

Effects of traffic noise, land use types and ecotones on the distribution of resident birds in a natural reserve in the Ruhr area, Germany

Philipp ANTONIOU¹; Dr. -Ing. Bryce LAWRENCE²

¹ Technical University of Dortmund, Germany

² Technical University of Dortmund, Germany

ABSTRACT

While being one of the most densely populated and formerly heavily industrialized regions of Germany, the Ruhr area still offers space for many diverse ecosystems whose preservation is regulated by law. Nevertheless auditory impairments, especially by traffic noise and due to spatial restrictions are likely. This study examines acoustic effects of traffic noise on the spatial distribution of birds in a natural reserve being in close proximity to two roads with heavy traffic. Furthermore the effects of the land use and transition zones between two land uses (ecotones) on avian distribution were evaluated. To answer the posed research questions sound measurements were taken throughout the whole natural reserve and analyzed utilizing five acoustic indices. The results of the indices were used in a statistical analysis to investigate correlations between the distance to roads and the amount of biophony as well as differences between various land uses and ecotones. Methodological insights regarding the use of acoustic indices, correlations between the distance to roads and the amount of biophony, as well as significant differences between acoustic environments recorded in different land use types were found.

Keywords: Soundscape, traffic noise, biophony

1. INTRODUCTION

The aim of the present work is to investigate factors influencing the distribution of bird vocalizations in natural and protected areas using the example of the nature reserve 'Im Siesack' using acoustic indices. The factors considered to explain vocalizations are time, land cover type (including the transition areas between land uses) and distance to roadway. Given the scope of the study, it was not possible to analyze the effects of other factors (such as distance from nearby villages, or wildlife population characteristics) and apply further analysis to understand explanatory power of many factors. Rather, the focus of the study was limited to the effects of roadways and land cover on the acoustic environment and content of biophonic sound in German nature reserves. The determination of the influence of traffic noise on nature conservation areas is of particular relevance in the densely populated Ruhr area, as many nature conservation areas are located in the immediate vicinity of busy traffic routes. According to Section 23, Paragraph 2 of the Federal Nature Conservation Act, "all actions that could lead to the destruction, damage or alteration of the nature reserve or its components or to a lasting disturbance (...) are prohibited". Accordingly, it must be determined to what extent the natural acoustic environment of the study area is altered by the noise of the adjacent roads. The acoustic environment can in turn be used to draw conclusions about the distribution of birds and the species diversity. In addition, the influence of land use on the acoustic environment will be determined in accordance with Pijanowski et al. (1) in order to identify connections between the natural

¹ Philipp.antoniou@tu-dortmund.de

² Bryce.lawrence@tu-dortmund.de

environment and the composition of the acoustic environment. Of particular interest are the ecotones as transition zones between two land uses.

Farina et al. define the term soundscape and its components geophony, biophony and anthrophony as follows: "The soundscape can be defined as every sound produced by any abiotic and biological component of an ecosystem (geophonies and biophonies, respectively) together with anthropogenic sounds (anthrophonies). It is thus the result of the energy released by both natural processes and human technologies (2)." The geophony was represented in the study area mainly in the form of wind, the biophony was formed almost exclusively by bird vocalizations and the anthrophony is dominated by the traffic noise of the two adjacent major traffic routes. Acoustic indices were used to analyze the acoustic environments. Acoustic indices are automatically calculated and represent, among other things, the relationship between biophony and anthrophony as well as characteristic properties of the acoustic environment such as its acoustic diversity (3).

2. STATE OF RESEARCH

2.1 Influence of noise on bird vocalization and habitat distribution

Numerous studies have already investigated the influence of noise on the distribution of birds. Particularly noteworthy is Garniel et al. (4), whose systematic study of 132 bird species forms the basis for the legal regulations on the consideration of bird habitats in road construction projects (5). It was found that for some species, such as the Little Bittern, at a critical sound level (52 dB(A)) habitats are completely devalued, while other species such as many birds of prey are almost completely insensitive to road noise (5). Experimental studies by McClure et al. show a decline in the number of species by a total of 25% along a noise gradient of 44 - 51 dB(A) at a linear noise source (6). In addition to the influence on the absolute number of species and species composition as described above, it has also been demonstrated that noise changes the behaviour of birds and in particular the timing, frequency, level and redundancy of their vocalization, which in turn can affect reproduction success (7).

