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Birdsong As an Element of the Urban Sound Environment: A Case Study Concerning the Area of Warnemünde in Germany

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Summary
Birds are common species in urban ecosystems and birdsong is an important element of many urban sound environments. Perceptions of birdsong loudness, based on a case study in Warnemünde, a coastal area in Germany, were analysed in terms of its role in urban sound environment, the relationships with other sounds, spatiotemporal characteristics, as well as the relationships with underlying landscape characteristics. An important and positive role of birdsong in urban soundscape perception in the study area was recognised. The analysis of the relationships between birdsong perception and other sounds suggested that, although birds could adjust their songs with continual urban traffic sounds, they are still sensitive to excessive sounds related to human appearance (adult voice, child voice and footstep) or human activities (construction sounds, music). The spatiotemporal patterns of perceived loudness of birdsong suggested the adapted patterns of bird species in urban areas. Perceived loudness of birdsong showed close relationships with the underlying landscape characteristics indicated by a series of landscape spatial pattern indices. Positive relationships were found with construction density, road density, vegetation density, as well as fragmentation status indicated by patch density, largest patch index, landscape shape index, fractal dimension and contagion.

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1. Introduction

Urban areas are generally characterised 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 well-being [1, 2, 3]. Birds that use songs (i.e. Oscines) for communicating territorial claims and mate attraction could be more sensitive to the urban acoustic environment [4, 5]. At the same time, it is found that birdsong could enhance landscape visual enjoyment and be a positive element in urban acoustic environment [6, 7, 8, 9].

The European Directive on environmental noise states that authorities across the EU should design, implement, and execute plans of action against urban noise, with the aim of improving the acoustic conditions of cities, and develop strategic noise maps to assess the associated levels of annoyance and sleep-disturbance [10]. However, as previous research has found, the acoustic environment cannot be effectively improved only by noise control strategies [11]. A more general concept than noise is soundscape, which considers not only unfavourable noises, but also desirable environmental sounds [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23]. Thus, desirable sounds like birdsong and water sound, which are possible inputs for a better accepted urban environment, are given more research attention [7, 8, 24, 25, 26]. While previous researches have 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.

The aims of this research are: 1) to recognise the role of birdsong as a significant element in urban sound environment; 2) to reveal the relationships between loudness perception of birdsong and other sounds; 3) to analyse spatiotemporal characteristics of loudness perception of birdsong through thematic mapping techniques; and 4) to identify the landscape characteristics that may affect loudness perception of birdsong.

2. Methods

2.1. Study area

The study area is located in northeast Germany, in the Warnemünde district of Rostock on the Baltic Sea. It is

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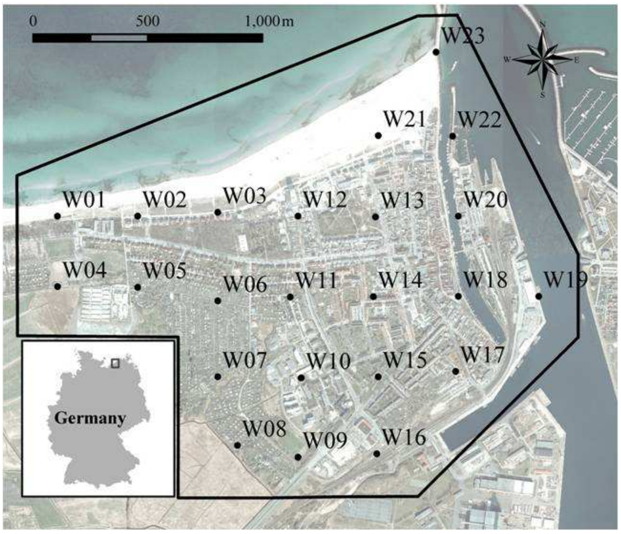

Figure 1. Location of the study area and distribution of the 23 sampled sites (W01-W23).

on the left bank of the Warnow river mouth, and extends almost 2,400 m East–West and 2,000 m North–South as shown in Figure 1. This area is characterised by diverse land use types and good ecological conditions with both natural (e.g. beach, sea, forest) and semi-natural landscapes (e.g. park, garden), attracting many local people and tourists especially in summer time. The study area was divided into 23 sampled sites, evenly distributed with approximately 350m between adjacent sites. Figure 2 shows landscape photos of some sampled sites, namely W12, W14 and W21 (see Figure 1).

