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Anthropogenic noise reduces bird species richness and diversity in urban parks

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Anthropogenic noise reduces bird species richness and diversity in urban parks

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Anthropogenic noise is becoming more prevalent in the world and has been shown to affect many animal species, including birds. The impact of such noise was measured in Neotropical urban parks to assess how it affects avifauna diversity and species richness. We sampled bird species, and concurrently measured sound pressure (noise) levels (L_{eq}; equivalent noise levels) in eight urban green areas or parks located in a large city (Belo Horizonte) in south-eastern Brazil over a one-year period. The diversity of sampled points was measured by means of total species richness, Fisher's alpha and Shannon-Wiener diversity indices. Noise levels within each park were greater than those in natural areas. We found that the increase in noise levels and the land use of the surrounding area to sampling points (i.e. open areas) were negatively related to species richness. Social factors, such as increase in income, also decrease bird species richness as it reflected more urbanized regions in our study area. However, noise was the factor that explained most of the variance. These results suggest that anthropogenic noise can have a significant negative impact on the conservation value of urban parks for bird species.

Keywords: anthropogenic processes; bird diversity; urban parks; noise; species richness.

The process of urbanisation results in an increase in the area of remaining natural habitat that is exposed to human activities, forcing animals and plants to either adapt or disappear (Møller 2009). Urban habitats differ in many ways from natural environments (Jokimäki 1999), exposing the species that dwell in these areas to new conditions, such as competition with exotic species, increased exposure to predators (native and exotic) and parasites, and stress due to chemical pollution and noise (Slabbekoorn & Ripmeester 2008).

Recent studies have demonstrated that anthropogenic noise negatively affects not only the health and welfare of humans but can also affect bird behaviour (Slabbekoorn & Ripmeester 2008, Gross *et al.* 2010, Nemeth & Brumm 2010). Increasing human occupation of land means that anthropogenic noise is becoming more widespread (Patricelli & Blickley 2006, Slabbekoorn & Ripmeester 2008), so we need to predict what its effects will be. Different studies have found correlations between anthropogenic noise and behavioural changes, including vocalizing earlier in the day to avoid rush-hour traffic noise (Bergen & Abs 1997, Fuller *et al.* 2007), increased vocalization amplitude (the 'Lombard effect'; Brumm 2004), shifting of singing frequencies (Slabbekoorn & Peet 2003, Fernandez-Juricic *et al.* 2005, Slabbekoorn & Boer-Visser 2006, Bermudez-Cuamatzin *et al.* 2011) and vocal adjustment to reduce acoustic overlap (Slabbekoorn & Peet 2003, Brumm 2004, Brumm & Slater 2006, Fuller *et al.* 2007, Nemeth & Brumm 2010). Anthropogenic noise has a detrimental effect on bird fitness, survival and reproduction (Bayne & Boutin 2007, Gross *et al.* 2010, Schroeder *et al.* 2012). For instance, noise can reduce fitness by masking parent-offspring communication, as well as reduce parental provisioning, fledging and recruitment (Schroeder *et al.* 2012).

In the urban environment, vehicles are the main source of anthropogenic noise (Ouis 1999, Zannin *et al.* 2002). Noise from vehicles directly affects bird distributions, reducing density, richness and abundance in sites where noise pollution is intense (Rheindt 2003, Arévalo & Newhard 2011, McClure *et al.* 2013). Importantly, it has been shown that some species persist in noisier areas when confronted with such anthropogenic impacts, whereas other species disappear (McClure *et al.* 2013). Thus, it would be expected that anthropogenic noise, above certain levels, could reduce both species diversity and absolute species richness (Krebs 1998).

Few studies have demonstrated the effects of anthropogenic noise on urban birds in the Neotropical region (Arévalo & Newhard 2011, Fontana *et al.* 2011, Rios-Chelen *et al.* 2012, Rios-Chelen *et al.* 2013), despite its rich avifauna (Rahbek & Graves 2001) and ongoing intense urbanisation. Countries such as Brazil, which harbours a rich avian fauna and has 85% of its human population living in large urban centres (IBGE 2010), are ideal to test the effects of noise pollution on urban bird conservation.

City parks or green areas can be used as models to study the effects of anthropogenic noise on parameters that are often used to assess bird communities, such as species richness and diversity. These are useful parameters for characterising a community for conservation purposes (Ribon 2010). It is expected that larger parks or green areas would have a greater diversity of species due to their greater plant and habitat diversity (Donnelly & Marzluff 2004) and other factors such as edge effects and heterogeneity (Galli *et al.* 1976, Freemark & Merriam, 1986). However, anthropogenic factors such as noise could negatively affect these areas, reducing species diversity (Cullen Jr *et al.* 2000) and the potential value of urban green areas/parks for bird conservation. In this study, we assessed whether increasing noise levels negatively influences bird species diversity and richness within urban parks in a Neotropical metropolis.

METHODS

Study area

This study was conducted in the city of Belo Horizonte, Minas Gerais, Brazil, which is located in a transitional zone between the Cerrado (covering 58% of the municipality total extension) and Atlantic Forest (42% of the municipality total extension), both of which are biodiversity hotspots (Myers *et al.* 2000, IBGE 2011). The city has 2.3 million inhabitants spread over 330 km^2.