2.2 Influence of land use and ecotones on the spatial distribution of bird vocalizations

The influence of land use on the acoustic environment was investigated by Pijanowski et al. (1). The study shows that the acoustic environment of forested areas shows characteristics associated with biophony to a greater extent than agricultural or urban areas. It should be noted, however, that the biophony can be composed not only of bird vocalizations but also of insects, which is not the case in the present study. With regard to the influence of margins or ecotones on species diversity, Walz describes that they have a clear influence on species diversity and composition. Studies in agrarian areas in Saxony-Anhalt show that the diversity of species in the margins is up to twice as high as in surrounding areas (8).

3. METHODS

3.1 Study site

The study area was selected according to the following criteria: It had to be a natural area with several types of land use, protected as a nature reserve and in the immediate vicinity of major traffic routes. The nature reserve 'Im Siesack' fulfils these criteria. It covers almost 170 ha and has a very heterogeneous landscape structure. The main components are arable land (17% of the total area), bush and grassland (18%), meadows and pastures (20%) and woodland (30%). The area was designated a nature reserve due to its high biodiversity and structural richness (9). It is also in the immediate vicinity of a motorway (called BAB 2) and a country road with heavy traffic (called L 609). According

to the environmental noise mapping of the Ministry for the Environment, Agriculture, Nature Conservation and Consumer Protection of the State of North Rhine-Westphalia, the traffic noise exposure of the area lies between 60 and 70 dB(A) above a 24-hour level in the north and west of the nature reserve (10). In addition, an industrial site is located directly south of the nature reserve, but it does not emit any significant noise emissions. Due to the limited accessibility of numerous open land and forest areas used as pastures, the study area was narrowed down after a first measurement run. Figure 1 shows the study area, the narrowed-down study area and the location of the traffic routes.

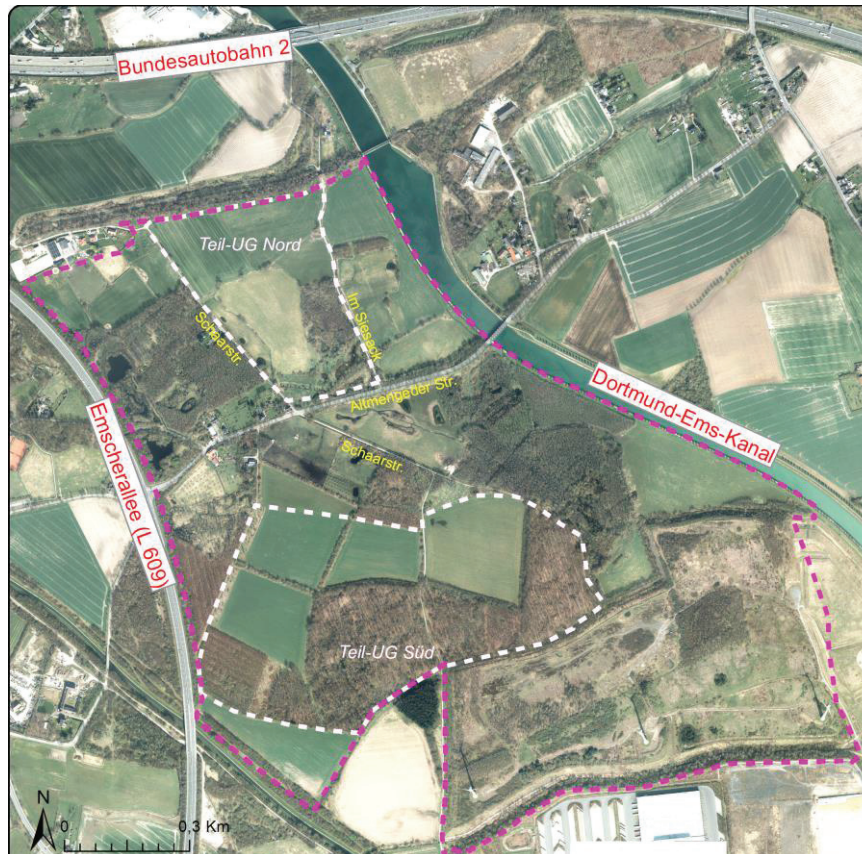


Figure 1 – Overview of the study area and the traffic routes (L 609, BAB 2) in the surrounding area. The study area is marked in pink, the narrowed-down study area is marked in white (Source: the author's own compilation based on the Web Map Service 'DOP NRW' by: Land NRW (2019) Datenlizenz Deutschland - Namensnennung - Version 2.0 (www.govdata.de/dl-de/by-2-0))