In terms of bird species, Passer domesticus, Turdus merula, Parus major, Parus caeruleus, Carduelis chloris, Pica pica, Larus argentatus, Larus canus, etc. are main species commonly appearing in summer time, bringing rich birdsongs to the study area. It is noted that the species of bird in terms of the effect of their songs on soundscape preference is of high importance, as shown by Schulte-Fortkamp *et al.* [27], during a redevelopment of Nauener Platz in Berlin. Figure 3 shows some typical spectra on site W12, W14 and W21, based on 4-minute sound recordings. Combining with playback of the sound recordings, the spectra suggest that the sound environments in these sampled sites were of considerable diversity. For example, on site W12, birdsongs (about 1k to 4k Hz) and low frequency background traffic sounds (about 30-400 Hz) occurred almost during all the recording period with relatively high levels. On site W14, the background traffic sound levels were relatively low, with foreground traffic sounds and birdsong appearing occasionally. On site W21, wind blowing acted as the background sounds with relative high levels, with human sounds and birdsong appearing occasionally.

2.2. Field soundscape investigation

There are different approaches to measure soundscapes [28]. In this research, soundscape is considered as the full

Figure 2. Landscape photos on sample sites W12, W14, and W21.

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 [29]. Individual sounds with their respective perceived loudness were recorded and evaluated subjectively by observers but with control process.

A list of commonly occurring soundscape elements in the study area was established in pilot studies to assist on-site investigation, as shown in Table I. The soundscape investigation was conducted by 12 observers, including

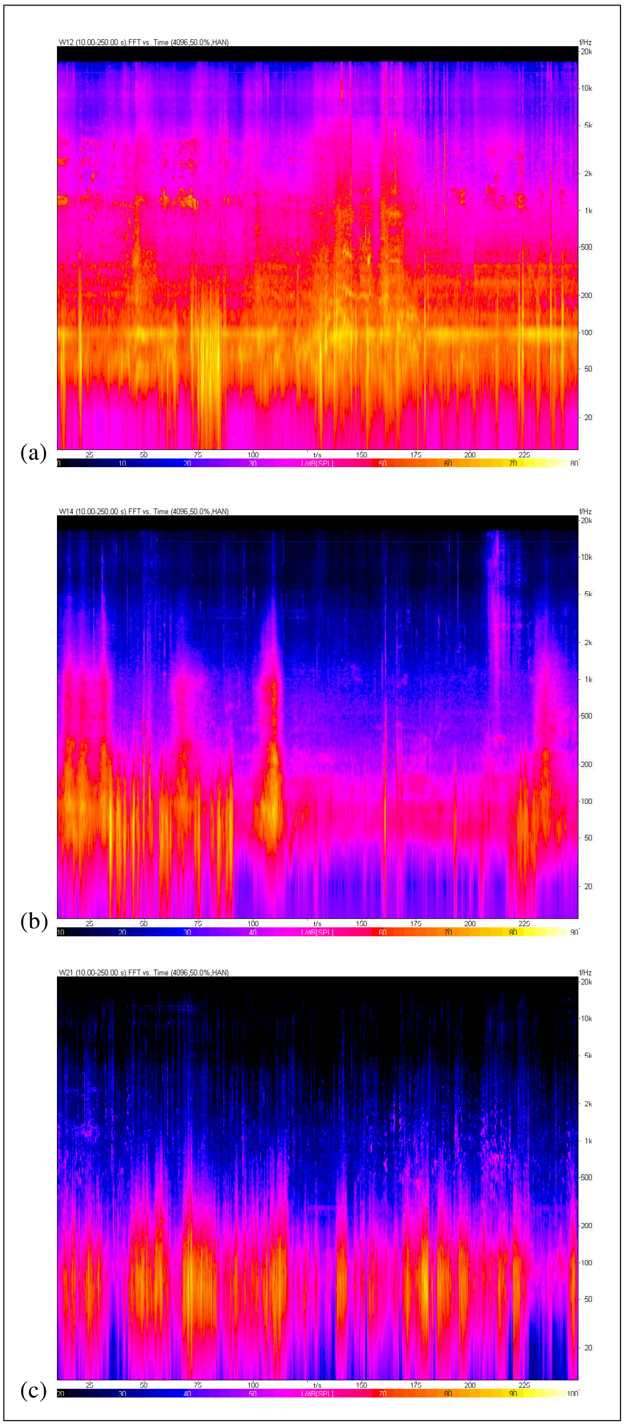

Figure 3. Typical spectra in the study area, where the SPL is relative. (a), W12; (b), W14; (c), W21.

