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Meta-Analysis of the Effect of Anthropogenic Noise on Bird Song and Abundance

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Abstract

Urbanization is one of the most pervasive forms of environmental change, with anthropogenic noise posing a major challenge for birds that depend on acoustic communication for reproduction and survival. Human-generated noise overlaps with avian vocal frequencies and can disrupt these signals, altering bird behavior with consequences for population persistence and overall diversity. Although many studies have examined how birds respond to urban noise, differences across species and habitats make drawing general conclusions difficult. To address this gap, I conducted a systematic review and meta-analysis that examined shifts in vocal behavior and abundance across urban and rural habitats. Results revealed that birds consistently increased both song loudness and frequency in noisy environments, with the strongest effects observed in urban areas. Abundance responses were more variable: passerines, with naturally higher-pitched songs, exhibited higher urban abundance, whereas corvids showed evidence of needing higher vocal adjustment, potentially impacting their abundance. Habitat moderated outcomes, with urban green spaces associated with smaller increases in vocal effort compared to city centers, and rural wildlife preserves supporting the highest abundance. These findings demonstrate that urban noise reshapes avian communication and communities by favoring species capable of vocal adjustment.

Keywords: anthropogenic noise, noise pollution, urbanization, bird vocal behavior, song frequency, avian abundance, passerines, corvids, meta-analysis

1. Introduction

Urbanization is rapidly transforming landscapes, replacing natural habitats with roads, buildings, and residential areas (Arévalo et al., 2022; Proppe et al., 2012). These changes reduce resources and alter conditions critical for wildlife survival (Halfwerk et al., 2011; Kight et al., 2012). Birds are particularly affected because they rely on vegetation for nesting and foraging, open areas for movement, and sound environments that allow effective communication (Arévalo et al., 2022; Proppe et al., 2013). Within cities, birds face challenges such as light pollution, reduced food availability, and high levels of human-made noise (Halfwerk et al., 2010; Kight et al., 2012; Önsal et al., 2022). These pressures influence where birds can live, how they behave, and their ability to maintain stable populations. Reductions in population abundance can ultimately lead to the disappearance of species (Arévalo et al., 2022) and have cascading ecological consequences on arthropod and plant communities.

Noise pollution directly interferes with communication, as birds rely on vocalizations to defend territories, attract mates, and warn of predators (Dowling et al, 2012; Önsal et al., 2022; Shannon et al., 2015). Background noise can mask these signals, prompting birds to increase song pitch or avoid noisy areas (Arroyo-Solís et al., 2013; Potvin et al., 2016; Juárez et al., 2021; Kleist et al., 2016). Prolonged exposure can also cause stress or impair development, limiting survival and reproduction (Engel et al., 2024; Deoniziak & Osiejuk, 2021; Bahía et al., 2024). Overall, noise can reduce species diversity and population resilience (Proppe et al., 2013).

Despite extensive research, no clear consensus exists on the effects of noise on birds (Almarza-Batuecas et al., 2025; Potvin et al., 2016; Van Donselaar et al., 2018; Halfwerk et al., 2011; Huet des Aunay et al., 2014), potentially due to high heterogeneity among species and habitat types. Urbanization can fragment habitats, limit resources, and ultimately favor tolerant species (Proppe et al., 2013; Nordt & Klenke, 2013); some species can exploit noisy areas when competitors struggle (Blickley et al., 2012; Wood & Yezerinac, 2006). Species-specific traits such as song type, social structure, and noise sensitivity may further influence outcomes (Montenegro et al., 2021; Anobie et al., 2024; Senzaki et al., 2020; Francis et al., 2011).

This study examines the impact of anthropogenic noise on bird abundance and vocal behaviors (loudness and frequency), incorporating potential heterogeneity across habitat types and functional groups. There were many hypotheses at the outset of this investigation. First, as anthropogenic activity in urban areas generally produces persistent low-frequency noise that overlaps with bird vocalizations (Long et al., 2017; Önsal et al., 2022), birds may respond by singing louder or at higher frequencies. It was also expected that the abundance and diversity of birds would be negatively impacted in urban environments because of overcrowding. There was a focus on passerines and corvids to compare species' ability to tolerate noise, as they are most frequently studied in existing literature. Passerines have higher-pitched songs than corvids and require smaller changes in vocal behavior to be heard in noisy environments, which also makes them more abundant in cities (Potvin et al., 2016; Halfwerk et al., 2011). To evaluate these predictions systematically, we conducted a targeted review of empirical studies on urban noise and bird responses.

