Biological Conservation 255 (2021) 108996

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Short communication

Listening to cities during the COVID-19 lockdown: How do human activities and urbanization impact soundscapes in Colombia?

Juan Sebastian Ulloa *, Angélica Hernández-Palma, Orlando Acevedo-Charry, Bibiana Gómez-Valencia, Cristian Cruz-Rodríguez, Yenifer Herrera-Varón, Margarita Roa, Susana Rodríguez-Buriticá, Jose Manuel Ochoa-Quintero

Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Avenida Paseo Bolívar 16-20, Bogotá, Colombia

ARTICLE INFO

Keywords:
Urban acoustics
Noise pollution
Biological sounds
Community science
Human perception
Noise masking

ABSTRACT

Noise is one of the fastest growing and most ubiquitous type of environmental pollution, with prevalence in cities. The COVID-19 confinement in 2020 in Colombia led to a reduction in human activities and their associated noise. We used this unique opportunity to measure the impacts of noise on urban soundscapes, and explore the effects of urbanization intensity independently of human activity. We launched a community science initiative inviting participants to collect audio recordings from their windows using smartphones. Recordings were taken during severe mobility restrictions (April), and during a period of lightened restrictions (May–June). From the data collected, we measured changes in sound pressure levels (SPL), acoustic structure (soundscape spectro-temporal characteristics), and human perception between the two periods. A 12% increase in human activities had a detectable acoustic footprint, with a significant increase of SPL (2.15 dB, 128% increase), a shift towards dominance of low-frequency broadband signals, and a perceived dominance of human-made over wildlife sounds. Measured changes in SPL and acoustic structure were directly proportional to urbanization; however, perception of these changes was not. This gap may be associated with a masking effect generated by noise or a disconnect of humans from nature in large cities. The mobility restrictions created a chance to better understand the impacts of urbanization and human activities on the soundscape, while raising public awareness regarding noise pollution effects on people and wildlife. Information analyzed here might serve in urban planning in developing countries where urban expansion is occurring in a rapid, unplanned fashion.

1. Introduction

The soundscape, which refers to human and natural sounds in a landscape (Pijanowski et al., 2011), is composed of rich acoustic textures with information about the surrounding environment, and it is crucial to define our sense of place (Stocker, 2013). Human activities are transforming the soundscapes, producing an acoustic overload that is ubiquitous and louder than most natural sounds (Schafer, 1993). Noise pollution is an emerging environmental issue that has been shown to have adverse effects on human health (WHO, 2011), as well as on wildlife behavior and communication (Barber et al., 2010; Shannon et al., 2016; Brumm and Slabbekoorn, 2005); these impacts on animal communities can ultimately alter the ecological services they provide (Francis et al., 2012).

Noise, anthropic sounds that can be physically harmful or distracting to humans and wildlife (Francis et al., 2009), can alter the soundscape structure and inhibit the perception of sounds by people and wildlife, a phenomenon known as masking (Barber et al., 2010). In human health assessments and urban planning, noise has been considered using primarily sound pressure levels (SPL) (Warren et al., 2006). Although noise is a noticeable element of urban acoustics, it is not the only component characterizing city soundscapes. Therefore, a better management of noise pollution depends on a more integral understanding of the impacts of human activities, complementing sound pressure measurements with other facets of the soundscape.

During 2020, human confinement due to the COVID-19 pandemic created dramatic changes in city life (Rutz et al., 2020). It also created an opportunity to measure the impact of human activities on urban soundscapes under a before-after scenario never experienced before (Bates et al., 2020). With most people staying at home, noise dropped

---

* Corresponding author at: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Avenida Paseo Bolívar 16-20, Bogotá, Colombia.
E-mail address: julloa@humboldt.org.co (J.S. Ulloa).

https://doi.org/10.1016/j.biocon.2021.108996
Received 15 September 2020; Received in revised form 8 January 2021; Accepted 16 January 2021

significantly (Zambrano-Monserrate et al., 2020), providing a cleaner background to document urban soundscapes independent of human activity. It also created the possibility of exploring the effects of urbanization intensity, a common challenge in urbanization studies (Joo et al., 2011; Kuehne et al., 2013). Finally, the COVID-19 pandemic also represented an opportunity to involve the community in data collection, raise awareness about the environmental impacts of noise pollution (Sonne and Alstrup, 2019), and to evaluate urban dwellers' sensitivity to soundscape changes.