10 students from the Agricultural and Environmental Faculty, University of Rostock, 1 audio engineer and 1 musician, all without hearing deficiencies. Among them there were 7 males and 5 females, and their mean age was 26, with a standard deviation of 2.8. All the observers participated into the training process one month before the on-site survey, including getting familiar with the list of sounds through watching videos recorded on site, and making field practice to control for observation bias, in order to guarantee a consistent and comparable evaluation of

Table I. Main sounds identified in the study area.

Sound	Code	Sound	Code
Birdsong	BS	Traffic (foreground)	TSF
Insects	IS	Traffic (background)	TSB
Frog croaking	FR	Ship in motion	SM
Chicken	CG	Train in motion	TM
Dog barking	DB	Aeroplane in flight	AF
Grass rustling	GR	Bicycle riding	BC
Tree rustling	TR	Motorcycle in motion	MR
Sea shore waves	SW	Construction activity	CT
Rain	RS	Grass cutting	GM
Wind	WF	Emergency signals	ES
Water flowing	WS	Bell ringing	BR
Child voice	CS	Music	MS
Adult voice	AS	Other anthropogenic sounds	OA
Footstep	FS		

soundscapes. In other words, the training was not to make the observers as expert listener, rather, to make sure that they understand what was required to evaluate as common listeners, so that comparable results can be obtained. Results of this pilot study showed that the average inter-rater reliability of perceived loudness of birdsong and other major sounds was 0.91 (Cronbach's Alpha, sample size 70). The observers were then divided into 6 groups of 2 to conduct the evaluation respectively, each responsible for 3 or 4 sampled sites (cf., [30]).

The investigation was carried out on the 3rd and 4th of August 2011. The perceived loudness of birdsong and other sounds were recorded in eight two-hour successive sampled periods between 06:00 and 22:00 hours (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), covering the main daily active periods for birds in summer time in the study area. Within each sampled period, the evaluation data were recorded in a randomly chosen 10 minute slot, which was further divided into twenty sequential time-steps, each of 30 seconds. The perceived loudness of birdsong and other sounds were evaluated with a five-point linear scale (1 = very quiet, 2 = quiet, 3 = normal, 4 = loud, 5 = very loud). 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). The loudness score for each sound was given according to the highest one during the time-step. Any sound which did not appear in a given time-step was categorised as 0 during data process. The perceived loudness of individual sounds at a given site and during a given period was calculated by adding the scores obtained from the twenty sequential time-steps in the period. Similarly, the overall soundscape loudness was calculated by adding the perceived loudness of all individual sounds accordingly. The investigation generated a database of 3860 datasets (20*8*23). It is noted that, although the observers could all perceive the surrounding landscape at each sampled site during the investigation, the observers were required to focus on soundscape evaluation. There was no problem reported by the observers during the investigation.

2.3. Extraction of birdsong information

Urban sound environments entail great spatial complexity and temporal variability [31, 32]. Analysis of spatiotemporal dynamics of individual sounds could shed a light on the overall sound environment dynamics. While the focus of this research was on the perceived loudness of individual sounds, no detailed analysis was made in terms of bird species, and this was also because strictly controlled consecutive time-steps hardly allowed the observers to discern exactly bird species. Birdsong information in terms of the perceived loudness was extracted from the survey datasets, served as the basis of the relationships with the other sounds and with the underlying landscape characteristic. The birdsong information was also mapped using a regularised spline with a tension interpolation method [33]. The interpolation was based on the sums of perceived loudness of birdsong at each sampled site during each sampled period. Then eight raster maps describing the spatial distribution of birdsong were visually presented for each sampled period. The daily accumulated perceived loudness of birdsong across the study area was also mapped to indicate the overall distribution, which could indicate the relationships between birdsong perception and underlying landscape characteristics.