2. Methods

A systematic review was conducted using the ProQuest and JSTOR databases (searches completed on February 17, 2025). Following Population, Intervention, Comparator, and Outcome (PICO) guidelines, the following combination of search terms was used: (wildlife OR animal) AND (urban) AND ("noise effect" OR "anthropogenic noise" OR communication OR behavior OR biodiversity). The searches were refined by excluding terms related to non-urban contexts, such as "traffic" and "highway," and excluded results taking the form of graduate theses and government reports. The literature search resulted in over 10,000 potential publications. The PRISMA guidelines were followed for the filtering process (Page et al., 2021).

The filtering process consisted of three phases. Phase I involved a comprehensive search using ProQuest and JSTOR databases, employing a structured keyword strategy across three conceptual levels: subject, setting, and effect, and combining terms with Boolean operators. Doing this resulted in 144 studies. Abstracts of the remaining studies were reviewed, and relevant articles were saved to a metadata spreadsheet. After this phase, 134 articles were retained. Phase III involved full-text screening to assess study robustness and clarity in reported results parameters. Only studies that met the inclusion criteria were retained for analysis. Inclusion criteria were as follows: focusing on urban anthropogenic noise as the source; with independent variables including noise level (decibels), observation time period, and form of sound (frequency); and response variables such as animal noise level (decibels), communication time period, communication duration, and communication type. Exclusion criteria included non-empirical studies (reviews, opinions, meta-analyses), no data, and studies where the source of noise was highway traffic exceeding 55 mph (the generally accepted definition of high speed). Altogether, the included studies provided a solid foundation for assessing the effects of anthropogenic noise on urban wildlife behavior and biodiversity. After Phase III, 42 studies remained.

Detailed data were extracted from each included study covering several categories. Study location and context were recorded by noting geographic region (country, city, or ecosystem type) and habitat type (urban, suburban, mixed, or other). Noise pollution characteristics were standardized to include noise source (e.g., construction, public transport, human activity, or mixed), noise level in decibels (mean ± SD, range, or peak values), and noise frequency (Hz, if reported). For animal species and taxonomy, species names (common and scientific) and taxonomic groups (bird, mammal, amphibian, etc.) were noted. Study design details encompassed the sample size.

Statistical measures describing the relationship between noise exposure and avian outcomes were converted to Cohen's d using standard formulas (Lajeunesse, 2013). When means, standard deviations, and sample sizes were available, Cohen's d was calculated directly; otherwise, conversions were made from t, F, X2, or other effect size measurements. Effect sizes were negative when noise exposure was associated with a decrease in the measured trait (e.g., vocal amplitude) and positive when noise was associated with an increase (e.g., song frequency shift). For studies reporting multiple traits, species, or independent locations, each observation was treated as a separate data point. Multiple effect sizes from a single study were combined using multilevel meta-analysis models to calculate composite species-level effects where appropriate. All analyses were conducted in R (R Development Core Team, 2019) using the metafor package (Viechtbauer & Cheung, 2010).

2.1. Publication Bias

To assess the possibility of publication bias—graphical (funnel plots) and statistical errors—Kendall's rank correlation test was utilized (Rothstein et al., 2005). The funnel plot (Figure 1) showed that effect sizes were distributed symmetrically around the mean, with most data points clustered near zero and a relatively even spread on both sides despite having a slight right-hand tail, suggesting minimal asymmetry. A small number of outliers with large positive effect sizes and high standard errors were observed. The Kendall's Tau test indicated no significant relationship between effect size and standard error (Kendall's Tau = 0.12, p = 0.21), supporting no evidence of publication bias in the dataset.