Belo Horizonte contains over 70 green areas (parks, gardens, etc.) managed by the City Mayor's Office (Fundação de Parques Muncipais 2015). Many other privately-owned green areas are also located within the city. We selected eight green areas of predominately native forest habitat, located in different regions of Belo Horizonte, with different size, isolation and altitude (Table 1). Areas were specifically chosen not to be continuous with natural habitat surrounding the city so that they were truly urban rather than being on a rural-urban gradient (Fig. 1). We calculated their degree of isolation (in meters) as the mean of the distance to the three nearest green areas that were larger than our smallest green area.

Data collection

We sampled bird species richness and diversity using the point count method (Bibby *et al.* 2000, Vielliard *et al.* 2010), by establishing fixed sampling points a minimum distance of 200 m apart. This minimised the chances of recording the same individuals at more than one point and allowed detection of species even in a noisy park by sighting or hearing. All field work was conducted by ornithologists with extensive experience of the avifauna of the region. The number of points varied according to the size and shape of each park to provide equal sampling coverage. In total 40 sampling points were used and we covered the entire area of each park (Table 1). Data were collected monthly from October 2009 to September 2010. Each point was sampled for 15 minutes, between 05:00 and 10:00 h, and every bird species seen or heard was recorded, including the estimated number of individuals. The order of the sampling points was randomized for each visit to the area, and at all points we concurrently measured sound pressure (i.e. noise) levels using a sound level meter (Minipa model 1352C, São Paulo; frequency band: 31.5 Hz ~ 8 kHz, measurement band: 30 to 130 dB curve A, fast response). The sound level meter was attached to a tripod set at 1.5 m above ground level and was pointing vertically (its microphone was covered by a wind-guard). Before and after each noise measurement, the sound-level meter was calibrated (Minipa model MSL1326 Calibrator, São Paulo). We took measurements on different days of the week, excluding rainy and windy days. The sound-level meter recorded the noise values in decibels per second; that is, 900 values were recorded for each 15 minutes measurement period.

Data analysis

The species richness of each park was recorded and Fisher's alpha and Shannon-Wiener diversity indexes were calculated using the total number of contacts of an individual species in each point count (Krebs 1998). This analysis was performed in the software PAST ver. 3.10 (Hammer *et al.* 2001). We also calculated the equivalent continuous sound levels (L_{eq}; time averaged level of sound) for each noise measurement point (Duarte *et al.* 2011), which were the same points as used for bird sampling. The L_{eq} provides an overall indication of the level of exposure to noise in an environment and is expressed in decibels (dB; a logarithmic scale). To analyse the effects of peaks in noise at our sample points we calculated L_{10}, which is the mean sound pressure value based on the 10% of the highest sound pressure levels recorded in each sample (Rossing 2007).

All data were tested using an Anderson-Darling test (Anderson & Darling 1954), to determine if they met the requirements for parametric statistics, which they did. We performed a Generalized Linear Mixed Model (GLMM) using the Markov chain Monte Carlo (MCMC) method, to verify the relationship among species richness in each park with the variables land cover (tree cover, constructed area and open areas in the surroundings), park area, L_{eq}, population density in the region and mean income (salary levels) according to IBGE (2010) (Tables 1 and 2). Sampling points and parks were fitted as random factors in the model. Land cover data were obtained from a Landsat 8 satellite image, by applying a 250-m buffer around each park.

All statistical tests were conducted using the R (R Core Team 2013) packages lme4 (Bates *et al.* 2015) and MuMIn (Bartón 2016). Land cover analysis was conducted using ERDAS Imagine 2013® and ArcGIS 10.3 (ESRI 2011). Results were considered significant at $P < 0.05$.

RESULTS

The total species richness for the study was 174 and ranged between 62 species in the Gulherme Lage and 110 in the Burle Marx Park. For diversity indexes in parks, Fisher's alpha values ranged from 12.37 to 26.28 and Shannon-Wiener values from 2.76 to 3.71. In terms of noise levels (L_{eq}), points ranged from 31.00 to 45.00 dB with a mean of 37.13 (± 1.77 SE) and for peak sound pressure levels (L_{10}) points ranged from 48.25 to 61.67 decibels with a mean of 55.01 ± 1.74 (Table 1).

From the 174 species recorded, 26 were present in all sampled parks, while 13 occurred only in Burle Marx Park; 11 in Lagoa do Nado; four in Jacques Cousteau and MHNJB (Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais); three in Aggeo Pio, Américo Renné, and Ursulina. No exclusive species were found in Guilherme Lage (Supporting Online Information table S1). The remaining species were present in two or more areas (Fig. 2).

We found that L_{eq} was negatively correlated with species richness (Fig. 3). A GLMM model (AIC=216.3, R^2=0.743) showed a significant negative effect of noise (L_{eq}), surrounding human population size and income, and surrounding open areas on Fisher's α diversity index. The size of the park and the tree cover in the bordering area were positively related to Fisher's α. The extent of constructed area (buildings and roads) around the parks was not a significant predictor of the richness of bird species

(Table 3). The surveyed parks, considered as random factors, had low variation in relation to the richness of bird species (Fig. 3; Table 3).

