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)

My 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. I had several 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. I also expected that the abundance and diversity of birds would be negatively impacted in urban environments because of overcrowding. I 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, I conducted a targeted review of empirical studies on urban noise and bird responses.

Methods

I conducted a systematic review using the ProQuest and JSTOR databases (searches completed on February 17, 2025). Following Population, Intervention, Comparator, and Outcome (PICO) guidelines, I used the following combination of search terms: (wildlife OR animal) AND (urban) AND ("noise effect" OR "anthropogenic noise" OR communication OR behavior OR biodiversity). I refined the searches 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. I followed the PRISMA guidelines 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 considered 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 3, 42 studies remained.

I extracted detailed data from each included study covering several categories. I recorded study location and context by noting geographic region (country, city, or ecosystem type), and the 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, and 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).

Publication Bias

To assess the possibility of publication bias, I used both graphical (funnel plots) and statistical (Kendall's rank correlation test; Rothstein et al., 2005) approaches. 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.

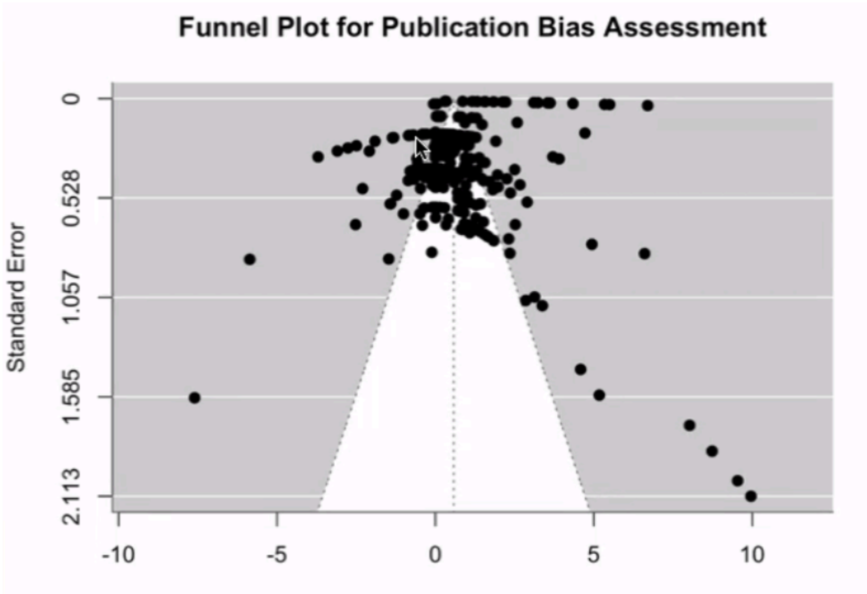

Figure 1: Publication Bias Funnel Plot

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

Results

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

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
I^2 heterogeneity	99.7%
Q statistic	120119.8

Publication bias p-value	0.0063

Table 1: Overall meta-analysis statistics

Caption: 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.

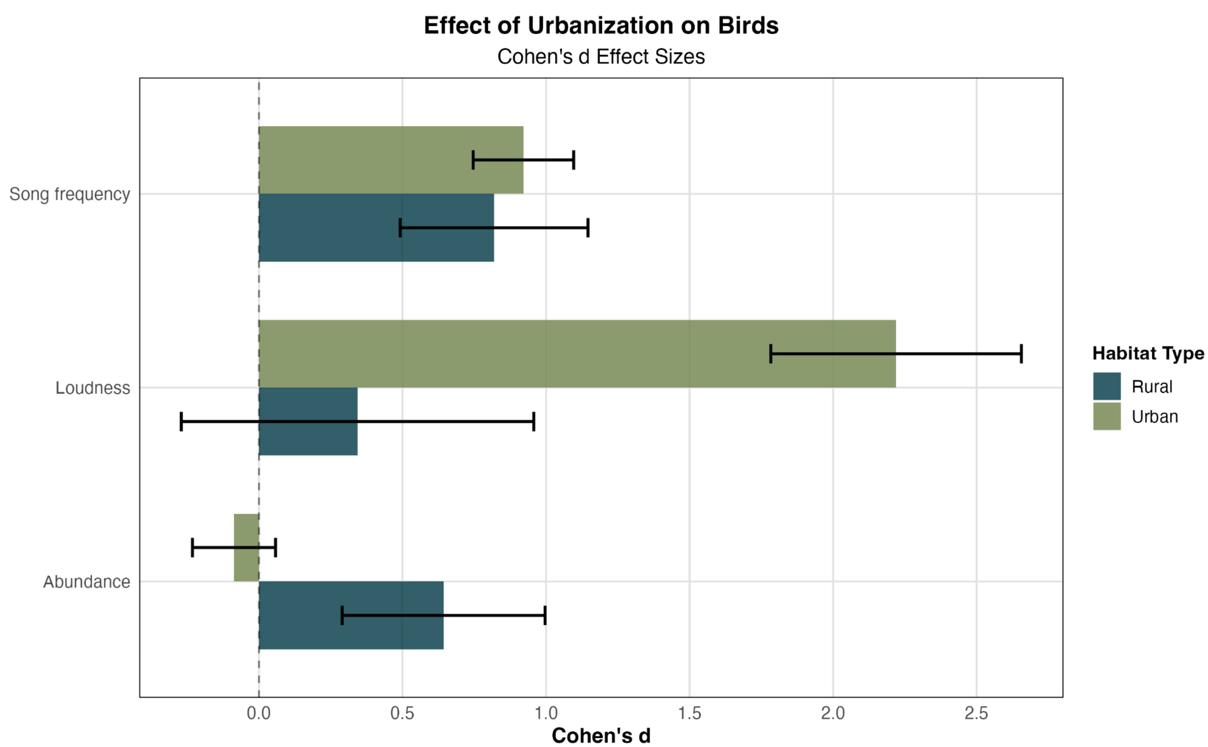

Figure 2. Effect of urban vs rural environments on different variables among birds

Caption: Urban vs Rural environments on the effect of noise on birds. Abundance, Song Frequency, and Song Loudness were recorded.

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).

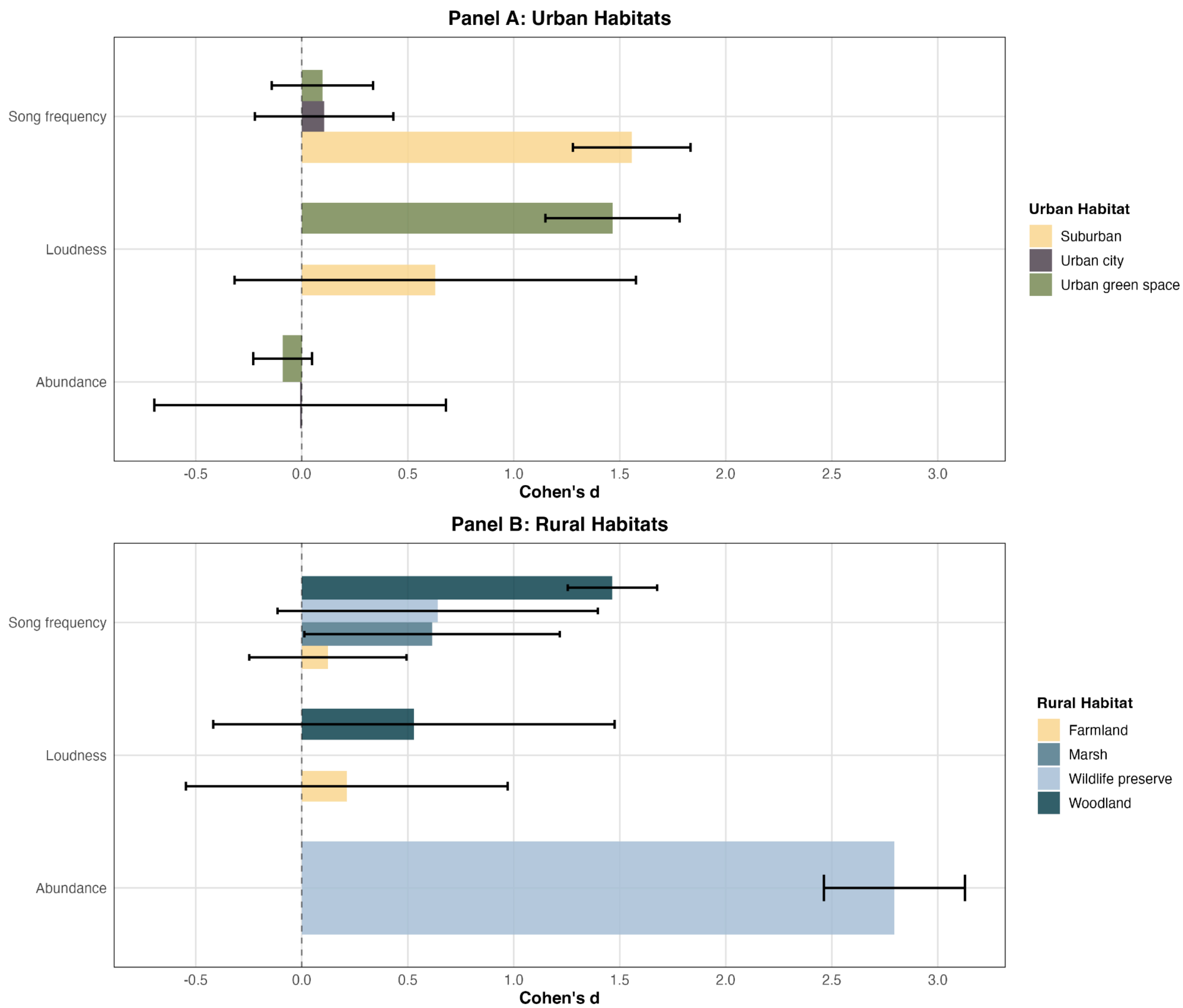

Figure 3. Effect of specific urban vs rural environments on different variables among birds

Caption: Specific Urban vs Specific Rural environments on the effect of noise on birds. Abundance, Song Frequency, and Song Loudness were recorded.