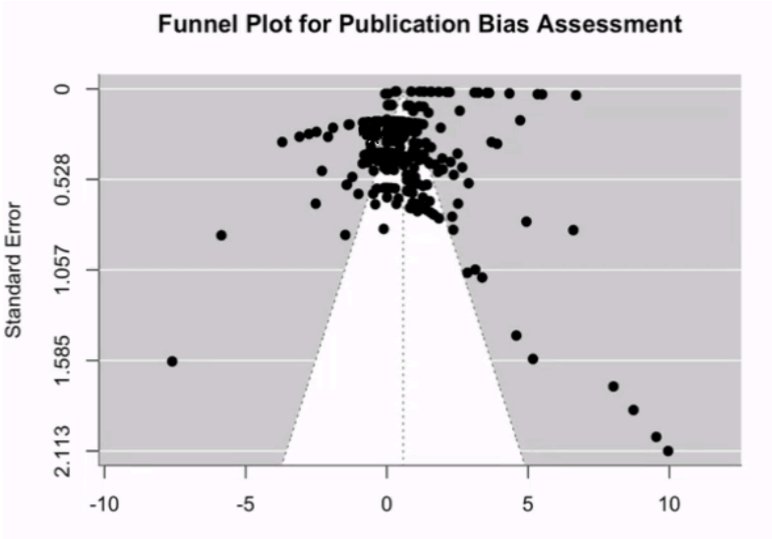

Figure 1: Publication bias funnel plot

Note: Funnel plot displaying how much bias all studies that were looked at have, based on the years they were published.

3. Results

The overall multi-level meta-analysis revealed a large effect size of noise on birds.

Table 1: Overall meta-analysis statistics

Metric	Value
Original effect sizes	438
Recalculated effect sizes	298
Studies included	42
Studies with multiple effects	35
Primary effect size (multi-level)	0.655
Primary standard error	0.147
Primary p-value	8.35E-06
Single-level effect size	0.5785805
Single-level standard error	0.082

Note: Summary of overall multi-level meta-analysis statistics on the effect of noise on birds, including effect sizes, standard errors, heterogeneity, and publication bias.

Effect sizes indicated an overall increase in birds' vocal traits and variable abundance responses due to urbanization (Figure 2). Birds generally became louder and increased their frequency. Loudness increased significantly in urban environments but was not significant in rural areas, while song frequency consistently increased across both urban and rural habitats. Overall effects on abundance were not significant, although trends suggested increased abundance in rural areas and slight declines in urban areas.

