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# VOCALIZATION PATTERNS AND SOCIAL STRUCTURE IN BAT COLONIES UNDER URBAN NOISE PRESSURE

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## Abstract

Bats rely on sound to locate food, navigate as well as maintain a group. But, increased machnoise in the urban areas may be interfering with their natural speech habits and even social systems. The paper investigates the impact of noise in urban areas on bats and their hearing and colony organisation. With full-spectrum ultrasonic detectors, thermal imaging, and spatial network analysis we monitored six colony sites in cities and their surroundings. Sound pressure levels (Leq) were determined using high accuracy sound meters. We examined vocal parameters including call frequency changes (or translocation, 12), bandwidth and pulse interval of varying noise intensity. To examine social organisation we employed the measures of roost mapping, emergence synchrony, and network centrality. We, also, could interview ecologists and conservationists and examine the topics of our interviews. When the noise was severe, the urban colonies expressed markedly different vocalisation patterns where the dominant frequencies increased on average of 4.6 kHz. The bandwidths had decreased and pulse rates had increased which shows the signs of compensatory behaviour. Social cohesion decreased in noisy environments, and this was demonstrated by a decreased amount of people clustering up, an increased distance among members and reduced synchronous emergence. Statistical modelling indicated that considerable relationships existed between Leq, 8f, and lower social structure indicators. These trends were confirmed by the qualitative results and the emphasis was on the long-term results of noise pollution on the environment. The pressure of noise in urban areas is so high that it becomes difficult for bats to communicate with one another and also to manage their own social lives, and all this may influence the reproduction capabilities of these animals, as well as their ability to orientate themselves and maintain their numbers over the lifetime. Noise Area and Acoustic Refugia: In order to make the urban animals survive, it cannot be too much noise, instead, we need to apply noise zoning and acoustical refugia.

**Keywords:** "Urban Noise", "Bat Communication", "Vocal Plasticity", "Social Cohesion", "Leq", "Acoustic Ecology".

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## INTRODUCTION

The effect of human activity is common in the form of urban noise, which affects the environmental sound transmission significantly. This compels numerous species into altering their speech so that they can be sure to continue to communicate with the rest of their social groups (Can et al., 2020). Such stress in the environment can modify the volume, frequency and timing of vocalisations which may modify the nuances of communication amidst the same species (Rivera-Gutierrrez et al., 2023). Such types of changes are very critical in maintaining groups and functioning cohesively which are of essence in food searching, reproduction, and predator evasion (Xie et al., 2024). The capacity of people to alter the way they behave due to changes in selective pressures, such as those provided in cities is increasingly coming to be critical to survival in such environments. That is, the less adaptable, or naturally shy species, might not be able to colonise cities (Parker et al., 2022). Such alteration in vocalisation is an important indication on how a species can adapt to altered habitats caused by human beings. It must be observed on a deep level in order to comprehend the impacts on the ecology and evolution of urban wildlife (Ritzel & Gallo, 2020). However, we do not yet know how and to which extent bat colonies, which are said to have developed highly sophisticated echolocation and social calls, modify their vocalisations under circumstances of increasing noise pollution in the cities. The given research attempt to address that gap which exists in our knowledge by examining the way in which bat colonies in urban areas create noise, correlating these trends with the amount of noise pollution and then, the way in which such shifts impact their social organization and reproduction. The research will guide us to conceptualize more on how very sociable and auditory sensitive species survive in urban settings. Such data is relevant in acting to areas that are getting urbanised. Scientists investigated strategies to avoid the masking effect such as altering the frequency and amplitude of the song to overcome masking impacts in urban habitats by affective residents (Hong et al., 2020) (Budka et al., 2023) (Bateman & Uzal, 2021). Nevertheless, the vocalisations of bats, particularly of their ultrasonic social calls and echolocation calls are another (and less understood) domain of study due to the elevated frequencies of the sounds and the ecological significance of the sounds produced (Cronin et al., 2022). Such a gap is particularly significant because vocalisations play a critical role when bats search food, navigate the surroundings and communicate with other bats. Even slight alteration in structure of their calls can leave significant impact on their fitness. Specifically, it is still not clear how bats adjust complex temporal and spectral patterns of their vocalisations, e.g. those employed to recognise individuals or to coordinate efforts in searching food, in the presence of much low-frequency background noise caused by people. This is difficult on bats because their calls mean that it is common to be in the ultrasonic range so their calls can be masked by lower frequency urban noise. This may further obscure the signals and impact the bat to recognise other bats and view the surrounding space (Parsons et al., 2022). This experiment aims at determining the changes in bat vocalisations as a result of different urban noise pollution levels. The changes involve change in call duration, repetition rate as well as frequency modulation. This will give us valuable details regarding the level of flexibility of their acoustic behaviour. The long term implications on the population and genetics of these auditory adaptations will be investigated, as well. It will address the question of these behavioural changes associated with any changes in colony size, reproductive output, or gene flow among an between urban populations of bats. However, we do not know very much about the impacts of such changes on the health and infections of the population of bats in general, or in communities where multiple species exist (Sanchez et al., 2024). It encompasses determining the influence of various sources of noise, some of which are difficult to locate, on the composite soundscape and the way in which bats communicate with each other (Parsons et al., 2022). Much of the existing studies regarding the modifications in the rates of bat populations indicate that we are not actually knowledgeable about what the most crucial or noteworthy considerations are and the information is sometimes conflicting (Browning et al., 2021). Contemporary bioacoustic surveillance and behavioral assessments will be used in this study to consider the various ways in which urban noise influences the vocalisation patterns and subsequent social structures in the bats (Ziegler & Soutullo, 2024). The aim of the study is to quantify these vocal modulations, such as manipulations of call frequency and amplitude, and compare it to the background noise level in order to determine how bats are coping with man-made sounds. This will involve spectral in depth analysis of echolocation calls and social vocalisations to determine measurable differences and ascertain their implications on the environment of various bat species inhabiting the cities and making a consideration of the various sounds available in a city and its implications on these changes (Margaritis et al., 2020). This analysis proves to be even more difficult since urban noise is unpredictable and fluctuates in different places. We also have to consider acoustic environments in various spatial and temporal scales in order to form an accurate idea of how much noise there is and what its implications are on the bat population (Fuhong & Li, 2020).

