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# Noisy environments: untangling the role of anthropogenic noise on bird species richness in a Neotropical city

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## Abstract

**Background:** Among urban stimuli, anthropogenic noise has been identified to be one of the behavioral drivers of species that rely on acoustic signals for communication. Studies have shown both species-specific and assemblage responses to urban noise, ranging from the modulation of their acoustic frequencies and spatiotemporal adjustments to declines in species richness. In this study, we assessed the citywide relationship between two anthropogenic noise variables (noise levels recorded during bird surveys and daily average noise levels) and vegetation cover with bird species richness.

**Methods:** This study was conducted in the city of Xalapa (Mexico) through a 114 citywide point-count survey. We recorded bird communities at each sampling site. We measured noise levels using a sound level meter while performing point-counts. Then, we generated a map of average daily noise of the city using an array of 61 autonomous recording units distributed across the city of Xalapa and calculated daily noise levels for the 114 points. We ran a linear model (LM) to assess potential relationships between both point-count and daily (24 h) noise values and vegetation cover with bird richness.

**Results:** Results from the LM show: (1) a negative relationship between maximum point-count noise and avian species richness, (2) no relationship between 24 h noise and bird species richness, and (3) a positive relationship between vegetation cover and bird species richness.

**Conclusions:** Results provide evidence that decreases in urban bird species richness do not necessarily imply the permanent absence of species, suggesting that birds can temporarily fly away from or avoid sites when noisy, become cryptic while noisy events are occurring, or be undetected due to our inability to record them in the field during noisy events.

**Keywords:** Avian ecology, Bird communication, Noise pollution, Species richness, Urban ecology

## Background

Urbanization is one of the most important forces of global transformation (Pickett et al. 2001; Grimm et al. 2008). Urban growth is rapid and pervasive (Paul and Meyer 2001), implying the modification, and even replacement, of preexisting conditions (Eldredge and Horenstein 2014). Besides the unmeasurable environmental impacts of urban metabolism at broad scales (Kennedy

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et al. 2011), cities represent systems with the widest array of pollutants, including solid waste, chemical pollution of air, water and soil, visual contamination, electromagnetic concentrations, and anthropogenic noise (Maldonado 2009). Given the environmental pressures that urbanization poses on biodiversity, it has been identified as one of the main causes of species endangerment and local extinction (Czech et al. 2000; McKinney 2002).

Although urbanization represents a semi-permeable ecological barrier for species from regional pools to colonize (MacGregor-Fors 2010), the set of species able to cope with the implied hazards and that survive on the available resources, among other factors, have shown to adjust, and even evolve, with urbanization (Johnson and Munshi-South 2017). Yet, evidence indicates that many of the urban stimuli are deleterious even for urban wildlife (Beaugeard et al. 2019). Among these stimuli, anthropogenic noise and artificial light at night have been considered crucial in understanding the response of birds to urbanization (Fröhlich and Ciach 2019).

Anthropogenic noise is regarded as a pollutant that can drive the behavior of species that rely on acoustic communication (Parris et al. 2009; Barber et al. 2010; Goodwin and Shriver 2011; Nemeth et al. 2013; Luther et al. 2016). Numerous animal species rely on acoustic signaling to perform some of the most elementary and complex processes, such as: (i) sexual signaling, (ii) territorial defenses, (iii) predator deterrence and/or avoidance, (iv) parental strategies, (v) foraging, and (vi) parent-offspring communication (Sanborn 2008; Dudzinski et al. 2009; Parris et al. 2009; Jacot et al. 2010). In particular, birds have been widely used as ecological models for the study of the alterations generated by anthropogenic noise in animals (Patricelli and Blickley 2006). Several types of responses to anthropogenic noise have been reported across literature, many of which have focused on the role of noisy urban sites. For instance, House Finches (*Haemorhous mexicanus*) have been shown to be able to modulate the minimum frequency of their songs in response to noise (Bermúdez-Cuamatzin et al. 2011). Great Tits (*Parus major*) have also been shown to switch to higher minimum frequencies when exposed to low frequency noise pollution (Slabbekoorn and den Boer-Visser 2006; Halfwerk and Slabbekoorn 2009; Slabbekoorn et al. 2012).

