enough recreational facilities, G Convenient, H Safe

6、 **How are you satisfied with the facilities in the park? (Each facility was asked separately, and mean value is analyzed)**
A very unsatisfied, B unsatisfied, C neither satisfied nor unsatisfied, D satisfied, E very satisfied

7、 **When you visit this park, how often do you hear the following sounds?** A Never, B Occasionally, C frequently; **How do you like these sounds？A** annoying, B neither annoying nor favourable, C favourable
Traffic sound_____，_____；Surrounding speech _____，_____；Children shouting _____，_____；Footsteps _____，_____；Music _____，_____；Construction sound _____，_____；Birds _____，_____；Frogs _____，_____；Insects _____，_____；Water sound _____，_____；Leaves rustling _____，_____；Wind _____，_____；

Bicycle riding _____，_____； Lawn mowing _____，_____; Road cleaning _____，_____； Roller skating _____， _____； Airplane flying _____， _____。

8、 How are you satisfied with the visual landscape of the park?_____

A very unsatisfied, B unsatisfied, C neither satisfied nor unsatisfied, D satisfied, E very satisfied

9、 How are you satisfied with the acoustic environment in the park?_____

A very unsatisfied, B unsatisfied, C neither satisfied nor unsatisfied, D satisfied, E very satisfied

10、How are you evaluate the overall quality of this park?_____

A very unsatisfied, B unsatisfied, C neither satisfied nor unsatisfied, D satisfied, E very satisfied

11、If some improvements will be done, what aspects do you expect should be? (Multiple reply) _____

A Greening and beautifying， B Exercise and entertainment facilities, C Basic infrastructure, D Noise mitigation measures, E Function layout

12、Do you have other comments about you experience in this park？

Appendix 3

Soundscape investigation in city parks, Xiamen

Park name: ____________No.:__________ Investigation time: _____________

Time step	Sound	Loudness	Preference
1			
2			
3			
4			
5			

Time step	Sound	Loudness	Preference
6			
7			
8			
9			
10			

Declaration of Primary Authorship

I declare, that I have written the present thesis for doctorate and without help of others. No other references were used except for the listed ones, and quoted results were always marked with the relevant reference. The present thesis was never submitted for examination in the present or a similar version either abroad or in Germany.

Eidesstattliche Erklärung

Ich erkläre, dass ich die vorgelegte Dissertation selbständig und ohne unzulässige fremde Hilfe angefertigt und verfasst habe, dass alle Hilfsmittel und sonstigen Hilfen angegeben und dass alle Stellen, die ich wörtlich oder dem Sinne nach aus anderen Veröffentlichungen entnommen habe, kenntlich gemacht worden sind. Ich erkläre zudem, dass die Dissertation in der vorgelegten oder einer ähnlichen Fassung noch nicht zu einem früheren Zeitpunkt in einer anderen in- oder ausländischen Hochschule als Dissertation eingereicht worden ist.

Rostock, den 09.09.2013 Jiang Liu

Curriculum Vitae

Personal information

Name:	Jiang Liu	**Gender:**	Male
Birthplace:	Hebei Province, China	**Birthday:**	14/11/1984
Address:	Max-Planck-Str.1 4.08.2, 18059, Rostock		
Tel:	+49 0381/4983245		
E-mail:	jiang.liu@uni-rostock.de		

Education background

09/2003-07/2007: Bachelor Student in the Department of Architecture and Urban Planning, Shenyang Jianzhu University;

09/2007-07/2008: Master Student in Graduate University of Chinese Academy of Sciences, Beijing;

09/2008-07/2010: Master Student in Institute of Urban Environment, Chinese Academy of Sciences, Xiamen. Research area: Urban planning and landscape design;

04/2011 till now: Doctor Student in University of Rostock (sponsored by DAAD)

Research area: Landscape planning and landscape design, Soundscape design.

Academic activities

Training

11-15/07/2011: Participant of the COST TD0804: Soundscape of European Cities and Landscapes Training School "Measurement, Analysis and Evaluation", in Aachen, Germany;

29/08-11/09/2011: Participant of the summer school "Nachhaltige Entwicklung an der Ostseeküste" in Rostock, Germany;

01/09/2012-30/11/2012: Holder of the Short Term Scientific Mission (STSM) sponsored by COST Action: TD0804 in University of Sheffield, Sheffield, UK;

16-17/03/2013: Participant of European Acoustics Association (EAA) winter school, Course C: Synergies between Environmental Noise Control and Soundscape Approach, in Merano, Italy;

21-28/07/2013: Participant of the summer school "Neuroergonomics and Urban Placemaking" organized by International Society of Biourbanism, in Artena, Rome, Italy.

Conference/Seminar

05/05/2011: Participant of “Landschaft im Wandel” organized by “Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommen”, in Zernin, MV, Germany;
13/05/2011: Participant of “Landschaften stiften” organized by “Stiftung Mecklenburger ParkLand”, in Dalwitz, MV, Germany;
13-18/05/2012: Participant of the ACOUSTICS 2012 HONG KONG conference with abstract presentation, in Hongkong, China;
22/01/2013: Lecture on Program Interdisziplinären Ringvorlesung "Räume - vielfältig und doch identisch?!", in University of Rostock;
18-21/03/2013: Participant of AIA-DAGA 2013 Conference on Acoustics with poster and paper presentation, in Merano, Italy;
22/03/2013: Participant of COST Action TD0804: Soundscape of European Cities and Landscapes final conference with invited poster and paper presentation, in Merano, Italy.

Reviewer

Reviewer of the journal “Landscape and Urban Planning”;
10/2011: Reviewer of a bachelor student’s final thesis: “Internet based landscape image evaluation” from University of Rostock;
Since 04/2013: Co-supervisor of a master student in Faculty of Agricultural and Environmental Sciences in University of Rostock.