3.2 Soundscape recordings

All measurements were carried out at the end of September in a total of three measurement cycles. Due to new insights during the conduct of the study, the methodology of the measurements varied.

- First measurement cycle: A grid of 128 points with a constant distance of 115 m to each other was created in ArcGIS. Due to the limited accessibility, however, measurements could only be carried out at 102 points. The measurements took place between 12:00 and 16:00 in order to ensure a constant traffic load during the entire measurement period. The duration of each measurement was five minutes.
- Second measurement cycle: Because of the low song activity of birds at the time of the first measurement, the second measurement was performed between 06:50 (sunrise) and 9:30. In order to make optimum use of this short period, the measurement time was reduced to three minutes and the measurements were carried out on the numerous paths of the study area that cross the study area evenly. The distances between the measuring points were 100 m. 31

measurements were taken. This was a test of the extent to which the measurements deviated from the first run.

- Third measurement cycle: Due to the positive results of the second measurement cycle, the recording times and lengths were retained during the third measurement cycle and the measurements were carried out in the narrowed-down study area. According to a modified approach of the 'sampling by land use category' by Brown and Lam (11), the 72 measuring points were mainly aligned with the edges of the land use patches, supplemented by measurements in the geometric center of each land use patch.

3.3 Data analysis

The software 'Rstudio' was used to calculate acoustic indices for the 204 usable recordings. The following indices were calculated:

- Acoustic Complexity Index (ACI): Calculation of the variability of sound intensity. The higher the ACI, the higher the proportion of biophony in the acoustic environment.
- Acoustic Diversity Index (ADI) and Acoustic Evenness Index (AEI): Splits the acoustic environment into frequency bands and applies the Shannon Index (ADI) or Gini Index (AEI) to them. The higher the proportion of biophony, the greater the diversity and the lower the evenness.
- Bioacoustic Index (BIO): The BIO is a function of the sound level as well as the frequency ranges occurring and exclusively reflects the degree of biophony in the recording.
- Normalized Difference Soundscape Index (NDSI): The ratio between biophony and anthrophony is calculated, whereby anthrophony is defined as components of the acoustic environment with low frequencies and biophony as components of the acoustic environment with high frequencies. (3)

The distribution of the index values determined over the study area is graphically displayed using a heat map in order to be able to recognize patterns.

In the following step, the determined index values were statistically evaluated using the software SPSS. For this purpose, the distance of each point to the L 609 and the BAB 2 was calculated using ArcGIS and each point was assigned a land use. The land use categories used were kept non-detailed in order to ensure that the sample size was as large as possible for each category. The data was checked for normal distribution using the Kolmogorov-Smirnov test. The Spearman's correlation test was used to answer the question as to whether the values of the index changed as a function of the distance to the traffic routes, based on Pieretti et al. (1). The Kruskal-Wallis test was used to answer the question of the extent to which the index values differed significantly depending on land use (based on Liu and Kang, 13).

4. RESULTS

4.1 Spatial distribution of index values

Figure two (left) shows the distribution of the NDSI as determined in the first measurement cycle. It can be clearly seen that in the areas which are closer to the traffic routes, the values are significantly lower and thus more strongly influenced by anthrophony than in areas further away from traffic routes. The environmental noise mapping of the MUNLV NRW as shown on the right side of figure two shows a similar pattern but differs regarding the degree of traffic noise impact by the L 609 and BAB 3. In contrast to the NDSI, the graphical representation of the distribution of the ACI, ADI, AEI and BIO show no clear dependence on the distance to the traffic routes or the land use. Only trends are discernible: Figure three shows that the linear woods between the fields in the south of the study area have higher (or in the case of the AEI lower) values for the ADI, AEI, BIO and NDSI than the fields themselves and can therefore be assumed to have a more pronounced biophony.