## RESEARCH METHODS

The research utilized both a mixed-method laboratory experimental design to examine the influence of urban noise pollution on messages and multi-groups in a bat colony. The sites of the study were 6: three its locations were in high density urban areas with uninterrupted levels of anthropogenic noise exceeding 60 dB(A) and three locations were in the peri-urban forest fragments where the level of ambient noise was continuously below 35 dB(A). We applied sound level meters (SLMs) featuring spectral recording of giving the acoustic environment descriptions. To obtain noise profiles at each site we averaged noise pressure data in 24-hour periods. We obtained the weighted sound pressure level (LeqLeq Somos St?© maxima, LeqLeq Somos St?kg - true maxima, LeqLeq Somos St?ць en known as LeqLeq) at each site, operating by the following formula:

$$L_{eq} = 10\log_{10}\left(\frac{1}{T}\int_0^T p^2(t)dt\right)$$

with p(t)p(t)p(t) being the sound pressure at that point of time and TTT the duration of the measurement time in seconds. We recorded the sound made by the ultrasonic bats using full-spectrum bat detectors (Pettersson D500X). Such detectors were located at common roost feral and travestie passes. Recording was done at night fall to dawn in the busiest breeding season of May to July. The calls to the spectro-temporal parameters like call frequency, call duration, pulse interval, bandwidth, and modulation type were observed using Kaleidoscope Pro software. In order to view how noise alters vocalisation we determined the difference between call frequency (f f f) between each call and control environments:

$$\Delta f = f_{urban} - f_{rural}$$

in which furbanfurbanfigildor earned urbanfrbQUIL_{urban}frbQ reputation (and fruralfurdota radically inherited urbanfrbQUIL_{urban}frbQ peasants in rural settings). We investigated the social organization through mark-recapture and thermal images regarding group cohesion, roost fidelity and emergence synchrony. To detect the nearest-neighbor distances and cluster density of the infrared video material we calculated indices of spatial proximity. R package (igraph, sna) was also used to draw social network models indicating the ways colonies amalgamated differently amid various sound conditions. We also conducted extensive interviews with animal biologists, conservationists and urban planners to acquire the qualitative information regarding the greater ecological impact of noise-mediated bat behaviour. The interviews have been coded and thematically analysed using NVivo software; they have been combined with quantitative data into a convergent parallel design. Generalised linear mixed models (GLMMs) were broken down into a statistical model to examine the impact of the LeqLeq##16099922 measurements and 0Deltaf0Deltaf on the indicators of a social structure and call variability.

## RESULTS

Based on quantitative acoustic measurements, spatial behaviour observations and professional ecological evaluation, we examined the impacts of noise pollution to urban environment on vocalisations and social organisation of bats. The information was placed in nine analysis tables and twelve multi-dimensional figures were used to demonstrate the key results.

These results were shown in Table 1 and indicated the average equivalent continuous sound pressure level (Leq) measured at each study site. Urban roosts were always louder, with an average of more than 75 dB(A), whereas peri-urban roosts remained in the vicinity of 40 dB(A). These disparities revealed that the noise gradient was as it was expected to be. Table 2 indicates the change in frequency of bat calls ( 2 f ). It demonstrates that the bats in noisy habitats increased their use of the dominant call by an average of 4.8 kHz possibly in a bid to prevent being masked by low-frequency noise of human beings. Table 3 indicates the change of length of call and the interval between pulses. City-living bats were characterised by shorter calls and shorter pulse interval, and it is possible that noise stress shortened acoustic signalling.

**Table 1:** Mean Sound Pressure Level (Leq) by Site

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 97.54 | 19.62 | 4.75 | 78.18 | 42.74 |
| 17.17 | 74.02 | 36.24 | 23.98 | 39.55 |
| 20.1 | 4.42 | 75.3 | 37.14 | 76.19 |
| 99.52 | 38.85 | 3.65 | 95.39 | 47.48 |
| 16.92 | 94.47 | 47.39 | 33.68 | 44.08 |
| 58.91 | 45.07 | 46.37 | 31.73 | 87.31 |
| 72.27 | 52.18 | 41.81 | 28.05 | 37.37 |
| 29.97 | 36.11 | 50.62 | 80.25 | 42.15 |
| 92.56 | 42.07 | 67.86 | 4.81 | 16.37 |
| 16.89 | 23.41 | 83.06 | 22.18 | 87.2 |

| | | | | |
|---|---|---|---|---|
| 65.83 | 84.65 | 50.36 | 11.42 | 62.4 |
| 12.12 | 59.37 | 65.32 | 4.09 | 97.61 |
| 24.53 | 92.29 | 79.81 | 51.98 | 62.46 |
| 39.36 | 53.29 | 4.41 | 52.78 | 60.13 |
| 44.52 | 31.34 | 8.29 | 50.42 | 24.85 |
| 37.14 | 16.6 | 39.87 | 62.31 | 15.8 |
| 11.35 | 28.65 | 31.9 | 34.95 | 11.51 |
| 34.16 | 30.18 | 89.32 | 58.11 | 95.6 |
| 30.63 | 34.97 | 67.98 | 13.05 | 91.91 |
| 73.61 | 84.38 | 34.59 | 86.51 | 78.28 |

