forum acusticum 2026
8-12 September · Graz, Austria

Investigating Associations Between Human Perception and Ecoacoustic Indices: Short Term Measurements and Soundwalks in Natural or Protected Areas

Giacomo Gozzi[1,2], Simone Torresin[1], Matteo Anderle[2], Tin Oberman[3], Chiara Paniccia[2], Jarek Scanferla[2], Emmanuel Requena[2], Sara Favargiotti[1]

[1]*Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy*
[2]*Institute for Alpine Environment, Eurac Research, Bozen, Italy*
[3]*Institute of Environmental Design and Engineering, University College London, United Kingdom*

This paper is a revised version of the authors' submitted manuscript that was peer-reviewed by at least two anonymous reviewers.

Abstract

Within the field of soundscape studies, two distinct approaches have consolidated: a human-centric one, focused on people's perception; and the other related to soundscape ecology, which assesses biodiversity via bio- and ecoacoustic indices (EIs). These two branches frequently operate in silos, with minimal cross-disciplinary communication or data integration, even when collected from the same areas, as in the case of mountainous ones. To address this gap, the present study cross-references ISO 12913 standardized perceptual data collected from 219 participants during the "Silenzi in Quota" soundwalks, conducted in 10 European natural or protected areas, with EIs computed and bird species identified from 71 binaural recordings in 68 listening stops. Given the beneficial effects of natural sounds on humans, and the role of EIs as proxies for their presence, the goals are: 1) to identify associations between human soundscape perception and EIs, 2) and between these perceptual dimensions and bird species richness. Results from a preliminary correlational analysis revealed that more pleasant soundscapes are associated with sites characterized by higher total entropy (H), lower Acoustic Evenness Index (AEI), and higher number of species present, while more eventful soundscapes are related to higher Acoustic Biodiversity Index (BIO) and lower Spectral Entropy (sh) values.

Keywords: *soundscape, ecoacoustics, bioacoustics, natural area, birds*

Corresponding author: *giacomo.gozzi@unitn.it*

1. Introduction

Since its inception in the late 1960s, the concept of "soundscape" has expanded into a multidisciplinary domain, growing to encompass today fields such as ecoacoustics, engineering, and psychology. While the ISO 12913-1 [1] standard prioritizes human perception within an acoustic environment, fields like bio- and ecoacoustics are based on metrics regardless of the sound source such as antropophony, biophony, geophony [2] and single species (i.e., traditional bioacoustics on identifying and monitoring specific biological sound sources). Historically, ISO 12913 series work with short one-off measurements, including soundwalks, which are defined as a "*method that implies a walk in an area with a focus on listening to the acoustic environment*" [3] across a series of listening stops where the soundscape is characterized through questionnaires and binaural recordings. Conversely, ecoacoustic indices often rely on long term monitoring campaigns, such as passive acoustic monitoring (PAM) [4]. These distinct approaches have operated in isolation; however, a recent study by Ruiz Arana [5] suggests that integrating them could provide a more holistic understanding of natural environments, benefiting both biodiversity monitoring and human well-being. Indeed, human health and wellbeing research is finding evidence of positive effects to exposure to natural sounds [6], where bird sounds are key components [7]. One way to quantitatively measure biodiversity using environmental audio recordings is through bio- and ecoacoustic (EIs) indices [8] for instance, by leveraging bird diversity as a proxy for overall biodiversity [9]. The present study, therefore, aims to correlate soundscape perceptual data 1) with metric tools such as EIs and 2) with bioacoustic data, such as bird species presence derived from short-term recordings collected during soundwalks. The present study builds on data collected within the "Silenzi in Quota" (SiQ; Silence at High Altitude) initiative [10], which, since 2022, has been documenting, collecting, and analyzing the soundscapes of mountainous European natural or protected areas. The SiQ dataset [11] has therefore been examined from a novel perspective, by visualizing the patterns among human perception, EIs and the presence of bird species. The following sections will present: the architecture of the SiQ dataset, a concise overview of the applied bio- and ecoacoustic indices, the analytical methodologies, and the results derived from the comprehensive dataset.

2. Methods

This section outlines the SiQ dataset, the administered questionnaire, the participant demographics, and provides a brief overview of the applied EIs. For further methodological details in the soundwalks, see Oberman et al. [12].

