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Spatial-temporal change analysis of plant soundscapes and their design methods

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ABSTRACT

The aim of the study was to describe the soundscape elements, spatial-temporal changes and preferences in plant soundscape using quantitative measures, in order to recommend soundscape design methods. Both acoustic measurements and subjective evaluations of the soundscapes were conducted at various locations in Jinan Forest Park using 14 groups of plant spaces within the park. Our analysis investigated soundscape elements categorized as nature sounds, human activity sounds, and mechanical sounds. The soundscapes varied with time of day and season and were influenced by the surrounding environment and human behavior. Soundscape element preferences were correlated with a visitor's age and visitation frequency, with nature sounds receiving the highest preference scores. Closed nature spaces had lower sound levels and received the highest preference by visitors. The results were further analyzed according to five soundscape methods to improve visitor experience: sound-masking, sound-borrowing, sound-reinforcement, sound-contrasting, and sound-expectation, that are also consistent with Chinese classical garden design.

1. Introduction

Chinese classical gardens provide not only visual but also auditory aesthetics, such as "the patter of night rain on banana" and "the pine soughing valleys" (famous classical gardens). Modern landscape architecture often focuses on visual function, while ignoring other sensory perceptions, such as sound, smell, touch, and taste. Growing levels of urban noise pollution have made it difficult for people to experience nature sounds, leading them to seek them out. With the introduction and spread of soundscape theory in China (Li, 2004; Qin, 2005), researchers have been studying soundscape design methods and the characteristics and interactions of soundscape elements (Chen and Yang, 2014), especially in urban open spaces (e.g., city squares, parks and other public facilities) (Ge et al., 2006; Zhang and Ma, 2011). Researchers have examined variation and perception (Bani and Paulo, 2009; Brambilla et al., 2013; Grey and Robert, 2015; Jeon and Hong, 2015) and physiological effects (Ken and Mujthaba, 2013) of soundscape elements and visitor preference to them (Brown et al., 2011; Schwarz, 2013). The physical scope of the research has ranged from parks to whole cities (Antonio et al., 2012; Rehan, 2015). Soundscape designs are often considered in urban open space landscape design. Parks in China (e.g., Beijing Olympic Forest Park, blind park in Shanghai Chenshan Botanical Garden, Tangshan South Lake Park) and abroad (e.g., Bamboo Garden in Le Parc de la Villette, Brays Bay Foreshore Park, Shiru-ku Road pocket park in Japan, Miami Beach SoundScape Park) have created distinctive soundscapes using plants, water and other landscape elements.

Soundscape design involves the relationship among people, environment and sound, with sound elements being the basic focus. Sound elements mainly include nature sounds, human activity sounds, and mechanical sounds (Jeon and Hong, 2015). Nature sounds are formed by weather or natural geographical factors, and commonly include birds singing, frogs and insects chirping, leaves rustling in the wind, babbling brooks, etc. Nature sounds tend to heighten the atmosphere, lead the space and resonate positively with visitors. Human activity sounds usually include talking, children playing, singing and dancing, and people exercising. These sounds may adjust or disturb the environment. Mechanical sounds include traffic and construction noise, and usually negatively affect park enjoyment. The spatial and temporal distribution of soundscape in different environments is a key focus of the perception and evaluation of soundscape.

How to describe, perceive and evaluate soundscape has been an important question. There are a variety of quantitative and qualitative research methods for measuring the objective acoustic environment and

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subjective acoustic perception. The objective acoustic environment is usually analyzed through physical acoustic measures, noise and soundscape maps, soundwalks and other similar methods (Brambilla et al., 2013; Jeon and Hong, 2015; Hong and Jeon, 2017). A variety of psychological and physiological measures are used to analyze the subjective responses of listeners. Subjective responses are measured using interviews, questionnaires, semantic differential methods, sonic mind maps (Kang and Zhang, 2010; Marry and Defrance, 2013). Physical measures referred to analysis of changes in physiological indicators (Ken and Mujthaba, 2013; Medvedev et al., 2015) such as heart rate, respiration rate, and skin conductance level. Measurement and evaluation methods are often used in combination, with methods and instruments being continuously improved. Recent research has focused on the physiological and psychological impacts of noise reduction using plants (Yang et al., 2011), visual effects on noise reduction (Hong and Jeon, 2014), and the relationship between noise reduction and the soundscape. The core of soundscape is human perception, with perception being influenced by factors within and outside the environment. The diversity of the environmental landscape led to the diversity of perception (Pijanowski et al., 2011). Preis et al. (2015) found that the comfort assessment of audio-visual samples could be changed by manipulating the audio rather than the video part of the audio-visual sample. Zhang (2014) also found that different sound elements could produce different restorative effects. Nature sounds (e.g., birds singing, babbling brooks) gave people a good experience, while mechanical sounds (e.g., traffic noises) impeded restorative feelings in people. Human activity sounds (e.g., singing, dancing, exercising) improved or prevented a restorative experience.