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 habitats showed little to no effect. Passerines also showed a positive effect on song frequency in urban environments.

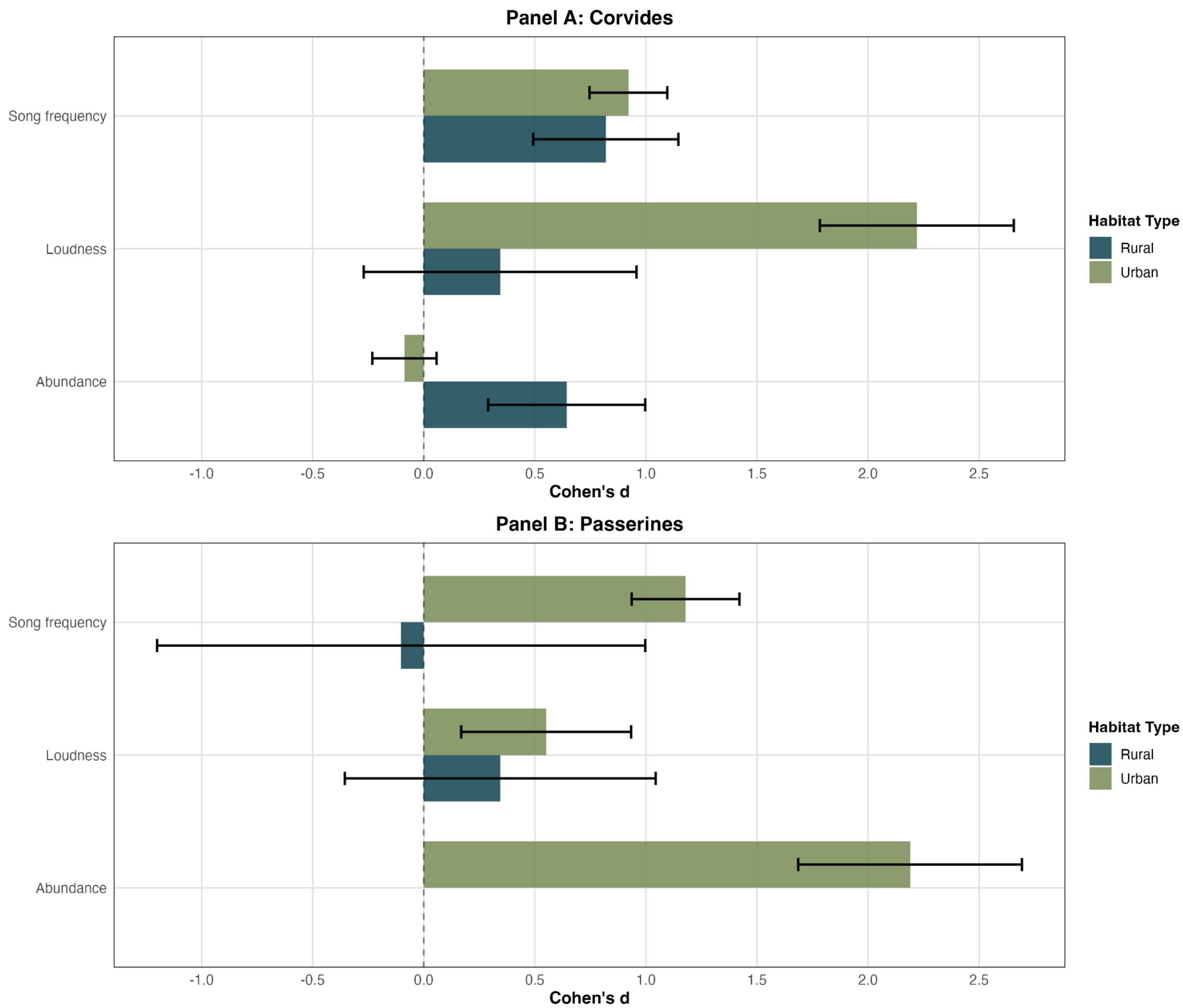

Figure 4. Effect of urban vs rural environments on passerines vs corvids

Caption: 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.

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.

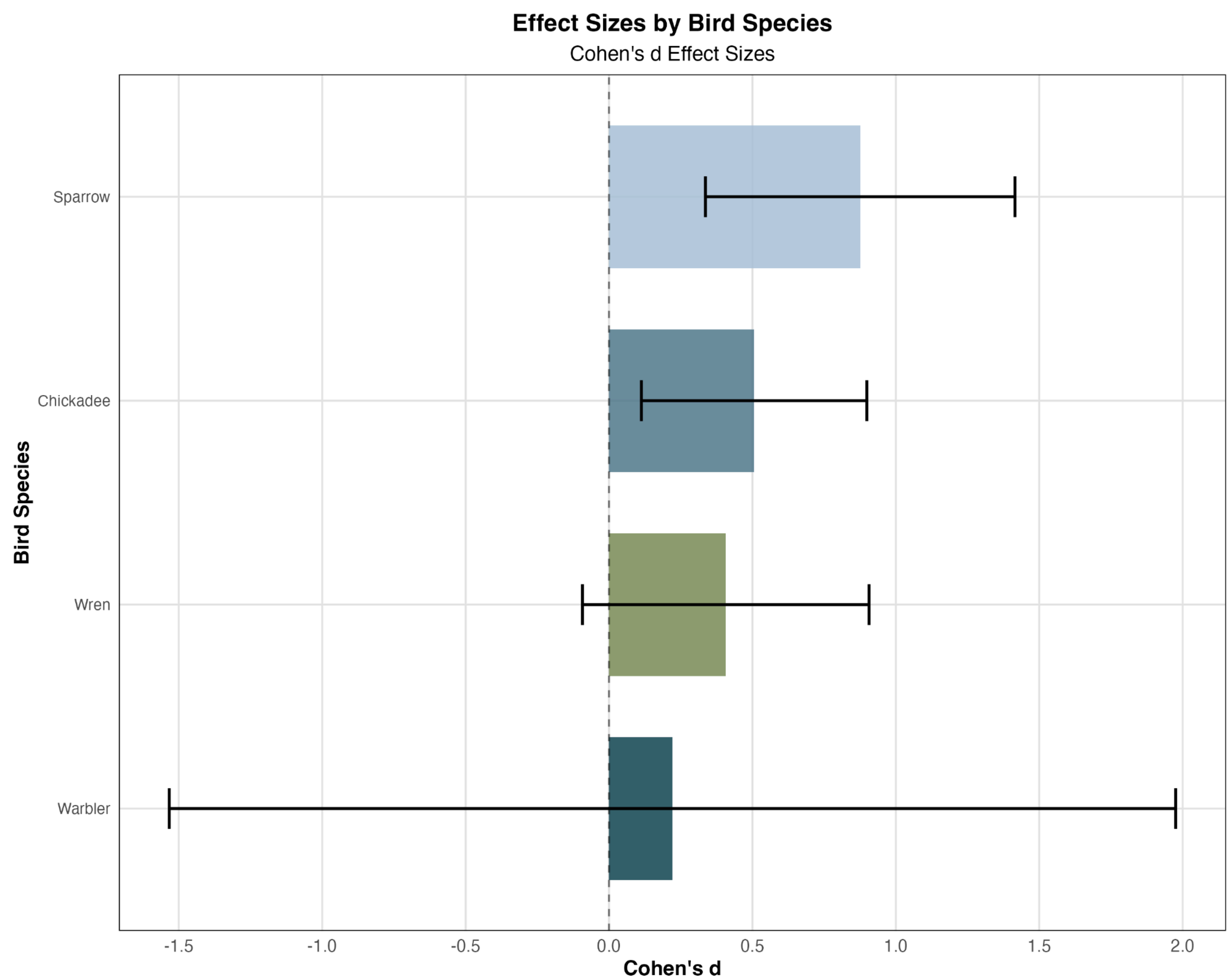

Figure 5. Effect of urban environments on specific species abundance

Caption: Urban vs Rural environments on the effect of noise on specific species with large enough sample sizes. Abundance was recorded.