Avian vocal adjustments to urban noise can vary spatiotemporally. Such is the case of Spotless Starlings (*Sturnus unicolor*) and House Sparrows (*Passer domesticus*) that have been found to start singing before dawn to avoid urban noise (Arroyo-Solís et al. 2013). Also, European Robins (*Erithacus rubecula*) seem to avoid acoustic interference with urban noise by singing at night in sites that are noisy during the day (Fuller et al. 2007).

Regarding spatial responses, some bird species tend to avoid anthropogenic noise due to the masking of their acoustic signals (McLaughlin and Kunc 2013). Studies have even provided evidence that supports the idea that urban noise plays an important role in the assemblage level. For example, a study from a Neotropical city found trends of avian assemblages singing earlier in noisier urban sites (Marín-Gómez and MacGregor-Fors 2019). Even declines in species richness, one of the best understood emergent properties of avian communities, have been reported for urban noisy areas (Carbó-Ramírez and Zuria 2011; Fontana et al. 2011; González-Oreja 2017; Perillo et al. 2017; De Camargo-Barbosa et al. 2020).

Given that previous studies have shown that birds can differentially respond to urban noise, ranging from not vocalizing while masking noise occurs to leaving noisy conditions, here we assessed the citywide relationship between anthropogenic noise levels and bird species richness in a Neotropical city. For this, we considered two urban noise measurements: (i) noise levels recorded during bird surveys (referred to as point-count noise hereafter) and (ii) daily average noise levels (referred to as 24 h noise hereafter). Given the available knowledge on the responses of birds to urban noise, we hypothesized two mutually exclusive outcomes. If birds are affected by urban noise in such a way that at least some of them avoid noisy sites, we predicted both noise measurements to be negatively related to avian species richness. Conversely, considering that vocalizations represent the most informative source when conducting point-counts (Ralph et al. 1995; Bibby et al. 2000), if some birds change their singing activities and become less detectable during surveys and/or momentarily fly away from noisy conditions, we expected a negative relationship between point-count noise levels and species richness, but no relation with 24 h noise. Finally, we also assessed the relationship between green cover and avian species richness, as green cover has been regarded as one of its main positive drivers in urban areas, and could contextualize our noise results (Fischer et al. 2012; Stirnemann et al. 2015; Schütz and Schulze 2015; Marzluff 2016).

## Methods

### Study area and survey sites

This study was conducted in the city of Xalapa, state capital of Veracruz (Mexico; 19° 32' 38" N, 96° 54' 36" W; 1120–1720 m asl; INEGI 2009). Original vegetation in the region where Xalapa is settled was mainly comprised by montane cloud, tropical dry, and temperate forests (Castillo-Campos 1991). We located a total of 114 sampling sites following a citywide framework. For this, we considered the 106 study sites used in Escobar-Ibáñez and MacGregor-Fors (2016) and added eight additional

sites along greenspaces to rise their representativeness in our sample (Fig. 1).

### Bird surveys

We conducted 10 min point-counts (50 m radius) at all 114 sampling sites from 6:00 to 10:00 h during the breeding season of 2019 (April 22 to May 6). We surveyed each location once and recorded all birds seen or heard [except overflying individuals; following Ralph et al. (1995)]. We decided to perform limited radius surveys to assure that all recorded birds were actively using the surveyed area. We located our survey sites at a minimum distance of 250 m from each other to assure that sampling sites did not spatially overlap with maximal recording distances reported in field manuals (Ralph et al. 1995; Bibby et al. 2000).

