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REVIEW ARTICLE

# The role of ecoacoustics in monitoring ecosystem degradation and restoration

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Ecoacoustic approaches are increasingly being used to monitor biodiversity, having emerged as a promising tool for monitoring ecosystem degradation and restoration in the last two decades. Despite the growth, their application in monitoring animal populations in changing ecosystems remains underutilized. In this systematic review and meta-analysis, we evaluate the effectiveness of ecoacoustic methodologies to assess ecosystem changes. We include studies focusing on ecoacoustic monitoring of species or soundscapes in ecosystem degradation or restoration contexts. A total of 187 studies (2003–May 2025) were included, with 124 focusing on degradation and 63 on restoration. Passive acoustic monitoring was used more frequently (89%) than manual acoustic monitoring. Bats were most studied, followed by birds, soundscapes, amphibians, invertebrates, and mammals. Most studies (66%) examined species diversity and other community characteristics, while 12% addressed population characteristics like a particular species' range. We highlight ecoacoustics as a growing, globally used, and scalable tool for ecosystem monitoring that effectively captures ecological changes, offering restoration experts unique advantages. A Bayesian multinomial meta-analysis was conducted to assess whether the direction of animal responses varies according to taxonomic groups, habitat change type, and drivers. Significant effects of habitat change type on animal responses were detected, while urbanization increased the likelihood of a decrease, and forest management supported an increase in animal response. While numerous studies document ecosystem degradation, there is a notable gap in research examining animal responses to ecosystem restoration. There is a need to investigate further how ecoacoustic monitoring can evaluate ecosystem restoration and its implications for biodiversity, especially in tropical regions. We recommend a multi-taxa approach in ecoacoustic monitoring, integrating soil and freshwater and employing diverse acoustic indices to provide a holistic view of ecosystem health.

**Key words: bioacoustics, biodiversity, degradation, ecoacoustics, passive acoustic monitoring (PAM), restoration, soundscapes, tropics**

### Implications for Practice

- Emphasizes the increasing importance of passive acoustic monitoring (PAM) for ecological assessments and flags out important research gaps that need to be addressed.
- Advocates that policymakers lobby for funding for ecosystem restoration monitoring and establishing monitoring frameworks using PAM, particularly in biodiverse regions like tropical ecosystems.
- Calls for future studies to integrate PAM in wildlife and ecosystem monitoring, expand its application to include under-represented taxa for a more comprehensive understanding of ecosystem dynamics, focus on ecosystem restoration, expand the geographic scope, and standardize acoustic indices.

## Introduction

The current state of tools for tracking ecosystem degradation and restoration is marked by notable gaps and constraints, particularly in generating coherent, standardized, and archivable datasets (Meroni et al. 2017; Murray et al. 2018). While satellite imagery can effectively capture broad ecological trends, it often lacks the granularity necessary to assess species diversity and intricate ecological interactions, which are critical for understanding ecosystem health (Lee et al. 2021).

Ecoacoustic monitoring emerges as a complementary solution to these limitations. This method provides real-time, archivable data that captures both species-specific activity and broader soundscape patterns, allowing researchers to document biodiversity and ecosystem dynamics at multiple scales, including those of nocturnal and cryptic species that are otherwise difficult to monitor (Gibb et al. 2019; Rappaport et al. 2022).

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Ecoacoustic sampling offers a direct, non-invasive method for quantifying animal presence, behavior, and diversity over time, making it well suited to detect ecological changes associated with degradation or restoration efforts (Gibb et al. 2019; Ducrettet et al. 2025).

Previous studies have shown that land use change, fragmentation, and degradation alter soundscape composition by reducing biophonic complexity and increasing anthropogenic noise levels (Choksi et al. 2023). These acoustic shifts can reflect declines in species richness, changes in community structure, and disruptions in ecological interactions. In addition, changes in soundscape composition can serve as sensitive indicators of ecosystem recovery, community reassembly, and the return of key functional groups (Choksi et al. 2023; Quinn et al. 2024). Therefore, ecoacoustic methods can capture both immediate and long-term ecosystem change in ways that traditional surveys might overlook. Understanding the effectiveness of ecoacoustic methods for monitoring ecosystem change is essential (Borker et al. 2020; Greenhalgh et al. 2021; Robinson et al. 2023).

Previous studies have reviewed published works in the ecoacoustic field, providing excellent resources for consolidating current knowledge on using ecoacoustics in terrestrial ecosystems. For example, Sugai et al. (2018) presented a roadmap for survey designs in terrestrial ecoacoustic monitoring. Here, the authors stress the limited use of passive acoustic monitoring (PAM) in terrestrial ecosystems but highlight its potential for evaluating biodiversity over extensive geographical and temporal ranges. Becker et al. (2022) presented a comprehensive overview of research over the last 70 years in Africa, focusing on developing bioacoustics as a scientific field and its application in various geographic, taxonomic, and thematic contexts throughout the continent. Similarly, Xavier et al. (2023) conducted a systematic mapping of research on bats in agricultural systems, highlighting trends in acoustic and mist-net sampling, while also identifying important regional and biome-specific gaps, particularly the underrepresentation of studies in the Afrotropics and non-forested ecosystems like savannahs.

However, although the aforementioned studies advance our understanding of ecoacoustics for biodiversity, the role of ecoacoustics in monitoring changing ecosystems (i.e. degraded and restored ecosystems) remains less established. Previous reviews have given limited attention to the use of ecoacoustic methods for monitoring community- and population-level characteristics in ecosystems undergoing change. Prior reviews have largely focused on forested systems and temperate regions, with little consideration of tropical ecosystems like savannahs, which are highly vulnerable to degradation yet under-represented in acoustic monitoring studies (Umuhoza et al. 2025). Considering the growing focus on biodiversity and ecosystem services in restoration endeavors (Ren et al. 2016), it is crucial to comprehensively assess the use of ecoacoustics for monitoring in this domain to realize its full potential.