The design and protection of soundscape has stirred the attention of researchers. Positive design, zero design and negative design were often used in traditional soundscape design (Ge and Bu, 2003). Positive design usually added new elements to the original soundscape, zero design usually maintained the original state, and negative design usually removed the incompatible elements from the original soundscape. Liu and Chen (2009) put forward sound-borrowing, sound-reinforcing, and sound-contrasting, based on Chinese classical garden design methods. Hao (2014) proposed sound-masking to control city noises. Ren and Kang (2016) proposed sound-expectation based on the rural soundscape comparison between Chinese and English gardens. Sound-borrowing, adapted from "scenery-borrowing" techniques in classical gardens, involves creating visual associations with water, wind, rain, etc., stimulating more senses. Sound-reinforcing can supplement or enhance the original soundscape to improve the landscape aesthetics, increase the sense of place, and highlight regional features. Sound-contrasting is used as a kind of foil for other elements in a landscape. For example, "cicadas singing makes forests quieter, and birds chirping makes mountains more silent" (an ancient Chinese poem) describes how sounds can make people feel a deep quietness. Sound-masking refers to features that reduce the perception of other sounds (Duriach, 2006). Sound-expectation refers to the expectation of hearing particular sounds when facing the landscape, in particular sounds, which are in harmony with the landscape. Siebein, 2013 presented the process of soundscape design (inspiration, planning, conceptual formation, construction, detail design) and included concrete steps. Moreover, many cities have carried out a series of projects of soundscape design.

Chinese classical gardens developed its own unique landscape and soundscape design, which differs from modern soundscape theory. At its core was the expression of feelings, not the control of soundscape physical parameters. Soundscapes have also been recorded and portrayed in many ancient Chinese verses and garden books. The sounds described in ancient verses (The books of songs) tended to be natural sounds, such as wind, rain, water, insects, and birds. These natural sounds were combined with garden plants and other elements to create unique soundscapes (Gardening theory of Yuanye). Plant landscape design in classical Chinese gardens was influenced by traditional philosophy and arts, and even the scholar-bureaucrat lifestyle, with a unique artistic approach. Xian Qing Ou Ji, written by Li Yu, pointed out that tree planting was not only for visual entertainment, but also for the ears. The concept of unique plant landscape design in Chinese classical gardens not only included nature sounds, such as wind rustling, rain pattering, birds singing, insects chirping, etc., but also expanded and enhanced the aesthetic connotation of these sounds by using artistic principles formed through long-term application.

The study of plant soundscape is still in its early stages, with most studies having been conducted using qualitative methods. The aim of the study was to quantitatively study the soundscape elements and their spatial-temporal variation and preference, with an objective of providing recommendations for plant soundscape design. Both acoustic measurements and subjective evaluations of the soundscapes were conducted at various locations in Jinan Forest Park using 14 groups of plant spaces within the park. Further we aimed at using the concepts of sound-masking, sound-borrowing, sound reinforcement, sound-contrasting and sound expectations to analyze the results in the present study. These recommendations may help to optimize the application of soundscape elements through soundscape design of urban environments to meet human needs.

2. Methodology

2.1. Study area

Jinan is located between latitude 36°10′ − 37°90′ N and longitude 116°12′ − 117°35′E, and is a typical land-locked city in northern China. Jinan is the capital of Shandong Province, located north of Taishan Mountain and south of the Huanghe River. The city's climate is a typical warm-temperature semi-humid continental monsoon climate with well-defined seasons. Jinan is a Chinese traditional landscape city, with mountains, springs, and lakes. There are a variety of large spatial structures, such as urban parks, roadside green corridors, and small pocket gardens in residential areas. Whether public, semi-public, or private, all areas play an important role in satisfying residents' requirements for outdoor enjoyment.

Jinan Forest Park is an urban park, with dense plant landscaping, and located at the foot of Kuangshan Mountain. It covers an area of 69.5 hm^2, with a green area of 60.1 hm^2 and a water area of 4.8 hm^2. Activities performed in the park include scientific surveys, hiking, relaxation, musical performances, and sports. The park design emphasizes the configuration of a natural community, especially the native wetland and terrestrial plant communities. Typical vegetation within the park includes *Cedrus deodara*, *Platycladus orientalis*, *Ligustrum quihoui*, *Metasequoia glyptostroboides*, *Salix matsudana*, *Populus tomentosa*, *Ginkgo biloba*, *Prunus persica*, *Forsythia. Suspense,* etc. Typical bird species present include sparrows, magpies, crows, egrets, and ducks. The 14 plant spaces (observation points) studied here were made up of plants and other garden elements within the park. The 14 observation points were termed S1-S14. S1 and S2 were at the park entrance, where there were fewer plants and sound elements but more traffic. The other 12 observation points were surrounded by different plants that were evenly distributed in the park. The plant spaces were classified into open space, semi-open space, closed space, or vertical space, based on the type of plant enclosure (Table 1, Fig. 1).

2.2. Procedure

Soundscape elements were recorded in early April, July, and October 2014 and January 2015, on days when the weather was fine with a light breeze. Acoustic measurements, including a weighted-equivalent sound pressure level (SPL) L_{Aeq} and frequency measured (Jeon and Hong, 2015), with an AWA 6228-3 noise spectrum analyzer (Hangzhou Aihua Instruments CO. Ltd. China), and the codes of the recorded sounds were entered into a table. Triplicate measurements were performed at all 14 observation points every 3 hours from 6:00 to