2.1 SiQ dataset

The SiQ database comprises data collected from 13 soundwalks (Table 1) conducted between April 24, 2022, and February 21, 2026. All soundwalks were conducted under sunny conditions or, at most, during very light precipitation. Wind speed data was not collected due to the lack of suitable equipment. During listening stops – ranging from 3 to 7 per soundwalk - a total of 71 binaural recordings were collected using binaural measurement kits: front end devices SQuadriga III or SQobold; binaural microphones BHS II binaural headset or BSU dummy head (all equipment by HEAD Acoustics GmbH).

Table 1. The structure and composition of the SiQ dataset, categorized by Site_ID (S_ID), Location_ID, Date (YYYY-MM-DD), Natural or Protected Area and Country – Italy (ITA), United Kingdom (GBR), Finland (FIN), Norway (NOR). Utilized instrumentation is reported in S_ID column as "*" for BHS II binaural headset, as "**" for BSU dummy head.

S_ID	Location_ID	Date	Natural or Protected Area (Country)
1 *	Braies	2022-04-24	Fanes-Sennes-Braies Natural Park (ITA)
2 *	Val Venegia	2022-06-19	Paneveggio-Pale di San Martino Natural Park (ITA)
3 *	Passo Rolle	2023-02-12	Paneveggio-Pale di San Martino Natural Park (ITA)
4 *, **	Glen Lui	2023-05-28	Cairngorms National Park (GBR)
5 *	Tre Cime	2023-06-25	Tre Cime Natural Park (ITA)
6 **	Seiser Alm	2023-12-17	Sciliar-Catinaccio Natural Park (ITA)
7 *	Malla	2024-02-21	Malla Strict Natural Reserve (FIN)
8 *	Rondane	2024-07-24	Rondane National Park (NOR)
9 **	Carezza	2024-12-08	Sciliar-Catinaccio Natural Park (ITA)
10 *	Val di Funes	2025-07-05	Puez-Geisler Natural Park (ITA)
11 **	Gran Paradiso	2025-07-31	Gran Paradiso National Park (ITA)
12 *	Fai della Paganella	2025-08-08	Adamello Brenta Natural Park (ITA)
13 **	Val Nambino	2026-02-21	Adamello Brenta Natural Park (ITA)

2.2 Questionnaire

The SiQ questionnaire adheres almost entirely to the technical specifications of ISO 12913-2, Method A [3] and was administered in three languages: Italian, English, and Norwegian. The Italian version was adapted from Aletta et al. [13], while the Norwegian version was translated within the framework of the Sounds Like Norway project [14].

2.3 Participants

A total of 219 participants took part in the study on a voluntary basis (112 females, 103 males, 2 preferred not to say, 1 preferred to self-describe, and 1 missing value), for a total of 1047 individual observations. Recruitment was carried out through the initiative's website, social media channels managed by the researchers, and via posters. The participation rate showed a mean of 16.85 participants per soundwalk, with a median of 18. In several instances, certain participants took part in multiple soundwalks; however, it is not possible to account for these recurrences as the data were collected anonymously. Participant ages ranged from 12 to 85 years, with a mean age of 40 years (SD = 14.80).

2.4 Bioacoustic and ecoacoustic indices

EIs are metrics employed to quantitatively assess proxy of biodiversity levels and the ecology of a given soundscape. Most EIs are based on the Acoustic Niche Hypothesis [15], which posits that different species sing/emit sounds at distinct frequencies to avoid competition. Indeed, the majority of these indices analyze the spectral distribution of acoustic recordings.

Bioacoustics, on the other hand, follows a more conventional and objective methodology. Species richness was streamlined through machine learning algorithms [16] and then validated. We decided to use the eleven most common EIs as presented in Alcocer et al. [17] (Table 2).

Table 2. The table presents the eleven Ecoacoustic indices utilized in this study, detailing their abbreviations, full names, Range and Main purpose.