Considering these opportunities, we aimed to characterize the impact of human activities on urban soundscapes in Colombia by testing two main hypotheses: 1) the acoustic impact of human activities is proportional to urbanization intensity, with highly urbanized cities showing the biggest input of anthropophony; 2) the masking effect of anthropic noise negatively affects human perception to changes in the soundscape. Through a community science initiative, we conducted a standardized acoustic sampling throughout Colombia during the most severe mobility restrictions due to COVID-19, and during the following period of lightened restrictions. Using the information provided by the participants, we evaluated three different perspectives: 1) changes in SPL, 2) changes in acoustic structure, and 3) changes in human perception.

2. Materials and methods

2.1. Sampling protocol and data curation

Data collection was carried out from April 02 to June 17, 2020, in two distinct periods. The first period (April 02–27) represented the Full lockdown (FL), when government policies announced a mandatory closure of all non-essential workplaces, and limited outdoor recreational activities and social gatherings. Compared with a baseline taken between January–February of the same year, this period saw mobility reduced by an average −72.08 percentual points (Google, 2020; Table A1). The second collection period (May 01–June 17) represents a Partial lockdown (PL), with a partial mobility re-activation of around 12.48 percentual points from the FL period (Table A1).

For at least two days per week, during sunrise (0500–0700 h) and sunset (1700–1900 h), participants collected 90-second audio recordings from their windows motivated by a community science campaign led by Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (Colombia) called "How does your city sound? Soundscapes from your window" ("¿Cómo suena mi ciudad? Paisajes sonoros desde tu ventana"). Recordings were made using the free application for smartphones Voice Record Pro® (WAV, 24 kHz sampling rate, 16-bit depth, mono channel). Uploads were accompanied by online forms asking participants about the presence of 12 soundscape components (wildlife: insects, amphibians, birds, mammals; anthropic: motorized transportation, construction, loudspeakers, human voices, domestic animals; abiotic: rain, wind, thunder), as well as the dominant perceived component in each recording.

A total of 202 participants from all over the country submitted 4556 recordings (Table 1, Fig. A1). We then selected participants that had at least six suitable recordings (sampling rate $>$ 22 kHz, audio length $>$ 60 s) per period, which reduced the dataset to 62 participants with 1909 recordings, from three major cities and a pool of other 19 smaller cities. Finally, we trimmed the beginning and end of each recording to 60 s and re-sampled all files to 22.050 kHz to have homogeneous file formats among participants. Recordings and accompanying forms were deposited at the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt data repository (https://doi.org/10.15472/enzm9u).

2.2. Data analysis

Change in SPL was estimated from changes in fitted values of root-mean-square amplitude (RMS) from each recording using a linear mixed model (LMM) with period (FL, PL) and city as fixed factors, and participant ID and time of day (am/pm) as random effects. AIC criterion corrected for small sample size (AICc) was used as a model selection procedure. We also fitted independent models for each city, keeping the same random structure. Root-mean-square amplitude was then transformed to sound pressure in decibels (Eq. (A1) and associated text for details).

Changes in acoustic structure were estimated through displacement differences between periods on a descriptive bidimensional space. Following Ulloa et al. (2018) and using all suitable recordings, we computed a spectrogram (512-sample window, no overlap between windows), and a set of 64 features depicting spectro-temporal patterns of the spectrogram that were derived by using 16 bidimensional wavelets (Morlet family, 8 scales, and 2 orientations) at four frequency bands (from 0 to 11 kHz in steps of 2.75 kHz). We used the t-distributed Stochastic Neighbor Embedding (t-SNE) (van der Maaten and Hinton, 2008) to project the data in a bidimensional space. In this space (t-SNE), samples with predominant anthropic noise located to the left, bird sounds to the right, insect sounds towards the bottom, and samples with few distant sounds towards the top (Fig. A2). A permutational multivariate analysis of variance (PERMANOVA) with Euclidean distance and permutations constrained to sample location, was used to test for displacement differences on t-SNE between periods and cities.

