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IMPACTS OF ANTHROPOGENIC SOUNDS ON BIRD CALL ACTIVITIES: A CASE STUDY IN AACHEN, GERMANY

Margret S. Engel[1*] **Amy E. Leedale**[1] **Robert J. Young**[1]
William J. Davies[2] **Michael D. Wood**[1]
[1] Environmental Research & Innovation Centre, University of Salford, UK
[2] Acoustic Research Centre, University of Salford, UK

ABSTRACT

Since the definition of the Environmental Noise Directive 2002/49/EC, various tools, reports, and action plans have been developed to assess and improve the sonic environment according to human perception and well-being. Few methodologies and reports consider the measurement of the impacts of anthropogenic sounds on wildlife at a European level. Noise pollution can impact communication, species richness, reproductive success, population size and distribution of wildlife. This study aims to analyse the impacts of anthropogenic sounds on birds in three parks and one public garden with different sizes and functionalities in Aachen, Germany. The data collection happened between 2015 and 2016 through soundwalks and sampled 192 omnidirectional recordings. The analyses of impacts consider: 1) acoustic, bioacoustic and psychoacoustic characterisation of the sonic environments; 2) birds call detection and characterisation using BirdNET, type of vocalisation and richness estimations at each location; 3) dominance of anthropogenic sounds in the sampled recordings; 4) assessment of the sound thresholds for humans, as well as the quality of the Quietness Suitability Index (QSI) for quiet areas (EEA, 2014), are considered. The results show an attempt to assess anthropogenic noise impacts on urban wildlife, aiming for a healthy urban sonic environment for humans and wildlife.

Keywords: *Bird vocalisations; Anthropogenic Noise Impact; Soundwalks; Quietness Suitability Index (QSI); Quiet Areas***.**

[*]***Corresponding author***: m.s.engel@salford.ac.uk

1. INTRODUCTION

Since 2002 the European Union has addressed in the Directive 2002/49/EC – Environmental Noise Directive (END) the regulation of noise pollution regarding transportation and industrial sound sources [1]. This directive acknowledges the need for the prevention or reduction of environmental noise levels that may negatively affect human health, including annoyance and sleep disturbance. Additionally, it also indicates that quiet areas should be preserved. These areas are identified through the combination of objective and subjective parameters. They are rated as good when the Quietness Suitability Index (QSI) presents a Lday between 45-55 dB(A) and Lden of 55 dB(A) in urban areas with moderate intense activity for humans [2].

In the Technical Report No.4/2014 for the European Environmental Agency – Good practice guide on quiet areas, it is highlighted the importance of quiet areas not only for humans but also for wildlife [2]. In the Technical Report to the United Nations, "Listening to Cities: from noisy environments to positive soundscapes", Aletta highlights how wildlife can be affected by anthropogenic noise in urban scenarios in the communication contexts, which can include territory defence, warning of danger, locating or attracting a mate, and caring for offspring [3].

Several methods can be adopted to assess quiet areas, such as noise mapping, measurement of sound pressure levels, the user or visitor experience and expert assessment [2]. Besides sound pressure levels, the acoustic quality of a sonic environment for humans can be measured by psychoacoustic indicators, such as Loudness, Sharpness, Roughness, Fluctuation Strength, and Tonality [4]. In the work of Tsaligopoulos *et al*. [5], bioacoustics indicators such as the Normalised difference

soundscape index (NDSI), Acoustic Complexity Index (ACI), together with an acoustic indicator, Noise Equivalent Level (Leq), were used for the verification of the quietness in urban environments.
According to Ratcliff *et al.* [6], sounds of nature are considered restorative for humans. Restoration is one of the dimensions of quietness according to the Technical Report No.4/2014 for the European Environmental Agency [2]. Ratcliff *et al.* [6] also highlighted that bird sounds are almost always present in soundscapes considered restorative. Based on this information, this study aims to verify and analyse, if the restorative environment for humans is also restorative for wildlife. The possible impacts of anthropogenic sounds on birds, will be analysed, in three parks and one public garden with different sizes and functionalities in Aachen, Germany, through the verification of sonic environment quality, the dominance of anthropogenic sounds, identification of common vocalisations from the birds, and suitability of these areas in terms of the classification of quiet areas for humans and wildlife.