### Noise measurements

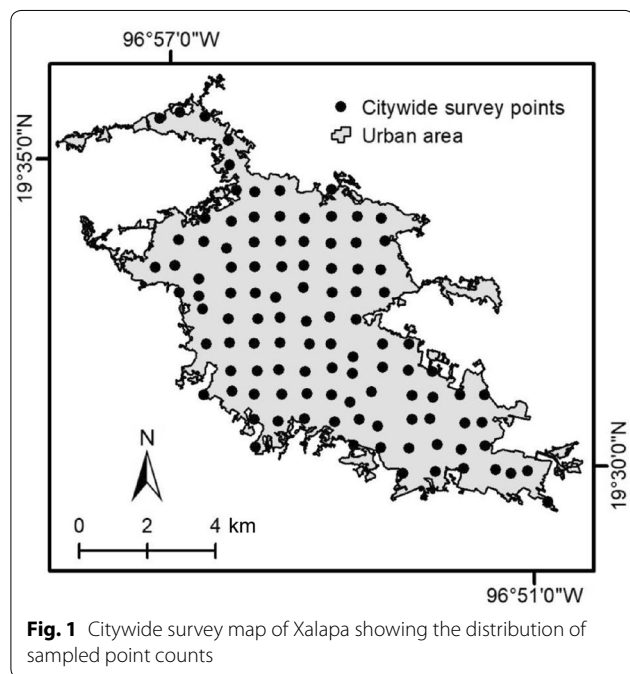
While point-counts were conducted, we measured point-count noise levels using a sound meter (B&K Precision model 732A; A-weighted scale, fast time 30–130 dB; frequency range: 31.5–8 kHz; resolution 0.1 dB). We recorded 72 noise level measurements during 3 min at each site with the sound meter mounted on a tripod at 1.5 m vertically-positioned. Afterward, we calculated the average, minimum, and maximum values of point-count noise for each survey site.

For 24 h noise levels we placed ARUs (Autonomous Recording Units, 16 SM4 and 6 SM3 song meters; Wildlife Acoustics Inc. ©, Maynard, MA) in 61 sites

distributed across the city of Xalapa. Given that we could not place ARUs safely at all 114 points, we placed them at safe sites located across a gradient of urbanization density of Xalapa. We programmed ARUs to record for three consecutive days (03 June 2017 to 18 June 2017) using the following schedule during an entire day (24 h): a continuous long recording (75 min) during dawn and dusk periods, and 5 min every 15 min (i.e., 5 min on, 10 min off) during the remaining time periods. We used the same sound gain settings for ARU microphones, both left and right (~24 dB), to accomplish comparable soundscape recordings among sampled sites. Moreover, we automatically extracted noise levels from recordings in Kaleidoscope Pro following a batch procedure maintaining the same parameters (i.e., 60 s sample period and 0.0 dB adjustment). This procedure allowed us to retrieve noise measurements that are comparable across sample sites and thus reflect relative noise amplitude values in band frequencies from 19.7 to 2000.0 Hz; commonly used on noise studies (Merchant et al. 2015; Wildlife Acoustics 2019). The overall data set obtained consisted of 1425.6 h of recordings. Using this information, we calculated the mean amplitude for each site per day as a sample period of 1-min recording every 1 min, resulting in a total of 655 noise measurements. For purposes of this study, we used a global proxy of noise level, defined as the average noise amplitude per day at each study site considering the 1/3-octave band levels (Luther and Gentry 2013; Slabbekoorn 2013). We then calculated the logarithmic average of noise values because noise levels are on a logarithmic scale, as decibels increase exponentially. As noise levels were expressed as a relative measure (dB relative to 1 Volt), we could not convert them to sound pressure units (SPL). Thus, in our data set, noisier sites had values near 0 dB and quieter sites had values around -100 dB. By using the logarithmic average values of noise, we generated a raster continuum of values that allowed us to retrieve 24 h noise levels in each one of the 114 sampling sites. We obtained rasterized values as result of an inverse distance weighting (IDW) interpolation, which estimates values using the nearest sample points available, which in turn, are weighted by a power proportional to the inverse of the distance between them and the desired value (Li and Heap 2008). Finally, we retrieved green cover values within 50 m radius buffers from all sampling sites using information of a satellite image classification [see Falfán et al. (2018) for further methodological details].

### Data analysis

We performed a single linear model (LM) to assess potential relationships between the independent variables (i.e., point-count noise, 24 h noise, vegetation cover) with bird richness (dependent variable). Given



that average, minimum, and maximum point-count noise values were correlated ( $r > 0.38$ ,  $p < 0.001$ ), we only considered maximum values, as they showed to have the highest statistical variance. We ran all statistical analyses in R (R Core Team 2019).