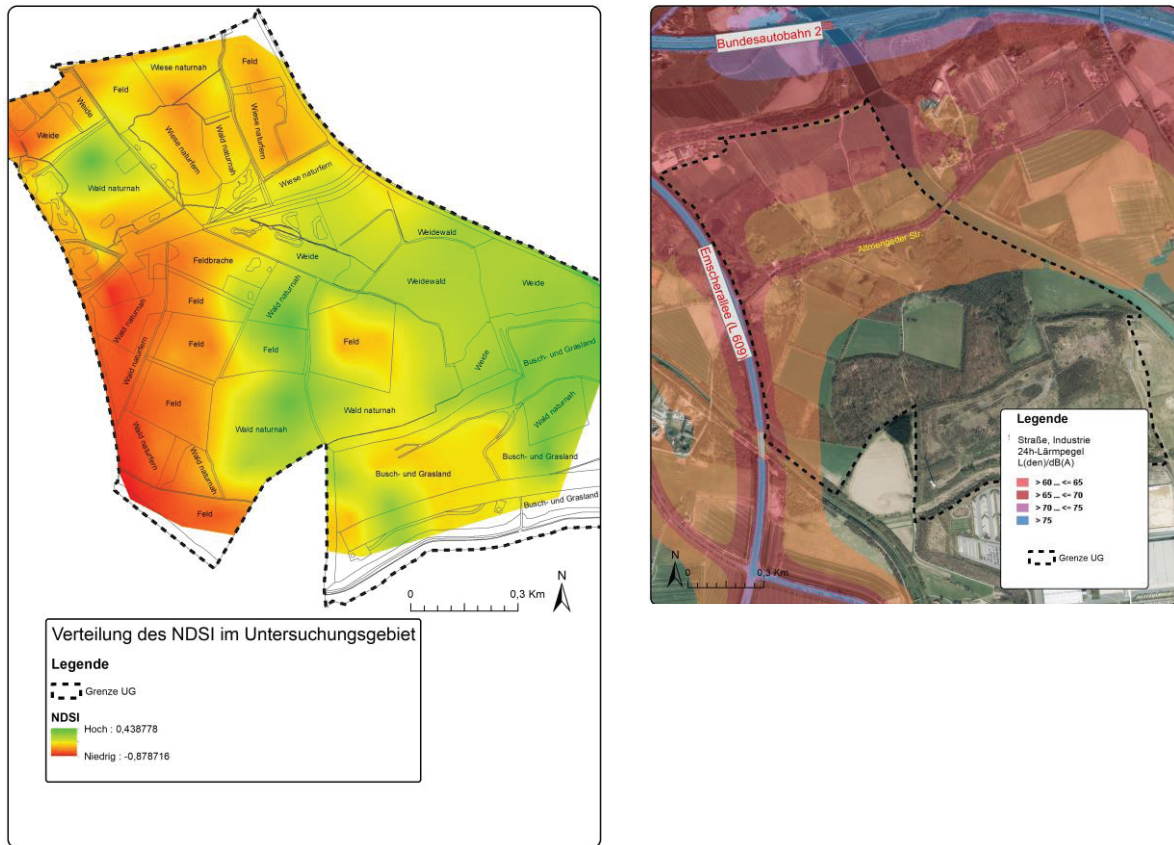


Figure 2 – Distribution of the NDSI during the first measurement run in comparison to the environmental noise mapping of the MUNLV NRW 2017 (Source: own research; Web Map Service ‘Umgebungsärmkartierung NRW’ and ‘DOP NRW’ by: Land NRW (2019) Datenlizenz Deutschland - Namensnennung - Version 2.0 (www.govdata.de/dl-de/by-2-0))