2. METHODOLOGY

2.1 Study areas

The study areas of this study comprise four areas, three urban parks and a garden, in Aachen, Germany.
Westpark (50° 46.456' N, 6° 6.172' E) has a 6.65ha area with a pond, barbecue area, playgrounds, sports courts, and trails to walk and run. "Stadtgarten" – Farwickpark (50° 46.935'N, 6° 5.653') is a bigger urban park with an area of 24.6 ha, it has a leisure area called Carolus Thermen, a casino, a conference hall, several sports courts, fountains, a spa and playgrounds. Veltmanplaz – "Ludwigsallee" (50° 46.918'N, 6° 4.929'E) is a linear park surrounded by avenues with heavy traffic with an area of 4.97 ha. The area contains a pond, a playground, and a memorial monument. Elisengarten – "Elisenbrunnen" (50° 46.306' N, 6° 4.098' E) is a garden in the city centre with an area of 1.97 ha. The garden has cafes, restaurants and shops, a historical pavilion with hot springs, fountains, and an archaeological area. In this study, Westpark (Figure 1 indicated in green) is the reference park due to the number of campaigns in different seasons.

Figure 1. Study areas. Satellite Images: [7]

2.2 Study design

The study design is subdivided into 'data collection', 'indicators calculation and analysis', 'species and vocalisation type recognition' and 'Quietness Suitability Index', as shown in Figure 2.

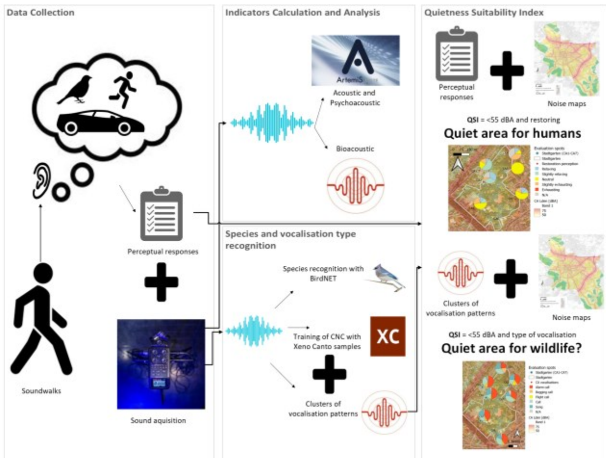

Figure 2. Study design. Source Images: [8-13]. Satellite Images: [7].

a) Data collection

To achieve the proposed aims, this work uses a dataset collected through soundwalks during 2015 and 2016 as a dataset of Dr. Engel's PhD studies. Each soundwalks counted with the participation of 30 subjects, except for "Elisenbrunnen", in which 44 subjects participated in the soundwalks. The participants had to evaluate three evaluation spots at the soundwalks. Simultaneously occurred the sound data acquisition with a ZOOM H6

multitrack recording device, connected to a set of Sennheiser KE-4 microphones with open dome, an omnidirectional microphone Sennheiser KE-3, which recorded audio data with a sampling rate of 44.1 kHz. The microphone calibration was performed with a B&K 4231 calibrator.
Regarding the perceptual responses, this study is analysing the following question [14]:

- Please evaluate the background sound regarding restoration (exhausting – slightly exhausting – neutral – slightly relaxing – relaxing) [14].

b) Indicators calculation and analysis

The recorded sounds were analysed with Artemis Suite®, where single values of acoustic and psychoacoustic indicators (SPL, SPLA, Loudness, Loudness N_5, and Tonality) were calculated. For the calculation of bioacoustics indicators (Normalised difference soundscape index and Acoustic evenness) it was used the software Kaleidoscope Pro®. These indicators help in the characterisation of the sonic environment and the if anthropogenic sounds are dominant in the investigated areas.

c) Species and vocalisation type recognition

The bird species recognition was possible through BirdNET Analyzer, which uses Convolutional Neural as a Machine Learning technique.

In Table 1 is possible to see the number and hours of measurements of each study area and the corresponding number of measurements and hours, which detected the species Eurasian blue tit (*Cyanistes caeruleus*). It also indicates how many times the perception of birds as sound sources was reported in each study area.

Table 1. Frequency sound recordings, detection of Eurasian blue tit and perception of birds as sound sources.

ID	Qty Measure-ments	Qty Hours Sound-walks	Qty Reports of Birds	Qty Measure-ments with Eurasian Blue Tit detection	Qty Hours vocalisation Eurasian Blue Tit
L(A)	21	01:54:00	37	2	00:10:00
CA(S)	33	04:47:00	87	31	04:32:00
WP(S)	39	04:56:00	82	7	00:54:00
WP(A)	43	06:31:00	42	13	01:58:00
EL(S)	41	04:23:00	52	6	00:38:00

Legend: L(A) = Ludwigsallee – Autumn, CA(S) = Stadtgarten – Spring, WP(S) = Westpark – Spring, WP(A) = Westpark – Autumn, EL(S) = Elisenbrunnen – Spring.