To further test for the effects of urban greenspaces on acoustic displacement, we selected data from the three major cities and modeled displacement (distance and angle from the FL centroid to the PL centroid, at each participant's location) against city and a set of standardized environmental covariates (number of trees, NDVI; Table 1). Although we considered other covariates (Table A2), only the selected ones had good spatial resolution to test for inter-city variation. Different variance structures (varIdent, and varExp) were tested to account for heteroscedasticity; the best model was selected with AICc.

Using the online forms, we computed a Soundscape Perception Index (SPI) as the combination of scores from each soundscape component (wildlife or anthropic, abiotic omitted) present in the recordings, plus the score of the dominant perceived component. Each component was

Table 1

Summary of sampling sites with number of samples and participants, spatial, and demographic variables. The reported area is the official urban perimeter without considering suburbs. Total samples indicate the total number of recordings per city, number of participants in parenthesis. Selected samples refer to the final number of samples used in the analysis, number of participants in parenthesis. The average number of trees is the count of urban trees within a buffer of 200 m centered at each participant's location. The vegetation was quantified using the Normalized difference vegetation index (NDVI); low values indicate less vegetation and higher vegetation more vigorous. Data sources detailed in Table A2.

Urban intensity	City	Urban perimeter area (km^2)	Population (millions)	Elevation (m)	Total samples (participants)	Selected samples (participants)	Avg. number of trees (sd)	Avg. NDVI value (sd)
High	Bogotá	1587	7.2	2600	1190 (56)	711 (21)	334.3 (426.1)	2681 (858.6)
Intermediate	Cali	619	1.8	1018	336 (22)	181 (7)	180.7 (244.6)	4052 (1271.7)
Intermediate	Medellín	380	2.4	1495	968 (37)	191 (10)	285.2 (692.1)	4218 (1346.0)
Low	Other (19 small cities)	46–2393	$<$0.6	15–2758	2062 (87)	826 (24)	NA	NA

given a score of 0.2 and SPI was computed as follows:

$$SPI = \frac{\Sigma\ wildlife\ components + (1 - \Sigma\ anthropic\ components)}{2}$$

The index varies from 0 to 1, with 1 indicating full dominance of anthropophony and 0 full dominance of wildlife sounds. We estimated SPI changes using the same modeling approach as for SPL.

Statistical analyses were performed in program R (R Core Team, 2020). Signal processing and audio characterization was done in Python 3 (Van Rossum and Drake, 2009).

3. Results

Between FL and PL periods, the full model, which included period and city, was the best model explaining overall changes in SPL (Table A3). The model indicated an overall significant increase in RMS amplitude, equivalent to 2.15 dB (128% increment, Fig. 1a). Similar directions of change were found using city-specific models (Table A4); although magnitudes were different. Change order decreases in sequence from Bogotá, Cali, other cities and Medellín, with Cali and Medellín being more variable (Fig. 1a). These differences were also evident on the bidimensional acoustic space where Bogotá falls in areas dominated by low frequency traffic noise, Medellín, and Cali show a balanced mix of sounds, and other smaller cities had mid to high-frequency wildlife sounds (Fig. 2).

Displacement on t-SNE between periods was significantly different among cities (PERMANOVA_F = 5.58, $R^2 = 0.03$, $p = 0.03$) and showed a marginal effect of counts of trees ($F = 2.95$, $R^2 = 0.02$, $p = 0.08$) but no from NDVI ($F = 0.37$, $R^2 = 0.002$, $p = 0.54$). During PL all cities moved towards areas with more anthropophony with magnitude of displacement decreasing (without statistical significance) in the sequence from Bogotá, Cali, and Medellín (Fig. 1c, Table A5), with Bogotá showing the sharpest turn (Fig. 1d, Table A5). Our analysis also showed that differences could be associated with trees around sampling points ($t = -2.19$, $p = 0.03$) with displacement magnitude decreasing as the tree density increases ($\beta = -0.004$, SE = 0.002).

