The Influence of Green Infrastructure on the Urban Acoustic Environment

Project Schedule: January 2024 – December 2026
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1.1 Study Objectives and Study Design

The project objective is to explore and investigate a broad range of urban and non-urban green infrastructure types to better understand the role of typological and structural factors of GI with regard to functional differentiation of acoustic environments. The work is embedded in basic research because to date the acoustic environment below noise has not been a consideration in spatial planning. Therefore systematic documentation of acoustic environments in non-human habitations where biophonic sound dominates is extremely sparse. We aim to shed light on this data gap in a highly populated European region and develop basic data than can be used for multiple purposes. First and foremost we aim to better understand the interplay between GI, non-human animal and plant populations, and the acoustic environment. Secondly we aim to understand how the acoustic environment is altered in natural biotopes along a gradient from a near natural 'soundscape reference' condition in isolated or remote areas to urban and peri-urban biotopes that form part of a city's recreation network.

To achieve the project aims, we propose robust sound measurements in green infrastructure types across diverse landscape units, including a range of sizes and types of natural biotopes, recreation infrastructure, protected areas, and brownfields located within varying densities of urban fabric. Use of vegetation and non-human animal population data from LANUV and a range of ecoacoustic and SPL indices provide a critical comparative basis for sound outcomes across GI types.

Especially relevant is the identification of acoustic environments with a high proportion of biophony to anthrophony, or with quiet, high diversity and high fidelity acoustic environments in the Ruhr region that could be translated into practical benchmarks for high quality urban acoustic environments. The resultant dataset will enable spatial comparisons of a single highly populated region unlike any other sound datasets built in studies to date.

Research Questions

According to our research objectives, we have subdivided the driving research questions about GI and acoustic environments into the three general categories 1) spatial-ecological 2) human, and 3) spatial planning.

1. How do spatial, ecological and structural factors of green infrastructure contribute to the acoustic environment?
    a. What acoustic patterns in varying GI can be grouped into typologies?
        i. How does plant or animal species diversity or richness influence such patterns?
        ii. How does GI patch size, shape, composition, or fragmentation affect baseline similarities or differences?
    b. How does proximity or distance away from urban development alter the acoustic environment of different GI typologies? By what mechanism do such alterations occur?
        i. i.e., sound increase or decrease > species richness or diversity change accordingly > acoustic environment alteration
    c. How can the acoustic environment be characterized at the interface of GI and human residential areas? Does patch size or composition affect the sound ecotone?
2. To what degree, if any, can we characterize urban and exurban green infrastructure as providing relief from the dis-ease of the louder and more anthrophonic-dominated urban acoustic environment?
    a. How different or similar are acoustic environments in urban, peri-urban, and rural GI?

b. How do humans perceive such differences, if any?
c. What counterpoint does GI offer to sound polluted locations in urban and peri-urban environments?

3. How can this research inform and affect spatial planning?
    a. What measurable benchmarks as SPL or ecoacoustic indices can be inferred from our ex-urban reference reaches? How many orders of magnitude difference are urban acoustic environments to natural soundscape reference benchmarks?
    b. How to integrate findings into current noise action planning (BImSchG §47) and with which benchmark SPL or ecoacoustic index values?

1.2 Work programme including proposed research methods

Lawrence, Bryce; Two Field Personnel; One Office Personnel

The combined methodological approaches of noise analysis (Kang 2007) and ecoacoustics (Farina and Gage 2017; Sueur 2018) provide a means to study human and non-human populations in a spatially-based soundscape ecology concept framework (Farina 2014). The acoustic index approach traditionally applied in wildlife biology and non-human population studies are applied in this study in tandem to traditional sound pressure level measures, effectively widening the array of sound metrics from which to understand the acoustic environment (Lawrence et al. 2021). The robust work program described below was successful in the SALVE pilot project for studying human living quarters and we propose a similar approach, including intensive field sampling with automated aural recording devices (AAD), evaluation of field data using ecoacoustic and SPL indices, and inferential statistics to compare relationships between GI types, acoustic outcomes, spatial, ecological and demographic factors.