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, I found consistent effects of urban noise on bird vocal behavior, with increases in both song loudness and frequency. However, I did not find concomitant consistent impacts on avian abundance. 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 create opportunities for others, and ultimately influence long-term diversity in bird communities.

The most prominent result from my 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.

My 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. My results show that passerines are 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: urban green spaces and rural preserves both 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.

Acknowledgments

I would like to thank [redacted by Managing Editor] for her guidance and support throughout this project. I am also grateful to my family for their encouragement and support along the way.

Appendix

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.

References

Almarza-Batuecas, P. & Pescador, M. (2025). Noise pollution and urban birds breeding in the center of the Iberian peninsula: Effects on diversity and abundance. Diversity, 17(5), 338. https://doi.org/10.3390/d17050338

Anobie, M., Ivande, S. T., Ottosson, U., & Osinubi, S. T. (2024). Difference in acoustic responses to urbanisation in two African passerines. *Ostrich. Journal of African Ornithology*, 95, 32–44 https://doi.org/10.2989/00306525.2024.2310683

Arévalo, C., Amaya Espinel, J. D., Henríquez, C., Ibarra, J. T., & Bonacic, C. (2022). Urban noise and surrounding city morphology influence green space occupancy by native birds in a Mediterranean-type South American metropolis. *Scientific Reports*, 12, 1–10. https://doi.org/10.1038/s41598-022-08654-7

Arroyo-Solís, A., Castillo, J. M., Figueroa, E., López-Sánchez, J. L., & Slabbekoorn, H. (2013). Experimental evidence for an impact of anthropogenic noise on dawn chorus timing in urban birds. *Journal of Avian Biology*, 44(3), 288–296. https://doi.org/10.1111/j.1600-048X.2012.05796.x

Bahía, R., Lambertucci, S. A., & Speziale, K. L. (2024). Anthropogenic city noise affects the vocalizations of key forest birds. *Biodiversity and Conservation*, 33, 2405–2421. https://doi.org/10.1007/s10531-024-02862-5

Bermúdez-Cuamatzin, E., Ríos-Chelén, A. A., Gil, D., & Macías Garcia, C. (2009). Strategies of song adaptation to urban noise in the house finch: Syllable pitch plasticity or differential syllable use? *Behaviour*, 146(9), 1269–1286. https://doi.org/10.1163/156853909X423104

Bermúdez-Cuamatzin, E., Slabbekoorn, H., & Macías Garcia, C. (2023). Spectral and temporal call flexibility of house finches (Haemorhous mexicanus) from urban areas during experimental noise exposure. *Ibis*, 165(3), 571–586. https://doi.org/10.1111/ibi.13161

Blickley, J. L., & Patricelli, G. L. (2010). Impacts of anthropogenic noise on wildlife: Research priorities for the development of standards and mitigation. *Journal of International Wildlife Law & Policy*, 13(4), 274–292. https://doi.org/10.1080/13880292.2010.524564

Blickley, J. L., Blackwood, D., & Patricelli, G. L. (2012). Experimental evidence for the effects of chronic anthropogenic noise on the abundance of greater sage-grouse at leks.

Conservation Biology, 26(3), 461–471. https://doi.org/10.1111/j.1600-048X.2012.05796.x

Blickley, J. L., Word, K. R., Krakauer, A. H., Phillips, J. L., Sells, S. N., Taff, C. C., Wingfield, J. C., & Patricelli, G. L. (2012). Experimental chronic noise is related to elevated fecal stress hormones in lekking greater sage-grouse. *PLoS ONE*, 7(11), e50462, https://doi.org/10.1371/journal.pone.0050462

Brancaccio-Pérez, E., & Ortiz-Pulido, R. (2024). Urban noise effects on foraging activity of a hummingbird community. *The Wilson Journal of Ornithology*, 136(2), 254–261. https://doi.org/10.1676/23-00029

Carral Murrieta, C. O., García Arroyo, M., Marín Gómez, O. H., Sosa López, J. R., & MacGregor Fors, I. (2020). Noisy environments: Untangling the role of anthropogenic noise on bird species richness in a Neotropical city. *Avian Research*, 11, 1–11. https://doi.org/10.1186/s40657-020-00218-5

Deoniziak, K., & Osiejuk, T. S. (2021). Seasonality and social factors, but not noise pollution, influence the song characteristics of two leaf warbler species. *PLOS ONE*, 16(9), e0257074. https://doi.org/10.1371/journal.pone.0257074

Derryberry, E. P., Danner, R. M., Danner, J. E., Derryberry, G. E., Phillips, J. N., Lipshutz, S. E., Gentry, K., & Luther, D. A. (2016). Patterns of song across natural and anthropogenic soundscapes suggest that white-crowned sparrows minimize acoustic masking and maximize signal content. *PLOS ONE*, 11(4), e0154456. https://doi.org/10.1371/journal.pone.0154456

Dowling, J. L., Luther, D. A., & Marra, P. P. (2012). Comparative effects of urban development and anthropogenic noise on bird songs. *Behavioral Ecology*, 23(1), 201–209. https://doi.org/10.1093/beheco/arr176

Eens, T. R., Pinxten, R., Casasole, G., Dehnhard, N., & Eens, M. (2017). Ambient anthropogenic noise, but not light, is associated with the ecophysiology of free-living songbird nestlings. *Scientific Reports*, 7, 1–9. https://doi.org/10.1038/s41598-017-02940-5

Engel, M. S., Young, R. J., Davies, W. J., Waddington, D., & Wood, M. D. (2024). A systematic review of anthropogenic noise impact on avian species. *Current Pollution Reports*, 10, 684–709. https://doi.org/10.1007/s40726-024-00329-3

Entry, K. E. G., Derryberry, E. P., Danner, R. M., Danner, J. E., & Luther, D. A. (2017). Immediate signaling flexibility in response to experimental noise in urban, but not rural, white-crowned sparrows. *Ecosphere*, 8(12), e01916. https://doi.org/10.1002/ecs2.1916

Francis, C. D., Ortega, C. P., & Cruz, A. (2011). Vocal frequency change reflects different responses to anthropogenic noise in two suboscine tyrant flycatchers. *Proceedings of the Royal Society B: Biological Sciences*, 278(1714), 2025–2031. https://doi.org/10.1098/rspb.2010.1847

Fröhlich, A., & Ciach, M. (2018). Noise pollution and decreased size of wooded areas reduces the probability of occurrence of tawny owl (Strix aluco). *Ibis*, 160(3), 634–646. https://doi.org/10.1111/ibi.12554

Gough, D. C., Mennill, D. J., & Nol, E. (2014). Singing seaside: Pacific wrens (Troglodytes pacificus) change their songs in the presence of natural and anthropogenic noise. The Wilson *Journal of Ornithology*, 126(2), 269–278. https://doi.org/10.1676/13-088.1

Halfwerk, W., Holleman, L. J. M., Lessells, C. M., & Slabbekoorn, H. (2011). Negative impact of traffic noise on avian reproductive success. *Journal of Applied Ecology*, 48(1), 210–219. https://doi.org/10.1111/j.1365-2664.2010.01914.x

Halfwerk, W., & Slabbekoorn, H. (2015). Pollution going multimodal: The complex impact of the human-altered sensory environment on animal perception and performance. *Biology Letters*, 11(4), 20141051. https://doi.org/10.1098/rsbl.2014.1051

Hamza, F., Hanane, S., Almalki, M., & Chokri, M.-A. (2022). How urbanization and industrialization shape breeding bird species occurrence in coastal Mediterranean oasis system. *Urban Ecosystems*, 26, 185–196. https://doi.org/10.1007/s11252-022-01271-2

Huet des Aunay, G., Slabbekoorn, H., Nagle, L., Passas, F., Nicolas, P., & Draganoiu, T. I. (2014). Urban noise undermines female sexual preferences for low-frequency songs in domestic canaries. *Animal Behaviour*, 87, 67–75. https://doi.org/10.1016/j.anbehav.2013.10.010

Juárez, R., Araya-Ajoy, Y. G., Barrantes, G., & Sandoval, L. (2021). House wrens (Troglodytes aedon) reduce repertoire size and change song element frequencies in response to anthropogenic noise. *Ibis*, 163(1), 52–64. https://doi.org/10.1111/ibi.12844

Kight, C. R., Saha, M. S., & Swaddle, J. P. (2012). Anthropogenic noise is associated with reductions in the productivity of breeding eastern bluebirds (Sialia sialis). *Ecological Applications*, 22(7), 1989–1996. https://doi.org/10.1890/12-0133.1

Kleist, N. J., Guralnick, R. P., Cruz, A., & Francis, C. D. (2016). Anthropogenic noise weakens territorial response to intruder's songs. *Ecosphere*, 7(3), e01259. https://doi.org/10.1002/ecs2.1259

Lajeunesse, M. 2 2 Power statistics for Meta-analysis: tests for Mean effects and Homogeneity. Retrieved September 17, 2025, from http://lajeunesse.myweb.usf.edu/papers/Lajeunesse_2013_Chapter_22_Handbook_of_Meta-analysis_in_Ecology_and_Evolution.pdf