Interestingly, the estimated changes between periods were perceived differently by participants in different cities. In congruence with sound pressure, SPI became more anthropic during PL (Fig. 1b). Nevertheless, city ranking on perceived change differed from sound pressure with decreasing SPI changes from Cali, Medellín, Bogotá, and other cities; with Cali and Medellín being the most variable (Tables A6, A7). The sound components most frequently reported were birds (FL = 83%, PL = 82%) and motorized transportation (FL = 72%, PL = 81%). The latter was also the component with the strongest change between periods showing a 12.5% increase (Fig. A3).

4. Discussion

We characterized the impact of human activities on urban soundscapes in Colombia using a community science initiative during the COVID-19 lockdown. As confinement restrictions were eased (PL), we found a significant increase of SPL, a shift towards dominance of low-frequency broadband signals (0–2.75 kHz), and a perceived dominance of human-made sounds over wildlife sounds. Following our expectations, increasing human activities had an effect on the acoustic environment, which was proportional to urbanization intensity, with the most urbanized city (Bogotá) having the strongest change. However, perception of these changes was not in line with the measured changes, supporting our second hypothesis.

Our study provides the baseline impacts of urbanization and human activities on soundscapes. A 12% increase in human activities had a detectable mark on soundscapes, with cities significantly shifting towards higher sound pressure levels and dominance of anthropic sounds. The most urbanized city (Bogotá) had the sharpest change in SPL and acoustic structure, yet one of the weakest perceived changes, with a shift in soundscape perception comparable to the least urbanized sites in our sample. Previous studies have found a positive relationship between human activity and sound levels in urban areas (Mennitt and Fristrup, 2016). In particular, traffic noise is known to be closely related to urban density (Salomons and Pont, 2012). The higher levels of anthropic noise in the most urbanized city generates a dense background that masks and