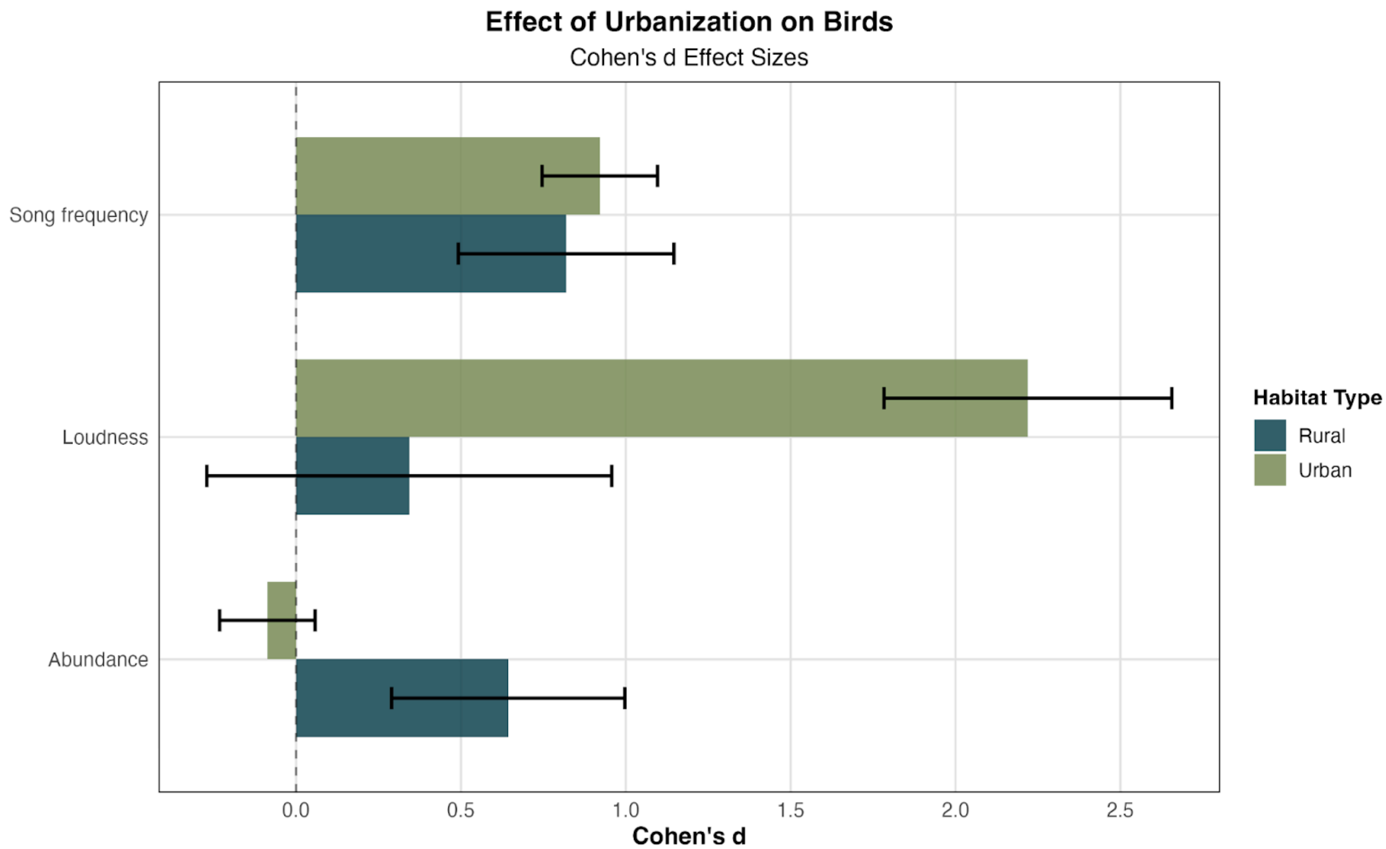

Figure 2: Effect of urban vs rural environments on different variables among birds, sample size = 442
Note: Urban vs. rural environments on the effect of noise on birds. Abundance, Song Frequency, and Song Loudness were recorded. The y-axis represents the habitat type (urban vs rural), and the x-axis shows Cohen's d effect sizes. The bars represent the standard error.

Analysis of specific urban habitat types showed that urban green spaces exhibited a positive association with increased bird song loudness, whereas suburban environments showed a positive effect on bird song frequency (Figure 3, Panel A). Urban city environments showed limited effects on abundance and frequency. Within rural habitats, the largest positive effects were observed on bird abundance in wildlife preserves and on song frequency in woodlands. Farmland and marsh habitats were not significant (Figure 3, Panel B).