Ecoacoustic indices	Range	Main purpose
ACI (Acoustic Complexity Index) [18]	≥ 0	To measure the dynamic variability of sound intensity over time
ADI (Acoustic Diversity Index) [19]	≥ 0	To evaluate how sound is distributed and diversified across various frequency bands
AEI (Acoustic Evenness Index) [19]	0 - 1	To measure the degree of evenness in the distribution of sound across frequency bands
NDSI (Normalized Difference Soundscape Index) [20]	-1 - 1	To determine the ratio between biological sounds (biophony) and human-generated noise (anthrophony)
AR (Acoustic Richness) [21]	0 - 1	To rank recordings. estimating the variety of different species or sounds present in a site combining temporal entropy and median amplitude
BIO (Acoustic Biodiversity Index) [22]	≥ 0	To quantify the volume and variety of biological sounds (specifically in the 2–8 kHz range)
fpeaks (Frequency Peaks) [23]	≥ 0	To count the number of distinct spectral peaks in a specific frequency bin
H (Total Entropy) [24]	0 - 1	To represent the overall complexity or randomness of the soundscape, combining Spectral and Temporal Entropy
M (Amplitude Index) [21]	0 - 1	To calculate the median amplitude of the sound signal
sh (Spectral Entropy) [24]	0 - 1	To measure the evenness of energy distribution across the frequency spectrum
th (Temporal Entropy) [24]	0 - 1	To measure how sound energy is distributed and varies over time

2.5 Analysis

All the 71 binaural recordings were standardized to a duration of one minute to remove parts affected by wind interference, transient noise from participants, and occasional technical issues. Acoustic and psychoacoustic analyses were conducted using Artemis 16.7 (HEAD Acoustics) software. The ISOpleasantness (ISOp) and ISOeventfulness (ISOe) scores were derived through the trigonometric reduction of a participant's ratings across the eight affective attributes defined by the technical specification ISO/TS 12913-2— into a couple of coordinates (ISOp; ISOe) for each listening stop, representing a point in the perceptual space defined by the pleasantness and eventfulness axes (i.e., the soundscape circumplex). For this study, the standard angular coordinates were employed (0°: pleasant; 45°: vibrant; 90°: eventful; 135°: chaotic; 180°: annoying; 225°: monotonous; 270°: uneventful; 315°: calm) without adaptation to the specific language of the questionnaire [25]. EIs were calculated using RStudio (R version 4.5.2) using the default parameters for each index, primarily leveraging the *soundecology* package [26] for core soundscape metrics and the *seewave* package [27] for advanced spectral and temporal analysis. Data manipulation and file processing were handled via *tidyverse*, while *tuneR* was utilized for audio data management. For the correlational analyses, the maximum of each EIs value between the two channels (Left and Right) were utilized, following the recommendations for psychoacoustic indices in the ISO 12913 standard [25]. A list of bird species and a total number of species recorded per listening stop (Species Richness) were compiled using BirdNet Analyzer 2.4 [28] and validated by an expert ornithologist, applied to the full-length recordings which ranged between approximately 3 and 5 minutes per listening stop. This approach was adopted to maximize the identification of species actually present at each location; the one-minute segments used for the acoustic indices might have omitted specific species that were present and audible to participants during the full observation period. Given the non-normal distribution of the variables under investigation (Shapiro-Wilk test: $p=0.003$ for ISOe, and $p<0.001$ for all other variables), Spearman's rank correlation coefficient [29] was employed for studying associations between ISO dimensions and EIs; and between ISO dimensions and Species Richness. The dataset violates the assumption of independence of observations due to the repeated-measures design, wherein each participant provided evaluations across multiple listening stops within the same location. However, applying the Spearman's rank correlation coefficient is considered acceptable given the study's exploratory scope.

3. Results

3.1 Association between soundscape perception and ecoacoustic indices

Spearman's correlation coefficients between EIs and ISOp/ISOe are summarized in Figure 1. As regards ISOeventfulness the BIO parameter showed the strongest positive correlation (Spearman's ρ=0.33, p<0.001), indicating that sites with higher BIO values were perceived as more eventful (see Figure 2). The data show significant dispersion and multiple overlaps, reflecting high individual variability in how participants perceived different acoustic environments. In contrast, the parameter sh exhibits the strongest negative correlation (ρ=-0.26, p<0.001). Regarding ISO Pleasantness, among the variables showing significant associations, the strongest positive correlation is observed for H (ρ=0.40, p<0.05), whereas the strongest negative correlation is found with AEI (ρ=-0.32 p<0.001).