## Results

We recorded a total of 82 bird species, with average 13.19 ( $\pm$  SD 7.92) species richness per point-count. The most abundant species recorded was the Great-tailed Grackle (*Quiscalus mexicanus*,  $n = 409$ ), followed by Social Flycatcher (*Myiozetetes similis*,  $n = 149$ ), House Sparrow ( $n = 144$ ), and Rock Pigeon (*Columba livia*,  $n = 130$ ). As expected, our results show a positive relationship between vegetation cover and bird species richness (Table 1, Fig. 2).

The minimum point-count noise was 33 dBA, which is comparable to that of a library or a bedroom at night, while the maximum point-count noise was 97.6 dBA, similar to the sound made by a gas lawn mower or a diesel truck. The average point-count noise was 54.79 dBA, which corresponds to that of the noise produced in a commercial area (FAA 2018). In the case of 24 h noise levels, and considering that the scale is inverted (i.e., quieter sites are closer to  $-100$  dB, and noisier sites are closer to 0 dB; see Methods for further details), minimum 24 h noise level was of  $-89.62$  dB, while the maximum

value was of  $-44.52$  dB, with an overall average of  $-68.39$  dB. Our records indicate that the noise recorded in our surveys is within the thresholds of a common city (Chepesiuk 2005; McAlexander et al. 2015; Kamenov 2016). We found a negative relationship between maximum point-count noise and avian species richness. Conversely, we did not find relationship between 24 h noise and bird species richness (Table 1, Fig. 2).

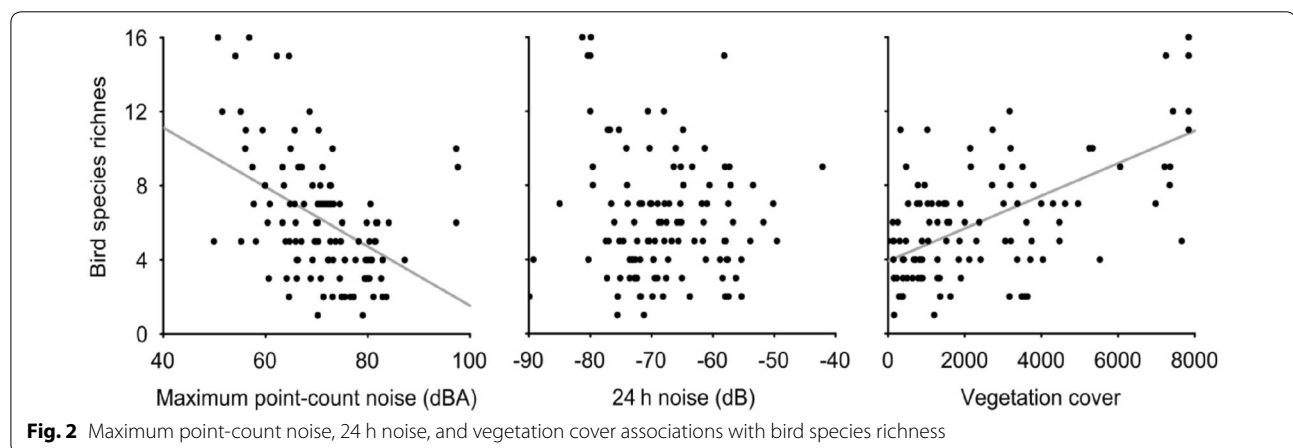
## Discussion

Birds that dwell within cities, including their greenspaces, are subject to numerous stimuli, pressures, and threats that vary spatiotemporally (Warren et al. 2006; Evans et al. 2011; Marzluff 2016; Santiago-Alarcon and Delgado-V 2017). In fact, the complex array of urban conditions and scenarios has been shown to mold the birds that are able to dwell within them (Melles et al. 2003; Evans et al. 2009; MacGregor-Fors and Schondube 2011; MacGregor-Fors and García-Arroyo 2017). As expected, our results showed a positive association between vegetation cover and bird species richness. This is consistent with the mounting evidence that urban vegetation plays a crucial positive role for urban-dwelling birds [see Marzluff (2016) for an updated review]. Empirical evidence has clearly shown that well-vegetated urban sites provide a wider array of conditions and resources that allow for many avian species that are not tolerant to the urban life to be present within cities (Crocì et al. 2008; Evans et al. 2011; Sol et al. 2013). Actually, when a recent ecological study was contrasted with the historical list of birds of Xalapa, it was evident that most bird species of this biodiverse city are concentrated along its greenspace network and well-vegetated residential areas (González-García et al. 2014; Escobar-Ibáñez and MacGregor-Fors 2016).