After species recognition, which species were most frequent in each area was quantified. Based on this information, it was observed that the Eurasian blue tit presented a significant number of observations, especially in Stadtgarten and Elisenbrunnen. Based on this information, this species was selected for the subsequent task, which was vocalization-type recognition. This task was possible through vocalisation pattern clustering, using vocalisation samples obtained from the open-source library Xeno Canto [12]. The adopted vocalisation examples for Eurasian blue tit are observed in Table 2 and served as training samples for the vocalisation patterns Clusters, which occurred through Kaleidoscope Pro®. As a clustering configuration, it was adopted a maximum distance of the centre of 1.0 for the formation of clusters. Clusters with dubious results were checked, and one vocalisation sample had to be reclassified due to inappropriate classification in the Xeno Canto library [12].

Table 2. Sound samples from Xeno Canto [12].

Type of call	Code
Alarm call	XC790333
Alarm call	XC789117
Alarm call	XC778133
Alarm call[1]	XC777303
Alarm call	XC744123
Alarm call	XC712892
Alarm call	XC698551
Alarm call[2]	XC726129
Call	XC780461
Call	XC782705
Call	XC788499
Call	XC788739
Call	XC788773
Call	XC790856
Song	XC787149
Song	XC790963
Begging call	XC733934

Begging call	XC738333
Flight call	XC697541
Flight call	XC767812
Flight call	XC767166

Legend: [1] with high pass filter. [2] classified as Begging call in Xeno Canto.

d) Quietness Suitability Index (QSI)

According to the European Environment Agency, the methodology for defining quiet areas considers the noise disturbance because of noise propagation, with quantitative data, in this case, Lden areas exposed to less than 55 dB, and the perceptive dimension quietness for humans. Since the investigated restoration question is one of the dimensions of quietness, this question represents the qualitative component of the QSI in this work [2].

The perceptual data were coded, tabulated, and used to verify the sound quality of the investigated areas, helping to define the 'Quietness Suitability Index' and Lden data obtained through the Noise Map of the city of Aachen [13].

Since the methodological EEA report about Quiet Areas does not present a specifical methodology regarding quiet areas for wildlife, we are suggesting in this work the observation of birds' vocalisations, classified regarding the type of vocalisation, to verify the presence of birds and how they interact in the evaluation site. In this case, we plotted with the noise map which type of vocalisations of Eurasian blue tit was heard in each evaluation spot. The combination of the noise map and the perceptual data, as well as the bird vocalisation type, was combined through QGIS.

3. RESULTS

3.1 Characterization of the sonic environment

As observed in Table 3, when analysing the overall sonic environment during the soundwalks data collection period, Ludwigsallee (L) and Elisenbrunnen (EL) presented results of SPL(A) over 55 dB(A). The quiet areas guideline recommends a threshold of 55 dB(A) for Lden, or 45-55 dB(A) for Lday. The soundwalks of this study covered only the daylight period. However, there is an indication that these areas are not suitable for the classification of quiet areas. Additionally, it is observed that the greatest values of Loudness and Loudness N_5 in these areas indicate the probability of annoyance regarding acoustic comfort. Greater values of Tonality are observed in Westpark (WP) in the Spring Season (S), possibly indicating significant bird vocalisations.

Table 3. Acoustic and psychoacoustic indicators result from the soundwalks in the overall environment of the study areas.

Indic.	WP(S)		WP(A)		CA(S)		L(A)		EL(S)	
	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD
SPL	61.0	5.6	62.1	6.2	65.9	4.8	68.6	3.8	66.7	3.3
SPL(A)	48.6	4.5	48.6	4.9	51.4	3.1	**57.0**	4.8	**57.2**	3.4
N	7.2	3.4	6.7	2.7	8.2	2.0	12.5	3.9	12.8	2.8
N_5	8.1	4.4	8.3	3.6	9.7	2.6	14.3	5.1	20.4	4.4
T	0.06	0.01	0.05	0.02	0.05	0.02	0.05	0.01	0.00	1.53

Legend: SPL = sound pressure level in dB, SPL(A) = sound pressure level A-weighted in dB(A), N = Loudness in sone, N_5 = Loudness 5-percentile in sone, T = Tonality in tu.