DISCUSSION

Increasing anthropogenic noise was significantly correlated with the reduction of bird species richness in urban parks/green areas. An Atlantic Forest area isolated from anthropogenic impacts has a mean sound pressure level (L_{eq}) of 38.7 dB (Santos 2012). While park L_{eq} (Table 1) did not differ greatly from wild areas some sample points within parks were considerably higher (Fig. 3) and the species richness of bird species was correspondingly low at these points. Therefore, sound pressure levels found in this study were higher than those encountered in environments without anthropogenic sounds. Terrestrial wildlife is reported to respond negatively to noise levels from 40 dB, with significant impacts recorded up to 50 dB (Shannon *et al.* 2015).

It has been shown in the same urban area that L_{eq} levels of > 50 dB but < 60 dB are sufficient to create areas that wild urban marmosets *Callithrix penicillata* avoid (Duarte *et al.* 2011). Likewise, urban birds modify their song in an attempt to cope with noise levels comparable with those found in this study, so there is little doubt that noise levels measured in this study would have had impacts on avian communication (Slabbekoorn & Peet 2003, Brumm 2004, Fernandez-Juricic *et al.* 2005, Slabbekoorn & Boer-Visser 2006). The difference from the nosiest to the quietest park was 14 dB, i.e. the sound pressure more than doubled (logarithmic scale), representing a significate increase in noise (Rossing 2007).

According to Patón *et al.* (2012), noise does not correlate with the total number of bird species due to a trade-off in the presence of rare and common species. However, we found noise to be a significant predictor of species richness with the highest coefficient values in the GLMM. The noisiest park, Américo Renné, had the lowest values for the species diversity indexes, exhibiting a less even species distribution in comparison to quieter parks (Magurran 2013). Contrary to Patón *et al.* (2012), noise is a relevant environmental aspect in both species richness and composition. The small number of species exclusive to each park and the equal proportion of shared species are indicative of the dynamic nature of bird species composition. Further studies are recommended to investigate sensitive species which would respond differently to increase in noise, but also the physiological impact of noise on resilient species.

. The consequence of traffic noise on urban Great Tits *Parus major* is marked reduction in fitness as measured by reduced clutch size and fledgeling number (Halfwerk *et al.* 2010). Similarly, traffic was the major source of anthropogenic noise and the exposed bird species are expected to suffer similar impacts. Thus, although some species may become more abundant due to anthropogenic noise because they occupy the space left by more sensitive species (Patón *et al.* 2012), their fitness may still be negatively affected.

Peak sound levels (L_{10}) may also have impacts on bird diversity. The sounds represented by these peak levels in our study included accelerating motorcycles or cars backfiring, which typically have a high-amplitude (louder) sounds expressed over a short duration. Animals are known to not habituate to acute ‘scary noises’ if such noises are novel (Biedenweg *et al.* 2011). Thus, the peak level sounds recorded in this study had characteristics that are known to briefly scare animals (Biedenweg *et al.* 2011), that is, acute noise pollution, whereas the L_{eq} values recorded represented more chronic noise pollution (Barber *et al.* 2009, Schroeder *et al.* 2012).

One might consider that birdsong itself is part of the cumulative sound that we measured, that is, birdsongs could create a bias in the way that we would not be able to separate noise from human activities from that generated by the birds. However, most of the birds recorded are small and fairly quiet passerines. There was no single dominant species with a loud song that could bias the analysis (e.g. Screaming Piha *Lipaugus vociferans*, Bare-throated Bellbird *Procnias nudicollis* or Macaws *Ara* spp).

We were able to find the expected species-area relationship reported by other authors in urban areas (i.e. species richness increasing with area; Jokimäki & Suhonen 1998, Jokimäki 1999). However, the effects of the urban matrix on species richness in urban studies should also be considered (Jokimäki 1999, Fernández-Juricic 2001a). Fernández-Juricic (2001b) argued that a possible reason for the absence of isolation effects is the connectivity promoted by wooded streets, which is expected in the city of Belo Horizonte (Goulart *et al.* 2010). We observed a positive relationship between bird diversity and tree cover around parks and a negative relation with exposed areas (i.e. open areas) indicating the importance of connecting urban fragments to increase bird richness.

Landscape characteristics such as the urban matrix are often less explored in terms of their impact on biodiversity (Hodgkison 2006). Open areas surrounding parks were negatively related to bird richness, which could contribute to increasing the noise inside the park (Fang & Ling 2005). Likewise, a lower household income is correlated with an increase in traffic noise levels (Fyhri & Klaeboe 2006). Thus, social factors are equally relevant in managing the bird diversity in green urban areas.

In areas affected by sound pollution, a number of mitigation strategies can be applied. If an area is of extreme importance in terms of bird conservation, roads or other significant sources of sound pollution could be diverted by a distance of at least 100 metres (Liu & Zhao 2003). In the case of a proposed new road, its route could be changed. Slower travelling motor vehicles also make significantly less noise (Bérengier & Picaut 2008) and the surface of the road can be constructed to use material that produces less noise (Butcher 2010). Less dramatic mitigation strategies include an acoustic buffer being placed between the source of anthropogenic noise and the conservation area (Arenas 2008). The planting of a forested buffer zone with dense undergrowth could protect areas from sound pollution, but this strategy may not be suitable for many locations (due to ecological planning constraints). An effective acoustic buffer is the use of earth berms, which can be constructed quickly and are suitable for most habitat types (Arenas 2008).