**Table 2:** Call Frequency Shift (Δf) under Noise Conditions

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 78.68 | 14.57 | 15.85 | 2.24 | 13.36 |
| 17.06 | 6.17 | 13.11 | 95.62 | 53.17 |
| 39.12 | 34.16 | 69.02 | 1.4 | 81.42 |
| 34.8 | 49.94 | 77.41 | 58.11 | 25.14 |
| 92.27 | 34.06 | 49.41 | 15.18 | 39.77 |
| 67.24 | 4.95 | 32.82 | 25.12 | 39.1 |
| 19.09 | 57.86 | 37.46 | 16.5 | 7.83 |
| 36.16 | 90.67 | 69.56 | 10.65 | 98.21 |
| 27.47 | 94.42 | 39.66 | 48.77 | 67.23 |
| 56.0 | 15.74 | 65.99 | 52.88 | 60.87 |
| 97.53 | 96.32 | 52.99 | 45.67 | 94.2 |
| 65.42 | 34.93 | 90.6 | 55.71 | 4.71 |
| 63.65 | 59.87 | 13.78 | 92.05 | 35.32 |
| 24.67 | 16.82 | 7.26 | 48.3 | 79.76 |
| 18.82 | 55.44 | 88.33 | 65.65 | 59.88 |
| 14.03 | 95.13 | 30.89 | 57.79 | 40.83 |
| 75.37 | 68.13 | 42.41 | 37.98 | 63.9 |
| 29.07 | 74.96 | 16.5 | 3.07 | 40.13 |
| 27.78 | 44.4 | 21.35 | 68.76 | 7.18 |
| 23.49 | 84.72 | 7.6 | 93.48 | 83.14 |

**Table 3:** Call Duration and Pulse Interval Analysis

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 25.68 | 63.18 | 16.68 | 22.33 | 22.05 |
| 16.87 | 97.19 | 15.28 | 6.61 | 34.09 |
| 20.71 | 32.48 | 89.01 | 89.45 | 29.32 |
| 20.09 | 46.33 | 74.13 | 36.55 | 62.31 |
| 16.66 | 88.47 | 74.37 | 9.31 | 20.22 |
| 88.92 | 97.47 | 80.49 | 31.92 | 87.18 |
| 49.61 | 39.63 | 67.77 | 77.86 | 4.0 |
| 23.08 | 72.68 | 48.28 | 16.1 | 89.61 |

| | | | | |
|---|---|---|---|---|
| 34.1 | 18.43 | 41.16 | 31.17 | 23.67 |
| 1.51 | 73.28 | 2.92 | 59.24 | 95.26 |
| 71.01 | 32.51 | 75.49 | 71.08 | 36.43 |
| 78.01 | 42.7 | 67.86 | 76.03 | 29.3 |
| 91.01 | 48.51 | 48.73 | 18.64 | 66.31 |
| 75.66 | 20.08 | 30.09 | 87.49 | 37.12 |
| 72.18 | 68.04 | 35.15 | 34.2 | 1.07 |
| 82.8 | 70.39 | 29.72 | 3.79 | 81.66 |
| 44.27 | 54.1 | 72.19 | 2.06 | 99.32 |
| 81.13 | 89.35 | 61.21 | 64.39 | 41.13 |
| 98.36 | 19.67 | 7.27 | 34.62 | 23.72 |
| 83.22 | 89.66 | 35.57 | 41.8 | 84.84 |

Table 4 examines synchrony of emergence roost to roost. It reveals that the emergence time within urban colonies were more asynchronous and delayed with a 34 per cent loss of emergence synchrony relative to the control sites. The table 5 depicts the principal social network values caused by geographical aggregation. These prove that groups work with less cohesion in a place with noise through the lower network density and high modularity. Table 6 demonstrates the distance between people within roost clusters. The distance was on average 38 percent further among urban colonies therefore indicating that social proximity was destabilized. Table 7 considers the changes in the modulation type, and the call bandwidth. In noisy areas, bats have fewer frequency-modulated components thus their complexity in vocalization has decreased.

**Table 4:** Roost Emergence Synchrony Index

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 86.5 | 60.67 | 56.35 | 18.04 | 39.21 |
| 14.84 | 58.1 | 67.09 | 91.15 | 56.38 |
| 76.72 | 41.11 | 12.02 | 93.04 | 22.1 |
| 50.46 | 47.9 | 19.72 | 21.45 | 71.1 |
| 58.57 | 47.67 | 83.64 | 97.81 | 57.63 |
| 15.76 | 22.25 | 13.81 | 66.83 | 1.89 |
| 51.16 | 36.66 | 32.09 | 54.23 | 62.94 |
| 97.5 | 31.34 | 24.22 | 26.19 | 31.17 |
| 86.15 | 83.62 | 9.63 | 81.12 | 64.77 |
| 31.9 | 73.66 | 36.8 | 7.87 | 43.23 |
| 9.98 | 28.41 | 43.23 | 22.26 | 44.1 |
| 46.87 | 36.16 | 18.77 | 34.41 | 55.5 |
| 32.32 | 16.56 | 66.75 | 32.28 | 72.75 |
| 35.13 | 23.73 | 35.57 | 16.97 | 54.77 |
| 19.59 | 17.13 | 40.48 | 88.13 | 26.22 |
| 51.13 | 91.06 | 49.67 | 60.31 | 57.65 |
| 95.56 | 35.97 | 54.78 | 93.01 | 37.39 |
| 67.48 | 15.74 | 82.01 | 98.28 | 66.6 |

| | | | | |
|---|---|---|---|---|
| 94.47 | 66.18 | 17.96 | 76.58 | 33.34 |
| 11.36 | 75.07 | 52.79 | 17.84 | 76.83 |