The observation of the anthropogenic influence on the sonic environment through Bioacoustic indicators is possible by the Normalised difference soundscape index (NDSI). Values near +1 (range -1 to +1) indicate no sound in the anthrophony range [15]. In this case, the areas with a greater influence of anthropogenic sounds are Stadtgarten (CA) and Ludwigsallee (L). Avenues with heavy traffic surround both study areas. The acoustic evenness index (AEI) indicates the biodiversity of the investigated areas. Greater values indicate greater biodiversity. As expected, in the Spring season (S), this index is greater, especially in Stadtgarten (CA), followed by Westpark (WP) and Elisenbrunnen (EL).

Table 4. Bioacoustic indicators result from the soundwalks for the overall environment of the study areas.

Indic.	WP(S)		WP(A)		CA(S)		L(A)		EL(S)	
	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD
NDSI	0.76	0.08	0.99	0.40	-0.27	0.28	-0.48	0.17	0.22	0.09
AEI	0.78	0.08	0.42	0.41	0.83	0.07	0.74	0.07	0.77	0.07

Legend: NDSI = Normalised difference soundscape index, AEI = Acoustic evenness index.

3.2 Species and vocalisation type recognition

As reported in the methodology part, it was used the software BirdNET Analyzer [10] for the recognition of bird species. In Table 5 is possible to observe that the vocalisations of birds are more frequent during Springtime, especially in the parks (Stadtgarten - CA and Westpark - WP). Considering that Elisenbrunnen (EL) is in a garden with a small area, the number of observed vocalisations is slightly less than the number of observations in Westpark (WP) during the Autumn season. As expected, the area with fewer observed bird vocalisations was the linear park at

Ludwigsallee in Autumn (L(A)), characterised by heavy traffic in the nearby avenues.

The study area with more species recognition was in Stadtgarten (CA) during the Spring season, with 71 recognised species. There most frequently identified species was the Eurasian blue tit with 580 observations, followed by Eurasian blackbird (*Turdus merula*) with 175 observations and short-toed treecreeper (*Certhia brachydactyla*) with 59 observations.

The software Kaleidoscope Pro provides, together with the clustering of vocalisation type patterns, the mean, maximum and minimum fundamental frequencies of the vocalisations. Figure 3 shows the mean fundamental frequency for the vocalisations types of Eurasian blue tit. In Ludwisgalle (L) is possible to observe that the mean frequency is greater for ‘alarm calls’ and slightly greater for ‘songs’ compared with the reference samples obtained in the Xeno Canto library [12]. The same phenomenon happens for ‘call’ and ‘flight calls’ in Westpark (WP) during Autumn and ‘calls’ in Springtime at Stadtgarten (CA). The use of higher frequencies in the communication of this species in Ludwigsallee (L) and Stadtgarten (CA) indicates a vocal effort adaptation, avoiding low-frequency masking due to traffic sound sources observed in that sonic environment [16]. In Westpark (WP), the vocal effort of the birds is due to the masking of sounds from sports-related activities (football and basketball). From 5409 vocalisation pattern observations in all areas, 207 (3.8%) observations did not match a vocalisation category, indicated as N/A in Figure 3.

Table 5. Number of recognised species, frequency of overall vocalisations observations and subdivision of most frequent recognised species.

ID	Area / Season	Total Sp.	Total Obs	Sp. 1	Sp.2	Sp.3
L	Ludwigsallee - A	31	158	9	23	11
CA	Stadtgarten - S	71	2418	**580**	175	59
WP	Westpark - S	60	1657	30	479	47
WP	Westpark - A	68	787	57	63	93
EL	Elisenbrunnen -S	30	603	**73**	35	0

Legend: Sp.1 = Eurasian Blue Tit (*Cyanistes caeruleus*), Sp.2 = Eurasian Blackbird (*Turdus merula*), Sp.3 = Short-toed Treecreeper (*Certhia brachydactyla*).

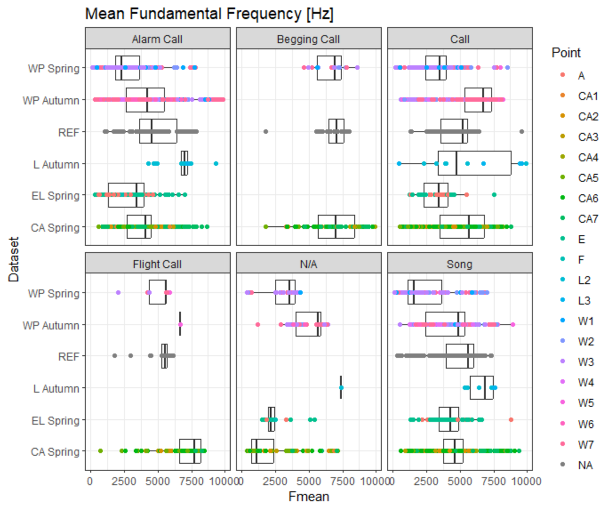

Figure 3. Fundamental frequencies mean observed in the vocalisations of the Eurasian blue tit in each study area.