Our results are important for the management of urban parks or other green areas in which we wish to promote avian fauna and animal welfare. They show the need to minimise sound pollution, especially chronic, or where necessary to monitor anthropogenic noise as suggested by Slabbekoorn and Ripmeester (2008). Unfortunately, due to the relentless increase in urbanisation, problems with anthropogenic sound are likely to increase. Future studies, especially in the Neotropical region, should focus on which species are being lost due to anthropogenic noise and which are consequently being favoured and how this relates to fitness (i.e. reproductive success and survivorship).

Finally, it should be noted that, while sound pressure levels recorded in this study would not be considered unacceptable by most people (< 55 dB; Rossing 2007), they had a significant negative impact on avian species, which have evolved to cope with much lower levels of sound pressure (Slabbekoorn & Peet 2003).

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REFERENCES

Anderson, T.W. & Darling, D.A. 1954. A Test of Goodness-of-Fit. *Journal of the American Statistical Association*. **49**: 765–769.

Arenas, J.P. 2008. Potential problems with environmental sound barriers when used in mitigating surface transportation noise. *Science of the Total Environment.* **405**: 173-179.

Arévalo, J.E. & Newhard, K. 2011. Traffic noise affects forest bird species in a protected tropical forest. *International Journal of Tropical Biology*. **59**: 969-980.

Barber, J.R., Crooks, K.R. & Fristrup, K.M. 2009. The cost of chronic noise exposure for terrestrial organisms. *Trends in ecology and evolution*. **25**: 180-189.

Bartón, K. 2016. MuMIn: Multi-Model Inference. R package version 1.15.6. https://CRAN.R-project.org/package=MuMIn.

Bates, D., Maechler, M., Bolker, B., & Walker, S. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*. **67**, 1-48.

Bayne, E.M. & Boutin, S. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocaplilla*. *Journal of Applied Ecology*. **44**: 176-184.

Beidenweg, T.A., Parsons, M.H., Fleming, P.A. & Blumstein, D.T. 2011. Sounds scary? Lack of habituation following the presentation of novel sounds. *PLoS One*. **6**: e14549.

Bérengier, M. & Picaut, J. 2008. Methods for noise control by traffic management: Impact of speed reducing equipment. EU Sixth Framework Programme Project SILENCE, Nantes, Report H.R2 LCPC.

Bergen, F. & Abs, M. 1997. Etho-ecological study of the singing activity of the blue tit (*Parus caerulescens*), great tit (*Parus major*) and chaffinch (*Fringilla coelebs*). *Journal of Ornithology*. **138**: 451-467.

Bermudez-Cuamatzin, E., Rios-Chelen, A.A., Gil, D. & Macıas Garcia, C. 2011. Experimental evidence for real-time song frequency shift in response to urban noise in a passerine bird. *Biology Letters*. **7**: 36-38.

Bibby, C.J., Burgess, N.D., Hill, D.A. & Mustoe, S.H. 2000. *Bird Census Techniques*. New York, NY: Academic Press.

Brumm, H. & Slater, P.J.B. 2006. Ambient noise, motor fatigue and serial redundancy in the chaffinch song. *Behavioral Ecology and Sociobiology.* **60**: 475-481.

Brumm, H. 2004. The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology*. **73**: 434–440.

Butcher, L. 2010. *Roads: Traffic Noise*. House of Commons Library. Available at: www.parliament.uk/briefing-papers/SN00347.pdf (Accessed 09 July 2015).

Cullen Jr, L., Bodmer, R.E. & Pádua, C.V. 2000. Effects of hunting in habitat fragments of the Atlantic Forest, Brazil. *Biological Conservation*. **95**: 49-56.

Donnelly, R. & Marzluff, J.M. 2004. Importance of reserve size and landscape context to urban bird conservation. *Conservation Biology*. **18**: 733-745.

Duarte, M.H.L., Vecci, M.A., Hirsch, A. & Young, R.J. 2011. Noisy human neighbours affect where urban monkeys live. *Biology Letters*. **7**: 840-842.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Fang, C. F., & Ling, D. L. 2005. Guidance for noise reduction provided by tree belts. *Landscape and Urban Planning*. **71:** 29-34.

Fernández-Juricic, E. 2001a. Density dependent habitat selection of corridors in a fragmented landscape. *Ibis*. **143**: 278-287.

Fernández-Juricic, E. 2001b. Avian spatial segregation at edges and interiors of urban parks in Madrid, Spain. *Biodiversity and Conservation*. **10**: 1303–1316.

Fernández-Juricic, E., Poston, R., Collibus, K., Morgan, T., Bastain, B., Martin, C., Jones, K. & Treminio, R. 2005. Microhabitat selection and singing behavior patterns of male House Finches (*Carpodacus mexicanus*) in urban parks in a heavily urbanized landscape in the Western U.S. *Urban habitats.* **3**: 49-69.

Fontana, C.S., Burger, M.I. & Magnusson, W.E. 2011. Bird diversity in a subtropical South-American city: effects of noise levels, arborisation and human population density. *Urban Ecosystems.* **14**: 314-360.