Additionally, our findings are consistent with our second prediction (i.e., negative relationship between

**Table 1** LM showing the relationship of point-count noise, 24 h noise levels, and vegetation cover with bird richness in the city of Xalapa, Veracruz

Variable	Estimate	SE	F	df	P
Point-count noise	-0.0187	0.0276	17.269	1	< 0.001
24 h noise	0.0067	0.0261	0.011	1	0.918
Vegetation cover	0.0007	0.0001	76.889	1	< 0.001





point-count noise levels and species richness, but no relation with 24 h noise). This finding is in partial agreement with previous studies that measured noise during or after surveys were performed and related it to bird species richness in urban areas (e.g., Carbó-Ramírez and Zuria 2011; Fontana et al. 2011; González-Oreja 2017; Perillo et al. 2017; De Camargo-Barbosa et al. 2020). Even studies performed in non-urban highways have found this relationship to hold, with noisier conditions associated with lower avian species richness (Herrera-Montes and Aide 2011).

Nevertheless, day-round noise (24 h noise) was not associated with variations in avian species richness in this study, suggesting that birds leave noisy sites or stop vocalizing in a short time-scale, like that of short ecological surveys (e.g., point-counts, transects). This result is particularly interesting, as previous studies have shown that birds can be importantly affected by prolonged, chronic noise (Habib et al. 2007; Leonard and Horn 2008; Blickley et al. 2012) and can also adjust their behavior in relation to noise in differing times of the day (e.g., Fuller et al. 2007; Gil et al. 2015; Lee et al. 2017). Thus, not finding a relationship between 24 h noise and bird species richness suggests that urban birds may be capable of tolerating anthropogenic noise more than shown in previous studies measuring focal noise during or close to survey times. Such response is in agreement with the growing amount of evidence that urban wildlife can be highly phenotypically plastic (Bonier et al. 2007). For example, several bird species have been shown to be quieter in noisy conditions, often avoiding vocalization overlap with anthropogenic noise (Fuller et al. 2007; Halfwerk and Slabbekoorn 2009).

Although our results clearly agree with our second prediction, there are some methodological limitations that need to be considered in future studies seeking to untangle bird richness patterns in different urban noise conditions. Most importantly, noise measurements reflecting their variability across the day should be taken in the exact same sites. Also, given that bird detection probability decreases in sites exceeding ~45 dBA (as noise reduces the distance and area where the acoustic signaling of birds can be perceived; Barber et al. 2010; Ortega and Francis 2012), field surveys should include the use of bird song recordings in order to assure that birds are not singing during noisy events, which can be easily identified in spectrograms using simple freeware (e.g., Audacity, Raven).

## Conclusions

Results of this study support the hypothesis that decreases in urban bird species richness do not necessarily imply the permanent absence of species in the

surveyed sites, shedding light on potential factors related to measuring noise while bird diversity surveys are performed. Thus, these findings suggest that birds could: (i) temporarily fly away from or avoid sites when noisy, (ii) stop vocalizing while noisy events are occurring to avoid their signals being masked, or (iii) be undetected due to our inability of recording them because of the noisy events. Thus, future studies could test if our findings are generalizable and which of the suggested scenarios are driving them.

## Abbreviations

ARU: Autonomous recording units; dB: Decibel; dBA: A-weighted decibels; FAA: Federal Aviation Administration; LM: Linear model; IDW: Inverse distance weighting; SPL: Sound pressure units.

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## Authors' contributions

IM-F, MG-A, and OHM-G conceived the idea; OHM-G and COC-M lead the field work; COC-M, MG-A, and IM-F performed the analyses and lead the writing, with all authors contributing significantly to the final version. All authors read and approved the final manuscript.

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## Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Competing interests

The authors declare that they have no competing interests.