3.2 Association between soundscape perception and bird Species Richness

The total number of bird species recorded across the entire SiQ dataset was 17. Species Richness per listening stop was similarly limited, ranging from 0 to a maximum of 5. The most frequently recorded species per listening stop were the Common Chaffinch *Fringilla coelebs* (7 observations), followed by the Common house-martin *Delichon urbicum* (5), Coal tit *Periparus ater* (4), Eurasian Siskin *Spinus spinus* (3), and Willow warbler *Phylloscopus trochilus* (3). Investigating the correlation between the number of bird species identified at each listening stop and human perception provides key insights into the interplay between biodiversity and auditory experience. Spearman's rank correlation analysis revealed a negligible correlation between Species Richness and ISOe (ρ=0.08, p=0.012); similarly, a weak correlation was observed with ISOp (ρ=0.11, p<0.001) (Figure 3).

4. Discussions and final remarks

ISOeventfulness was found to be positively correlated with the BIO index and negatively correlated with the sh index. As expected, environments with a higher presence of biotic sounds are perceived as more eventful, as also shown in previous literature [30]. Conversely, the relationship with sh suggests that sites with lower median sh values (e.g., Passo Rolle, Seiser

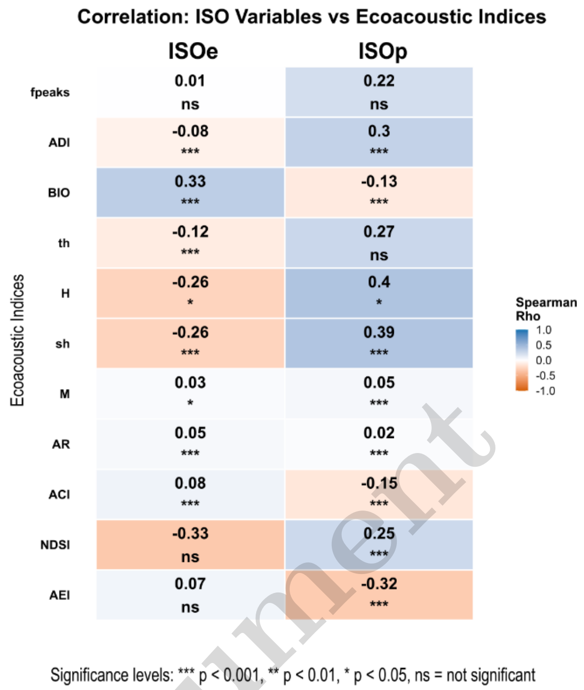

Figure 1. Spearman's rank correlation heatmap of ecoacoustic indices and ISOeventfulness (ISOe)/ISOpleasentness (ISOp) dimensions for the complete Silenzi in Quota dataset.

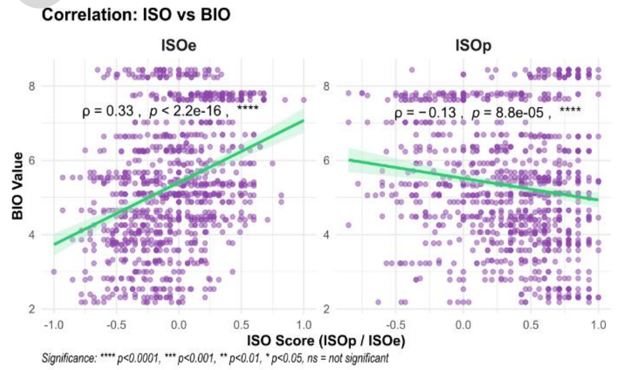

Figure 2. Scatterplots showing the Spearman correlation between Acoustic Biodiversity Index (BIO), ISOeventfulness (ISOe)/ISOpleasentness (ISOp). Each data point represents the coordinates of an ISOe/ISOp dimension for a single participant at a specific listening stop (N=1047). While trends are visible, it is important to note that the Spearman correlation values are relatively weak (ρ=0.33 for ISOe; ρ=0.13 for ISOp).