Long, A. M., Colón, M. R., Bosman, J. L., Robinson, D. H., Pruett, H. L., McFarland, T. M., Mathewson, H. A., Szewczak, J. M., Newnam, J. C., & Morrison, M. L. (2017). A before–after control–impact assessment to understand the potential impacts of highway construction noise and activity on an endangered songbird. *Ecology and Evolution*, 7(15), 1–13. https://doi.org/10.1002/ece3.2608

Montenegro, C., Service, W. D., Scully, E. N., Mischler, S. K., Sahu, P. K., Benowicz, T. J., Fox, K. V. R., & Sturdy, C. B. (2021). The impact of anthropogenic noise on individual identification via female song in black-capped chickadees (Poecile atricapillus). *Scientific Reports*, 11, 1–11. https://doi.org/10.1038/s41598-021-96504-3

Muñoz Santos, I., & Ríos Chelén, A. A. (2023). Vermilion flycatchers avoid singing during sudden peaks of anthropogenic noise. *Acta Ethologica*, 26, 201–210. https://doi.org/10.1007/s10211-022-00409-x

Nelson-Olivieri, J. R., Layden, T. J., Antunez, E., Khalighifar, A., Lasky, M., Laverty, T. M., Sanchez, K. A., Shannon, G., Starr, S., Verahrami, A. K., & Bombaci, S. P. (2023). Inequalities in noise will affect urban wildlife. *Nature Ecology & Evolution*, 7(8), 1051–1058. https://doi.org/10.1038/s41559-023-02257-9

Nordt, A., & Klenke, R. (2013). Sleepless in town – Drivers of the temporal shift in dawn song in urban European blackbirds. *PLOS ONE*, 8(8), e71476. https://doi.org/10.1371/journal.pone.0071476

Önsal, Ç., Yelimlieş, A., & Akçay, Ç. (2022). Aggression and multi-modal signaling in noise in a common urban songbird. *Behavioral Ecology and Sociobiology*, 76, 102. https://doi.org/10.1007/s00265-022-03207-4

Ozkan, K., Langley, J. M., Talbott, J. W., Kleist, N. J., & Francis, C. D. (2024). Divergent effects of short-term and continuous anthropogenic noise exposure on western bluebird parental care behavior. *PeerJ*, 12, e18558. https://doi.org/10.7717/peerj.18558

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Aki, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, *18*(3), Article e1003583. https://doi.org/10.1371/journal.pmed.1003583

Parris, K. M., & Schneider, A. (2008). Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and Society*, 14(1), 29. https://doi.org/10.5751/ES-02761-140129

Perillo, A., Mazzoni, L. G., Passos, L. F., Goulart, V. D. L. R., Duca, C., & Young, R. J. (2017). Anthropogenic noise reduces bird species richness and diversity in urban parks. *Ibis*, 159(3), 638–646. https://doi.org/10.1111/ibi.12481

Potvin, D. A., Curcio, M. T., Swaddle, J. P., & MacDougall-Shackleton, S. A. (2016). Experimental exposure to urban and pink noise affects brain development and song learning in zebra finches (Taeniopygia guttata). *PeerJ*, 4, e2287. https://doi.org/10.7717/peerj.2287

Proppe, D. S., Sturdy, C. B., & St. Clair, C. C. (2013). Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. *Global Change Biology*, 19(4), 1075–1084. https://doi.org/10.1111/gcb.12098

Redondo, I., Muriel, J., de Castro Díaz, C., Aguirre, J. I., Gil, D., & Pérez Rodríguez, L. (2021). Influence of growing up in the city or near an airport on the physiological stress of tree sparrow nestlings (Passer montanus). *European Journal of Wildlife Research*, 67, 91. https://doi.org/10.1007/s10344-021-01509-y

Ríos-Chelén, A. A., Lee, G. C., & Patricelli, G. L. (2015). Anthropogenic noise is associated with changes in acoustic but not visual signals in red-winged blackbirds. *Behavioral Ecology and Sociobiology*, 69(7), 1139–1151. https://doi.org/10.1007/s00265-015-1928-7

Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2005). Publication bias in meta-analysis: prevention, assessment, and adjustments. Wiley. https://doi.org/10.1002/0470870168

Senzaki, M., Barber, J. R., Carter, N. H., Cooper, C. B., Ditmer, M. A., Fristrup, K. M., McClure, C. J. W., Mennitt, D. J., Tyrrell, L. P., Vukomanovic, J., Wilson, A. A., & Francis, C. D. (2020). Sensory pollutants alter bird phenology and fitness across a continent. *Nature*, 587(7834), 605–609. https://doi.org/10.1038/s41586-020-2903-7

Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., Warner, K. A., Nelson, M. D., White, C., Briggs, J., McFarland, S., & Wittemyer, G. (2015). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*, 91(4), 982–1005. https://doi.org/10.1111/brv.12207

Van Donselaar, J. L., Atma, J. L., Kruyf, Z. A., LaCroix, H. N., & Proppe, D. S. (2018). Urbanization alters fear behavior in black-capped chickadees. *Urban Ecosystems*, 21, 1043–1051. https://doi.org/10.1007/s11252-018-0783-5

Viechtbauer, W. & Cheung, M. W. -L. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*. 1(2), 112-125. https://doi.org/10.1002/jrsm.11

Walters, M. J., Guralnick, R. P., Kleist, N. J., & Robinson, S. K. (2019). Urban background noise affects breeding song frequency and syllable-type composition in the northern mockingbird. *The Condor*, 121(2), duz002. https://doi.org/10.1093/condor/duz002

Wood, W. E., & Yezerinac, S. M. (2006). Song sparrow (Melospiza melodia) song varies with urban noise. *The Auk*, 123(3), 650–659. https://doi.org/10.1093/auk/123.3.650

September 29^{th}, 2025

Author 100105

Submission 100099

Reviewer Final Recommendation: Accept with minor revisions

Reviewer Feedback:

Taken together this paper highlights the importance of studying the effect of urbanization and anthropogenic noise on various measures of bird song and abundance to emphasize the deleterious effects this urbanization has on bird behavior in various habitats. This manuscript implements a meta-analysis of 42 studies, following three phases of quality control, to determine specific effects of anthropogenic noise on bird behavior to bridge the gap in understanding and raise awareness of species specific and environment specific modulations in bird song and abundance. The manuscript is extremely well written with a rigorous experimental design, data inclusion criteria, and in-depth description of main statistical findings. The figures and graphs of the main results are clear and easy to interpret. Overall, the manuscript makes a strong case for further investigation of the heterogenous effects of anthropogenic noise on birds. Minor revisions are included below to bolster the manuscript for acceptance:

- The introduction is beautifully written with seamless flow from one paragraph to the next, ensuring clear and concise language that allows the reader to easily follow the narrative. In your last paragraph of the Introduction, try incorporating words or phrases such as “The current study…” or “This study” in place of I and/or my. This also can apply to the sentences describing the hypotheses (i.e., “The main hypotheses tested were…” or “We hypothesize…”) as well as in various places throughout the manuscript where you use I and/or my (i.e., in the methods section, Discussion section).
- Great description of the meta-analysis methodology, data filtering, statistical measures, and outcome variables assessed in your Method section!
- Adding more detail to the figure legends may aid in orienting the reader to the data that is being portrayed in the figure to supplement the text (i.e., description of axes, brief main findings, brief description of variables and statistics implemented).
- Inclusion of the n’s per group (i.e., the number of studies per outcome variable assessed in your Results section and/or the number of birds per group per analysis) would be helpful to interpret the main statistical findings. You do state

that 42 studies remained for analysis following the phases of data quality control/filtering, however, providing the reader with the specific sample sizes per group for the effect of urbanization on birds, urban vs rural analyses, corvid vs passerines analyses, and species-specific analyses would aid in understanding the statistics at a deeper level.

- Wonderful job explaining your results in the Discussion section and linking them to physiological changes and behavioral changes in birds that may hinder their overall survival and biodiversity across different environmental areas. You do a great job tying together your findings to the broader implications of bird contribution to the ecosystem as well (i.e., ecological changes due to changes in foraging behavior and seed dispersal). Great work!

Originality & Significance-

- Overall, the author took a data-driven approach to understanding how human-derived ecological changes impact different species of birds. Specifically, they examined how urban vs. rural environments impact bird abundance, song frequency, and loudness. This research paper tackles important aspects of ecology, and highlights considerations for urban development that can mitigate urbanization's impact on wildlife species. This work is original, thoughtful, and logically developed.

Clarity & Structure-

- The author generally writes with great clarity and simplicity; however, an explanation of the corvid bird species is missing in the introduction. Since the study follows two populations, both should be described thoroughly.
- I also believe using a different citation style will improve readability. The use of parenthesis, particularly in the middle of sentences, detracts from the clarity.
- Also please address this parenthesis error: "To assess the possibility of publication bias, graphical (funnel plots) and statistical (Kendall's rank correlation test were utilized; Rothstein et al., 2005) approaches."
- The hanging sentence in the results section should also be included with the rest of the results first paragraph.