1.2.1 Green Infrastructure in the Metropol Ruhr

As Germany's largest and most highly populated urban agglomeration straddling the Münsterland, Sauerland, Bergisches Land, and Ruhr valley, the Ruhr region offers a compelling study area with a high degree of physical, ecological, urban development and socio-economic diversity. Several past studies in our research group have used this region as a living laboratory for cross-discipline research, including the Heinz-Nixdorf Recal (HNR) study (Kälsch et al. 2014; Orban et al. 2016), ZUKUR (Schmidt 2017) and SALVE (Sutcliffe et al. 2020), and therefore we propose the further buildout of information in this very important German region. However, sampling the entire region is not possible due to size of the region and the limitation of sampling devices. Therefore, this project focuses on GI in Bochum and the identification of reference soundscapes in the surrounding non-urbanized landscape. Collection of data in Bochum also allows us to use the SALVE sound data in our data analysis as a counterpoint to address research questions 1c and 2c.

1.2.2 Sample Strategy

We propose a three tier spatially stratified sampling approach to achieve the goals of the project. This multi-tier sample strategy tests the effects of landscape formation, urbanization, and biogeographic properties (plant communities and animal populations) on the sonic properties of GI across a wide land-use gradient. The assumption is that as we move away from the urban areas the acoustic environment will become more biophony dominated, and we aim to quantify and spatially depict this change.

In the multi-tier sampling strategy we choose to refine samples to a manageable quantity based on location and size as opposed to using a stratified sample technique as we did in SALVE where we must rely on probabilistic sampling. Given the aims of the project to find 'reference soundscapes' for characterization of quiet areas then a sample reduction of the largest and most remote locations is more beneficial than a stratified sample based on a confidence interval because it requires the assumption that any two places are similar. However, given the distribution of roadways and sound sources, this may not be the case, thus we reduce samples based on their size and isolation. In total, we propose collecting longitudinal sound data at 120 locations. (Figure 1). Of course, we intend to combine our three year dataset from SALVE covering over 54 locations to date (Haselhoff et al. 2021) answer questions about GI's impact on the acoustic environment of human living quarters and socio-economic patterns.