Alm in winter season) were perceived as more eventful, likely due to the presence of ski lift facilities.
Regarding ISOpleasantness, a positive correlation with the BIO index was initially expected, as the perception of natural sounds was shown to enhance pleasantness in a previous subset of this study [12]. Surprisingly, the BIO index showed a negative correlation. This discrepancy might be due to the fact that soundwalks with the highest median BIO (e.g., Val di Funes, Val

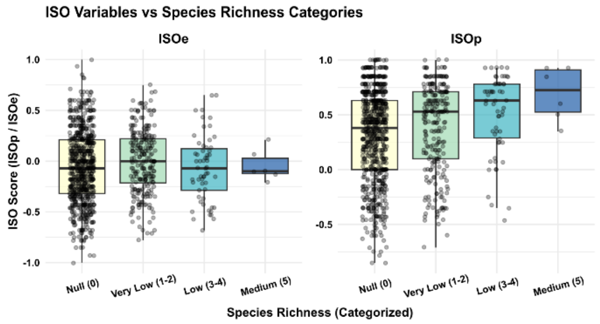

Figure 3. Boxplots illustrating individual participant ratings for the ISOeventfulness/ISOpleasentness dimension and categorized species richness (Null, Very Low, Low, Medium) per listening stop (N=1047).

Nambino, Gran Paradiso) included listening stops perceived as chaotic and unpleasant due to the concurrent presence of other visitors. Regarding BIO, the parameter therefore accurately approximated the presence of bird species in the 2–8 kHz band. However, the concurrent presence of human-generated sounds, which was not captured by the parameter, may have shifted perception toward more negative evaluations, as previously reported in natural and mountain contexts. [12].

Higher soundscape pleasantness was instead associated with sites characterized by higher values of H, sh, and lower values of AEI. The latter is driven by listening stops near streams and waterfalls, where acoustic energy is concentrated in the low-to-mid frequencies. As regards H and sh, the relationship with soundscape pleasantness might be due to the fact that such indices correlated with the perceived dominance of animal sounds (not shown here), which might be drivers of soundscape pleasantness [30]. High overall values of H (> 0.60) and sh (> 0.55) across the dataset reflect substantial spectral and temporal variation characteristic of natural soundscapes.

Interestingly, the negative correlation between AEI and pleasantness contradicts previous urban-context research, which reported a strong positive correlation ($\rho=0.68$, $p<0.01$) specifically with the Perceived Affective Quality Pleasantness attribute [31]. As expected, Species Richness showed a weak positive correlation with ISOp, as richness was higher during soundwalks with a greater presence of bird sounds, that are typically more pleasant [32]. Overall, the present study has shown that biodiversity proxies derived from binaural recordings from soundwalks are correlated with human perception of the soundscape. To refine these findings, future studies must employ more robust statistical frameworks, such as Mixed-Effects Models, accounting for the nested structure of the data, treating locations and participants as random effects rather than analyzing the dataset as a single aggregate. Moreover, it should be noticed that if EIs have been developed for data from fixed monitoring stations over extended periods, this study employed 3 to 5-minute recordings, with subsequent analyses performed on 1-minute segments. Future research will examine the extent to which EIs, derived from short-term soundwalk recordings, can both predict human perception in natural environments and still serve as meaningful proxies for biodiversity.

Acknowledgments

This work was funded by HEAD-Genuit-Foundation (Herzogenrath-Kohlscheid, Germany) [grant agreements No. P-25/03-W, P-25/04-W], the European Research Council [grant agreement No. 740696]; the UCL Global Engagement Fund (London, UK); the UK Acoustics Network Plus (via EPSRC); The Research Council of Norway [grant agreement No. 334724]; and supported by Montura (Zané, Italy) and HEAD Acoustics GmbH (Herzogenrath, Germany). The authors would like to express their gratitude to the Gran Paradiso Film Festival (Cogne, Italy) for their logistical support in organizing the soundwalk within the Gran Paradiso National Park. Special thanks also go to the Azienda per il Turismo Dolomiti Paganella Scrl Società Benefit (Andalo, Italy) for their assistance in coordinating the soundwalk held in Fai della Paganella.

References

[1] *ISO/TS 12913-1:2014 Acoustics—Soundscape Part 1: Definition and conceptual framework*, 12913–1, Geneva, Switzerland., 2014.