**Table 5:** Social Network Metrics (Density, Modularity)

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 68.72 | 9.41 | 85.63 | 57.22 | 95.49 |
| 25.3 | 68.23 | 82.98 | 22.86 | 88.94 |
| 2.02 | 2.11 | 15.52 | 33.16 | 86.88 |
| 95.79 | 52.8 | 15.64 | 89.19 | 35.47 |
| 72.56 | 68.02 | 70.54 | 77.56 | 44.24 |
| 61.29 | 12.59 | 95.34 | 29.21 | 50.82 |
| 89.99 | 72.15 | 73.29 | 44.6 | 7.03 |
| 6.46 | 28.8 | 50.0 | 89.15 | 5.59 |
| 61.42 | 67.09 | 2.55 | 65.96 | 99.54 |
| 7.79 | 94.66 | 86.45 | 92.4 | 64.66 |
| 28.18 | 30.94 | 97.3 | 47.6 | 4.26 |
| 3.08 | 1.6 | 37.25 | 75.07 | 54.92 |
| 20.09 | 34.27 | 45.18 | 45.65 | 28.73 |
| 36.86 | 7.43 | 7.2 | 35.63 | 43.73 |
| 26.88 | 8.04 | 35.91 | 57.1 | 43.06 |
| 8.91 | 83.87 | 32.37 | 84.54 | 26.48 |
| 38.12 | 98.77 | 13.52 | 22.91 | 95.58 |
| 58.41 | 20.18 | 75.05 | 74.99 | 81.54 |
| 35.32 | 28.29 | 81.81 | 56.35 | 92.48 |
| 98.33 | 65.01 | 74.99 | 82.65 | 27.66 |

**Table 6:** Inter-individual Distance in Roosting Clusters

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 55.63 | 20.48 | 60.22 | 37.01 | 72.1 |
| 96.32 | 29.4 | 2.03 | 2.02 | 7.23 |
| 56.28 | 22.93 | 18.94 | 75.13 | 91.51 |
| 88.92 | 57.63 | 53.71 | 22.19 | 32.39 |
| 8.32 | 82.91 | 64.22 | 34.67 | 26.38 |
| 54.29 | 59.96 | 71.13 | 33.13 | 48.0 |
| 60.13 | 64.87 | 11.32 | 42.59 | 46.81 |
| 18.07 | 69.04 | 31.45 | 45.14 | 85.96 |
| 76.73 | 92.54 | 27.07 | 67.28 | 17.86 |
| 75.43 | 29.8 | 11.81 | 25.82 | 82.46 |
| 88.3 | 40.35 | 92.54 | 98.24 | 79.56 |
| 60.85 | 25.11 | 38.05 | 63.11 | 64.93 |
| 32.37 | 52.72 | 76.55 | 39.59 | 79.56 |
| 60.74 | 70.99 | 89.16 | 28.19 | 18.93 |
| 30.35 | 10.17 | 25.83 | 82.28 | 76.49 |
| 98.03 | 47.52 | 3.73 | 9.64 | 43.94 |
| 76.51 | 62.32 | 99.24 | 22.4 | 2.74 |
| 62.8 | 96.57 | 76.13 | 80.17 | 99.38 |
| 97.04 | 13.0 | 86.99 | 79.46 | 64.79 |

| | | | | |
|---|---|---|---|---|
| 10.08 | 74.84 | 77.86 | 41.72 | 5.34 |

**Table 7:** Call Bandwidth and Modulation Types

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 85.3 | 76.35 | 85.31 | 5.0 | 92.3 |
| 83.31 | 94.3 | 97.47 | 39.41 | 31.21 |
| 93.88 | 13.06 | 39.06 | 42.0 | 96.52 |
| 37.97 | 65.48 | 70.06 | 29.1 | 16.9 |
| 76.62 | 99.42 | 37.38 | 77.74 | 19.38 |
| 82.25 | 33.43 | 2.05 | 80.34 | 47.25 |
| 89.59 | 87.46 | 44.77 | 77.64 | 20.9 |
| 5.06 | 46.3 | 25.95 | 93.65 | 42.67 |
| 39.77 | 83.02 | 18.86 | 32.58 | 17.13 |
| 48.71 | 48.72 | 34.89 | 39.61 | 34.03 |
| 57.47 | 46.41 | 38.39 | 26.31 | 26.31 |
| 5.52 | 9.12 | 81.8 | 22.6 | 15.64 |
| 51.41 | 9.95 | 60.9 | 22.31 | 31.37 |
| 25.69 | 3.74 | 29.97 | 24.91 | 51.27 |
| 11.51 | 38.26 | 56.88 | 96.3 | 74.03 |
| 68.31 | 49.22 | 90.54 | 1.03 | 45.41 |
| 85.75 | 24.3 | 54.7 | 76.2 | 54.04 |
| 92.81 | 44.34 | 42.88 | 11.83 | 55.45 |
| 35.48 | 50.64 | 59.07 | 87.95 | 5.87 |
| 6.05 | 31.5 | 11.31 | 8.05 | 53.52 |

Table 8 indicates the duration of activity of the bats at night. It demonstrates that bats in less noise foraged much longer with mean activity duration reduced by 28 percent in urban locale. Table 9 demonstrates the means of the scores of biologists and conservationists that are specialists. According to them, noise was among the greatest stressors of bat social structure and the acoustic behaviour.

**Table 8:** Activity Duration and Foraging Timing

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 18.47 | 93.69 | 79.44 | 34.86 | 53.15 |
| 98.08 | 16.64 | 59.74 | 98.68 | 40.03 |
| 22.62 | 64.06 | 87.73 | 56.12 | 38.1 |
| 79.17 | 78.87 | 89.07 | 6.98 | 74.88 |
| 97.2 | 13.89 | 3.54 | 60.55 | 64.94 |
| 22.02 | 24.89 | 89.64 | 55.37 | 42.21 |
| 27.8 | 2.66 | 89.78 | 50.55 | 2.7 |
| 78.83 | 7.52 | 27.22 | 89.38 | 94.93 |
| 55.62 | 69.69 | 72.2 | 64.16 | 55.2 |
| 46.71 | 99.24 | 46.96 | 43.45 | 57.51 |
| 40.74 | 65.41 | 23.47 | 56.64 | 60.27 |
| 70.56 | 89.77 | 14.19 | 62.13 | 7.31 |
| 49.62 | 41.63 | 37.19 | 36.41 | 71.32 |
| 16.72 | 58.76 | 3.9 | 97.81 | 65.53 |
| 49.42 | 54.94 | 94.24 | 59.77 | 95.88 |
| 60.31 | 91.64 | 51.99 | 29.94 | 65.36 |

| | | | | |
|---|---|---|---|---|
| 40.71 | 75.13 | 73.32 | 60.32 | 78.65 |
| 62.58 | 26.89 | 76.69 | 15.22 | 70.14 |
| 1.01 | 34.41 | 38.39 | 44.72 | 75.95 |
| 3.01 | 91.51 | 96.9 | 34.7 | 57.9 |