Use of Evidence & Research Methods

- The author does an excellent job describing their methods for paper selection
- Statistical methods are adequately stated
- Graphs should contain an indicator of statistical significance (usually a *) that is described in the figure legend (Ex: * $p < .05$, ** $p < .01$)

Engagement with Literature-

- The author used over 40 articles to generate these datasets, showing high level engagement with the literature.

Grammar & Language

- The author writes with clarity, proper grammar, and an appropriate scientific tone.

Other notes:

- Please include more detailed figure legends. Figure legends should clarify statistical limits on p values and other relevant mathematical terms, like the number of data points per group (n).
- Please clarify what the comparator groups are for figure 3.

- The disappearance of certain groups within multiple figures is confusing, especially in the absence of error bars it is difficult to understand whether that group was dropped for a particular variable or measured. Furthermore, the width of the bars in the bar graphs should be equivalent across measurements.
- Make figure titles more informative, especially figure 5, without reading the text the graph is difficult to interpret.
- Abundance in rural settings for passerines is missing from figure 4.

The author should spend the most time revising the figures for visual clarity; as such I recommend this paper be accepted with minor revisions.

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, a targeted review of empirical studies was conducted on urban noise and bird responses.

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 were 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 considered 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 3, 42 studies remained.

Detailed data was extracted from each included study covering several categories. Study location and context were recorded by noting geographic region (country, city, or ecosystem type), and the 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, X^2 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, and 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).

Publication Bias

To assess the possibility of publication bias, graphical (funnel plots) and statistical (Kendall's rank correlation test were utilized; Rothstein et al., 2005) approaches. 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.

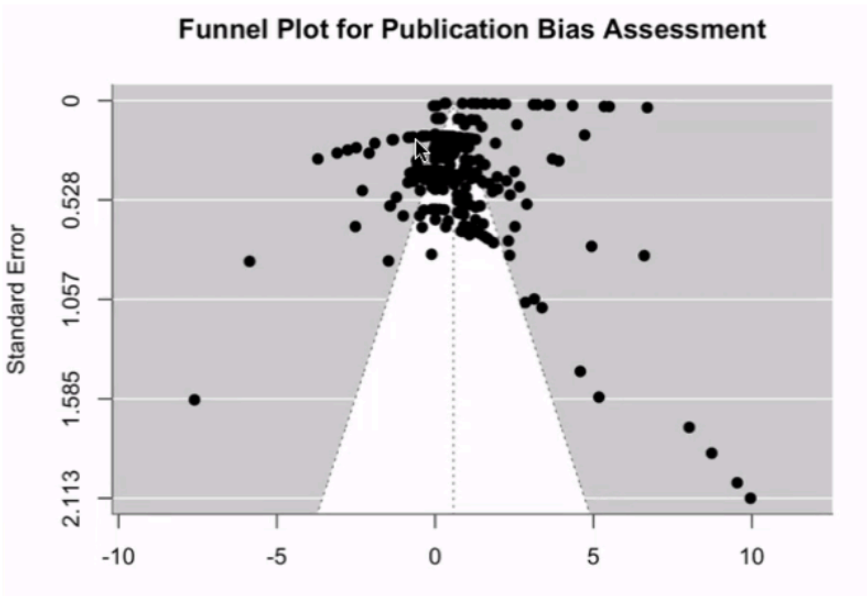

Figure 1: Publication Bias Funnel Plot
Caption: Funnel Plot displaying how much bias all studies that were looked at have, based on the years they were published.

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

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
I^2 heterogeneity	99.7%

Q statistic	120119.8
Publication bias p-value	0.0063

Table 1: Overall meta-analysis statistics

Caption: 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.

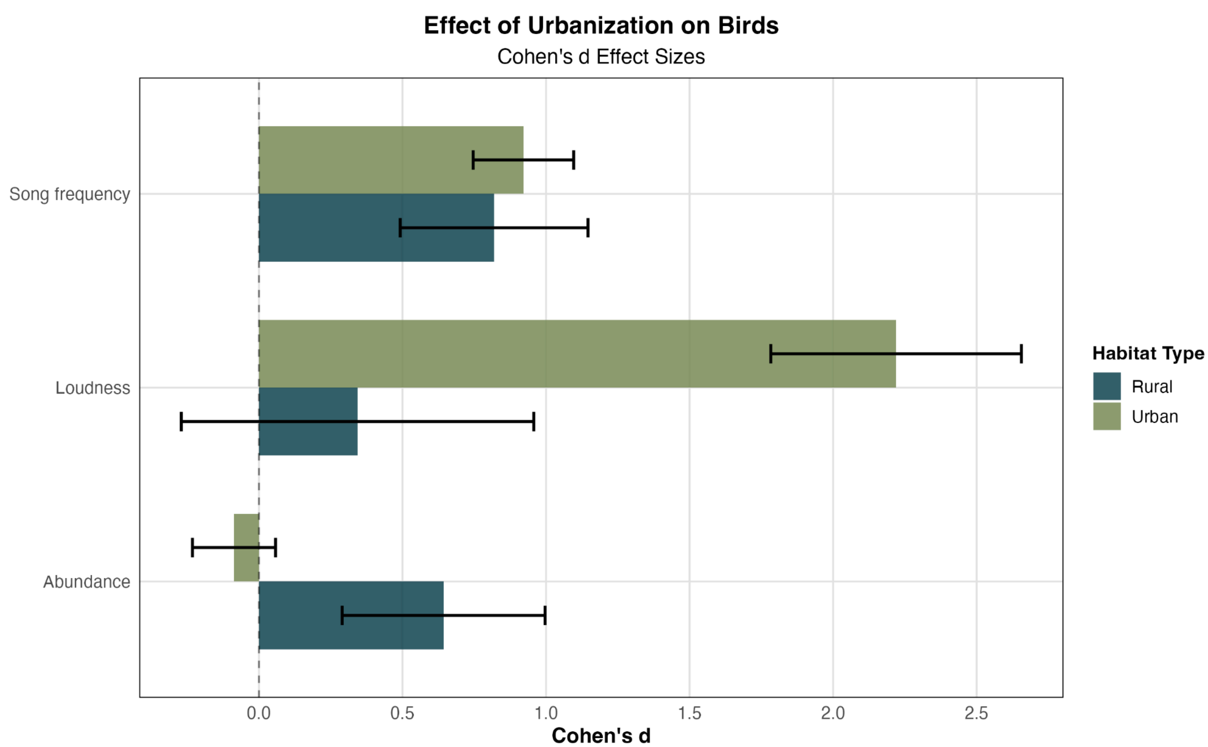

Figure 2. Effect of urban vs rural environments on different variables among birds, sample size = 442

Caption: 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.

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).