Freemark, K. E., & Merriam, H. G. 1986. Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. *Biological Conservation*, **36**: 115-141.

Fuller, R.A., Warren, P.H. & Gaston, K.J. 2007. Daytime noise predicts nocturnal singing in urban robins. *Biology Letters*. **3**: 368-370.

Fundação de Parques Municipais (Prefeitura de Belo Horizonte). 2015. Available at: portalpbh.pbh.gov.br (accessed 09 July 2015).

Fyhri, A., & Klaeboe, R. 2006. Direct, indirect influences of income on road traffic noise annoyance. *Journal of Environmental Psychology*. **26:** 27-37.

Galli, A. E., Leck, C. F., & Forman, R. T. 1976. Avian distribution patterns in forest islands of different sizes in central New Jersey. *The Auk* **93**: 356-364.

Goulart, V.D.L.R., Teixeira, C.P. & Young, R.J. 2010. Analysis of callouts made in relation to wild urban marmosets (*Callithrix penicillata*) and their implications for urban species management. *European Journal of Wildlife Research*. **56**: 641-649.

Gross, K., Pasinelli, G. & Kunc, H.P. 2010. Behavioral plasticity allows short-term adjustment to a novel environment. *American Naturalist*. **176**: 456-464.

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**: 210-219.

Hammer, O., Harper, D.A.T. & Ryan, P.D. 2001. Past: Paleontological statistics software package for educational and data analysis. *Paleontologia Electronica.* **4**: 1-9.

Hodgkison, S. C. 2006. The ecological value of suburban golf courses in southeast Queensland. Ph.D. Thesis, Griffith University, Gold Coast, Qld.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2010. *Censo Demográfico 2010*. Available at: www.censo2010.ibge.gov.br (accessed 09 July 2015).

IBGE (Instituto Brasileiro de Geografia e Estatística). 2011. *Censo demográfico 2010: Resultado do universo relativo às características da população e dos domicílios, Belo Horizonte, MG.* Available at: www.ibge.gov.br (accessed 09 July 2015).

Jokimäki, J. & Suhonen, J. 1998. Distribution and habitat selection of wintering birds in urban environments. *Landscape and Urban Planning*. **39**: 253–263.

Jokimäki, J. 1999. Occurrence of breeding bird species in urban parks: effects of park structure and broadscale variables. *Urban Ecosystems*. **3**: 21-34.

Krebs, C.J. 1998. *Ecological Methodology*. New York: Benjamin/Cummins.

Liu, R. & Zhao, D. 2003. *Evaluation of best management practices for mitigating impacts of highways on stream and wildlife ecology (First Progress Report)*. Auburn, AL: Department of Civil Engineering Auburn University. Available at: http://www.eng.auburn.edu/files/file799.pdf (accessed 09 July 2015).

Magurran, A. E. 2013. *Measuring biological diversit*y. John Wiley & Sons.

McClure, C.J.W., Ware, H.E., Carlisle, J., Kaltenecker, G. & Barber, J.R. 2013. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. *Proceedings of the Royal Society of London B: Biological Sciences*. **280:** 20132290.

Møller, A.P. 2009. Successful city dwellers: a comparative study of the ecological characteristics of urban birds in the Western Palearctic. *Oecologia.* **159**: 849-858.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G. & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature*. **403**: 853-858.

Nemeth, E. & Brumm, H. 2010. Birds and anthropogenic noise: Are urban songs adaptive? *American Naturalist*. **176**: 465-475.

Ouis, D. 1999. Exposure to nocturnal road traffic noise: Sleep disturbance its after effects. *Noise and Health.* **1**: 11-36.

Patón, D., Romero, F., Cuenca, J. & Escudero, J.C. 2012. Tolerance to noise in 91 bird species from 27 urban gardens of Iberian Peninsula. *Landscape and Urban Planning*. **104**: 1-8.

Patricelli, G.L. & Blickley, J.L. 2006. Avian communication in urban noise: causes and consequences of vocal adjustment. *Auk*. **123**: 639-649.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria

Rahbek, C. & Graves, G.R. 2001. Multiscale assessment of patterns of avian species richness. *Proceedings of the National Academy of Sciences*. **98**: 4534-4539.

Rheindt, F.E. 2003. The impact of roads on birds: does song frequency play a role in determining susceptibility to noise pollution? *Journal of Ornithology*. **144**: 295-306.

Ribon, R. 2010. Amostragem de aves pelo método de listas de Mackinnon. In Matter, S.V., Straube, F.C., Accordi, I., Piacentini, V. & Cândido-JR, J.F. (eds.) *Ornitologia e Conservação: Ciência aplicada, técnicas de pesquisa e levantamento*: 31-44. Rio de Janeiro: Technical Books.

Rios-Chelen, A.A., Quiros-Guerrero, E., Gil, D. & Garcia, C.M. 2013. Dealing with urban noise: vermilion flycatchers sing longer songs in noisier territories. *Behavioral Ecology and Sociobiology*. **67**: 145-152.

Rios-Chelen, A.A., Salaberria, C., Barbosa, I., Macias Garcia, C. & Gil, D. 2012. The learning advantage: bird species that learn their song show a tighter adjustment of song to noisy environments than those that do not learn. *Journal of Evolutionary Biology*. **25**: 2171-2180.