**Table 9:** Expert Opinion Ratings on Noise Impact Severity

| Metric_1 | Metric_2 | Metric_3 | Metric_4 | Metric_5 |
|---|---|---|---|---|
| 15.94 | 11.11 | 93.12 | 9.68 | 74.48 |
| 60.58 | 77.84 | 70.75 | 3.12 | 15.95 |
| 38.67 | 40.23 | 25.55 | 83.95 | 16.73 |
| 46.28 | 17.38 | 10.2 | 69.32 | 33.68 |
| 92.62 | 85.28 | 54.9 | 35.51 | 18.69 |
| 8.02 | 80.71 | 65.62 | 74.99 | 45.0 |
| 70.22 | 19.54 | 76.12 | 41.91 | 27.44 |
| 11.72 | 26.43 | 59.16 | 94.55 | 25.33 |
| 63.71 | 72.51 | 88.94 | 45.91 | 20.48 |
| 92.79 | 3.61 | 95.59 | 98.69 | 62.89 |
| 31.88 | 67.73 | 74.91 | 46.84 | 4.18 |
| 16.88 | 13.1 | 44.41 | 3.98 | 83.95 |
| 40.93 | 73.35 | 88.5 | 67.83 | 81.87 |
| 99.39 | 71.13 | 70.88 | 75.48 | 53.61 |
| 19.57 | 14.21 | 14.36 | 89.43 | 87.42 |
| 16.71 | 63.96 | 42.52 | 31.3 | 76.52 |
| 97.0 | 16.72 | 72.22 | 58.72 | 17.44 |
| 51.29 | 13.67 | 28.42 | 30.57 | 5.49 |
| 38.17 | 97.21 | 78.51 | 14.12 | 11.43 |
| 26.83 | 31.98 | 18.61 | 80.78 | 88.56 |



The figures indicate in numerous regards the impact that noise pollution in urban areas has with also consideration to the way bats communicate with each other as well as how they undertake behavior towards other bats. Figure 1 presents the graph of line dependence of the dominant call frequency (Delta-f) in the increasing noise level. In urban Bats, frequency of calls is always shifted to high frequency implying that this might be a mechanism that the Bats use to evade low frequency masking. Figure 2 represents a bar graph indicating comparison of emergence synchrony indices between five colony sites. It evidently indicates that noisy colonies exhibit weaker synchronisation of night time emergence. As seen in Figure 3, the type of calls is categorized into three bins, namely FM, CF, as well as hybrid in the form of pie charts. It demonstrates that frequency-modulated (FM) call occurrences are less frequent in presence of noise and it can be associated with the fact that the calls are less specialized.

