forum acusticum 2026
8-12 September · Graz, Austria

Assessing the impact of outdoor music festivals on biodiversity

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Abstract

Outdoor music festivals are often organized outside urban areas to minimize nuisances for city dwellers. This results in possible proximity of festivals to natural areas and potential impact on biodiversity in these areas. However, assessments of festival impact often use anthropocentric modelling or monitoring, approaches. Music is targeted at human experience and therefore its frequency range and spectral temporal modulations aim at creating an emotional response in humans. Other organisms may exhibit different responses to humans. Hence, it is proposed to focus assessment on the relevant taxa by including their hearing thresholds. Moreover, we propose combining impact monitoring with passive acoustic monitoring (PAM) of biodiversity. The proposed approach is tested at a medium-sized outdoor music festival in Flanders. During successive editions, directivity of the loudspeaker arrangement was suggested as a mitigation measure. To validate the directivity of the loudspeaker arrangement, drone-based mobile acoustic measurements were performed.

Keywords: effects on biodiversity, music festival, hearing-level weighting, directivity

1. Introduction

Outdoor music festivals have increased in both numbers and size over the last decades. Multi-stage events powered by increasingly capable Public Address (PA) systems can generate high sound levels. To prevent hearing damage among attendees and staff, many countries have implemented regulatory noise limits. Since the late twentieth century, attention has also turned to the surrounding communities that experience negative side effects during festival periods [1]. These regulations have, among other factors, encouraged organizers to relocate festivals toward more rural or suburban areas, which in turn require new policy approaches [2][3][4].

Relocating events outside densely populated zones, however, introduces noise into natural environments and protected biodiversity areas. The effects of anthropogenic noise on biodiversity are diverse and depend strongly on both the characteristics of the sound and the species exposed to it [5]. Only a limited number of studies have examined the specific impacts of outdoor festivals on animal behavior [6][7]. Harley et al. [8], for example, investigated effects within the controlled yet unnatural setting of a zoo, which enabled observation across a wide variety of species. Their results showed substantial differences in responses between species, illustrating the inherent complexity of assessing ecological impacts of festival noise.

In this work, we start from the premise that perceiving the sound is a prerequisite for any biological effect, and that the sound level above the hearing threshold provides an initial indicator of potential impact on biodiversity. This suggests that the conventional reliance on dB(A) (and dB(C) for music) in noise control engineering may be insufficient when assessing ecological impacts, and that more nuanced acoustic metrics may be required.

Several approaches exist to assess the environmental impact of a music festival. (1) Monitoring the source involves characterizing how sound radiates into the

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environment. For multi-stage events employing vertical line arrays and extensive subwoofer setups, this requires careful evaluation of the overall directivity pattern of the stage. In addition, accurate propagation modeling through natural areas—where temperature and wind gradients vary locally—can present substantial challenges. (2) Monitoring appropriately weighted sound levels over time at strategically selected locations provides another option. However, this approach must address separating festival-related sound from other anthropogenic or biophonic contributions. (3) Directly monitoring changes in animal behavior, potentially approximated through passive acoustic monitoring of vocalizations, offers yet another assessment pathway. Here as well, distinguishing animal vocalizations from concert-related sounds remains a significant challenge.
Assessing the impact can be relevant for an ongoing edition of an event, but more importantly, it allows to reduce impacts of future editions. Here, we present as a case study, a festival in Belgium where sound was continuously monitored in 2024 and 2025 around the festival for 3 days. In addition, the directivity of noise emission was characterized.

2. The case study

The case study was at an outdoor weekend dance festival in Belgium, editions 2024 and 2025, at the end of June. Both editions were 3 days with 6 music stages and around 20.000 visitors at the busiest moment. The festival site (Fig.1) is very close to areas of conservation importance The area west of the festival site is designated under the EC Habitat Directive. The area north of the site is part of the Flemish Ecological Network (VEN) area. The forest age is approximately 50 to 150 years old; the forest is primarily anthropogenic and was established during afforestation efforts in the 19th and 20th centuries. The dominant tree species are mainly coniferous species, especially Pinus sylvestris (Scots pine) and Larix (larch). This is accompanied by deciduous species such as Betula (Birch) and Quercus (oak). The blue line (Fig.1) is a highway with an average traffic intensity of 55.000 motorcars per 24 hours [9] . The measurement point West has influence of this highway; the measurement point North has almost no influence.