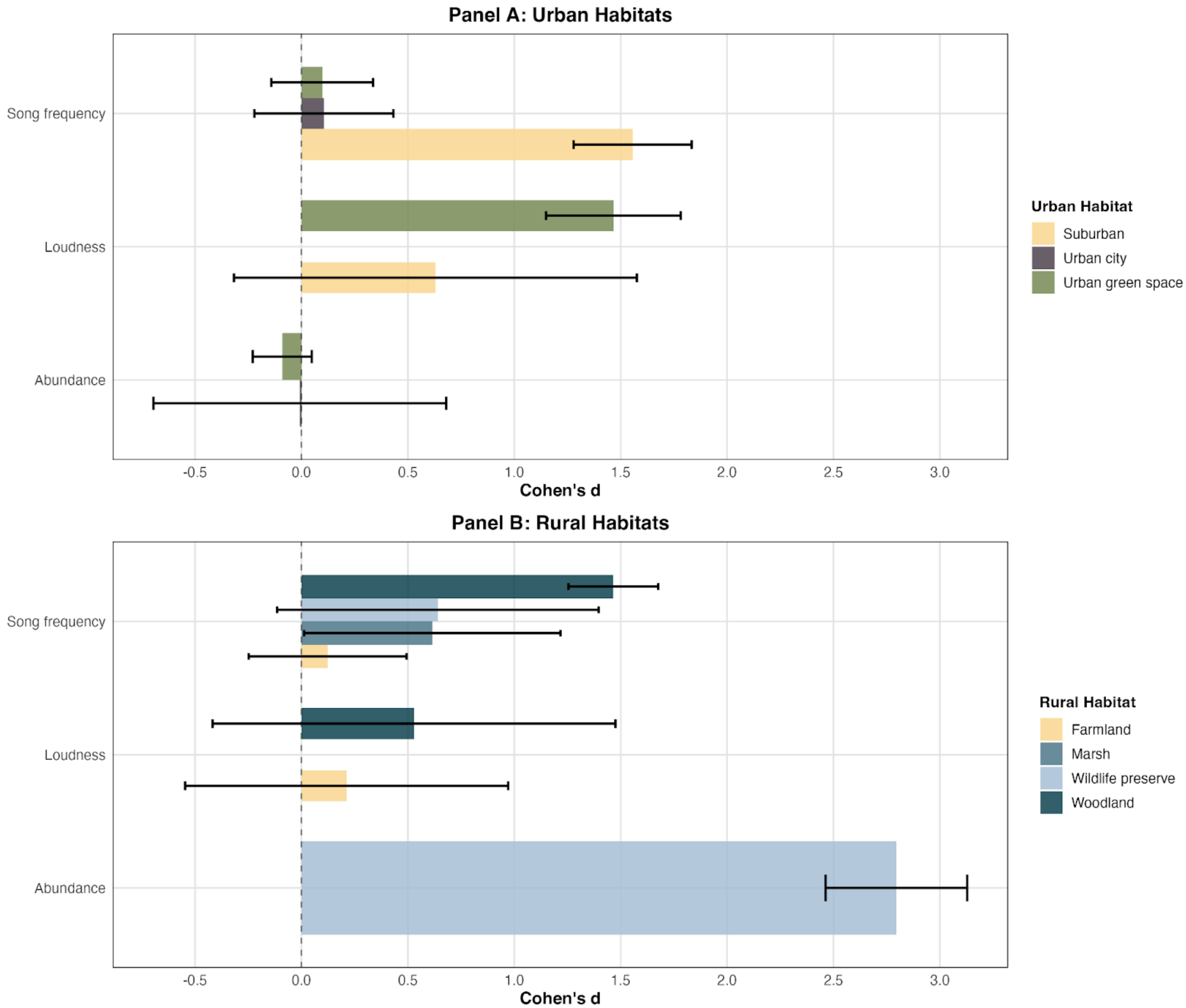

Figure 3: Effect of specific urban vs rural environments on different variables among birds, sample size = 442

Note: Specific urban vs specific rural environments on the effect of noise on birds. Abundance, Song Frequency, and Song Loudness were recorded. The *y*-axis lists specific habitat types, and the *x*-axis indicates Cohen's d effect sizes. The bars represent the standard error.

Analysis by a taxonomic group revealed that corvids increased both loudness and song frequency in urban environments, but their abundance remained unaffected (Figure 4). In contrast, passerines exhibited higher abundance in urban environments, while rural data for passerines were unavailable. Passerines also showed a positive effect on song frequency in urban environments.