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## References

- Arroyo-Solis A, Castillo JM, Figueroa E, López-Sánchez JL, Slabbekoorn H. Experimental evidence for an impact of anthropogenic noise on dawn chorus timing in urban birds. *J Avian Biol.* 2013;44:288–96.
- Barber JR, Crooks KR, Fristrup KM. The costs of chronic noise exposure for terrestrial organisms. *Trends Ecol Evol.* 2010;25:180–9.
- Beaugeard E, Brisichoux F, Henry P-Y, Parenteau C, Trouvé C, Angelier F. Does urbanization cause stress in wild birds during development? Insights from feather corticosterone levels in juvenile house sparrows (*Passer domesticus*). *Ecol Evol.* 2019;9:640–52.
- Bermúdez-Cuamatzin E, Ríos-Chelén AA, Gil D, Macías-García C. Experimental evidence for real-time song frequency shift in response to urban noise in a passerine bird. *Biol Lett.* 2011;7:36–8.
- Bibby CJ, Burgess ND, Hill DA, Mustoe S. Bird census techniques. London: Academic Press; 2000.
- Blickley JL, Word KR, Krakauer AH, Phillips JL, Sells SN, Taff CC, et al. Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*). *PLoS ONE.* 2012;7:e50462.
- Bonier F, Martin PR, Wingfield JC. Urban birds have broader environmental tolerance. *Biol Lett.* 2007;3:670–3.
- Carbó-Ramírez P, Zuria I. The value of small urban greenspaces for birds in a Mexican city. *Landscape Urban Plan.* 2011;100:213–22.
- Castillo-Campos G. Vegetación y flora del municipio de Xalapa, Veracruz. Instituto de Ecología: UNESCO; 1991.
- Chepesiuk R. Decibel hell: the effects of living in a noisy world. *Environ Health Perspect.* 2005;113:A34–41.
- Croci S, Butet A, Clergeau P. Does urbanization filter birds on the basis of their biological traits? *Condor.* 2008;110:223–40.
- Czech B, Krausman PR, Devers PK. Economic associations among causes of species endangerment in the United States. *Bioscience.* 2000;50:593–601.
- De Camargo-Barbosa KV, Rodewald AD, Ribeiro MC, Jahn AE. Noise level and water distance drive resident and migratory bird species richness within a Neotropical megacity. *Landsc Urban Plan.* 2020;197:103769.
- Dudzinski K, Jeanette T, Justin G. Communication in marine mammals. In: Perrin W, Würsig B, Thewissen JGM, editors. *Encyclopedia of marine mammals*. London: Academic Press; 2009. p. 260–9.
- Eldredge N, Horenstein S. Concrete jungle: New York City and our last best hope for a sustainable future. Oakland: University of California Press; 2014.
- Escobar-Ibáñez JF, MacGregor-Fors I. Peeking into the past to plan the future: assessing bird species richness in a neotropical city. *Urban Ecosyst.* 2016;19:657–67.
- Evans KL, Newson SE, Gaston KJ. Habitat influences on urban avian assemblages. *Ibis.* 2009;151:19–39.
- Evans KL, Chamberlain DE, Hatchwell BJ, Gregory RD, Gaston KJ. What makes an urban bird? *Global Change Biol.* 2011;17:32–44.
- Falfán I, Muñoz-Robles CA, Bonilla-Moheno M, MacGregor-Fors I. Can you really see 'green'? Assessing physical and self-reported measurements of urban greenery. *Urban for Urban Gree.* 2018;36:13–21.
- Federal Aviation Association (FAA): Fundamentals of noise and sound; 2018. [https://www.faa.gov/regulations\\_policies/policy\\_guidance/noise/basic/](https://www.faa.gov/regulations_policies/policy_guidance/noise/basic/). Accessed 02 Dec 2019.
- Fischer RA, Valente JJ, Guilfoyle MP, Kaller MD, Jackson SS, Ratti JT. Bird community response to vegetation cover and composition in riparian habitats dominated by Russian olive (*Elaeagnus angustifolia*). *Northwest Sci.* 2012;86:39–52.
- Fontana CS, Burger MI, Magnusson E. Bird diversity in a subtropical South-American City: effects of noise levels, arborisation and human population density. *Urban Ecosyst.* 2011;14:341–60.
- Fröhlich A, Ciach M. Nocturnal noise and habitat homogeneity limit species richness of owls in an urban environment. *Environ Sci Pollut Res.* 2019;26:17284–91.
- Fuller RA, Warren PH, Gaston KJ. Daytime noise predicts nocturnal singing in urban robins. *Biol Lett.* 2007;3:368–70.
- Gil D, Honarmand M, Pascual J, Pérez-Mena E, Macías García C. Birds living near airports advance their dawn chorus and reduce overlap with aircraft noise. *Behav Ecol.* 2015;26:435–43.