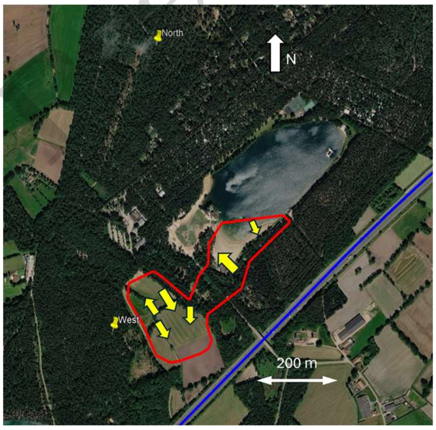

Figure 1, festival site

In Fig. 1, the red line is the enclosure of the festival area, the yellow arrows are music stages with directions, the blue line is the highway.

3. Taxa specific hearing-level weighting (dBHL)

A-weighting used for human listeners tries to capture approximately perceived loudness. For other taxa, determining how loud sound is perceived is beyond reach. Different animals use sounds for different purposes with communication being one of them. In previous work we focused on bird song interference to propose a song-interference weighting [10]. Communication interference weighting has the advantage that it can be derived from recorded communication. However, animals may also use sound for prey finding or for being warned about possible danger. Hence, we rely on the level above the hearing threshold as a more versatile measurement. Recognizing that assessing every individual species in a given area would not be practical, the proposed approach starts by identifying relevant representative species for the area of interest. Here we opted for an average songbird, an owl (Tyto alba), a fox (Vulpes vulpes), and a deer (Odocoileus virginianus) (Fig.2). These cover mammals and birds and different uses of sound [11].

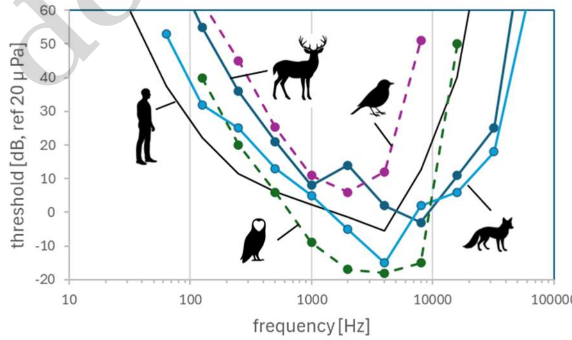

Figure 2. Hearing threshold of key species compared to human hearing threshold.

4. Monitoring taxa-weighted levels

Two monitoring stations were placed in the natural areas: one at 100 meters to the west (edition 2024 and 2025) and 700 m to the north of the festival site (edition 2025). The measurement height was 4 meters. Decibel monitoring started on Thursday evening before the festival started on Friday and continued for 3 days until the end of the festival at late Sunday evening. Festival opening times were Friday (15-24), Saturday (12-01) and Sunday (12-23 hr). The soundscape at location West is affected by the sound of the highway at 700 m south of the measurement location while location North is more distant from any other anthropogenic sound source. The meteorological conditions are described in Table 1.

Table 1. Meteorological conditions during festivals.

	Day	*wind direction*	*Wind speed*	*Temperature*
2024	Friday	West	6-3 m/s	22 degr.Celsius
	Saturday	East	2	26
	Sunday	West	5-2	21
2025	Friday	West	7-3	25
	Saturday	West	5-3	24
	Sunday	North	4-2	28

In Fig. 3 and 4 , the measurement results are translated into various weightings.

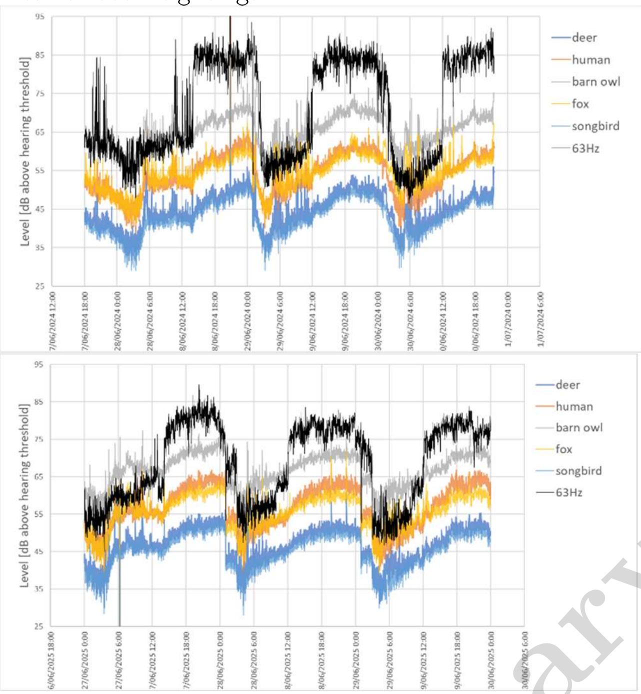

Figure 3. Temporal evolution of the hearing threshold weighted levels for representative species and 63Hz octave band level as an indication of the activity of the festival at measurement location 1. Upper: 2024 edition, lower: 2025 edition.