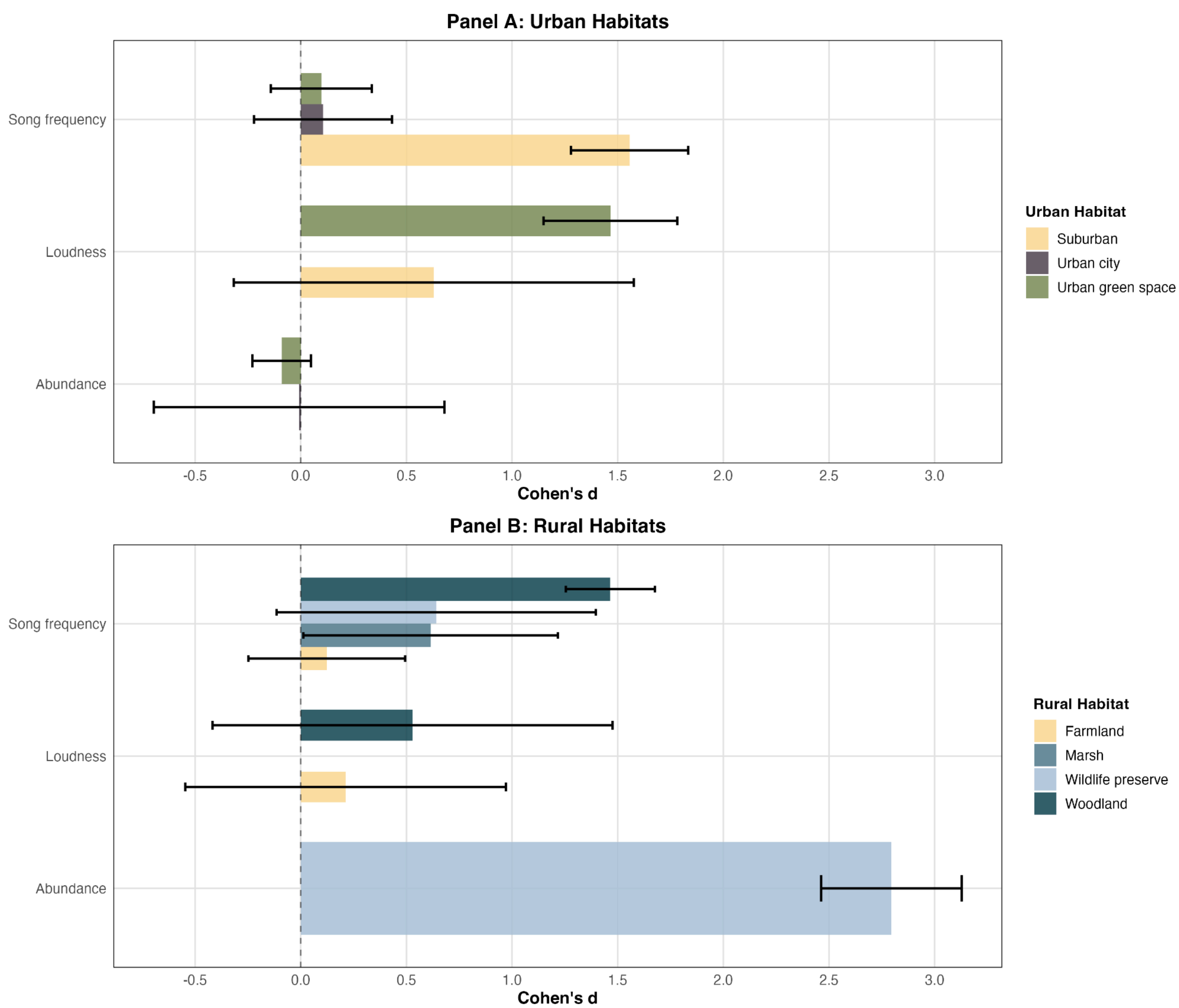

Figure 3. Effect of specific urban vs rural environments on different variables among birds, sample size = 442

Caption: 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 y-axis indicates Cohen's d effect sizes.

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 habitats showed little to no effect. Passerines also showed a positive effect on song frequency in urban environments.

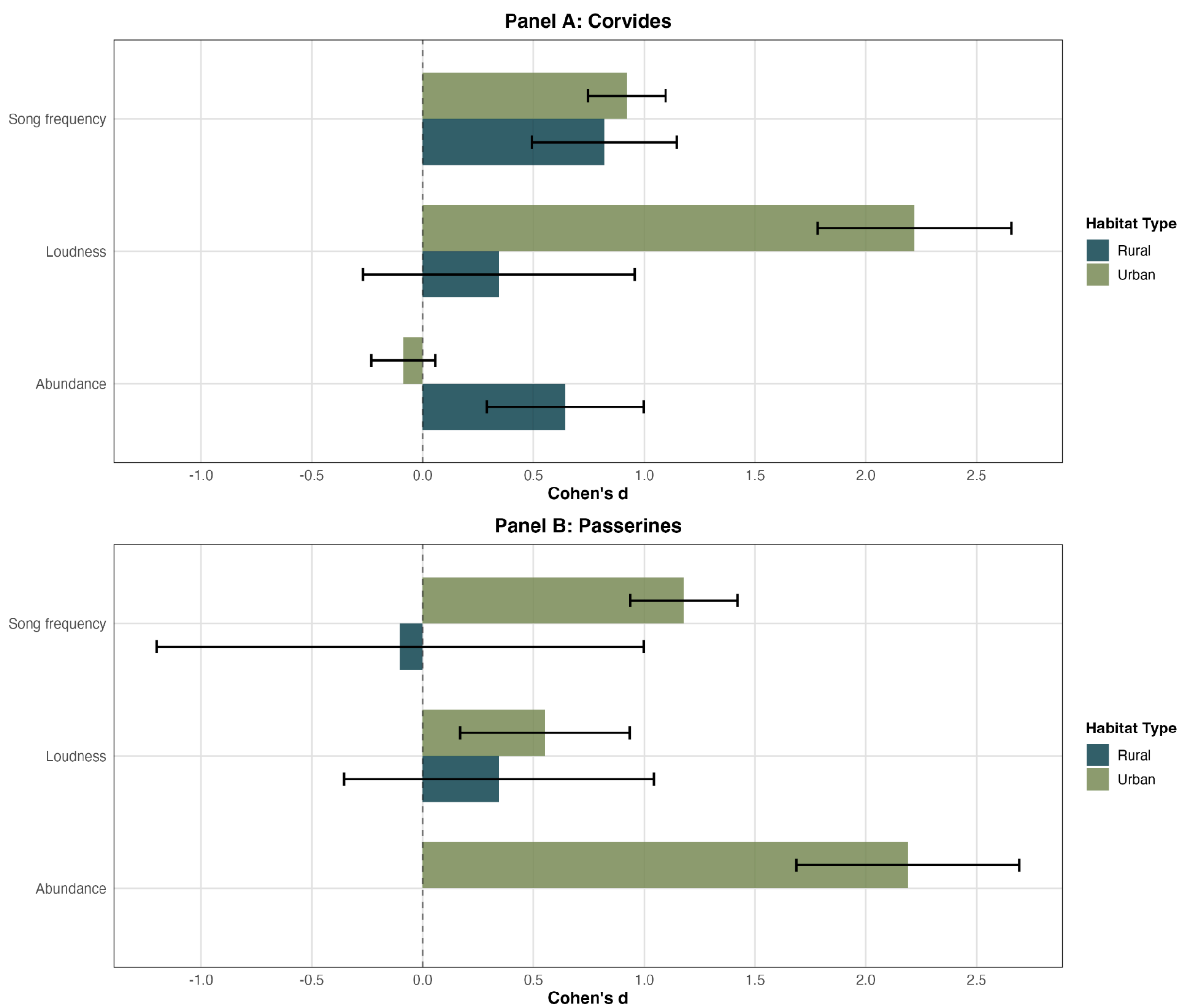

Figure 4. Effect of urban vs rural environments on passerines vs corvids, sample size = 385

Caption: 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.

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.

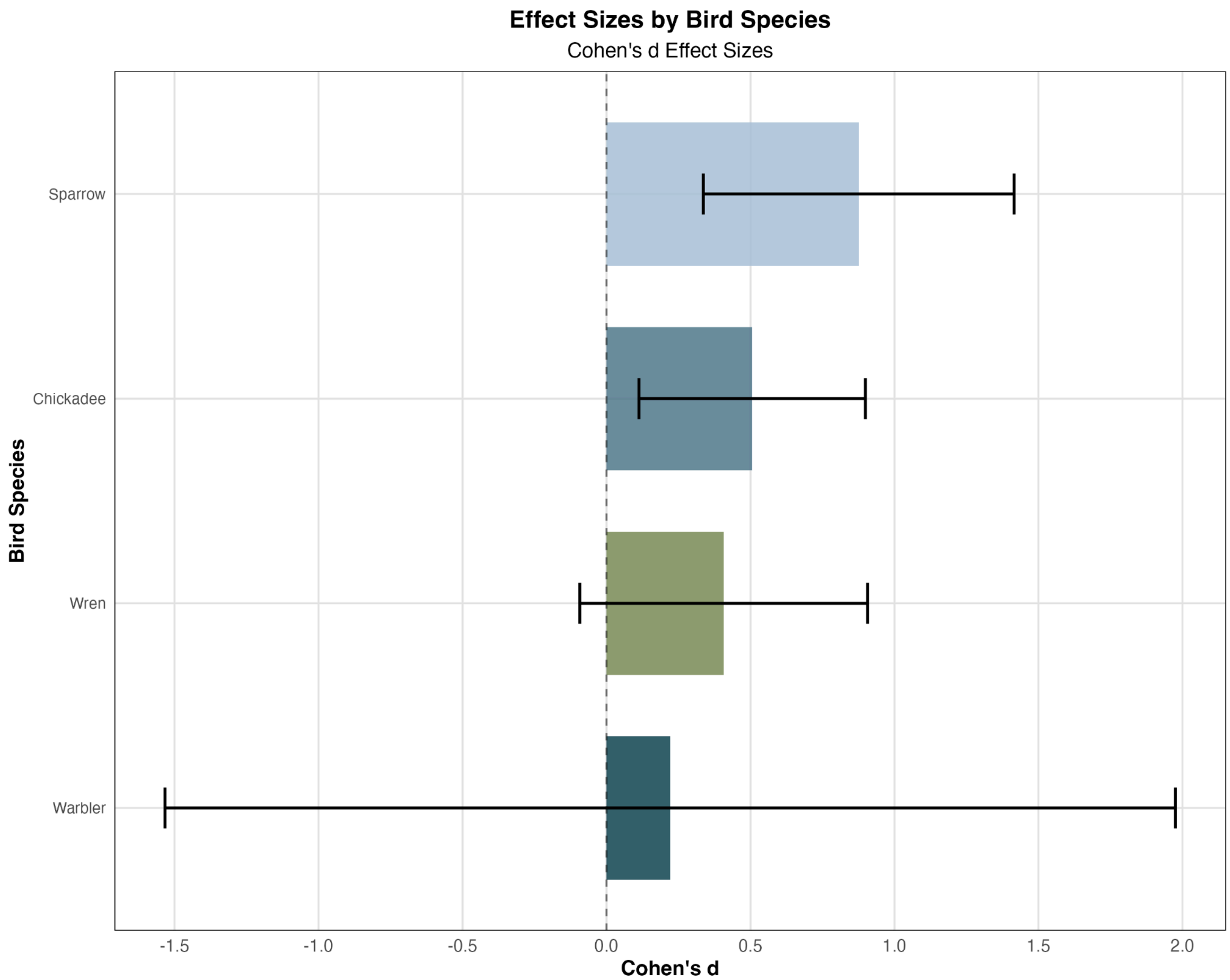

Figure 5. Effect of urban environments on specific species abundance, sample size = 189

Caption: 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.