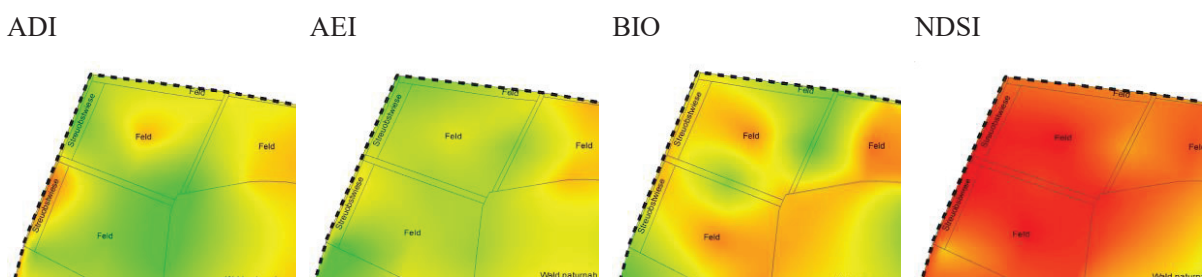


Figure 3 – Distribution of the index values in an agricultural area in the south of the study area; third measurement cycle (Source: own research)

4.2 Influence of traffic noise on the acoustic environment and the spatial distribution of bird vocalizations

The following table shows the results of Spearman's correlation test. Only statistically significant results (significance level > 0.05) are presented.

1st Measurement run			2nd and 3rd Measurement run		
	Distance L 609	Distance BAB 2		Distance L 609	Distance BAB 2
ACI	0,204	-	ACI	-	-
ADI	-	-	ADI	-	0,327
ADI2	-0,274	-	ADI2	-	0,346
AEI	0,392	-	AEI	0,260	-0,195
BIO	-0,265	-	BIO	-0,340	-
BIO2	-	-	BIO2	-0,274	-
NDSI	0,608	-	NDSI	0,304	0,529
NDSI2	0,600	-	NDSI2	0,348	0,551

Table 1: Significant Spearman's correlation coefficients of the three measurement runs (Source: own research)

The calculation of the indices was carried out with the following parameters:

- ADI, AEI: Division of acoustic environments into 1,000 kHz wide frequency ranges
- ADI2, AEI2: Division of acoustic environments into 100 kHz wide frequency ranges
- BIO: Definition of biophony as the frequency range between 2,000 - 8,000 kHz ranges
- BIO: Definition of biophony as the frequency range between 3,000 - 11,500 kHz ranges
- NDSI: Definition Anthrophony: 1,000 - 2,000 kHz; Biophony: 2,000 - 8,000 kHz ranges
- NDSI2: Definition Anthrophony: 1,000 - 3,000 kHz; Biophony: 3,000 - 8,000 kHz ranges

The graph of the NDSI distribution and the corresponding Spearman's correlation coefficient show that the greater the distance to the roads, the more anthrophony decreases. Consequently, the relationship between anthrophony and biophony also changes across the study area. However, due to the fact that the BIO does not correlate with the distance to the roads in the expected way, it can be concluded that the intensity of the biophony is not significantly influenced by traffic noise. Traffic noise therefore decreases with increasing distance from the traffic routes, but the biophony does not increase. Concerning the degree of acoustic diversity, no such clear correlations as with NDSI could be found, but the weak to moderate correlations of ADI and AEI with the distance to the BAB 2 in the second and third measurement cycle indicate that the distance to traffic routes influences the distribution of birds. However, this is only one of many factors and the influence of traffic noise is a minor one.

4.3 Influence of land use and ecotones on the acoustic environment and the spatial distribution of bird vocalizations

To determine the influence of land use, all points were divided into four land use categories:

- 1: Field, meadow, pasture (n = 53)
- 2: Small-scale woodland (n = 41)
- 3: Ecotones (n = 35)
- 4: Forest (n = 53)

Points that could not be assigned to any of the four categories were not used. Figure four shows the results of measurement cycles two and three for the various land uses. Clear differences between the different land uses are visible: fields, meadows and pastures tend to have low values (or higher values in the case of the AEI), forests have high values, small-scale woodland and ecotones occupy an intermediate position. At measurement run one, less clear differences could be observed due to the lower biophony, possibly because of the time of day.