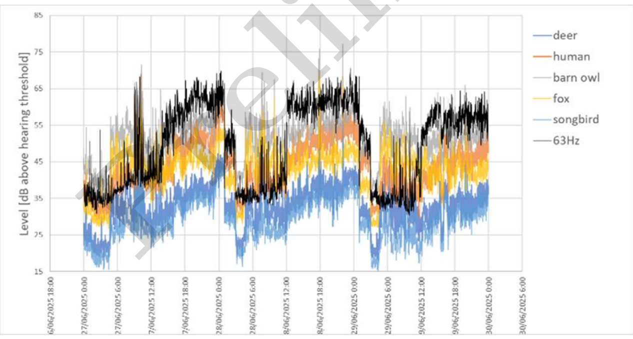

Figure 4. same as Fig. 3 but for location North in 2025.

At location West, on Friday morning, before the festival, the sound level increases for all weightings in a similar way due to traffic noise . During that period the relationship between them is almost linear. However, when the festival starts to contribute, the relationship between weightings changes, yet the additional difference on top of an offset that represents global noise sensitivity is seldom more than 5 dB. To compare the sound level caused by two editions at location West, the equivalent noise level between 22:00 and 23:59 on the Saturday night of the festival are calculated: the 63 Hz octave band level drops from 84.3 dB in 2024 to 78.9 dB in 2025, but this is not reflected in hearing level weighted that increase from 50.0 to 51.7 for dear, from 70.0 to 71.5 for the owl, from 59.1 to 60.7 for the fox, and from 48.6 to 50.0 for songbirds. In Table 2 the difference at point West for 2 editions is displayed for the timeframe average on Saturday evening 22-24 hr.

Table 2. Comparison of 2 editions at point West.

Year:	LAeq	LCeq
2024	66,0 dB	92,6
2025	66,4 dB	87,9

There is a small increase of 0,4 dB(A) and a decrease of 4,7 dB(C) at point West.

At location North, the 63 Hz octave band level, which is an indication for the contribution of the festival, remains significantly lower but at the same time also the overall traffic noise level is lower. The more natural soundscape fluctuates more strongly from 1 minute to the next. At night, before the festival days and during the festival the after-party finishes at 3 a.m. levels are 20 dB lower than at location West independent of the species HL weighting. At morning twilight levels increase quickly. Overall weighted levels for species like the fox increase to a level comparable to the level observed during the festival hours. This similar "loudness" nevertheless does not imply that the meaning of the sound at both moments is the same.

In view of the popularity of A-weighting for impact assessment of open-air festivals on the environment, we compare instantaneous levels (1-minute Leq) for different weightings. Fig. 5 shows this comparison for the fox and the songbird HL-weighting. Apart from an offset between HL weighting and A-weighting, also a different trend can be observed depending on the dominant sound source. For measurement point 1, two clusters can be identified related to traffic noise and concert noise where for the latter the noise for foxes and songbirds is lower than expected based on A-weighting. In measurement point 2, three different clusters can be identified, one related to the night background noise, one related to daytime noise, and finally the one related to the festival noise which gives the highest A-weighting levels.

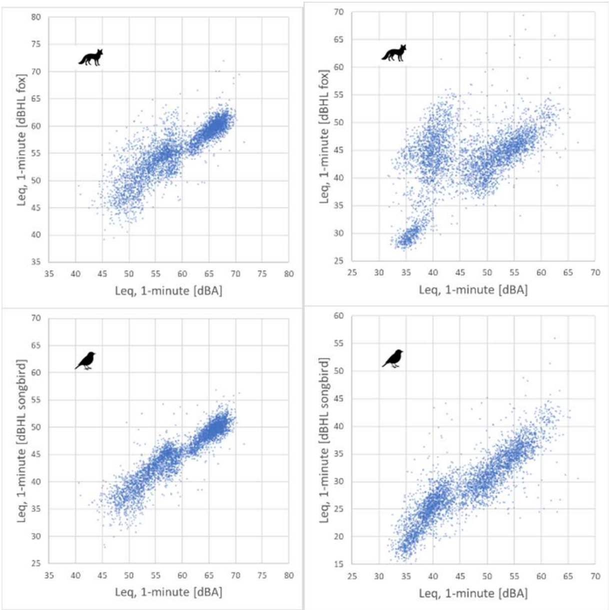

Figure 5. Comparison of HL weighted levels (fox and songbird) to A-weighting at location West (left) and location North (right). Note that for songbirds, the vertical axis is shifted by 10 dB.