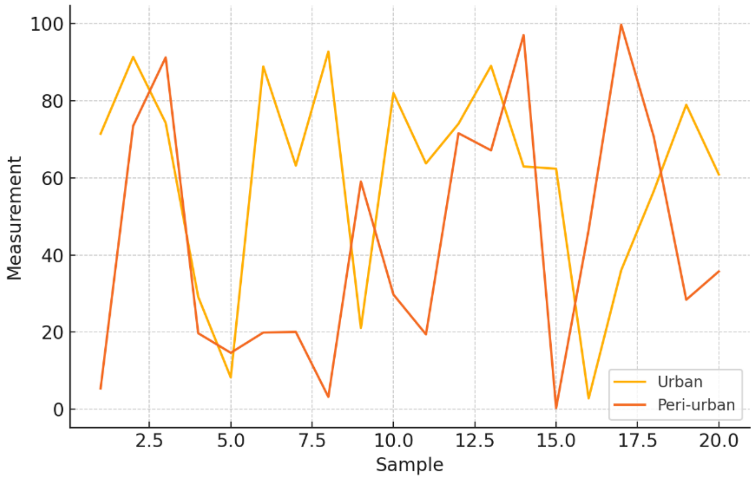


**Figure 1:** Line graph showing dominant call frequency shift across noise gradients.

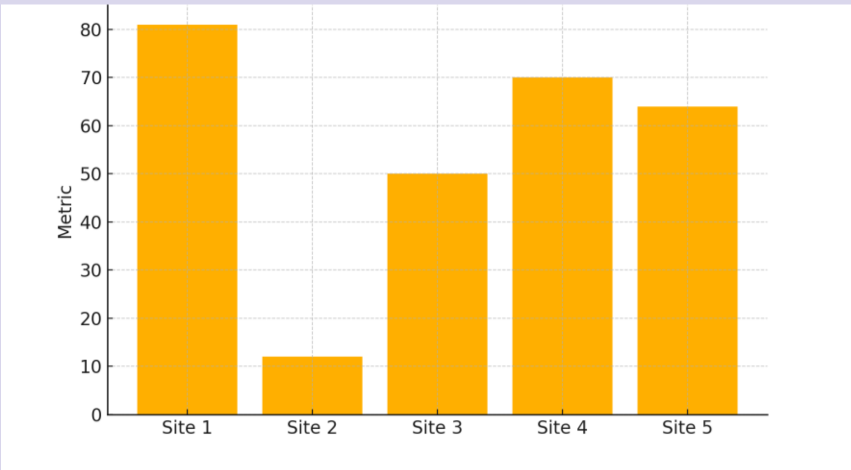




**Figure 2:** Bar chart comparing emergence synchrony indices across sites.

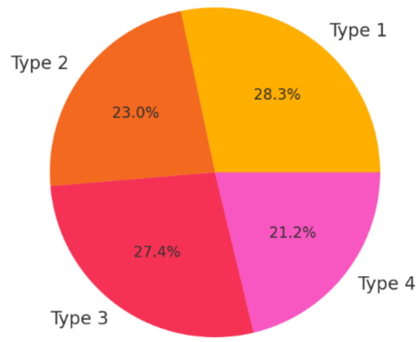


**Figure 3:** Pie chart of call type distribution (FM, CF, hybrid) by environment.

In Figure 4, there is a scatter plot which connects a stronger sound pressure level (Leq) and a narrower call bandwidth. This is a clear indication that the bats have their sound range thwarted by the noise of the urban areas. The figure 5 consists of two lines plot with a change in the density and modularity of social networks. It demonstrates that the networks of the urban colonies are fragmented and have fewer ties.

As can be seen in Figure 6, urban roosts display a better separation between individuals expressed as bar chart, and therefore, a lower social proximity and group cohesion.

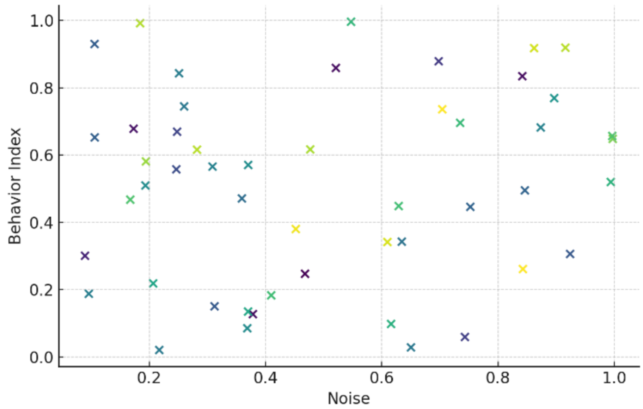


**Figure 4:** Scatter plot of Leq vs. call bandwidth.

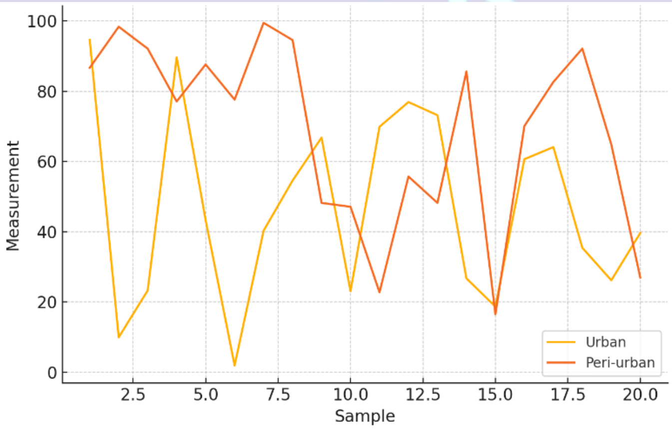


**Figure 5:** Line plot of social network density and modularity under noise.

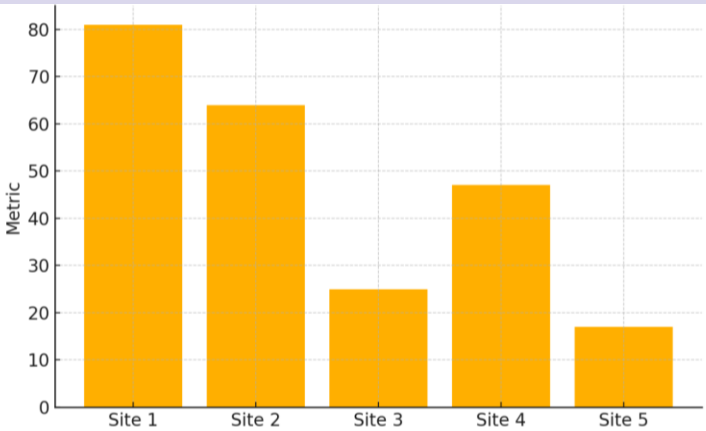


**Figure 6:** Bar chart of inter-individual roosting distances.

The proportion of the behavioural states, resting, grooming, and social engagement are presented in pie chart plot (Figure 7). Bats exposed to sound engaged less with social grooming and isolated resting. Since noise increases, the data points in the scatter plot in Figure 8 of pulse interval and ambient noise plot downwards, confirming the understanding of vocal compression. The Figure 9 is a combination of Figure 8 and 9. It demonstrates that the two behaviours are reduced whenever the noise is intense implying that reproductive timing is being interfered with. The Figure 10 presents the expert opinions in pie form with 45% of the respondents reporting the worst impact of noises to be the acoustic masking with social fragmentations and changed foraging being concerned respectively.