2.4. Analysis of the underlying landscape characteristics

The effects of local landscape characteristics on birdsong perception were analysed in terms of landscape spatial pattern which was quantified by a series of landscape indices in respect to landscape composition and configuration. Landscape composition indices include construction density (CD), road density (RD), vegetation density (normalized difference vegetation index (NDVI)), patch density (PD), largest patch index (LPI), Shannon diversity index (SHDI) and Simpson's evenness index (SIEI). Landscape configuration indices include distance to construction (DTC), distance to main road (including railway and water way) (DTR), landscape shape index (LSI), contagion (CONT) and fractal dimension (FRAC). In terms of the significance of these indices, NDVI is a simple graphical indicator that assess whether the target being observed contains live green vegetation or not; PD in basic utility is the same as the number of patches as an index, but facilitates comparisons among landscapes of varying size; LPI quantifies the percentage of total landscape area comprised by the largest patch and is a simple measure of dominance; both LSI and FRAC could measure the total shape complexity of patches; SHDI measures diversity of patch types; SIEI indicates a structural component of diversity, with the maximum evenness resulted from an even distribution among landscape types and low evenness related to either one or just a few dominant elements; CONT

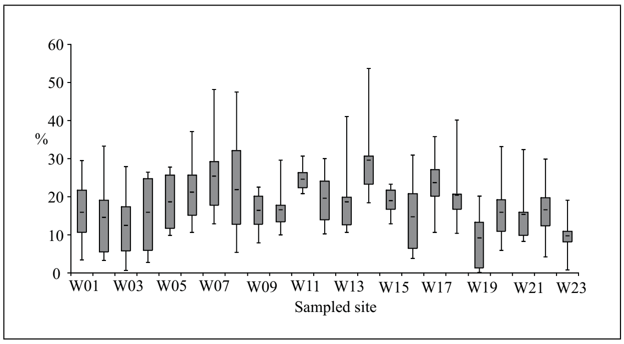

Figure 4. Contribution of birdsong to the overall soundscape loudness (%) during all sampled periods at each sampled site.

measures the aggregation extent of landscape patches, and a few large, contiguous patches result in higher values. Overall, most of the landscape metrics could indicate landscape fragmentation status from different aspects, such as size (LPI), shape (LSI, FRAC), composition (SIEI), distribution (CONT), and heterogeneous status (PD, SHDI) of land use patches. More detailed information about the landscape metrics could refer to the researches by McGarigal and Marks [34] and Wu [35]. In this study, all these landscape indices were calculated based on a 175 m radius buffer area centred on each sampled site, except that DTC and DTR were calculated based on the whole study area by considering the shortest distances. The calculation was mainly based on the digitalized land use/cover maps in ArcMap 9.1 and Fragstats software [34], while NDVI value was calculated based on the Landsat TM image (30 m) on July 27, 2011 from U.S. Geological Survey (USGS).

3. Results

3.1. Role of birdsong in urban sound environment

On the spatial scale, Figure 4 shows contributions of perceived loudness of birdsong to overall soundscape loudness during all the 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 contribution s were over 15%. On the temporal scale, Figure 5 shows the contribution of birdsong to the overall soundscape loudness at all the 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. 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 indicates that birdsong in the study area could be a positive input for the local soundscapes, and this is in line with several former studies [7, 8, 9]. In conclusion, the results indicate that in

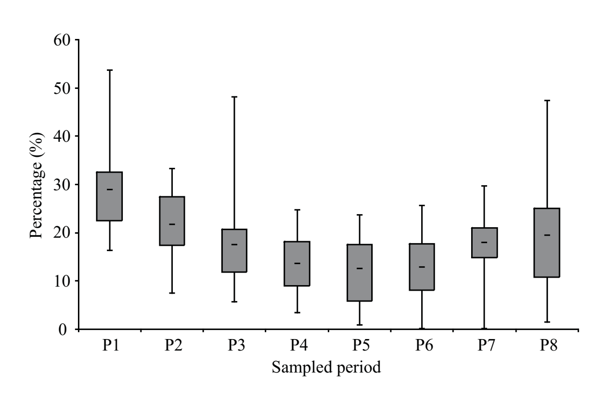

Figure 5. Contribution of birdsong to the overall soundscape loudness (%) at all sampled sites during each sampled period.

Table II. Sounds 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 activity	-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

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.