5. Combining with passive acoustic monitoring

As high frequency components of the music are directed strongly at the audience and as these high frequencies are strongly absorbed by the air, it can be expected that sound at frequencies over 8 kHz have a local origin. As a significant part of bird vocalizations and insect sounds occur at these frequencies, the same measurement equipment can be used for limited passive acoustic monitoring. This is illustrated in Fig. 6.

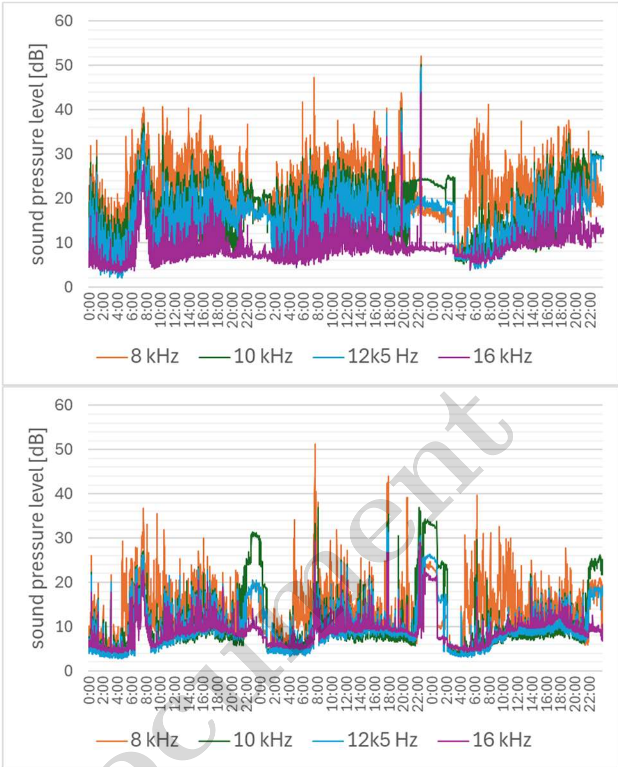

Figure 6. High frequency sound (Leq,1minute) indicative of animal vocalizations. Upper: measurement point West, lower: measurement point North, 2025 edition.

For this festival site and date, the sunrise is at 05:27; sunset is at 22:01. At morning twilight the bird chorus, characterized by 8 kHz and higher 1/3 octave band, starts. On Friday, before the festival starts, the morning peak spans all bands and is constant for several minutes. The second and third day, after a festival night the morning peak is still a little pronounced in measurement point North, but the dawn increase is more continuous at location West. Frequencies around 12.5 kHz and 16 kHz seem to occur later during the day and might be attributed to insects. Sound activity in these bands drops around midnight, but remains higher during festival nights. Unfortunately, a more continuous sound probably of mechanical origin occurs around midnight at measurement point North and to a lesser amount at measurement point West. Recordings could have resolved the ambiguities. For the 2026 festival edition, audio recordings will be added to allow sound recognition software to identify vocalizing species even in the presence of music.

6. Directivity of loudspeaker configuration as mitigation measure

Music festival noise is shaped by the desire to create a dynamic and engaging experience for visitors while keeping environmental impact under control. Any measure that concentrates or steers the sound from the stage toward the audience therefore supports both ambitions: it enhances the auditory experience for festival goers while reducing unnecessary sound exposure in the surrounding environment. Fig. 7 describes the frequency response of a modern PA system at a distance of 30 meters, measurement height of 2 meters. The front-to-back ratio is around 10 dB for low frequencies (bass array) while from 125 Hz, and higher the ratio is 20 to 28 dB (line array). With this knowledge, an optimal layout can be generated for a festival site. This is done most of the time with respect to residential areas, but not often for the biodiversity areas.

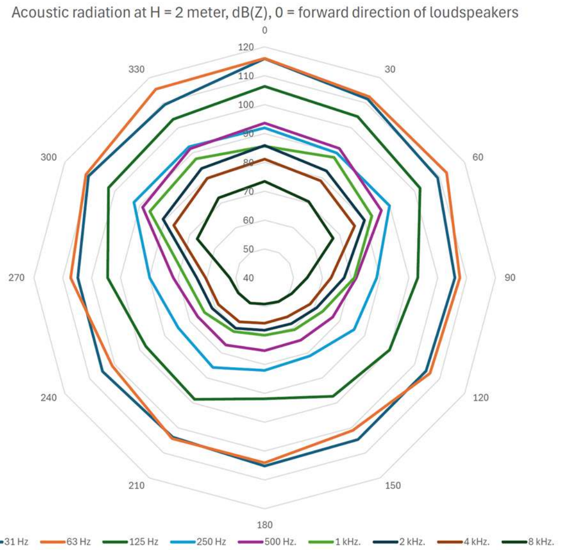

Figure 7. Directivity of a modern public address system as used by this festival, measured at 30 meters from stage.