- González-Oreja JA. Relationships of area and noise with the distribution and abundance of songbirds in urban greenspaces. *Landsc Urban Plan.* 2017;158:177–84.
- González-García F, Straub R, García JAL, MacGregor-Fors I. Birds of a neotropical green city: an up-to-date review of the avifauna of the city of Xalapa with unpublished records. *Urban Ecosyst.* 2014;17:991–1012.
- Goodwin SE, Shriver G. Effects of traffic noise on occupancy patterns of forest birds. *Conserv Biol.* 2011;25:406–11.
- Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, et al. Global change and the ecology of cities. *Science.* 2008;319:756–60.
- Habib L, Bayne EM, Boutin S. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. *J Appl Ecol.* 2007;44:176–84.
- Halfwerk W, Slabbekoorn H. A behavioural mechanism explaining noise-dependent frequency use in urban birdsong. *Anim Behav.* 2009;78:1301–7.
- Herrera-Montes MI, Aide TM. Impacts of traffic noise on anuran and bird communities. *Urban Ecosyst.* 2011;14:415–27.
- Instituto Nacional de Estadística y Geografía (INEGI). *Prontuario de la información geográfica municipal de los Estados Unidos Mexicanos*. Xalapa, Veracruz de Ignacio de la Llave: Clave geoestadística; 2009.
- Jacot A, Hendrik R, Forstmeier W. Individual recognition and potential recognition errors in parent-offspring communication. *Behav Ecol Sociobiol.* 2010;64:1515–25.
- Johnson MTJ, Munshi-South J. Evolution of life in urban environments. *Science.* 2017;358:eaam8327.
- Kamenov A. The noisiest cities in the U.S. In: *City-Data.com - comprehensive information about United States*; 2016. <http://www.city-data.com/blog/2259-noisiest-cities-us/>. Accessed 10 Dec 2019.
- Kennedy C, Pincetl S, Bunje P. The study of urban metabolism and its applications to urban planning and design. *Environ Pollut.* 2011;159:1965–73.
- Lee JGH, MacGregor-Fors I, Yeh PJ. Sunrise in the city: disentangling drivers of the avian dawn chorus onset in urban greenspaces. *J Avian Biol.* 2017;48:955–64.
- Leonard ML, Horn AG. Does ambient noise affect growth and begging call structure in nestling birds? *Behav Ecol.* 2008;19:502–7.
- Li J, Heap AD. A review of spatial interpolation methods for environmental scientists. *Geoscience Australia, Record 2008/23*; 2008.
- Luther D, Gentry K. Sources of background noise and their influence on vertebrate acoustic communication. *Behaviour.* 2013;150:1045–6.
- Luther DA, Phillips J, Derryberry EP. Not so sexy in the city: urban birds adjust songs to noise but compromise vocal performance. *Behav Ecol.* 2016;27:332–40.
- MacGregor-Fors I. How to measure the urban-wildland ecotone: redefining 'peri-urban' areas. *Ecol Res.* 2010;25:883–7.
- MacGregor-Fors I, García-Arroyo M. Who is who in the city? Bird species richness and composition in urban Latin America. In: MacGregor-Fors I, Escobar-Ibáñez JF, editors. *Avian ecology in Latin American Cityscapes*. Cham: Springer International Publishing; 2017. p. 33–55.
- MacGregor-Fors I, Schondube JE. Gray vs green urbanization: Relative importance of urban features for urban bird communities. *Basic Appl Ecol.* 2011;12:372–81.
- Maldonado JM. Ciudades y contaminación ambiental. *Revista de Ingeniería.* 2009;30:66–71.
- Marín-Gómez OH, MacGregor-Fors I. How early do birds start chirping? Dawn chorus onset and peak times in a Neotropical city. *Ardeola.* 2019;66:327–41.
- Marzluff JM. A decadal review of urban ornithology and a prospectus for the future. *Ibis.* 2016;159:1–13.
- McAlexander TP, Gershon RRM, Neitzel RL. Street-level noise in an urban setting: assessment and contribution to personal exposure. *Environ Health.* 2015;14:18.
- McKinney ML. Urbanization, biodiversity, and conservation. *Bioscience.* 2002;52:883–90.
- McLaughlin KE, Kunc HP. Experimentally increased noise levels change spatial and singing behaviour. *Biol Lett.* 2013;9:20120771.
- Melles S, Glenn S, Martin K. Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient. *Conserv Ecol.* 2003;7:5.
- Merchant ND, Fristrup KM, Johnson MP, Tyack PL, Witt MJ, Blondel P, et al. Measuring acoustic habitats. *Methods Ecol Evol.* 2015;6:257–65.
- Nemeth E, Pieretti N, Zollinger SA, Geberzahn N, Partecke J, Miranda AC, et al. Bird song and anthropogenic noise: vocal constraints may