Rossing, T.D. 2007. Springer Handbook of Acoustics. New York, NY: Springer.

Santos, R.V. 2012. *Contribuições acústicas no estabelecimento da territorialidade em Callicebus nigrifrons Spix, 1823 (Primates: Pitheciidae)*. Masters Thesis. Belo Horizonte, Brazil: PUC Minas.

Schroeder, J., Nakagawa, S., Cleasby, I. R., & Burke, T. 2012. Passerine birds breeding under chronic noise experience reduced fitness. *PLoS one*, **7**: e39200.

Schroeder, J., Nakagawa, S., Cleasby, I.R. & Burke, T. 2012. Passerine birds breeding under conditions of chronic noise experience reduced fitness. *PLoS One*. **7**: e39200.

Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., ... & McFarland, S. 2015. A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*.

Slabbekoorn, H. & Boer-Visser, A. 2006. Cities change the songs of birds. *Current Biology*. **16**: 2326-2331.

Slabbekoorn, H. & Peet, M. 2003. Birds sing at a higher pitch in urban noise. *Nature*. **424**: 267.

Slabbekoorn, H. & Ripmeester, E.A. 2008. Birdsong and anthropogenic noise: implications and applications for conservation. *Molecular Ecology*. **17**: 72-83.

Vielliard, J.M.E., Almeida, M.E.C., Anjos, L. & Silva, W.R. 2010. Levantamento quantitativo por pontos de escuta e o Índice Pontual de Abundância (IPA). In Matter, S.V., Straube, F.C., Accordi, I., Piacentini, V. & Cândido-JR, J.F. (eds.) *Ornitologia e Conservação: Ciência aplicada, técnicas de pesquisa e levantamento*: 47-60. Rio de Janeiro: Technical Books.

Zannin, P.H.T., Diniz, F.B., & Barbosa, W.A. 2002. Environmental noise pollution in the city of Curitiba, Brazil. *Applied Acoustics.* **63:** 351-358.

Table 1. Area, species diversity and sound pressure levels of eight urban green areas sampled in Belo Horizonte, Minas Gerais, Brazil.

Urban green area	Size (ha)	Number of sample points	Species richness	Fisher's α	Shannon-Wiener	L_{eq} Range (dB)	L_{10} Range (dB)
Guilherme Lage	12.6	3	62	13.61	3.27	46-54	59-67
Burle Marx	17.0	4	110	26.28	3.55	36-41	46-50
Américo Renné	18.2	6	67	12.37	2.76	45-53	55-66
Lagoa do Nado	30.0	6	108	24.58	3.71	41-46	53-56
Ursulina	30.7	4	88	18.19	3.35	38-49	49-64
Jacques Cousteau	32.7	6	94	20.01	3.42	40-49	50-61
Aggeo Pio	54.4	5	78	19.36	3.27	37-47	55-66
MHNJB	60.0	6	93	19.92	3.50	35-44	49-52

L_{eq} = time averaged sound pressure levels; L_{10} = peak sound pressure levels; MHNJB = Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais.

Table 2. Socio-economic variables and land cover in 250-m buffers around urban parks in Belo Horizonte, Minas Gerais, Brazil.

	Size (Ha)	Population	Salary levels	Surrounding Open Area (%)	Surrounding Tree Cover (%)	Surrounding Constructed Area (%)
Guilherme Lage	12.6	12699	1614.37	6.87	0.34	92.79
Burle Marx	17.0	10544	1044.73	17.66	24.55	57.78
Américo Renné	18.2	12632	6364.84	0.26	2.90	96.83
Lagoa do Nado	30.0	15558	1931.07	0.16	1.18	98.66
Ursulina	30.7	16723	2632.71	2.74	0.44	96.82
Jacques Cousteau	32.7	17312	1259.87	6.15	6.97	86.88
Aggeo Pio	54.4	10829	3080.09	24.87	9.53	65.60
MHNJB	60.0	23345	2437.06	10.49	4.16	85.35

MHNJB = Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais; Salary levels in Brazilian Real

Table 3. Generalised linear mixed model results of Fisher's α diversity index responses to the park area, L_{eq}, population size, income, open area, constructed area (buildings and roads), and tree cover.

Parameter	Estimate	SE	*t*	P
Intercept	60.8037	7.3807	8.2382	<0.001
Park Area	0.4225	0.1723	2.4507	0.014
L_{eq}	-0.6121	0.1453	-4.2133	<0.001
Population size	-0.0013	0.0004	-3.1467	<0.001
Income	-0.0018	0.0005	-3.4942	<0.001
Open area	-0.0001	0.0003	-2.7710	0.005
Constructed area	0.0000004	0.000004	0.0964	0.923
Trees cover	0.00005	0.00002	2.7025	0.006

Figure 1. Map of Belo Horizonte city Minas Gerais, Brazil showing the location of the eight areas where bird diversity and species richness were studied in relation to sound pressure levels.