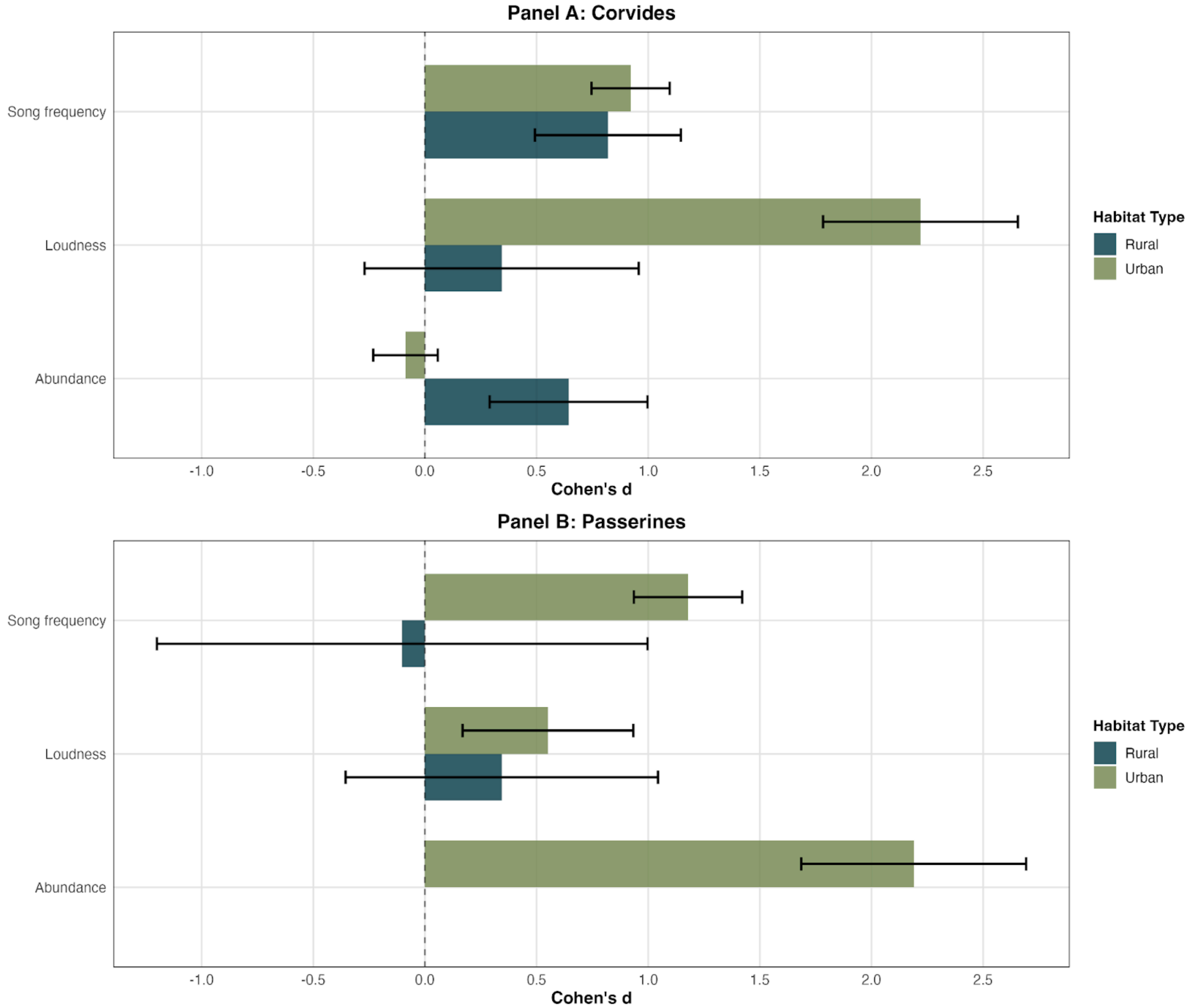

Figure 4: Effect of urban vs rural environments on passerines vs corvids, sample size = 385

Note: Urban vs. rural environments on the effect of noise on specific species groups with large enough sample sizes. Abundance, song frequency, and song loudness were recorded. The y-axis indicates habitat type (urban vs rural), and the x-axis shows Cohen's d effect sizes. The bars represent the standard error.

At the species level, warblers and wrens showed non-significant trends in abundance. Sparrows and chickadees exhibited the strongest response (Figure 5). Overall, urbanization affected bird loudness across taxonomic groups, but abundance responses varied.