- explain why birds sing higher-frequency songs in cities. *Proc R Soc B*. 2013;280:20122798.
- Ortega CP, Francis CD. Effects of gas-well-compressor noise on the ability to detect birds during surveys in northwest New Mexico. *Ornithol Monogr*. 2012;74:78–90.
- Parris KM, Velik-Lord M, North JMA. Frogs call at a higher pitch in traffic noise. *Ecol Soc*. 2009;14:25.
- Patricelli GL, Blickley JL. Avian communication in urban noise: causes and consequences of vocal adjustment. *Auk*. 2006;123:639–49.
- Paul MJ, Meyer J. Streams in the urban landscape. *Annu Rev Ecol Evol S*. 2001;32:333–65.
- Perillo A, Mazzoni LG, Passos LF, Goulart VD, Duca C, Young RJ. Anthropogenic noise reduces bird species richness and diversity in urban parks. *Ibis*. 2017;159:638–46.
- Picket STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WV, et al. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annu Rev Ecol Syst*. 2001;32:127–57.
- R Core Team. R: A language and environment for statistical computing; 2019. <http://www.R-project.org/>.
- Ralph CJ, Droege S, Sauer JR. Managing and monitoring birds using point counts: standards and applications. In: Ralph CJ, Sauer JR, Droege S, editors. *Monitoring bird populations by point counts*. USDA Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-149; 1995.
- Sanborn A. Acoustic communication in insects. In: Capinera JL, editor. *Encyclopedia of entomology*. Dordrecht: Springer; 2008. p. 33–8.
- Santiago-Alarcon D, Delgado-V CA. Warning! Urban threats for birds in Latin America. In: MacGregor-Fors I, Escobar-Ibáñez JF, editors. *Avian ecology in Latin American Cityscapes*. Cham: Springer International Publishing; 2017. p. 125–42.
- Schütz C, Schulze CH. Functional diversity of urban bird communities: effects of landscape composition, green space area and vegetation cover. *Ecol Evol*. 2015;5:5230–9.
- Slabbekoorn H. Songs of the city: noise-dependent spectral plasticity in the acoustic phenotype of urban birds. *Anim Behav*. 2013;85:1089–99.
- Slabbekoorn H, den Boer-Visser A. Cities change the songs of birds. *Curr Biol*. 2006;16:2326–31.
- Slabbekoorn H, Yang X-J, Halfwerk W. Birds and anthropogenic noise: singing higher may matter. *Am Nat*. 2012;180:142–5.
- Sol D, Lapiedra O, González-Lagos C. Behavioural adjustments for a life in the city. *Anim Behav*. 2013;85:1101–12.
- Stirnemann IA, Ikin K, Gibbons P, Blanchard W, Lindenmayer DB. Measuring habitat heterogeneity reveals new insights into bird community composition. *Oecologia*. 2015;177:733–46.
- Warren PS, Katti M, Ermann M, Brazel A. Urban bioacoustics: it's not just noise. *Anim Behav*. 2006;71:491–502.
- Wildlife Acoustics. <https://www.wildlifeacoustics.com/products/kaleidoscope-pro/tutorial-videos>. Accessed 20 May 2019.

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