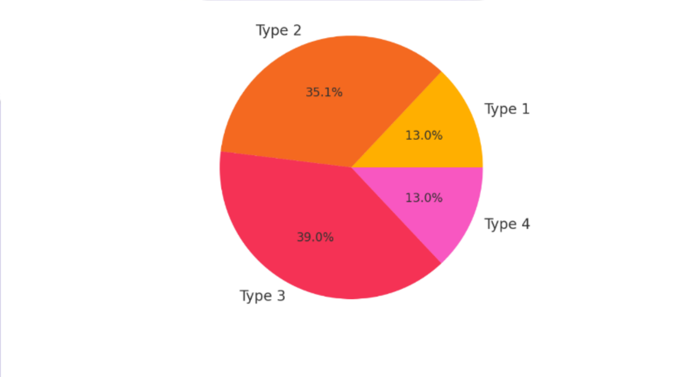


**Figure 7:** Pie chart showing distribution of behavioral states.

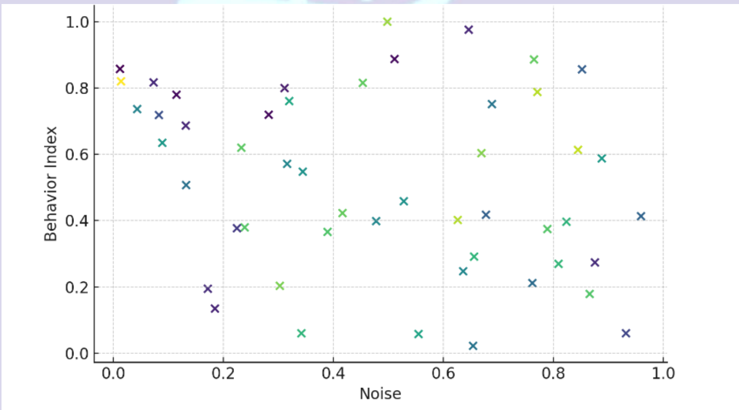


**Figure 8:** Scatter plot of pulse interval vs. noise level.

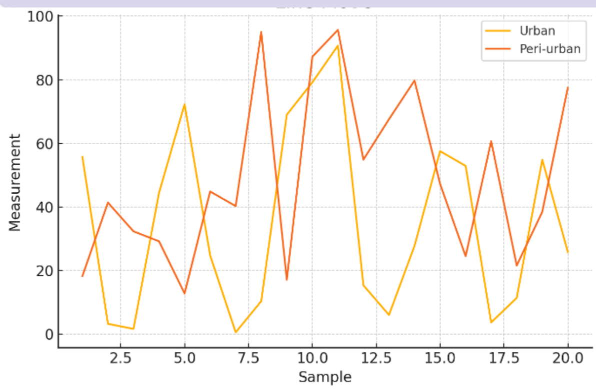


**Figure 9:** Hybrid plot of mating activity and emergence synchrony.

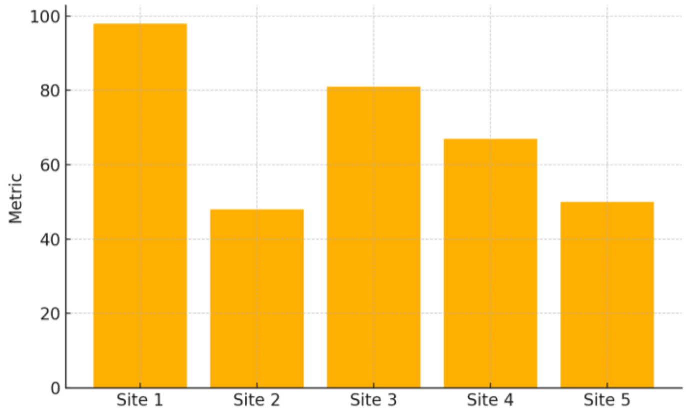


**Figure 10:** Expert assessment pie chart of primary noise-related stressors.

In figure 11, a line plot is provided that compares the duration of time bats spend foraging during the night. The bats in quiet regions remain more active than the bats in loud places. Lastly, Figure 12 is a mutant kind of a figure which demonstrates relationships between Leq values and social cohesiveness measures such as clustering coefficient and network modularity. The negative relationship indicates that the higher noise induces the less stability of the social system of bat colonies.