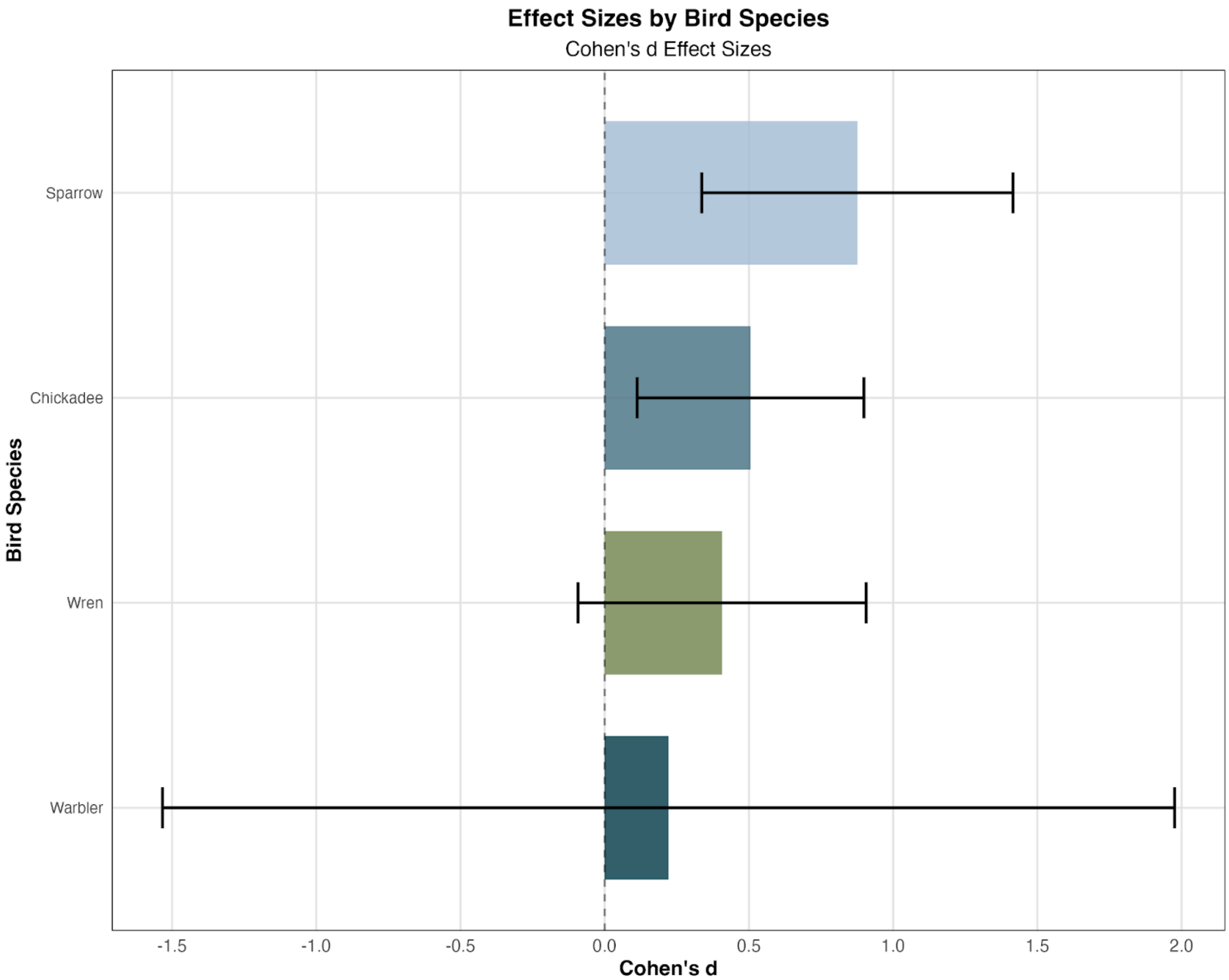

Figure 5: Effect of urban environments on specific species abundance, sample size = 189

Note: Urban vs. rural environments on the effect of noise on specific species with large enough sample sizes. Abundance was recorded. The y-axis shows selected species (warblers, wrens, sparrows, chickadees), and the x-axis shows Cohen's d effect sizes. The bars represent the standard error.

4. Discussion

The results of the meta-analysis provide broad evidence that urban anthropogenic noise drives avian behavioral change and community structure, with high context-dependency driven by habitats and species. Overall, consistent effects of urban noise on bird vocal behavior were found, with increases in both song loudness and frequency. However, consistent impacts on avian abundance were not found. The impacts of noise on vocal behaviors varied across habitats and species. Some habitats, such as urban green spaces and rural wildlife preserves, had a less pronounced effect on avian vocalization. Meaningful differences in bird abundance also emerged, with passerines exhibiting higher numbers in cities, while others, such as corvids, did not show similar gains. The patterns observed here demonstrate that urban noise can impact bird vocalization, constrain certain species while creating opportunities for others, and ultimately influence long-term diversity in bird communities.

The most prominent result from the analysis is that anthropogenic noise consistently alters avian vocal behavior, with the strongest effects observed in urban environments. Urban noise was associated with the largest effect on song loudness (Figure 2), indicating that birds in cities consistently sing much louder to be heard over background sounds such as traffic and construction. These changes are not trivial: producing louder songs requires greater energetic investment, may elevate stress, and can reduce the acoustic complexity critical for mate attraction and signaling individual identity (Blickley et al., 2012; Bermúdez-Cuamatzin et al., 2009; Potvin et al., 2016). Such changes may directly affect reproductive success and social interactions (Halfwerk et al., 2011). In contrast, rural habitats showed no notable change in song loudness across all habitat types (Figure 3), suggesting that in less disturbed environments, birds can communicate at normal levels.

This analysis also revealed consistent increases in song frequency across both urban and rural habitats (Figure 2). This indicates that frequency shifts may not be limited to cities but could instead represent a general coping strategy in the presence of anthropogenic noise. Higher-frequency tones can reduce song complexity and may be less effective for mate attraction and rival signaling, as they usually require louder delivery due to the faster attenuation of high frequencies (Derryberry et al., 2016). These constraints suggest that while frequency shifts help maintain communication in noisy conditions, they may come at a cost to long-term reproductive success.

The need for birds to sing louder and at higher frequencies in urban areas also affects the effort required to produce their song, which can, in turn, impact their abundance (Francis et al., 2011). Overall abundance was higher in rural areas, while urban environments showed no significant effect (Figures 2, 3). Patterns of abundance also differed by species. These results showed that passerines were more abundant in cities, while corvids did not show such increases (Figure 4). Passerines, with naturally higher-frequency songs, were more abundant in urban areas, whereas corvids showed no comparable increase. Within passerines, sparrows showed the strongest abundance gain (Figure 5). While more studies are needed to determine whether other factors, such as foraging habits, nesting choices, or social behavior, also play a role in passerine abundance, these outcomes could have broader ecological impacts, particularly on wider ecological processes that depend on corvids, such as seed dispersal and scavenging.