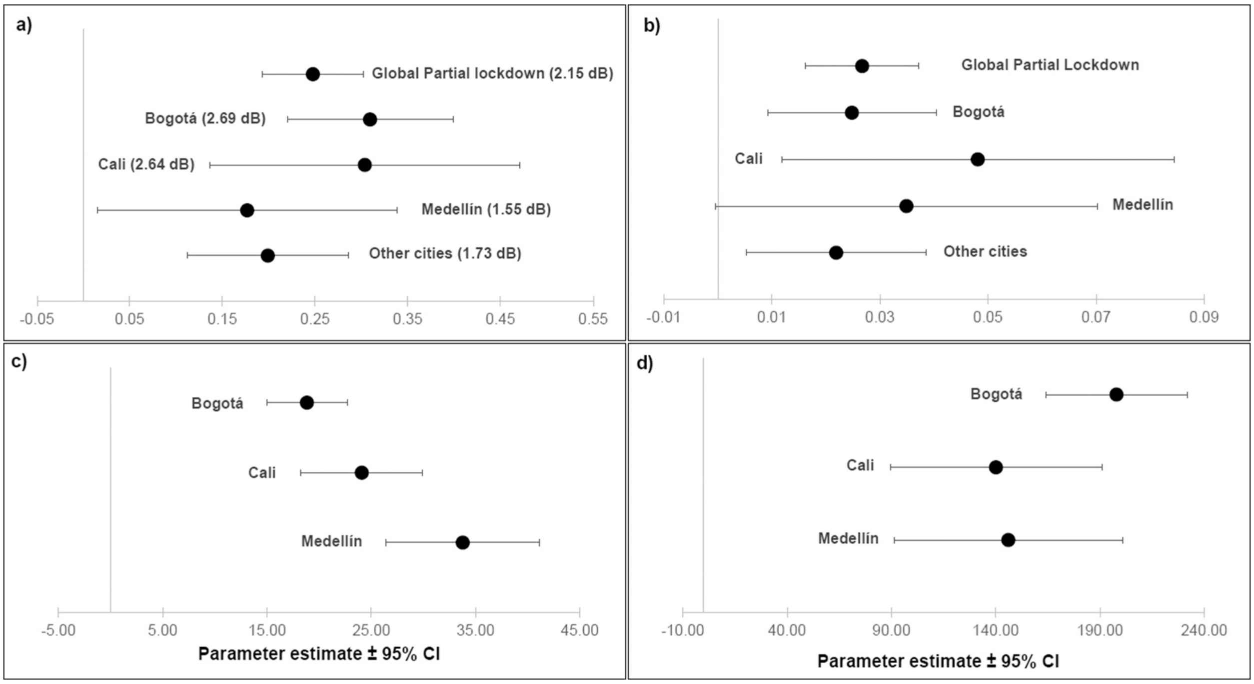

Fig. 1. Parameter estimates and 95% confidence intervals for the best fit model predicting changes during Partial Lockdown with respect to Full Lockdown in: a) root-mean-square (RMS), b) Soundscape Perception Index (SPI), c) displacement distance on t-distributed Stochastic Neighbor Embedding (t-SNE) space, and d) displacement angle on t-SNE space.