Legend: WP (Westpatrk), REF (Reference samples from Xeno Canto), L (Ludwigsallee), EL (Elisenbrunnen) and CA (Stadtgarten).

3.3 Quietness suitability index (QSI)

a) QSI for humans

The combination of the noise mapping (Lden) and perceptual responses provides the Quietness Suitability Index (QSI), where quiet areas should present Lden below 55 dB(A), and Lday between 45-55 dB(A) and restoration answers with a tendency to relaxing sensation, at least 50% with a good-positive tendency (cold colour in the graphical representation).

These characteristics were observed through soundwalks in Stadtgarten at the evaluation spots CA1 and CA2 (CA - Figure 4), near the residential areas and in Elisenbrunnen in the evaluation spots E and F (behind the Elisenbrunnen pavilion, which protects the area from sound sources of the bus station. The other study areas presented Lden over 55 dB(A) and perceptual responses with neutral and exhausting tendencies) (EL - Figure 4).

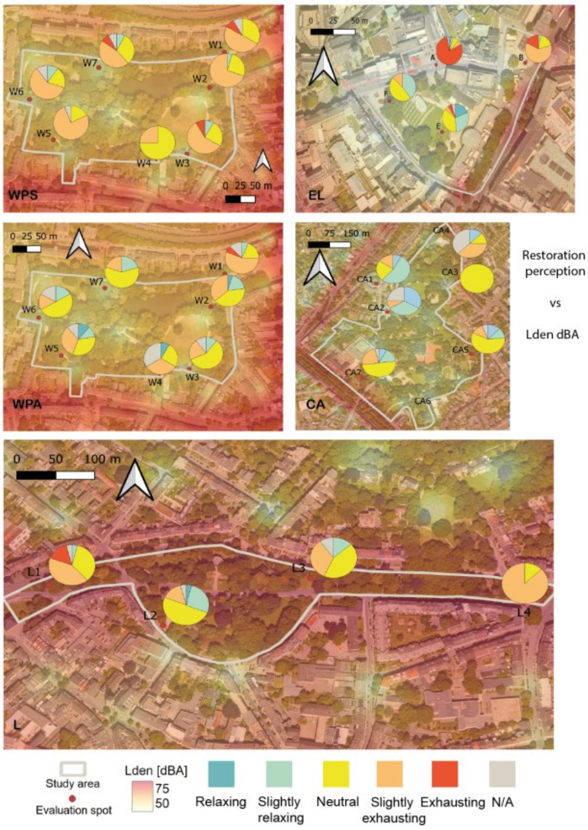

Figure 4. Quietness Suitability Index results for humans

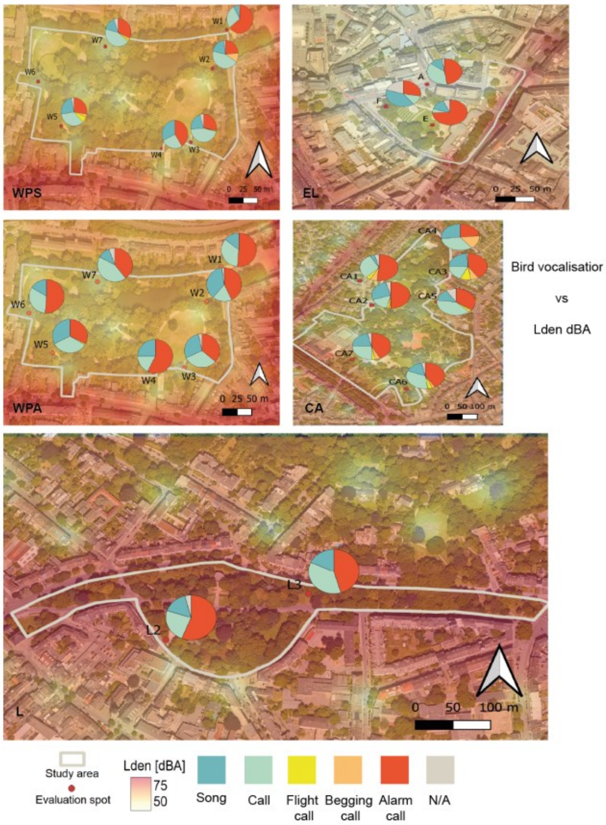

Figure 5. Quietness Suitability Index results for wildlife

b) QSI for wildlife

The observation of the graphs with the combination of noise maps and bird vocalisations indicates that in most evaluation spots, the birds vocalise most frequently 'alarm calls', especially in Ludwigsallee (L – Figure 5). These vocalisation characteristics show that the birds are presenting stress in their behaviour, indicating that the evaluation spot area could present annoyance characteristics for them. There are exceptions in Westpark, where in Spring (WPS – Figure 5) and Autumn (WPA – Figure 5) seasons, specifically spot W5 presented 'calls' and 'songs' as vocalisation predominance. Elisenbrunnen at spot F also presented tranquil characteristics with 'songs' predominance (EL – Figure 5). Three spots in Stadtgarten showed a predominance of 'calls' on bird vocalisations, CA4-CA6 (CA - Figure 5).

4. DISCUSSION

4.1 Characterization of the sonic environment

According to the acoustic and psychoacoustic results for the sound quality characterisation through soundwalks, Ludwigsallee (L) and Elisenbrunnen (EL) presented the greatest values of SPL, SPLA, Loudness and Loudness N_5. In these areas, the SPLA was greater than 55 dB(A), showing unsuitability for quiet areas. Additionally, the NDSI shows a greater influence of anthrophony in Ludwigsallee (L) and Stadtgarten (CA). The AEI indicates lower biodiversity in Ludwigsallee (L) and Westpark (WP) during the Autumn season. This index could be lower in these areas due to seasonal motivation and the migration of birds to warmer areas.

4.2 Species and vocalisation type recognition