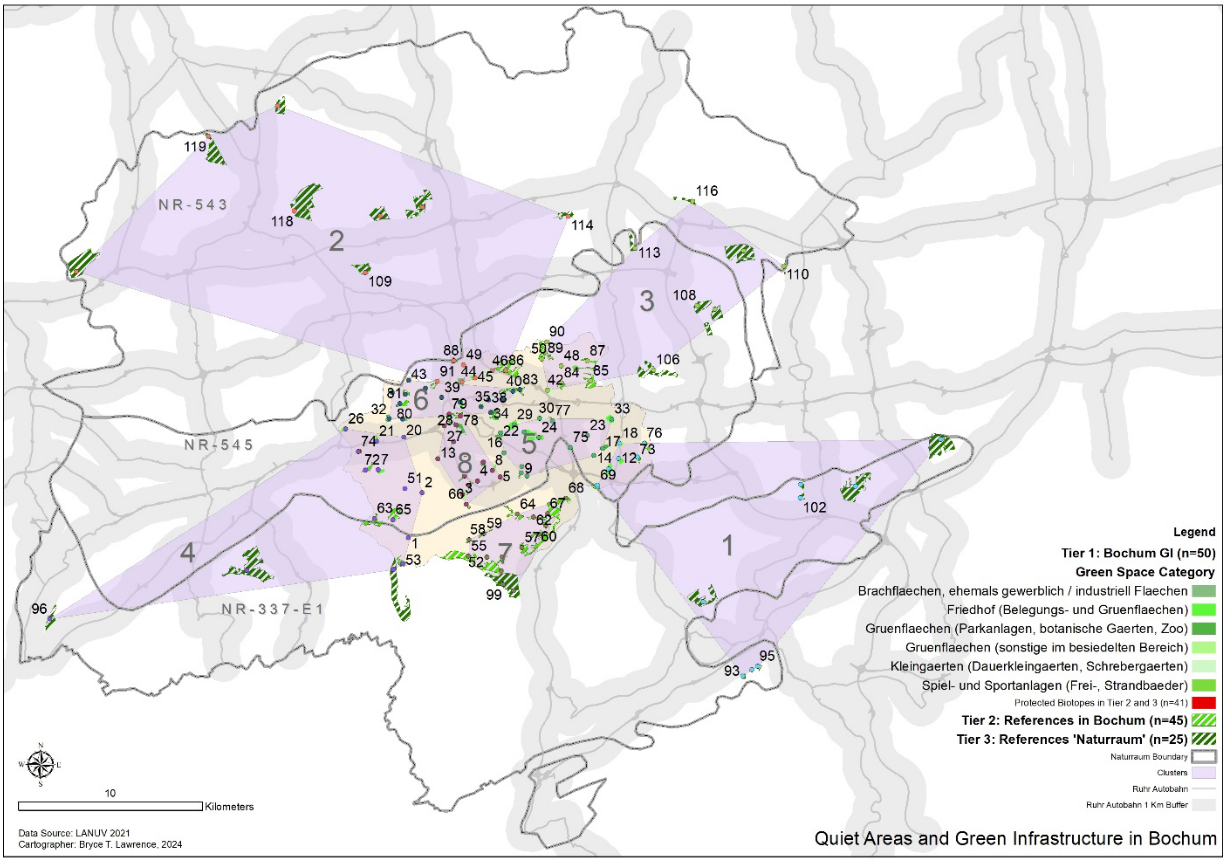

Figure 1: Quiet Areas and Green Infrastructure in Bochum

1.2.2.1 Spatial Sampling Tiers

Sample Tier 1: Land-Use Based GI Samples in Bochum (n=50)

The first level focuses on sampling urban and peri-urban GI within the City of Bochum to cover a broad range of GI typologies, including public parks, brownfields, play and sport uses, and burial grounds. This sample consists of all land use parcels in the aforementioned land use categories within the City of Bochum with an area over 1 ha (n=50). Generally, these samples are smaller designed urban green infrastructure such as community and neighborhood parks, sport and active recreation areas, cemeteries, brownfields, or linear parks.

Type of Urban Green Space	No. Of Obs.
Park, Botanical Garden, Zoo	7
Greenspace in Residential Area	5
Cemetery	16
Community Garden Plot	18
Sport and Recreation Area	1
Brownfield	3

Table 1: Land Use and Number of Tier 1 Observations

Sample Tier 2: Biotope Based Soundscape Reference Samples in Bochum (n=45)
The second level is a sample of natural biotopes within Bochum that are greater than 4ha. This serves as a sample of large contiguous natural plant community areas of mostly forests and grasslands (n=45). Fourty-one of the Tier 2 samples are located in polygons of designated protected biotopes ('Geschützte Biotope') within the 4 ha parcel and four tier 2 locations are located in forest patches that do not contain a protected biotope. Sound recording devices are placed within the protected biotopes, within the 4ha parcel, because biological and ecological characteristics for protected biotopes from LANUV can be linked to sample locations to provide a dimension of wildlife population ecology, species richness or biodiversity that can be linked to sound data or support data analysis conclusions.