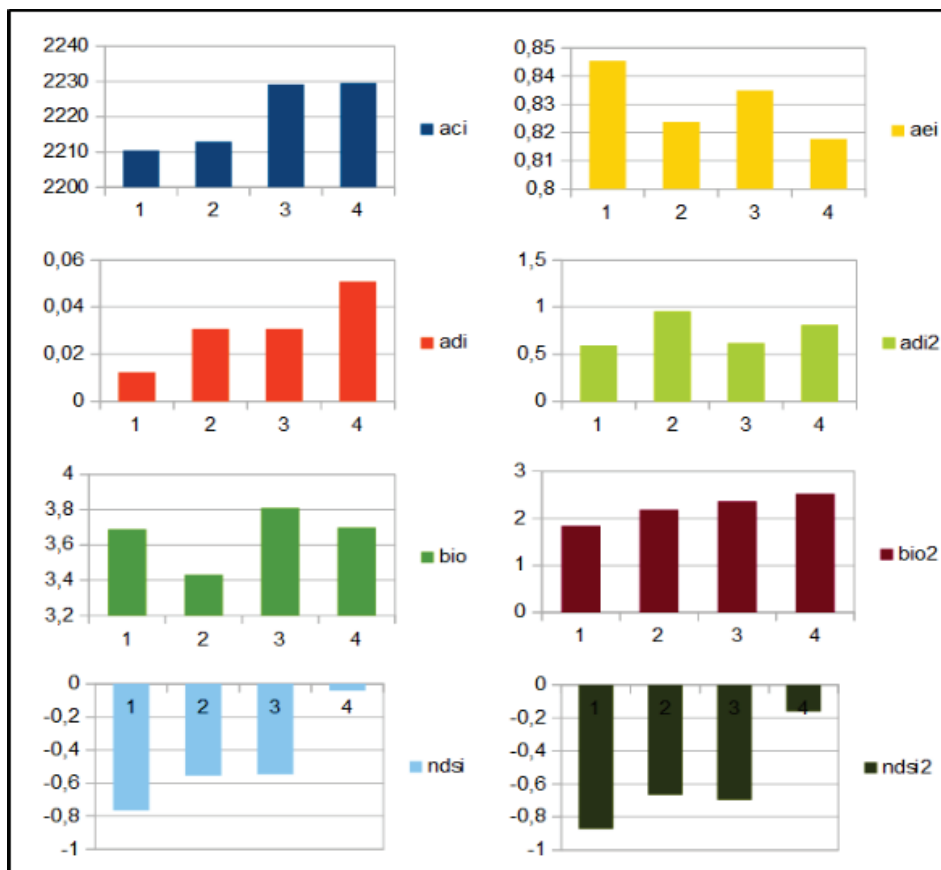


Figure 4 – Results of measurement cycles two and three, sorted by land use (Source: own research)

The Kruskal-Wallis test shows that there are significant differences between varying land use types regarding the ACI, AEI, BIO, NDSI and NDSI2 for the first measurement cycle. This is the case for the ADI, ADI2, NDSI and NDSI2 for the measurement cycles two and three. A correlation between land cover types and indices was not considered in this study but is recommended in future similar studies to determine if land cover type or roadway noise have more relationship to the acoustic environment.

5. CONCLUSIONS

The results of this study demonstrate that the distance to disturbance sources influence the values of (bio)acoustic indices and thus most likely the distribution of bird vocalizations in the nature reserve 'Im Siesack'. They also show that the surrounding traffic routes and especially L 609 emit noise into the nature reserve. Furthermore, the variation of the acoustic indices depending on the land use indicate a relationship between the land use or even avian habitat structure and the acoustic environment in the study area. Nevertheless, there is a large number of factors that influence the distribution of bird vocalizations that has not been part of this study. Garniel et al. (4) provide a good overview of these influencing factors. Methodological insights were also gained. For example, changes in the parameters with regard to the frequency ranges used to calculate the indices may have a significant effect on the results and should be adapted to the specific conditions of the study area. In addition, it was recognized that the results from Pijanowski et al. (1) could be partly reproduced with a short recording time and a simplified approach adapted to the terrain when determining the measuring points. In this respect, an initial overview of the biophony and noise in a protected area in the sense of the 'Rapid Acoustic Survey for Biodiversity Appraisal' (14) could be obtained.

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