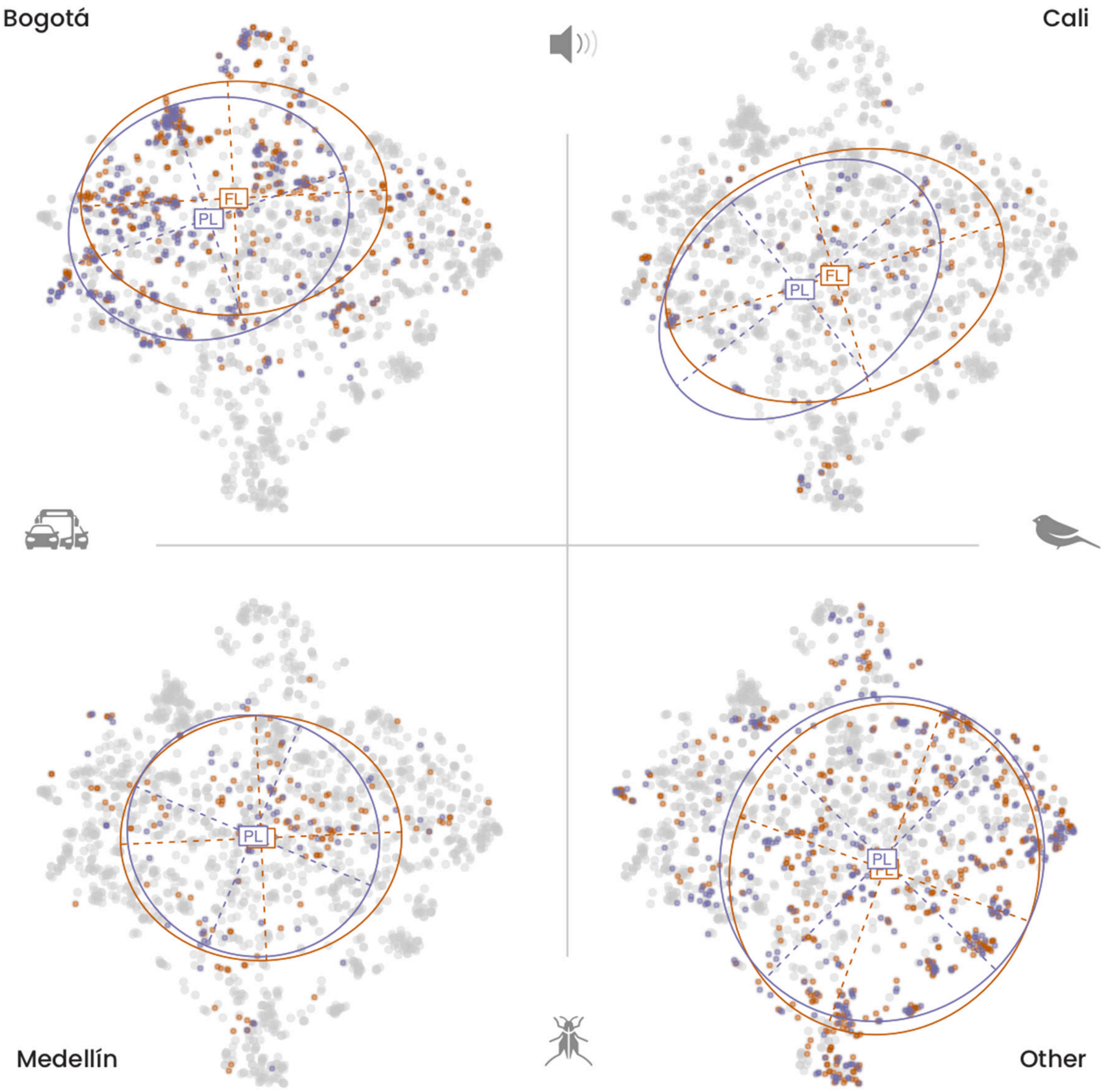

Fig. 2. Embedding of acoustic data in a common descriptive feature space evidences the change of acoustic structure in Colombian cities between two sampling periods: full lockdown (FL) and partial lockdown (PL). A t-distributed Stochastic Neighbor Embedding (t-SNE) was used to visualize a 2D projection from the full 64-dimensional acoustic feature space, where x and y axes are dimensions 1 and 2 of the t-SNE. Each sampling site has a dedicated figure with FL samples in orange, PL samples in purple, and centroids of sampling periods are denoted by a label and an ellipse of point dispersion. In this space, samples with predominant anthropic noise located to the left, bird sounds to the right, insect choruses towards the bottom, and samples with few distant sounds towards the top. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

impairs the perception of sounds, resulting in the so-called lo-fi soundscape (Schafer, 1993). In this lo-fi system overloaded with acoustic signals, little can emerge with clarity, perspective is reduced, and changes are harder to perceive. Hence, the difference in magnitude between measured and perceived change could be explained by this masking effect of noise.

Alternatively, humans could be less in tune with their surroundings in highly urbanized cities, which translates into a lower sensitivity to changes in their soundscape. It has been argued that urbanization promotes the separation of humans from nature (Turner et al., 2004), leading to people living in larger cities to be less perceptive to changes compared to people from smaller cities (Miller, 2005). Either by the masking effect or the decreased sensitivity, elevated noise levels can affect the perception of wildlife in large cities, disrupting human-nature interactions and undermining positive attitudes of people towards nature (Soga and Gaston, 2016).

Acoustic structure results showed an inversely proportional relationship between urbanization intensity and wildlife sounds. A recent meta-analysis found that the density of species in cities is best explained by anthropic features (land cover, city age) rather than by environmental factors such as geography, climate, and topography (Aronson et al., 2014). Both of our moderately urbanized cities (Medellín and Cali) showed a similar response in acoustic structure between periods despite the former being ~30% more populated than the later. One possible explanation for this is the buffering effect of greenspaces in cities (Fang and Ling, 2003); both of these moderately urbanized cities have similar vegetation indices that are comparably higher than the most urbanized city in our sample, suggesting that greener cities could promote a higher diversity of natural sounds.

Although the use of smartphones allowed us to reach a large audience and cover a larger sampling area, it is important to consider that: 1) different brands have variability in the recording quality (microphone and pre-amplifiers), and 2) these sensors are less sensitive to low frequencies (<300 Hz). As a solution for the first aspect, we used paired samples and compared the change measured by each recording device individually. As for the second aspect, since anthropic noise is characterized by energy at low frequencies, our results should be regarded as conservative; therefore, changes in SPL and acoustic structure are likely higher than measured.

Colombia is a developing country with an immense biodiversity. Most of the cities in the country are rapidly growing, prioritizing infrastructure over greenspaces. These urban greenspaces serve as wildlife refugia, noise barriers, and provide opportunities for human-nature interactions. Adequate soundscape management to mitigate anthropic noise in such green spaces could increase the use of these habitats by wildlife, which can in turn facilitate human-nature interactions, ultimately fostering the conditions for human well-being and wildlife in a positive feedback loop (Levenhagen et al., 2020). The dramatic decrease in human activities and their associated noise due to the COVID-19 confinement was a unique opportunity to measure not only the impacts of human activities in the acoustic environment, but also to highlight the importance of greenspaces to buffer noise pollution. Moreover, this was also an occasion for community volunteers to open their ears and experience the surrounding wildlife in cities from their windows, showing that even indoor activities can be designed to strengthen their connection with nature (Collins et al., 2020). While largely underexplored, community science initiatives that incorporate active listening have the potential to raise public awareness regarding urban wildlife and noise pollution effects (Sonne and Alstrup, 2019; Kuehne et al., 2013), engaging volunteers in the establishment and maintenance of more suitable human and wildlife habitats.