Biotope Type	**Qty**
91E0 - Erlen-Eschen- und Weichholz-Auenwälder	**1**
NCA0-ung. - Schutzwürdige und gefährdete Moore, Sümpfe, Riede und Röhrichte (nicht FFH) auf Primärstandorten	**4**
NCC0 - Sümpfe, Riede und Röhrichte	**4**
NEC0 - Nass- und Feuchtgrünland incl. Brachen	**12**
NFD0 - Stillgewässer	**7**
NFK0 - Quellbereiche	**6**
NFM0 - Fließgewässer	**6**

Biotope Type	**Qty**
91E0 - Erlen-Eschen- und Weichholz-Auenwälder	**1**
NCA0-ung. - Schutzwürdige und gefährdete Moore, Sümpfe, Riede und Röhrichte (nicht FFH) auf Primärstandorten	**4**
NCC0 - Sümpfe, Riede und Röhrichte	**4**
NEC0 - Nass- und Feuchtgrünland incl. Brachen	**12**
NFD0 - Stillgewässer	**7**
NFK0 - Quellbereiche	**6**
NFM0 - Fließgewässer	**6**
	40

Table 2: Protected Biotope Type and Number of Tier 2 Observations

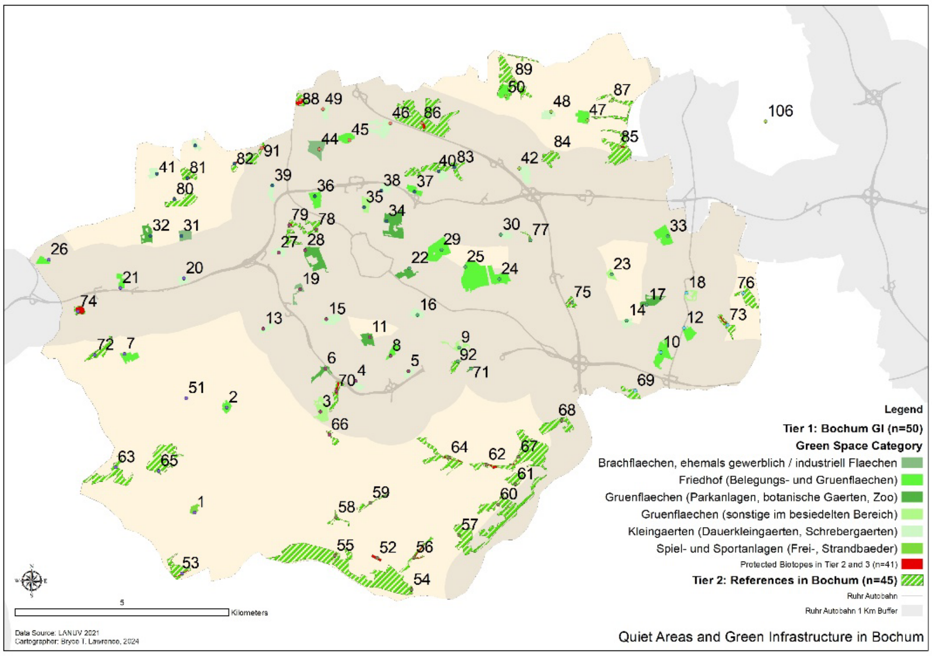

Figure 2: Tier 1 and Tier 2 Sample Locations in Bochum Legend in English, please…

Sample Tier 3: Biotope Based Soundscape Reference Samples in 'Naturraum' (n=25)
The third level is a sample of natural biotopes within the three landscape units ('Naturräume') that intersect the city of Bochum and are aimed at identifying 'Soundscape References' that serve as benchmarks for quality assessment of urban and peri-urban GI AE. The soundscape reference sample at the landscape unit (Naturraum)-scale is intended to capture the largest, most remote, and most unique acoustic environments where biophonic sounds dominate and anthrophonic sound incursions are much lower than in urban and peri-urban areas. The sample frame covers three different landscape units ("Naturräume") that have different physical, hydrology, vegetative, historical and visual characteristics (LANUV, 2020) but remain in spatial proximity. At this scale we sample biotopes from LANUV that are over 1 square kilometer in area and are over 1km away from state and federal highways, following basic recommendations for 'quiet area' designation from the European Environmental Agency (2014). These areas act as 'reference soundscapes' (n=25) that will provide the study with benchmarked ecoacoustic indices as a sort of 'natural acoustic fingerprint'. The reference soundscape areas comprise unique large-scale protected natural areas.