[2] B. C. Pijanowski, A. Farina, S. H. Gage, S. L. Dumyahn, and B. L. Krause, 'What is soundscape ecology? An introduction and overview of an emerging new science', *Landsc. Ecol.*, vol. 26, no. 9, pp. 1213–1232, Nov. 2011, doi: 10.1007/s10980-011-9600-8.

[3] *ISO/TS 12913-2:2018 Acoustics—Soundscape Part 2: Data collection and Reporting Requirements*, 12913–2, Geneva, Switzerland., 2018.

[4] T. Napier, E. Ahn, S. Allen-Ankins, L. Schwarzkopf, and I. Lee, 'Advancements in preprocessing, detection and classification techniques for ecoacoustic data: A comprehensive review for large-scale Passive Acoustic Monitoring', *Expert Syst. Appl.*, vol. 252, p. 124220, Oct. 2024, doi: 10.1016/j.eswa.2024.124220.

[5] U. Ruiz Arana, *Multispecies soundscapes: A more-than-human approach*. 2024.

[6] A. L. Montenegro *et al.*, 'Exploring the relationship between urban acoustic environments and mental well-being', *Appl. Acoust.*, vol. 242, p. 111092, Jan. 2026, doi: 10.1016/j.apacoust.2025.111092.

[7] D. M. Ferraro *et al.*, 'The phantom chorus: birdsong boosts human well-being in protected areas', *Proc. R. Soc. B Biol. Sci.*, vol. 287, no. 1941, Dec. 2020, doi: 10.1098/rspb.2020.1811.

[8] T. Bradfer-Lawrence *et al.*, 'The Acoustic Index User's Guide: A practical manual for defining, generating and understanding current and future acoustic indices', *Methods Ecol. Evol.*, vol. 16, no. 6, pp. 1040–1050, 2025, doi: 10.1111/2041-210X.14357.

[9] M. Anderle *et al.*, 'Efficiency of birds as bioindicators for other taxa in mountain farmlands', *Ecol. Indic.*, vol. 158, p. 111569, Jan. 2024, doi: 10.1016/j.ecolind.2024.111569.

[10] M. Pedron and G. Gozzi, 'Silenzi in Quota', Silenzi in Quota. Accessed: Mar. 17, 2026. [Online]. Available: https://silenziinquota.mypixieset.com/

[11] T. Oberman, S. Torresin, G. Gozzi, and M. Pedron, 'Silenzi in Quota Dataset: Questionnaires with Acoustical and Contextual Information from Soundwalks in Protected Natural Areas (International)'. Zenodo, 2023. doi: 10.5281/zenodo.10253143.

[12] T. Oberman, A. Latini, F. Aletta, G. Gozzi, J. Kang, and S. Torresin, 'Human sounds and associated tonality disrupting perceived soundscapes in protected natural areas', *Sci. Rep.*, vol. 15, no. 1, p. 28759, Aug. 2025, doi: 10.1038/s41598-025-08524-y.

[13] F. Aletta *et al.*, 'Soundscape descriptors in eighteen languages: Translation and validation through listening experiments', *Appl. Acoust.*, vol. 224, 2024, doi: 10.1016/j.apacoust.2024.110109.

[14] 'Sounds Like Norway'. Accessed: Mar. 27, 2026. [Online]. Available: https://www.nina.no/english/Sustainable-society/Nature-and-society/Sounds-Like-Norway-en-GB

[15] B. Krause, 'The Niche Hypothesis: A virtual symphony of animal sounds, the origins of musical expression and the health of habitats', *Soundscape Newsl. World Forum Acoust. Ecol.*, Jun. 1993.

[16] D. A. Nieto-Mora, S. Rodríguez-Buritica, P. Rodríguez-Marín, J. D. Martínez-Vargaz, and C. Isaza-Narváez, 'Systematic review of machine learning methods applied to ecoacoustics and soundscape monitoring', *Heliyon*, vol. 9, no. 10, p. e20275, Oct. 2023, doi: 10.1016/j.heliyon.2023.e20275.

[17] I. Alcocer, H. Lima, L. S. M. Sugai, and D. Llusia, 'Acoustic indices as proxies for biodiversity: a meta-analysis', *Biol. Rev.*, vol. 97, no. 6, pp. 2209–2236, 2022, doi: 10.1111/brv.12890.