3.2. Relationships with other sounds

Relationships between perceived loudness of birdsong and the other main sounds based on Spearman's rho correlation analysis are shown in Table II. It can be seen 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 activity and music were also negatively correlated with perceived loudness of birdsong, with correlation coefficients of -0.217 and -0.288, respectively. The results clearly show that tolerance of bird species to human disturbance is limited, and losing of birdsong is an obvious result of the disturbance. The results are in line with former research result, which showed that human disturbance, even pedestrians, could negatively affect many urban bird species [36]. It is also reported by other researchers that noise from pervasive human disturbance in cities could promote nestedness of songbirds [37]. The relationships between birdsong and different kinds of anthropogenic 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 are next to busy traffic roads and with dense vegetation, birdsong still contributed a lot to the overall soundscapes. The result suggested that, although urban green areas could provide alternative habits for birds [36], they may have elevated the frequency and volume of their songs to avoid being masked by traffic sounds. The result is also 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, is an important factor for surviving in urban areas [5, 38]. However, 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.

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 that 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. 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. However, as also reported by some researchers, birds often stop singing when the weather condition is harsh such as windy or raining heavily [39]. 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.

Overall, the relationships between birdsong perception and anthropogenic sounds suggest that, although birds might adapt somewhat to persistent urban traffic sounds, they are still sensitive to sounds related with human appearance (e.g. adult voice, child voice, footstep) or human activities (e.g. construction activity, music). It is possible to enhance the contribution of birdsong to urban soundscapes through controlling the volume of other sounds. For example, human activities in birds' 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.

3.3. Spatiotemporal patterns of birdsong perception

Mapping results of spatial distribution of perceived loudness of birdsong in each sampled period are shown in Figure 6. 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

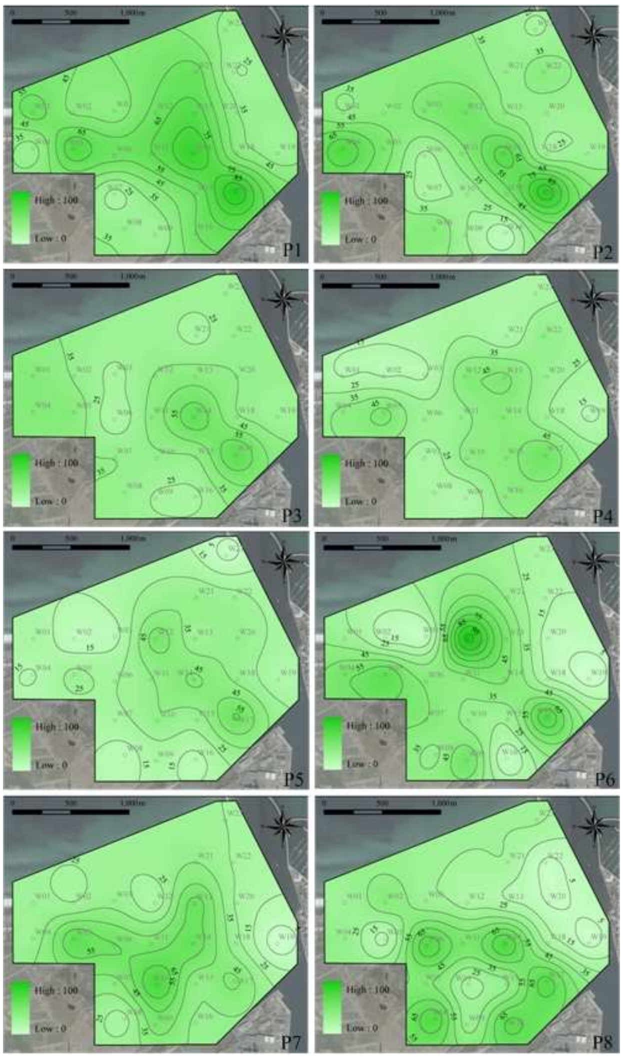

Figure 6. Perceived loudness of birdsong across the study area during the 1st to 8th sampled periods, respectively (map P1-P8).

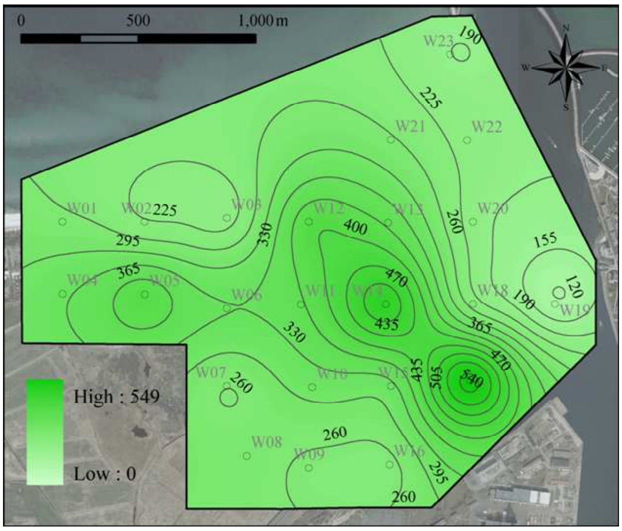

Figure 7. Daily accumulated perceived loudness of birdsong across the study area.