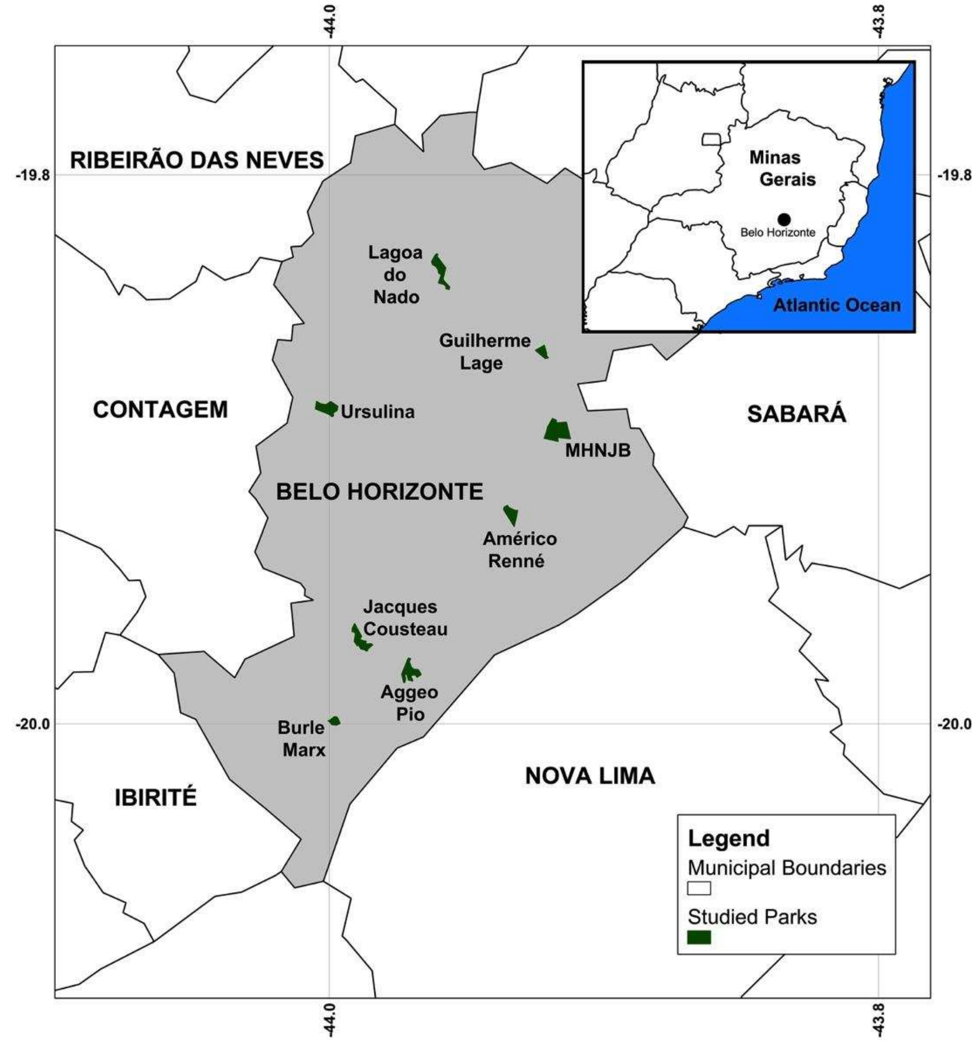
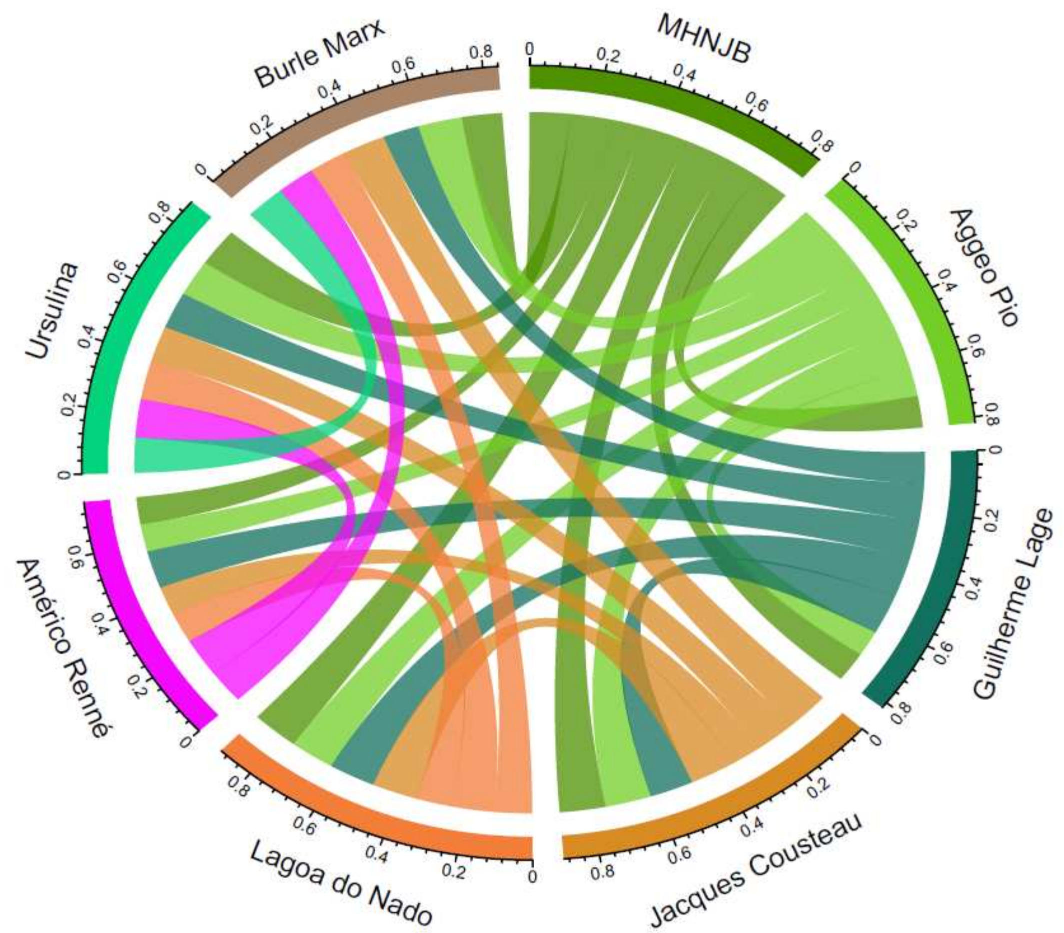
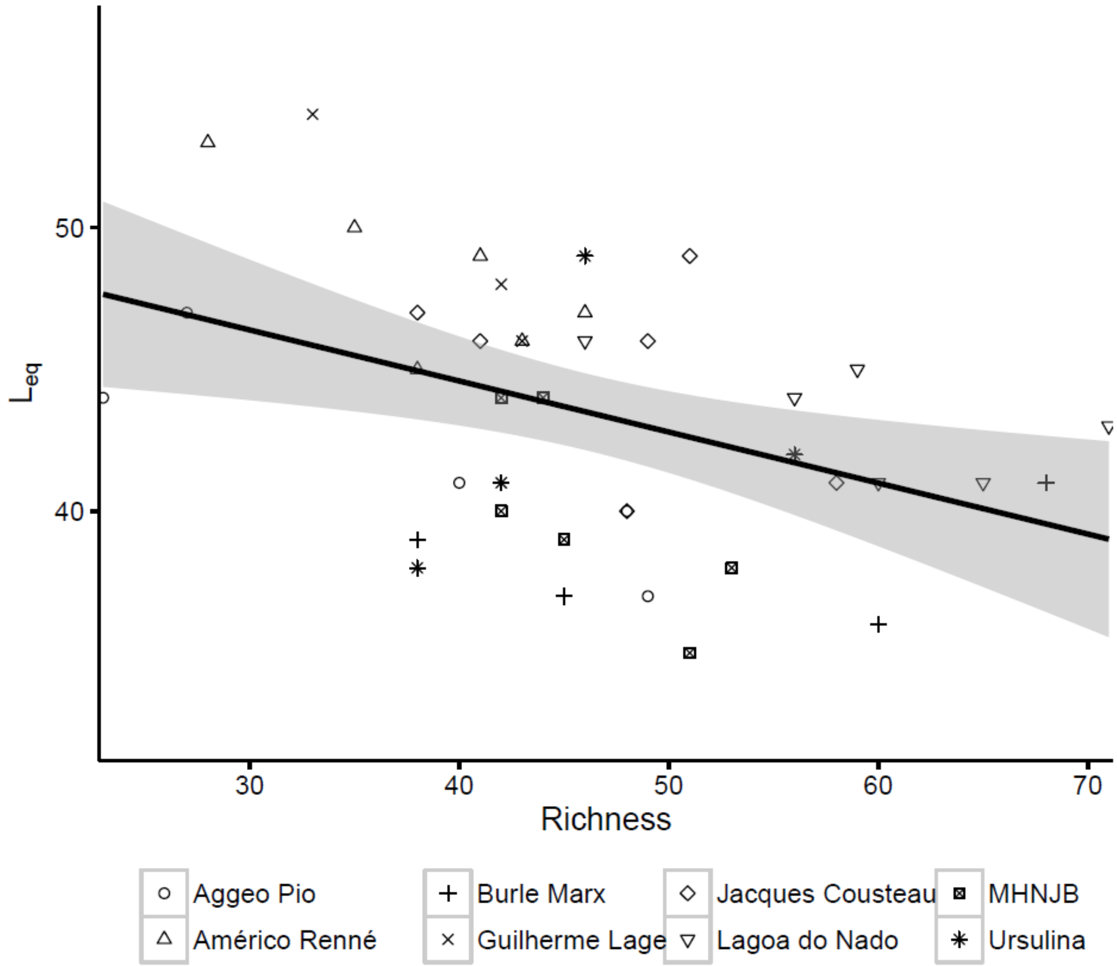


Figure 2. Proportion of common bird species across urban parks in Belo Horizonte, Brazil.



Species shared between parks are represented by stripes and the thickness represents the proportion of species demonstrating that communities are highly connected and the resulting species diversity is affected by anthropogenic noise.

Figure 3. Relationship of L_{eq} (noise level) and species richness per sampled points (n = 40) showing a tendency line and standard error (shaded area) in urban parks of Belo Horizonte, Brazil.



L_{eq} = time averaged sound pressure levels; Richness = number of different species observed