Habitat context further modulated the outcomes of urban noise. Within cities, birds in parks and green spaces demonstrated smaller increases in loudness compared to those in dense urban cores, suggesting that urban vegetation provides partial acoustic refuges (Figure 3). Similarly, rural wildlife preserves supported significantly higher bird abundances, emphasizing the value of intact habitats in mitigating the ecological impacts of noise. These findings reinforce the importance of habitat design, as both urban green spaces and rural preserves mitigate pressures imposed by anthropogenic noise.

Taken together, these results underline several ongoing challenges: anthropogenic noise varies widely across habitats, affects species differently depending on their vocal traits, and produces behavioral changes whose long-term demographic consequences remain uncertain. Addressing these uncertainties should be a priority for future work, particularly by linking altered vocal traits to measurable outcomes such as reproductive success, survival, and community structure. Additionally, research should assess the impact of urban green infrastructure, such as parks and green spaces, on avian diversity and abundance, as well as its potential to reduce noise exposure meaningfully. Such efforts would provide valuable insights for urban planning and conservation, ensuring that cities not only accommodate human needs but also support resilient bird communities.

In an increasingly urbanized world, noise impacts birds unevenly, with increased song loudness being the strongest and most consistent effect. Smaller effects in urban parks and green spaces highlight that planned green areas can act as refuges, reducing acoustic stress. Wildlife preserves in rural areas showed higher abundance, showing that careful habitat design in both urban and rural settings can strengthen diversity. Cities do not have to be hostile to birds; with intentional design, urban areas can support both people and wildlife. Continued research on noise and other urban stressors will refine conservation strategies, but practical solutions already include more parks, connected habitats, and planning that treats soundscapes as vital for biodiversity.

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Code and Data Availability

All data and code used in this manuscript are currently available on GitHub at https://github.com/atikshbordia/Meta-Analysis-of-the-Effect-of-Anthropogenic-Noise-on-Bird-Song-and-Abundance. Upon acceptance, the GitHub will be archived with Zenodo and issued a DOI.

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Author Biography

Atiksh Bordia is a student at Ethical Culture Fieldston School with a strong interest in ecology, conservation, and the impact of human activity on the natural world. His focus is on urban ecology, particularly how city noise affects bird populations. He began this work in New York City, studying birds in Van Cortlandt and Central Park, where he observed how some species adapt to noisy environments while others struggle, prompting questions about biodiversity and survival in cities.

Outside the classroom, Atiksh has gained hands-on experience through internships. At the Mianus River Gorge, he assisted with long-term research on deer populations and forest health. At Wave Hill, he worked as a Woodland Ecology Research Intern, learning how restoration projects protect fragile habitats. With the Bronx River Alliance, he supported cleanup and habitat projects while guiding community volunteers, highlighting the importance of connecting science with public engagement.

Atiksh's research continues to explore how birds adjust their behavior to urban noise, comparing species such as passerines and corvids. He is particularly interested in the intersections of science, public health, and city planning in supporting biodiversity. Through fieldwork and community involvement, Atiksh has developed patience, curiosity, and collaboration skills, which he hopes to build on to advance conservation in both urban and natural spaces.

Mentor Contribution Statement

Nathalie Sommer provided comprehensive guidance throughout the development of this research project. Her mentorship shaped the study's conceptual foundation, helping the author refine the central research question and situate the work within the broader field of anthropogenic noise ecology. Early conversations were instrumental in clarifying the theoretical motivation for examining noise impacts on birds and in identifying how a meta-analytic approach could meaningfully contribute to ongoing scientific discussions. Nathalie also offered detailed support in designing the methodological framework and determining the most appropriate analytical strategies for synthesizing the literature. She advised on the structure and clarity of the manuscript, particularly in the methods and results sections, ensuring that the analytical choices were well justified and communicated effectively. Throughout the writing process, she provided feedback that strengthened the logical flow, interpretive rigor, and overall coherence of the paper. Her role was limited to conceptual, methodological, and structural guidance; data extraction, statistical execution, interpretation, and writing were completed independently by the author. The mentorship provided a strong foundation for the project's development, encouraging precision in research design and thoughtful engagement with the ecological implications of anthropogenic noise.