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 Figure 7, 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 block much of the outside sounds especially traffic sounds, so that birdsong could be more easily perceived in these high quality acoustic environments [40]. The urban park in the study area has dense vegetation, and could be an ecologically good place for birds, although there are occasional human activities at the same time. The 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. 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, however, not so much birdsong as expected was perceived. A possible reason is that organisms have to colonize, adapt to or abandon urban areas, which is a highly artificial and novel ecosystem with altered habitat conditions [41]. 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 for birds. The results in the thematic maps in Figure 6 also suggest 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 Figure 6 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 Figure 5, where daily temporal pattern of birdsong loudness showed a ȘVŤ pattern, 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 for natural bird species [21, 41, 42]. Further researches focusing on different bird species and covering a longer temporal scale should be conducted to generate more detailed information for the management and planning process.

3.4. Relationships with landscape characteristics

Although it was reported in previous studies that bird species in urban areas have a close relationship with landscape features [43, 44, 45], these studies were seldom carried out from the perspective of urban soundscapes, or related to landscape spatial patterns. Given the dynamic na-

Table III. Pearson correlation coefficient between perceived loudness of birdsong and each of the landscape indices by time-step per-period (*$p < 0.05$, **$p < 0.01$).

Period	1	2	3	4	5	6	7	8
Landscape composition indices								
CD	0.413**	0.142**	0.337**	0.401**	0.436**	0.185**	0.221**	-0.048
RD	0.106*	0.042	0.150**	0.349**	0.263**	-0.064	-0.085	-0.108*
NDVI	-0.126**	0.042	-0.079	-0.076	-0.049	0.232**	0.164**	0.347**
PD	0.111*	0.019	0.077	0.222**	0.377**	0.093*	0.254**	-0.114*
LPI	-0.270**	-0.147**	-0.091	-0.225**	-0.190**	-0.121**	-0.130**	-0.031
SHDI	0.087	0.003	-0.047	0.015	0.055	-0.078	0.002	-0.229**
SIEI	0.252**	0.149**	-0.004	0.101	0.097*	0.001	0.030	-0.132**
Landscape configuration indices								
DTC	-0.068	-0.121**	-0.048	-0.078	-0.275**	-0.060	-0.071	-0.078
DTR	-0.252**	-0.129**	-0.194**	-0.179**	-0.337**	0.018	-0.018	0.073
LSI	0.063	0.031	0.146**	0.291**	0.376**	0.082	0.249**	0.000
CONT	-0.253**	-0.149**	0.021	-0-113*	-0.125**	-0.029	-0.053	0.110*
FRAC	-0.093*	-0.014	0.159**	0.231**	0.325**	0.016	0.142**	0.008

ture 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 III, 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 [40], 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 [46]. 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 [47].

4. Conclusions

This study analysed characteristics of birdsong as an element of the urban sound environment in the context of landscape. The important and positive role of birdsong in urban soundscape perception in the study area was recognised. The analysis of the relationships between loudness perception of birdsong and other sounds suggested that, although birds could get used to the chronic urban traffic sounds, they are still sensitive to sounds related to human appearance or human activities. The thematic maps revealed the dynamic characteristics of spatiotemporal patterns of perceived loudness of birdsong, and also indicated that bird species in urban areas may have adapted to urban environment by changing their singing spatiotemporal patterns.

A series of landscape indices were found in close relationships with loudness perception of birdsong in the study area, which could be generalised as follows (with indicators in the bracket): 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).

A better understanding of the relationships between birdsong perception and other sounds is important for planners when bringing certain functions or landscape elements to the birdsong sensitive areas, for which the thematic mapping technique could be a useful tool. The identified landscape indicators could be used by planners to compare different planning schemes for a bird friendly environment, although further tests are still needed with more case studies. Birdsong information involving more detailed bird species, considering the user profile, and response from the local community would also be necessary in practice [27, 48, 49].

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