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 show that passerines are 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: urban green spaces and rural preserves both 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.

Acknowledgments

I would like to thank Nathalie Sommer for her guidance and support throughout this project. I am also grateful to my family for their encouragement and support along the way.

References

Almarza-Batuecas, P. & Pescador, M. (2025). Noise pollution and urban birds breeding in the center of the Iberian peninsula: Effects on diversity and abundance. Diversity, 17(5), 338. https://doi.org/10.3390/d17050338

Anobie, M., Ivande, S. T., Ottosson, U., & Osinubi, S. T. (2024). Difference in acoustic responses to urbanisation in two African passerines. *Ostrich. Journal of African Ornithology*, 95, 32–44 https://doi.org/10.2989/00306525.2024.2310683

Arévalo, C., Amaya Espinel, J. D., Henríquez, C., Ibarra, J. T., & Bonacic, C. (2022). Urban noise and surrounding city morphology influence green space occupancy by native birds in a Mediterranean-type South American metropolis. *Scientific Reports*, 12, 1–10. https://doi.org/10.1038/s41598-022-08654-7

Arroyo-Solís, A., Castillo, J. M., Figueroa, E., López-Sánchez, J. L., & Slabbekoorn, H. (2013). Experimental evidence for an impact of anthropogenic noise on dawn chorus timing in urban birds. *Journal of Avian Biology*, 44(3), 288–296. https://doi.org/10.1111/j.1600-048X.2012.05796.x

Bahía, R., Lambertucci, S. A., & Speziale, K. L. (2024). Anthropogenic city noise affects the vocalizations of key forest birds. *Biodiversity and Conservation*, 33, 2405–2421. https://doi.org/10.1007/s10531-024-02862-5

Bermúdez-Cuamatzin, E., Ríos-Chelén, A. A., Gil, D., & Macías Garcia, C. (2009). Strategies of song adaptation to urban noise in the house finch: Syllable pitch plasticity or differential syllable use? *Behaviour*, 146(9), 1269–1286. https://doi.org/10.1163/156853909X423104

Bermúdez-Cuamatzin, E., Slabbekoorn, H., & Macías Garcia, C. (2023). Spectral and temporal call flexibility of house finches (Haemorhous mexicanus) from urban areas during experimental noise exposure. *Ibis*, 165(3), 571–586. https://doi.org/10.1111/ibi.13161

Blickley, J. L., & Patricelli, G. L. (2010). Impacts of anthropogenic noise on wildlife: Research priorities for the development of standards and mitigation. *Journal of International Wildlife Law & Policy*, 13(4), 274–292. https://doi.org/10.1080/13880292.2010.524564

Blickley, J. L., Blackwood, D., & Patricelli, G. L. (2012). Experimental evidence for the effects of chronic anthropogenic noise on the abundance of greater sage-grouse at leks. *Conservation Biology*, 26(3), 461–471. https://doi.org/10.1111/j.1600-048X.2012.05796.x

Blickley, J. L., Word, K. R., Krakauer, A. H., Phillips, J. L., Sells, S. N., Taff, C. C., Wingfield, J. C., & Patricelli, G. L. (2012). Experimental chronic noise is related to elevated fecal stress hormones in lekking greater sage-grouse. *PLoS ONE*, 7(11), e50462, https://doi.org/10.1371/journal.pone.0050462

Brancaccio-Pérez, E., & Ortiz-Pulido, R. (2024). Urban noise effects on foraging activity of a hummingbird community. *The Wilson Journal of Ornithology*, 136(2), 254–261. https://doi.org/10.1676/23-00029

Carral Murrieta, C. O., García Arroyo, M., Marín Gómez, O. H., Sosa López, J. R., & MacGregor Fors, I. (2020). Noisy environments: Untangling the role of anthropogenic noise on bird species richness in a Neotropical city. *Avian Research*, 11, 1–11. https://doi.org/10.1186/s40657-020-00218-5

Deoniziak, K., & Osiejuk, T. S. (2021). Seasonality and social factors, but not noise pollution, influence the song characteristics of two leaf warbler species. *PLOS ONE*, 16(9), e0257074. https://doi.org/10.1371/journal.pone.0257074

Derryberry, E. P., Danner, R. M., Danner, J. E., Derryberry, G. E., Phillips, J. N., Lipshutz, S. E., Gentry, K., & Luther, D. A. (2016). Patterns of song across natural and anthropogenic soundscapes suggest that white-crowned sparrows minimize acoustic masking and maximize signal content. *PLOS ONE*, 11(4), e0154456. https://doi.org/10.1371/journal.pone.0154456

Dowling, J. L., Luther, D. A., & Marra, P. P. (2012). Comparative effects of urban development and anthropogenic noise on bird songs. *Behavioral Ecology*, 23(1), 201–209. https://doi.org/10.1093/beheco/arr176

Eens, T. R., Pinxten, R., Casasole, G., Dehnhard, N., & Eens, M. (2017). Ambient anthropogenic noise, but not light, is associated with the ecophysiology of free-living songbird nestlings. *Scientific Reports*, 7, 1–9. https://doi.org/10.1038/s41598-017-02940-5

Engel, M. S., Young, R. J., Davies, W. J., Waddington, D., & Wood, M. D. (2024). A systematic review of anthropogenic noise impact on avian species. *Current Pollution Reports*, 10, 684–709. https://doi.org/10.1007/s40726-024-00329-3

Entry, K. E. G., Derryberry, E. P., Danner, R. M., Danner, J. E., & Luther, D. A. (2017). Immediate signaling flexibility in response to experimental noise in urban, but not rural, white-crowned sparrows. *Ecosphere*, 8(12), e01916. https://doi.org/10.1002/ecs2.1916

Francis, C. D., Ortega, C. P., & Cruz, A. (2011). Vocal frequency change reflects different responses to anthropogenic noise in two suboscine tyrant flycatchers. *Proceedings of the Royal Society B: Biological Sciences*, 278(1714), 2025–2031. https://doi.org/10.1098/rspb.2010.1847

Fröhlich, A., & Ciach, M. (2018). Noise pollution and decreased size of wooded areas reduces the probability of occurrence of tawny owl (Strix aluco). *Ibis*, 160(3), 634–646. https://doi.org/10.1111/ibi.12554

Gough, D. C., Mennill, D. J., & Nol, E. (2014). Singing seaside: Pacific wrens (Troglodytes pacificus) change their songs in the presence of natural and anthropogenic noise. The Wilson *Journal of Ornithology*, 126(2), 269–278. https://doi.org/10.1676/13-088.1

Halfwerk, W., Holleman, L. J. M., Lessells, C. M., & Slabbekoorn, H. (2011). Negative impact of traffic noise on avian reproductive success. *Journal of Applied Ecology*, 48(1), 210–219. https://doi.org/10.1111/j.1365-2664.2010.01914.x

Halfwerk, W., & Slabbekoorn, H. (2015). Pollution going multimodal: The complex impact of the human-altered sensory environment on animal perception and performance. *Biology Letters*, 11(4), 20141051. https://doi.org/10.1098/rsbl.2014.1051

Hamza, F., Hanane, S., Almalki, M., & Chokri, M.-A. (2022). How urbanization and industrialization shape breeding bird species occurrence in coastal Mediterranean oasis system. *Urban Ecosystems*, 26, 185–196. https://doi.org/10.1007/s11252-022-01271-2

Huet des Aunay, G., Slabbekoorn, H., Nagle, L., Passas, F., Nicolas, P., & Draganoiu, T. I. (2014). Urban noise undermines female sexual preferences for low-frequency songs in domestic canaries. *Animal Behaviour*, 87, 67–75. https://doi.org/10.1016/j.anbehav.2013.10.010

Juárez, R., Araya-Ajoy, Y. G., Barrantes, G., & Sandoval, L. (2021). House wrens (Troglodytes aedon) reduce repertoire size and change song element frequencies in response to anthropogenic noise. *Ibis*, 163(1), 52–64. https://doi.org/10.1111/ibi.12844

Kight, C. R., Saha, M. S., & Swaddle, J. P. (2012). Anthropogenic noise is associated with reductions in the productivity of breeding eastern bluebirds (Sialia sialis). *Ecological Applications*, 22(7), 1989–1996. https://doi.org/10.1890/12-0133.1

Kleist, N. J., Guralnick, R. P., Cruz, A., & Francis, C. D. (2016). Anthropogenic noise weakens territorial response to intruder's songs. *Ecosphere*, 7(3), e01259. https://doi.org/10.1002/ecs2.1259