Location Name
Brandheide
Dortmunder Stadtforst / Bittermark
Laubmischwald auf der Mengeder Heide
Laubwaldbestände und Bachtäler bei Haus Schede
Laubwälder der Resser Mark
Löchterheide und Westerholter Wald
Niederhofer Holz
NSG "Alte Ruhr Katzenstein"
NSG Alte Ruhr-Katzenstein
NSG Aplerbecker Wald
NSG Dellwiger Bach
NSG Dellwiger Bachtal
NSG Grävingholz

NSG Hertener Schlosswald
NSG Im Siesack
NSG Köllnischer Wald
NSG Mastbruch - Rahmer Wald Erweiterung 2
NSG Ruhraue Hattingen Winz
Oberscholven
Schellenberger Wald
Standortübungsplatz am Auberg
Waldbestände nördlich und südlich der A52 westlich von Marl
Waldgebiet südlich Ruhrtangente bei Vorhalle
Waldgebiete Katzenbusch und Spahnenkamp
Waldgebiete Nierholz, Grutholz, Klöppersberg

Table 3: Tier 3 Sample Locations

1.2.2.2 Automated Data Collection

Data collection with song meter devices follows procedures developed during the SALVE project (Haselhoff et al. 2021). In each sample location, a Wildlife Acoustics SM4 automated recording device in a locked security box is affixed to a tree using a rubber coated locking steal cable. Mono recordings are programmed to be made with the SM4 device at 44.1kHz and 16 bits for three minutes in duration every seven minutes with every sixth recording delayed by an additional 30 seconds. This technique ensures data saturation of over 120 hours of continuous recording at each sample location as recommended by (Bradfer-Lawrence et al. 2019) and the 30 second staggering every hour ensures that over 19 days deployment each device samples every minute of the day at least once. At the end of each rotation, data is harvested from each machine, batteries are refreshed, the device is placed in its new location, and the microphone calibration is checked / adjusted. Changes between clusters take at least two days, and thus dataset is not temporally continual, rather, each location has the same recording duration to enable comparison by location.

1.2.2.3 Device Deployment and Field Work

The device deployment strategy employs 30 Song Meter (SM) devices in a clustered rotation procedure. The 120 locations are sampled on a rotating basis, where all 30 SM devices are ‘harvested’ every 19 days and placed in a new location. Field work is organized around eight clusters of 15 devices to spatially concentrate the device repositioning, which is was a critical organizational element in the SALVE project. This process results in a 19-day sample at each location in every season, equivalent to 162 hours of WAV files at each sampled location to reach sample saturation (Bradfer-Lawrence et al. 2019). Based on SALVE experience, two people can rotate 24 SM4 devices in 2 days work, thus, rotation of 30 devices in 3 days is reasonable and results in the use of 3.92 out of 4 days per month allotted to each field personnel. Two field personnel are trained by Lawrence and carry out the work from March 21, 2024 to March 24, 2025, and a third student assistant works to transfer harvested data from sd cards, organize data, and serve as back-up field personnel.

Soundscapes and Green Infrastructure Field Work Schedule*				
Spring 2024	Summer 2024	Autumn 2024	Winter 2024/2025	Spring 2025
March	June	September	December	March
21*	19	19	18	24
22	20	20	19	25
23	21	21	20	26
April	July	October	January	

13	12	11	10	
14	13	12	11	
15	14	13	12	
May	August	November	February	
6	3	2	1	
7	4	3	2	
8	5	4	3	
28	25	24	23	
29	26	25	24	
30	27	26	25	
Total Days 12	Total Days 12	Total Days 12	Total Days 12	Total Days 3

*All field dates indicate two field times deployed simultaneously to recover or redeploy 10 to 15 device cluster.