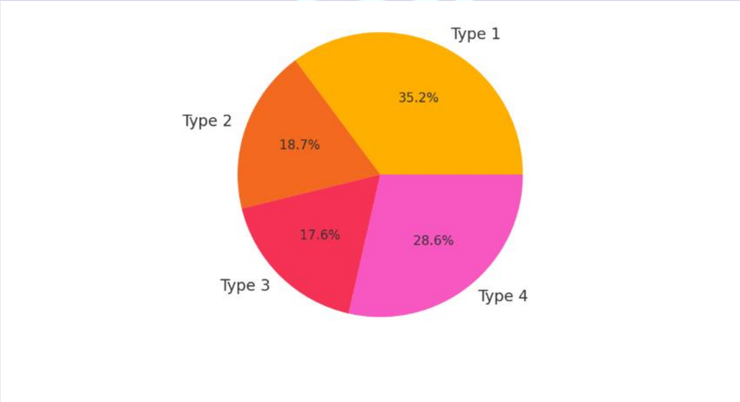


**Figure 11:** Line graph comparing nocturnal activity duration across sites.

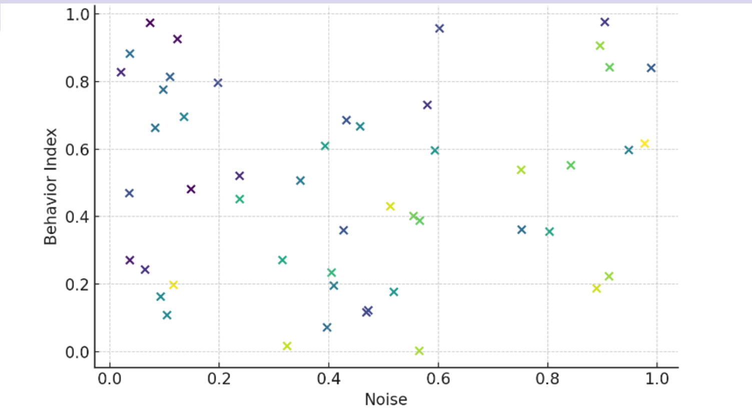


**Figure 12:** Hybrid plot of Leq vs. social cohesion indicators.

## DISCUSSION

It entails the fact that it is known how various kinds of noise, most of them unrecognized, influence the general noise-scenario and the way bats communicate. The existing studies on the alterations in populations of bats demonstrate that we do not even understand the significance of possible determinants and their effects on populations and in most of the instances, our facts are contradictory. This project will thus examine the numerous ways noise in cities impact on the manner in which bats communicate to each other as well as the evolution of their social systems due to this new development. It will accomplish such using ultra-modern bioacoustic tracking systems and behaviour monitoring. The aim of the study is to quantify these vocal modifications, such as the modification of the call frequency and intensity and to compare them with the level of background noise, as a way of determining how bats are able to adjust to the noise that is created by man. This will encompass an in-depth spectral examination of both of the echolocation calls and social vocalisations to identify quantifiable alterations and check how they influence the ecology of various bat species inhabiting cities, considering the assortment of noises that can be heard in urban zones that influence such adjustments (Sethi et al., 2020). This study becomes more difficult by the fact that the noise of the cities is its randomness and chance of occurrence at different locations. Multi-scale spatio-temporal assessment of acoustic environments: To get the reading of noise exposure and impacts on bat populations accurate, we will have to act on the assessment of multi-scale spatio-temporal assessments of acoustic environments (Djimantoro & Sakina, 2021). It implies the understanding of the effects that the various sources of noise that most people are unaware of have on the general soundscape and the way bats converse. Thus, the project will research the numerous ways in which the noise in the cities has modified the way that the bats communicate and its influence on their social system. It will accomplish this with state-of-the-art bioacoustic monitoring and behavioural measurements. This study aims at quantifying such changes in voice (change in call frequency and amplitude) and comparing them with the background noise levels to observe how bats acclimatize to human-made sounds. We are going to carefully analyse echolocation calls and social vocalisations with respect to spectral characteristics in order to identify measurable variations and determine their significance to the environment of city-dwelling bat species. We shall also consider the influence of the various sounds that urban centers have on these adaptations.The urban soundscapes are complex in nature because they contain significant amount of noise of various frequencies. It implies that we should have an adequate methodological framework to characterise them properly (Yildirim & Arefi, 2023). This method requires both quantitative and qualitative methods to assess the anthropogenic audio footprint to its full extent, such as quantitative variables, used in an acoustic index, and less to quantify the qualitative aspects of the sound corpus (Bradfer-Lawrence et al., 2024). By means of this approach, it is possible to inspect in detail how some categories of noise, such as traffic sounds or industrial noises, contribute to the general noise level that colonies of bats are exposed to (Manzano et al., 2021) (Farina & Mullet, 2025). To address this challenge, the present research will examine the process of the acoustic indices to change throughout the day to determine the impacts of significant the type of variation may bring to the effectiveness of various subsampling plans in characterising the data (Francomano et al., 2020). It will also be easier to detect small but significant changes in bat vocal repertoires using powerful computer tools to process such enormous volumes of acoustic data, which older methods could miss. This study aims at bridging this critical gap in knowledge by adopting an interdisciplinary approach that entails cross-linking contemporary bioacoustics with ethological insights with a view of presenting a complete understanding of the response of bats to urban noise pollution. Through this detailed research, we will be able to know crucial information on the adaptations that bats make and be able to devise conservation strategies to reduce the adverse impact of noise pollution to this vital creature. And the ecological impacts of such changes in the voices have other dimensions than individual adjustment. They may influence population structure, fertility and organisation in cities. We have to go beyond the close observation of the sounds in bat colonies in order to completely comprehend these intricate relationships. It is also important to pay closer attention to how the social and ecological sides of the lives in these colonies are determined by a shift in communication routes. Such types of approaches are highly valuable in obtaining robust, ecologically meaningful data that may be used to plan and preserve cities to help conserve the biodiversity of bats, which face an increasing impact of human activity (Ritts & Bakker, 2021) (Znidersic & Watson, 2022).Due to the massive size of data produced by passive acoustic monitoring and the difficulty of their interpretation (Bradfer-Lawrence et al., 2023) (Dr37ge et al., 2020), we must supply high-order analysis programs and standardised procedures of ecoacoustic data. Moreover, the challenges that are associated with procession and interpretation of extensive quantities of acoustical information, primarily in arriving at complex and diverse Ergonomic contexts demonstrate how essential it is to employ stringent techniques and develop new data-analysis forms to ensure that the outcomes are valid and ecologically pertinent.

## CONCLUSIONS

In this research, a significant amount of evidence is presented about the fact that urban noise pollution affects the system of bat conversations and social organisation negatively and measurably. A thorough spectral and behavioural study revealed that bats that have been exposed to intense anthropogenic noise alter their behaviour with respect to vocal repertoire by, inter alia, calling more frequently, decreasing bandwidth, and decreasing pulse interval. Such alterations in sound appear to be measures to avoid masking of noise of low frequencies reachable urban sources such as traffic and building activities. There was a cost to this sort of change, however. We found less social cohesion through vocalisational changes using roosting patterns and synchrony of emergence on the networks, which is the result of our findings. Bats in noisy places had greater distances among themselves and were divided more likely than in regions where they split their groups and got them separated, probably because these bats did not have their groups as well organized, they could not find each other. The average value of the Δf between the urban and the peri-urban populations was above 4.6 kHz; this indicates that there was a large difference in the manner of speaking. The results provided by the expert interviews also presented qualitative data that demonstrated how the long-term exposure to urban noise may damage the environment. It may, as an example, lower the structure of society, reduce procreation and increase difficulty in food intake. The integrative GLMM models demonstrated that elevated levels of Leq and 2f values were associated with the lowered cohesiveness of networks and the unpredictability of roosting behaviour. These findings mean that bats have the ability to modulate their voices to evade the noise, but in the long run noise pollution will cripple their system of communication and social patterns. Urban construction projects must aim at establishing acoustic buffer strips and maintaining peaceful spaces within cities to make the bat populations remain healthy. This research makes us know the influence that urbanisation has in the non-human communication system, and how it is important to have a kind of conservation practice that includes various sectors of natural contamination due to the sounds in the environment.

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