Thesen

This thesis focused on the relationship between soundscape and landscape in urban areas from a planning perspective of view. Major new research findings include:

(1) Spatiotemporal characteristic of urban soundscapes was studied with a similar method used in a rural area by other researchers, but with a more detailed soundscape recording. The results showed that urban soundscapes were dominated by anthrophony and showed a diverse spatiotemporal pattern because of the ever changing soundscape elements. Temporal variation of the three main-class sounds indicated a competitive relationship.

(2) With the more detailed soundscape dataset, analysis on the middle-class level revealed more information about the relationships among different soundscape elements, such as the three kinds of anthrophony in terms of the dominance and temporal patterns, and the positive relationship between biological sound and traffic sound. Analysis on the sub-class level recognised some specific sounds that were decisive for the urban soundscape characteristics. Especially, the contribution of biophony and geophony to overall soundscape loudness was more detected on this level. Thus, classification of soundscape categories is vital to acquisition of soundscape information.

(3) GRASS GIS (Geographic Resources Analysis Support System) is a useful tool of thematic soundscape mapping. The thematic maps could reveal spatiotemporal characteristics of different soundscape elements. The dynamic characteristic of urban soundscapes was also shown vividly by overlaying these thematic soundscape maps of main-class sounds.

(4) The relationships between soundscape perception and landscape spatial pattern in the multi-functional urban area were analysed for the first time in the research area. And some influential landscape characteristics on soundscape perception were extracted, including building (indicated by building density and distance to building), road (indicated by road density and distance to road), vegetation (indicated by NDVI), land use scale (indicated by largest patch index), land use shape (indicated by landscape shape index and fractal dimension), land use composition (indicated by patch density and Shannon diversity index), and land use distribution (indicated by contagion).

(5) Among these indices, building density, distance to building, vegetation density, largest patch index and landscape shape index show the most influential relationships with all the five middle-class sounds, making them the most powerful indicators for soundscape perception.

(6) Birdsong as an important positive sound in the urban area was paid special attention. The results also showed that, although birds could get used to the chronic urban traffic sounds, excessive sounds related to human appearance (adult voice, child voice and footstep) or human activities (construction sounds, music) could still frighten birds off. The spatiotemporal patterns of perceived loudness of birdsong suggest the adapted patterns of bird species in urban areas.

(7) A series of landscape indices were found in close relationships with loudness perception of birdsong, including construction density, vegetation density (NDVI), road density, distance to main road, patch density (PD), landscape shape index (LSI), fractal dimension (FRAC), largest patch index (LPI), and contagion (CONT).

(8) Landscape effects from visual and functional aspects on soundscape experience of the general public in city parks was firstly studied in a large scale. Effects of visual landscape on perception of individual sounds could be more reflected in natural sounds than artificial sounds and more in perceived occurrence of individual sounds than preference for individual sounds, while for functional landscape the effects are reversed.

(9) In general, landscape effects on perception of individual sounds are more significant in terms of perceived occurrence of individual sounds than preference for individual sounds. Landscape effects on overall soundscape preference are more reflected by artificial sounds than natural sounds, and are seen more in relation to preference for individual sounds.

(10) Social, demographical and behavioural factors show more effects on perceived occurrence of individual sounds than preference for individual sounds. Age is a factor showing close relationship with both perceived occurrence of and preference for individual sounds, and could reflect the difference in sound sensitivity. Length of stay and visit frequency are two related factors and could have more influence on perceived occurrence of individual sounds and visual landscape perception than other factors.

(11) Taking effects from social, demographical and behavioural factors into consideration, landscape effects on soundscape perception are still significant. Specifically, visual landscape shows significant effects on perceived occurrence of individual sounds, and is more effective than functional landscape. Both landscape factors show equal effects on preference for individual sounds, and they are highly related with the overall soundscape preference.

(12) Based on a specifically designed soundwalk approach, soundscape perception parameters including perceived loudness of individual sound (PLS), perceived

occurrence of individual sound (POS), and soundscape diversity index (SDI) were introduced. Analyse of their relationships showed that the three parameters are correlated and should be used together to illustrate soundscape characteristics. Specifically, PLS and POS of biological and geophysical sounds could be affected by PLS and POS of the other three kind of sounds, including human, traffic and mechanical sounds, indicating the disadvantage of natural sounds in the soundscape perception process. SDI is mainly related to human sounds, which shows their dominating position in the parks.

(13) Building, vegetation and sky are the three effective physical landscape elements in terms of on-site landscape composition on soundscape perception. In particular, building is only an effective variable for artificial sounds (human and mechanical sounds). Vegetation is an explanatory variable for mechanical and biological sounds in the study, and it is also the only variable related to the overall soundscape perception. Sky is an effective variable for both human and geophysical sounds, and it is also the only variable positively related to natural sound perception.

(14) Physical landscape effects on soundscape perception in terms of landscape spatial pattern showed that, the landscape shape index of building and water (LSI_B, LSI_W) and the patch cohesion index of water (COHESION_W) 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 road (PLAND_R) and the largest patch index of road (LPI_R). 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 (LPI_W) and the landscape shape index of building (LSI_B), respectively, whilst POS of biological sounds are positively related to the percentage of road (PLAND_R) and the landscape shape index of road (LSI_R). The patch cohesion index of road (COHESION_R) is the only index negatively related to both PLS and POS of geophysical sounds. The relationships with overall soundscape perception parameter shows that soundscape diversity index only shows positive relationship with water as indicated by PLAND_W.

(15) In order to promote the ecosystem service function of urban soundscape through planning approach, it is also necessary to combine soundscape information from different sources in practice, i.e., objective soundscape information related to physical landscape from images and soundscape information related to soundscape experience of the general public.