CRediT authorship contribution statement

Juan Sebastian Ulloa: Conceptualization, Data acquisition – curation, Formal analysis, Investigation, Methodology, Supervision, Validation. **Angélica Hernández-Palma**: Data curation, Formal analysis, Investigation, Methodology, Writing - review & editing. **Orlando Acevedo-Charry**: Investigation, Writing - review & editing. **Bibiana Gómez-Valencia**: Formal analysis, Investigation, Methodology, Writing - review & editing. **Cristian Cruz-Rodríguez**: Data acquisition – curation, Visualization, Writing - review & editing. **Yenifer Herrera-Varón**: Data curation, Visualization, Writing - review & editing. **Margarita Roa**: Data curation, Methodology, Visualization. **Susana Rodríguez-Buriticá**: Conceptualization, Formal analysis, Validation, Writing - review & editing. **Jose Manuel Ochoa-Quintero**: Conceptualization, Methodology, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Data collection was realized by the active participation of hundreds of people who selflessly contributed records to the citizen science initiative *¿Cómo suena mi ciudad? Paisajes sonoros desde tu ventana*, which had the support of the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt and the Red Ecoacústica Colombiana. We thank Carolina Gómez Navarro, Paola Olaya Arenas, and Charles Hathcock for language corrections and comments on the manuscript.

Funding sources

This work was supported by the Colombian Ministry of Environment and Sustainable Development (resolución 0041, 2020). JSU was funded by Colciencias Postdoctoral Grant (811-2018).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2021.108996.

References

Aronson, M.F.J., La Sorte, F.A., Nilon, C.H., Katti, M., Goddard, M.A., Lepczyk, C.A., Warren, P.S., Williams, N.S.G., Cilliers, S., Clarkson, B., Dobbs, C., Dolan, R., Hedblom, M., Klotz, S., Kooijmans, J.L., Kühn, I., MacGregor-Fors, I., McDonnell, M., Mörtberg, U., Pyšek, P., Siebert, S., Sushinsky, J., Werner, P., Winter, M., 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc. R. Soc. B 281, 20133330. https://doi.org/10.1098/rspb.2013.3330.

Barber, J.R., Crooks, K.R., Fristrup, K.M., 2010. The costs of chronic noise exposure for terrestrial organisms. Trends Ecol. Evol. 25, 180–189.

Bates, A.E., Primack, R.B., Moraga, P., Duarte, C.M., 2020. COVID-19 pandemic and associated lockdown as a "Global Human Confinement Experiment" to investigate biodiversity conservation. Biol. Conserv. 248, 108665. https://doi.org/10.1016/j.biocon.2020.108665.

Brumm, H., Slabbekoorn, H., 2005. Acoustic communication in noise. In: Advances in the Study of Behavior. Academic Press, pp. 151–209. https://doi.org/10.1016/S0065-3454(05)35004-2.

Collins, M., Dorph, R., Foreman, J., Pande, A., Strang, C., Young, A., 2020. A Field at Risk: The Impact of COVID-19 on Environmental and Outdoor Science Education (Policy Brief). Lawrence Hall of Science, University of California, Berkeley, California.

Fang, C.-F., Ling, D.-L., 2003. Investigation of the noise reduction provided by tree belts. Landsc. Urban Plan. 63, 187–195. https://doi.org/10.1016/S0169-2046(02)00190-1.

Francis, C.D., Ortega, C.P., Cruz, A., 2009. Noise pollution changes avian communities and species interactions. Curr. Biol. 19, 1415–1419. https://doi.org/10.1016/j.cub.2009.06.052.

Francis, C.D., Kleist, N.J., Ortega, C.P., Cruz, A., 2012. Noise pollution alters ecological services: enhanced pollination and disrupted seed dispersal. Proc. R. Soc. B 279, 2727–2735. https://doi.org/10.1098/rspb.2012.0230.

Google LLC, 2020. Google COVID-19 community mobility reports [WWW document]. URL. https://www.google.com/covid19/mobility/.