For the 2025 edition, most stages were oriented away from the forest. However, the ecological relevance of this mitigation cannot be inferred from directivity patterns alone. The receptor data show that a reduction in a low-frequency engineering indicator did not yield lower hearing-threshold-weighted exposure for the focal taxa, implying that mitigation effectiveness must be evaluated at ecologically relevant receptors, with explicit consideration of spectral redistribution, propagation conditions, stage synchronisation, and species-specific audibility.

7. Discussion and conclusions

This study shows that the audibility of outdoor music festivals in natural areas located just a few hundred meters from the venue depends heavily on the specific animal species. This difference materializes mainly as an offset in level above hearing threshold. When compared to A-weighted levels (Leq, 1 minute), within one source, there is a close-to-linear relationship that only slightly depends on the species considered. This is evident because of the similar spectrum of music or traffic noise with increasing levels. However, when comparing different sound sources – and thus spectra – the trend changes. At location West, where highway sound significantly contributes, it can be observed that using A-weighting overestimates the level observed by most animals. The obvious reason is the strong dominance of low frequency sound in the music and the higher hearing threshold at those frequencies for most animals of relevance in this area.

The broader literature indicates that this problem sits at the intersection of two evidence gaps. First, real festival studies remain rare relative to the much larger evidence base for transport and urban noise, so transferability from chronic noise contexts to recreational pulse events is limited. Secondly, biodiversity assessment is still too often based on human-oriented metrics even though recent syntheses show that the most frequent ecological responses concern behavior, communication/perception and reproduction, and that vulnerability differs among taxa and traits. The present case study therefore contributes less by establishing universal thresholds than by demonstrating a methodological point: ecologically relevant exposure around festivals should be assessed with source-aware and species-aware metrics rather than with A-weighting alone.

Interpreting the relationship between audibility and effect size should be treated with caution. Birds may have adapted to a sound that is always present and has a predictable diurnal pattern [12]. The sound of a concert that happens only one weekend a year may trigger a different response. Moreover, sound disturbance during a short period of the year may not trigger a significant effect on the local ecosystem and its biodiversity unless it coincides with a critical period in the reproductive cycle[13].

Noise monitoring in natural areas near outdoor music festivals could serve a dual purpose: monitoring the noise from the music festival and monitoring of animal vocalizations. Our measurements at two locations show that the overlap in frequencies between the sound of the music concert at a distance and vocalizations are very different. Pre-concert measurements and measurements outside operational hours show similar high frequency patterns that might be attributed to biophony. However, the recordings made by the sound level meter used for source identification of events were of insufficient quality to allow identifying the biophonic sounds using modern recognizers such as BirdNET [14].

In this case study, the stages were rotated to exploit the directivity of the PA. However, it was shown that the overall level during the peak hours of the festival, weighted for animal hearing thresholds, had slightly increased between years rather than having decreased. This implies that when implementing a change, a thorough prediction of impact changes should be conducted, including assessing directivity in detail and at different heights. Some alternatives are however still available such as moving the sound systems away from the edge of the festival site towards the center of the terrain, further optimizing directivity, or timewise: don't let all stages start at the same time and/or end at the same time, with focus on the music areas along the edge of the festival terrain.

In 2026, a new edition of the concert is planned. During this edition, noise measurements will be repeated at both measurement locations. In addition, sound will

now be recorded to allow joined analysis of contributions from the festival and animal vocalizations based on sound separation techniques that go beyond spectral analysis such as [15]. This will allow to study effects such as delayed onset of the morning bird chorus after a concert night [16].
Although the case study presented here illustrates how species-specific hearing thresholds can enable a more accurate assessment of the impact of outdoor concerts on biodiversity, obtaining reliable hearing thresholds for the relevant species remains a significant challenge. As part of future work within the Plan-B project [17], a comprehensive database of hearing thresholds will be developed, allowing users to easily retrieve available data or, when direct measurements are lacking, access thresholds from closely related species.

8. Acknowledgments

This publication was produced under the Horizon Europe programme (Grant Agreement No. 101135308) as part of the PLAN-B project. RK was also supported by the sMon project (Trend analysis of biodiversity data in Germany) of the German Centre for Integrative Biodiversity Research Halle-Jena-Leipzig - iDiv, funded by the German Research Foundation (DFG-FZT 118, 202548816).

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