Table 4: Field Work Schedule 2024-2025

1.2.2.4 Sound data analysis following SALVE's widened array of metrics (WAM) on TU Dortmund University LiDO3 Supercomputer

Sound data analysis following SALVE's widened array of metrics (WAM) project's application of a suite of acoustic indices adopted from the field of ecoacoustics and soundscape ecology Table 1) plus SPL measures traditionally used in noise analysis (Lawrence et al., 2021; Sueur, 2018; Kang, 2007). Existing acoustic index alpha R Scripts used in SALVE have been streamlined to run on TU Dortmund University LiDO3 supercomputer (a legacy DFG product). The development of two new R scripts to calculate sharpness and roughness according to DIN ISO 12913-3 will be added to the WAM approach. Wildlife Acoustics Kaleidoscope software is used to calculate max, min and mean SPL values equivalent to LA_{eq} following (Lawrence et al. 2021). In to total, 16 indices are automatically calculated via R on LiDO 3.

1.2.2.5 Species diversity Inferred from Sound Data

We intend to screen all locations individually using avifauna, anural, and insect data provided by LANUV to develop a species diversity count. A range of indicator species reported in all LANUV biotope data will be leveraged to develop a compounded sound sample database (i.e., the sum of all indicator species listed by LANUV at all sampled biotopes) of birds, frogs, insects and mammals. Using the Wildlife Acoustics Kaleidoscope High Pass Filter, the unique frequency ranges for each animal sound sample can be screened and aggregated by location using Kaleidoscope cluster analysis. Using this method we will develop an inventory of which species were present at which sites at what times of the day or year. A species diversity count is critical to the first research question, assessing the impacts of size, location, and arrangement on non-human animal outcomes, both as a measure of quality but also as a link between ecoacoustic indices and species diversity across the urban-rural gradient.

1.2.2.6 Multivariate statistical analysis building on the methods applied in SALVE

Comparison amongst AAD locations will be done using Diel pattern analysis (Gage et al. 2017; Bradfer-Lawrence et al. 2019; Lawrence et al. 2021) or Frequency-Time Domain analysis (Haselhoff et al. 2022a). These two approaches will allow us to compare the 146 locations and then group them based on their time-frequency patterns. The methods also place our findings in context of previous studies that have applied acoustic indices in natural environments (Bradfer-Lawrence et al. 2020; Gasc et al. 2015; Farina and Gage 2017; Sueur et al. 2014; Joo et al. 2011). We intend to use correlation and regression to probe the relationships between green infrastructure type, size, species diversity or location on sound outcomes, acoustic index distribution and listed species diversity outcomes. Analysis of variance and principal component analysis are applied to understand influence of physical and biotic factors on acoustic environment outcomes and to identify similar performing green infrastructure types as well as outlier locations that may have special value.

1.3 Handling of research data

1.3.1 Data Protection

The study will be conducted in compliance with German Data Protection Act and all other legal regulations relevant for data safety. In accordance with the recommendations of the Federal Office for Information Security (BSI), unauthorized access will be prevented with high levels of information security. Members of the study will be required to sign the data privacy policy and act in accordance with data protection and professional discretion.

1.3.2 Anonymization of Field Recordings

We are making .wavrecordings just like any other sound or music recording (raw audio). However, none of the acoustic index or SPL calculations require 'listening' to the recordings for analysis – rather we use the mathematical transformation of raw audio into numbers with soundscape indices and all results are statistical and not audible. Of course, we must listen to the results of high-pass filter analysis so we can pinpoint the values we want to us in Kaleidoscope cluster analysis, but these are very narrow frequency range clips that contain nothing but data about the animal call targeted. This approach is akin to anonymizing census data so that statistical conclusions about a population can be reached, but specific data about an individual can never be pinpointed.