Lajeunesse, M. 2 2 Power statistics for Meta-analysis: tests for Mean effects and Homogeneity. Retrieved September 17, 2025, from http://lajeunesse.myweb.usf.edu/papers/Lajeunesse_2013_Chapter_22_Handbook_of_Meta-analysis_in_Ecology_and_Evolution.pdf

Long, A. M., Colón, M. R., Bosman, J. L., Robinson, D. H., Pruett, H. L., McFarland, T. M., Mathewson, H. A., Szewczak, J. M., Newnam, J. C., & Morrison, M. L. (2017). A before–after control–impact assessment to understand the potential impacts of highway construction noise and activity on an endangered songbird. *Ecology and Evolution*, 7(15), 1–13. https://doi.org/10.1002/ece3.2608

Montenegro, C., Service, W. D., Scully, E. N., Mischler, S. K., Sahu, P. K., Benowicz, T. J., Fox, K. V. R., & Sturdy, C. B. (2021). The impact of anthropogenic noise on individual identification via female song in black-capped chickadees (Poecile atricapillus). *Scientific Reports*, 11, 1–11. https://doi.org/10.1038/s41598-021-96504-3

Muñoz Santos, I., & Ríos Chelén, A. A. (2023). Vermilion flycatchers avoid singing during sudden peaks of anthropogenic noise. *Acta Ethologica*, 26, 201–210. https://doi.org/10.1007/s10211-022-00409-x

Nelson-Olivieri, J. R., Layden, T. J., Antunez, E., Khalighifar, A., Lasky, M., Laverty, T. M., Sanchez, K. A., Shannon, G., Starr, S., Verahrami, A. K., & Bombaci, S. P. (2023). Inequalities in noise will affect urban wildlife. *Nature Ecology & Evolution*, 7(8), 1051–1058. https://doi.org/10.1038/s41559-023-02257-9

Nordt, A., & Klenke, R. (2013). Sleepless in town – Drivers of the temporal shift in dawn song in urban European blackbirds. *PLOS ONE*, 8(8), e71476. https://doi.org/10.1371/journal.pone.0071476

Önsal, Ç., Yelimlieş, A., & Akçay, Ç. (2022). Aggression and multi-modal signaling in noise in a common urban songbird. *Behavioral Ecology and Sociobiology*, 76, 102. https://doi.org/10.1007/s00265-022-03207-4

Ozkan, K., Langley, J. M., Talbott, J. W., Kleist, N. J., & Francis, C. D. (2024). Divergent effects of short-term and continuous anthropogenic noise exposure on western bluebird parental care behavior. *PeerJ*, 12, e18558. https://doi.org/10.7717/peerj.18558

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Aki, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, *18*(3), Article e1003583. https://doi.org/10.1371/journal.pmed.1003583

Parris, K. M., & Schneider, A. (2008). Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and Society*, 14(1), 29. https://doi.org/10.5751/ES-02761-140129

Perillo, A., Mazzoni, L. G., Passos, L. F., Goulart, V. D. L. R., Duca, C., & Young, R. J. (2017). Anthropogenic noise reduces bird species richness and diversity in urban parks. *Ibis*, 159(3), 638–646. https://doi.org/10.1111/ibi.12481

Potvin, D. A., Curcio, M. T., Swaddle, J. P., & MacDougall-Shackleton, S. A. (2016). Experimental exposure to urban and pink noise affects brain development and song learning in zebra finches (Taeniopygia guttata). *PeerJ*, 4, e2287. https://doi.org/10.7717/peerj.2287

Proppe, D. S., Sturdy, C. B., & St. Clair, C. C. (2013). Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. *Global Change Biology*, 19(4), 1075–1084. https://doi.org/10.1111/gcb.12098

Redondo, I., Muriel, J., de Castro Díaz, C., Aguirre, J. I., Gil, D., & Pérez Rodríguez, L. (2021). Influence of growing up in the city or near an airport on the physiological stress of tree sparrow nestlings (Passer montanus). *European Journal of Wildlife Research*, 67, 91. https://doi.org/10.1007/s10344-021-01509-y

Ríos-Chelén, A. A., Lee, G. C., & Patricelli, G. L. (2015). Anthropogenic noise is associated with changes in acoustic but not visual signals in red-winged blackbirds. *Behavioral*

Ecology and Sociobiology, 69(7), 1139–1151. https://doi.org/10.1007/s00265-015-1928-7
Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2005). Publication bias in meta-analysis: prevention, assessment, and adjustments. Wiley. https://doi.org/10.1002/0470870168
Senzaki, M., Barber, J. R., Carter, N. H., Cooper, C. B., Ditmer, M. A., Fristrup, K. M., McClure, C. J. W., Mennitt, D. J., Tyrrell, L. P., Vukomanovic, J., Wilson, A. A., & Francis, C. D. (2020). Sensory pollutants alter bird phenology and fitness across a continent. *Nature*, 587(7834), 605–609. https://doi.org/10.1038/s41586-020-2903-7
Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., Warner, K. A., Nelson, M. D., White, C., Briggs, J., McFarland, S., & Wittemyer, G. (2015). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*, 91(4), 982–1005. https://doi.org/10.1111/brv.12207
Van Donselaar, J. L., Atma, J. L., Kruyf, Z. A., LaCroix, H. N., & Proppe, D. S. (2018). Urbanization alters fear behavior in black-capped chickadees. *Urban Ecosystems*, 21, 1043–1051. https://doi.org/10.1007/s11252-018-0783-5
Viechtbauer, W. & Cheung, M. W. -L. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*. 1(2), 112-125. https://doi.org/10.1002/jrsm.11
Walters, M. J., Guralnick, R. P., Kleist, N. J., & Robinson, S. K. (2019). Urban background noise affects breeding song frequency and syllable-type composition in the northern mockingbird. *The Condor*, 121(2), duz002. https://doi.org/10.1093/condor/duz002
Wood, W. E., & Yezerinac, S. M. (2006). Song sparrow (Melospiza melodia) song varies with urban noise. *The Auk*, 123(3), 650–659. https://doi.org/10.1093/auk/123.3.650

Appendix

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.

Response to Reviewer Comments - All significant changes are highlighted in red

Comment 1:
"In your last paragraph of the Introduction, try incorporating words or phrases such as 'The current study…' or 'This study' in place of I and/or my. This also can apply to the sentences describing the hypotheses as well as in various places throughout the manuscript where you use I and/or my."

Response:
We went through the manuscript and replaced all "I" and "my" with neutral phrasing like "this study" or "the present study." This includes the Introduction, Methods, and Discussion sections.

Comment 2:

"Adding more detail to the figure legends may aid in orienting the reader to the data that is being portrayed in the figure to supplement the text (i.e., description of axes, brief main findings, brief description of variables and statistics implemented)."

Response:
All figure captions were updated to include axis descriptions and the type of statistics used (Cohen's d).

Comment 3:

"Inclusion of the n's per group (i.e., the number of studies per outcome variable assessed in your Results section and/or the number of birds per group per analysis) would be helpful to interpret the main statistical findings."

Response:
We added sample sizes everywhere it's relevant:

- Overall meta-analysis: 42 studies, 438 original effect sizes, 298 recalculated
- Urban vs rural analysis: 442 observations
- Taxonomic group (passerines vs corvids): 385 observations
- Species-specific analysis: 189 observations

Comment 4:
Minor wording improvements throughout the manuscript.

Response:
I made small edits throughout for clarity, readability, and smoother flow, including Methods and Results.

11/18/2025

Submission 100099, *"Meta-Analysis of the Effect of Anthropogenic Noise on Bird Song and Abundance"*

Post-Revision Critical Review:

Overall, the manuscript is well written with clear aims and hypotheses and highlights a significant gap in the literature that must be addressed to understand the impact of anthropogenic noise on bird abundance and vocal behaviors, specifically in passerines and corvids. The introduction flows logically and the methods are clearly written to describe in detail the methodology implemented for the meta-analysis and the various outcome measures reported on. The statistical methods used for data analysis were well thought out and the consideration of publication bias is impressive. Inclusion of the sample sizes, edits to the figures, and edits to the figure captions in the results section strengthen the readability of the main results and emphasize the main findings following the meta-analysis. To further increase the understanding of data in the figures, incorporating the number of observations for rural vs urban habitats (Figure 2), suburban vs urban city vs urban green space habitats (Figure 2A), farmland vs marsh vs wildlife preserve vs woodland habitats (Figure 2B), rural vs urban habitats (Figure 4A and 4B), and the number of sparrows vs chickadee vs wren vs warblers (Figure 5) is recommended. The discussion ties together the main findings well and emphasizes the broader implications of anthropogenic noise altering behavior across various bird species. The author does a great job explaining how the observed behavioral alterations may have detrimental downstream effects on various bird species and discusses changes to physiological demands which may affect the overall survival of the species long-term. In close, the author recommends future directions for additional research to be carried out for a more detailed understanding of how noise affects the longevity of bird species across habitats.

Final Decision: Accept with minor revisions