With the help of BirdNET Analyzer, it was possible to recognise the bird species in the investigated areas. The number of species vocalisation recognition was greater in the Springtime, as expected. Due to location area size, the greatest numbers were observed in Stadtgarten (CA), followed by Westpark (WP) and Elisenbrunnen (EL), which had similar numbers to Westpark in the Autumn season. The lowest number of vocalisation observations was in Ludwigsallee (L). The species that were often recognised are Eurasian blue tit, Eurasian blackbird, short-toed treecreeper. Based on this result, we analysed the clustering technique of the vocalisation types that are present in each investigation area. It was found that 'alarm calls' are almost half of all vocalisations. In areas such as Ludwigsallee (L), some evaluation spots from Stadtgarten (CA) and Westpark (WP), the birds elevated the mean fundamental frequency compared to the reference signal obtained in the Xeno Canto library, indicating an influence of the anthropogenic sounds on bird communication causing an adaptation on their vocalisation, avoiding masking of fundamental frequencies as observed in other studies [16].

4.3 Quietness suitability index (QSI)

Regarding the QSI for humans, some evaluation spots in Stadtgarten (CA1 and CA2) and Elisenbrunnen (E and F) were considered quiet areas when observing the combination of data from Noise Mapping from Aachen (Lden) and perceptual response from soundwalks. The QSI for wildlife, through observations vocalisations of Eurasian blue tits vocalisations together with Aachen's Noise Map, indicates that the spot with fewer alarm calls in Elisenbrunnen is position F. In Stadtgarten, fewer alarm calls were observed in CA4 – CA6. At the other evaluation spots, more than 50% of the vocalisations were alarm calls, which could show increased stress level but could be a normal situation due to prey-predator behaviour. In this case, additional observational investigations are required.

5. CONCLUSIONS

This study aimed to verify and analyse, if the restorative environment for humans is also restorative for wildlife. It was also analysed, if anthropogenic sounds can impact birds' communication in three parks and one public garden with different sizes and functionalities in Aachen, Germany. As observed in other studies, in the area with a high impact of anthropogenic sounds from transportation sources, the birds had to adapt the mean fundamental frequency of their 'alarm calls' and 'songs'.

Only five of twenty-two evaluation spots were considered quiet areas for humans, and additional behavioural observations are required to determine if these areas are also quiet areas for wildlife.

The combination of investigation methodologies, including soundwalks, noise mapping, measurements on-site and using different indicators, showed a complete overview of the urban sonic environment for humans and wildlife and determination of noise impacts.

6. ACKNOWLEDGMENTS

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