Joo, W., Gage, S.H., Kasten, E.P., 2011. Analysis and interpretation of variability in soundscapes along an urban–rural gradient. Landsc. Urban Plan. 103, 259–276. https://doi.org/10.1016/j.landurbplan.2011.08.001.

Kuehne, L.M., Padgham, B.L., Olden, J.D., 2013. The soundscapes of lakes across an urbanization gradient. PLoS One 8, e55661. https://doi.org/10.1371/journal.pone.0055661.

Levenhagen, M.J., Miller, Z.D., Petrelli, A.R., Ferguson, L.A., Shr, Y. (Jimmy), Gomes, D.G.E., Taff, B.D., White, C., Fristrup, K., Monz, C., McClure, C.J.W., Newman, P., Francis, C.D., Barber, J.R., 2020. Ecosystem services enhanced through soundscape management link people and wildlife. People and Nature, pan3.10156. https://doi.org/10.1002/pan3.10156.

van der Maaten, L., Hinton, G., 2008. Visualizing data using t-SNE. J. Mach. Learn. Res. 9, 2579–2605.

Mennitt, D.J., Fristrup, K.M., 2016. Influence factors and spatiotemporal patterns of environmental sound levels in the contiguous United States. Noise Control Eng. J. 64, 342–353.

Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. Trends Ecol. Evol. 20, 430–434.

Pijanowski, B.C., Farina, A., Gage, S.H., Dumyahn, S.L., Krause, B.L., 2011. What is soundscape ecology? An introduction and overview of an emerging new science. Landsc. Ecol. 26, 1213–1232. https://doi.org/10.1007/s10980-011-9600-8.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rutz, C., Loretto, M.-C., Bates, A.E., Davidson, S.C., Duarte, C.M., Jetz, W., Johnson, M., Kato, A., Kays, R., Mueller, T., Primack, R.B., Ropert-Coudert, Y., Tucker, M.A., Wikelski, M., Cagnacci, F., 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. Nat. Ecol. Evol. 4, 1156–1159. https://doi.org/10.1038/s41559-020-1237-z.

Salomons, E.M., Pont, M.B., 2012. Urban traffic noise and the relation to urban density, form, and traffic elasticity. Landsc. Urban Plan. 108, 2–16.

Schafer, R., 1993. The soundscape: our sonic environment and the tuning of the world. In: Destiny Books Distributed to the Book Trade in the United States by American International Distribution Corp. Vt. United States, Rochester.

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., 2016. A synthesis of two decades of research documenting the effects of noise on wildlife. Biol. Rev. 91, 982–1005.

Soga, M., Gaston, K.J., 2016. Extinction of experience: the loss of human–nature interactions. Front. Ecol. Environ. 4, 94–101.

Sonne, C., Alstrup, A.K.O., 2019. Using citizen science to speed up plastic collection and mapping of urban noise: lessons learned from Denmark. Mar. Pollut. Bull. 149, 110591. https://doi.org/10.1016/j.marpolbul.2019.110591.

Stocker, M., 2013. Hear Where We Are: Sound, Ecology, and Sense of Place. Springer-Verlag, New York. https://doi.org/10.1007/978-1-4614-7285-8.

Turner, W.R., Nakamura, T., Dinetti, M., 2004. Global urbanization and the separation of humans from nature. Bioscience 54, 585–590.

Ulloa, J.S., Aubin, T., Llusia, D., Bouveyron, C., Sueur, J., 2018. Estimating animal acoustic diversity in tropical environments using unsupervised multiresolution analysis. Ecol. Indic. 90, 346–355. https://doi.org/10.1016/j.ecolind.2018.03.026.

Van Rossum, G., Drake, F.L., 2009. Python 3 Reference Manual. CreateSpace, Scotts Valley, CA.

Warren, P.S., Katti, M., Ermann, M., Brazel, A., 2006. Urban bioacoustics: it's not just noise. Anim. Behav. 71, 491–502. https://doi.org/10.1016/j.anbehav.2005.07.014.

WHO, 2011. Burden of Disease From Environmental Noise: Quantification of Healthy Life Years Lost in Europe. World Health Organization. Regional Office for Europe.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813.