[18] N. Pieretti, A. Farina, and D. Morri, 'A new methodology to infer the singing activity of an avian community: The Acoustic Complexity Index (ACI)', *Ecol. Indic.*, vol. 11, no. 3, pp. 868–873, May 2011, doi: 10.1016/j.ecolind.2010.11.005.

[19] L. J. Villanueva-Rivera, B. C. Pijanowski, J. Doucette, and B. Pekin, 'A primer of acoustic analysis for landscape ecologists', *Landsc. Ecol.*, vol. 26, no. 9, pp. 1233–1246, Nov. 2011, doi: 10.1007/s10980-011-9636-9.

[20] E. P. Kasten, S. H. Gage, J. Fox, and W. Joo, 'The remote environmental assessment laboratory's acoustic library: An archive for studying soundscape ecology', *Ecol. Inform.*, vol. 12, pp. 50–67, Nov. 2012, doi: 10.1016/j.ecoinf.2012.08.001.

[21] M. Depraetere, S. Pavoine, F. Jiguet, A. Gasc, S. Duvail, and J. Sueur, 'Monitoring animal diversity using acoustic indices: Implementation in a temperate woodland', *Ecol. Indic.*, vol. 13, no. 1, pp. 46–54, Feb. 2012, doi: 10.1016/j.ecolind.2011.05.006.

[22] N. T. Boelman, G. P. Asner, P. J. Hart, and R. E. Martin, 'Multi-Trophic Invasion Resistance in Hawaii: Bioacoustics, Field Surveys, and Airborne Remote Sensing', *Ecol. Appl.*, vol. 17, no. 8, pp. 2137–2144, 2007, doi: 10.1890/07-0004.1.

[23] A. Gasc, J. Sueur, S. Pavoine, R. Pellens, and P. Grandcolas, 'Biodiversity Sampling Using a Global Acoustic Approach: Contrasting Sites with Microendemics in New Caledonia', *PLOS ONE*, vol. 8, no. 5, p. e65311, mag 2013, doi: 10.1371/journal.pone.0065311.

[24] J. Sueur, S. Pavoine, O. Hamerlynck, and S. Duvail, 'Rapid Acoustic Survey for Biodiversity Appraisal', *PLoS ONE*, vol. 3, no. 12, p. e4065, Dec. 2008, doi: 10.1371/journal.pone.0004065.

[25] *ISO/TS 12913-3:2025 Acoustics—Soundscape Part 3: Data analysis*, 12913–3, Geneva, Switzerland., 2025.

[26] 'soundecology'. Accessed: Mar. 23, 2026. [Online]. Available: https://ljvillanueva.github.io/soundecology/

[27] 'seewave package - RDocumentation'. Accessed: Mar. 23, 2026. [Online]. Available: https://www.rdocumentation.org/packages/seewave/versions/2.2.4

[28] S. Kahl, C. M. Wood, M. Eibl, and H. Klinck, 'BirdNET: A deep learning solution for avian diversity monitoring', *Ecol. Inform.*, vol. 61, p. 101236, Mar. 2021, doi: 10.1016/j.ecoinf.2021.101236.

[29] C. Spearman, 'The Proof and Measurement of Association between Two Things', *Am. J. Psychol.*, vol. 15, no. 1, pp. 72–101, 1904, doi: 10.2307/1412159.

[30] Ö. Axelsson, M. E. Nilsson, and B. Berglund, 'A principal components model of soundscape perception', *J. Acoust. Soc. Am.*, vol. 128, no. 5, pp. 2836–2846, Nov. 2010, doi: 10.1121/1.3493436.

[31] B. T. Lawrence *et al.*, 'Linking ecoacoustic indices to psychoacoustic perception of the urban acoustic environment', *Ecol. Indic.*, vol. 155, p. 111023, Nov. 2023, doi: 10.1016/j.ecolind.2023.111023.

[32] E. Ratcliffe, B. Gatersleben, and P. T. Sowden, 'Bird sounds and their contributions to perceived attention restoration and stress recovery', *J. Env. Psychol.*, vol. 36, pp. 221–228, 2013, doi.org: 10.1016/j.jenvp.2013.08.004