Here, we systematically search studies that used ecoacoustic methodologies to monitor the characteristics of soundscapes in changing ecosystems. In particular, we review studies focused on community characteristics (those applied to multiple species, like species diversity, interactions, succession, resilience, and stability) and population characteristics (those applied to single species, occurrence, activity, abundance, and distribution patterns). We further extend previous works by incorporating ultrasonic monitoring approaches, evaluating acoustic indices alongside traditional ecological indicators, and highlight opportunities for more holistic monitoring frameworks in both tropical and temperate ecosystems.

Through this review, we aim to synthesize the current body of literature, identify areas lacking in research, and provide recommendations for future studies to researchers and restoration practitioners. In addition, the review facilitates the identification of crucial ecological indicators and acoustic metrics that are most frequently used for evaluating the achievement of restoration success.

In particular, the specific objectives of this systematic literature review are to:

(1) Review the use of ecoacoustic methodologies in assessing ecosystem degradation and restoration.
(2) Evaluate the methodologies employed in the literature regarding the use of ecoacoustic tools to monitor the effects of ecosystem change on animal populations, communities, and the broader soundscapes.
(3) Assess how habitat change (gain or loss), taxonomic group, driver of habitat change, and the type of animal response influence the direction of animal response.
(4) Make recommendations to implement the use of ecoacoustics to assess animal and soundscape responses to ecosystem changes.

## Methods

### Protocol

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) approach, developed by Page et al. (2021), to report our systematic review.

### Eligibility Criteria

We structured the eligibility criteria reporting following the Population Intervention Comparison Outcome (PICO) framework (Page et al. 2016). *Populations*: Terrestrial ecosystems experiencing changes through gain or loss. *Intervention*: Research that utilized ecoacoustic methods to track ecosystem changes. *Comparator*: Non-ecoacoustic monitoring methods (if present). *Outcome*: Effects of ecosystem changes on the soundscapes, acoustic indices, statistical analyses of the acoustic energy patterns and distribution in digital soundscape recordings, and animal community characteristics. We considered studies that met the above PICO parameters for inclusion in the systematic review. We only included papers written in English and those that were primary research. There were no restrictions on the publication date.

### Information Sources and Search Strategy

We conducted a search of the literature using Web of Science, Scopus, and Google Scholar. All authors agreed upon the final set of keywords and selected them to meet the search criteria. The search comprised terms relating to acoustic monitoring, animal groups, biodiversity, and land use changes. We combined the search terms using Boolean operators (see Supplement S1 for complete search terms).

#### Selection Process

For initial screening (up to May 2024), we used DistillerSR (DistillerSR Inc. 2024), a web-based software that employs screening and quality assessment algorithms, to input literature and remove duplicate entries. We utilized the software to evaluate the research and ascertain eligibility based on the predefined criteria for inclusion (Higgins et al. 2022). The first author, C.G., conducted the initial screening during the title and abstract screening stage. A second author, A.U., independently reviewed 5% of the studies chosen at random. In the full-text screening stage, a third author, E.K., assessed 5% of randomly chosen studies. We deliberated over whether to include or exclude the studies until we agreed. We interpreted Cohen's kappa coefficient according to the guidelines provided by McHugh (2012). The authors exhibited a high level of agreement during both the title and abstract screening stage ($\kappa = 0.57$) and the full-text screening stage ($\kappa = 1.0$).

We also screened the papers included in relevant systematic review publications (Sugai et al. 2018; Alcocer et al. 2022; Becker et al. 2022; Xavier et al. 2023; Qiu et al. 2024; Turlington et al. 2024).

#### Data Collection Process and Extraction

We included details of the extracted information in Table S1.

To evaluate patterns in animal responses to habitat change, we fitted a Bayesian multinomial meta-analysis using the *brms* package (v2.22.0) in R (v4.4.3) (Bürkner 2017). The model assessed whether habitat gain or loss differentially influenced the direction (response variable, categorized as *Decrease*, *No effect*, or *Increase*) of animal response relative to control sites. Animal response included diversity, richness, evenness, occurrence, distribution, relative abundance, abundance, activity, composition, Acoustic Diversity Index (ADI), Bioacoustic Index (BI), and Acoustic Complexity Index (ACI), while those with a sample size less than 5 were grouped as "other (Acoustic Evenness Index [AEI], Normalized Difference Soundscape Index [NDSI], and Acoustic Entropy)." Fixed-effect predictors comprised the habitat change type (gain or loss), taxonomic group, and the interaction. Additionally, we included individual drivers of habitat change and the type of animal response as fixed-effect covariates to control for other potential sources of variation. Drivers of habitat loss included agricultural intensification, fragmentation, logging and deforestation, urbanization and infrastructure development, and wildfire, while those with a sample size less than 5 were grouped as "other (natural phenomena, growth of invasive species, industrial disturbance)." Habitat gain drivers include forest management, removal of invasive species, and reforestation and prescribed fire, while those with a sample size less than 5 were grouped as "other (regrowth/regeneration and restoration of a mine)." We incorporated study-level random intercepts to address between-study heterogeneity arising from multiple observations per publication. Posterior distributions of interaction terms revealed how response patterns varied across taxonomic groups, with model robustness verified through sensitivity analyses (Conn et al. 2018).

We evaluated model robustness through a comprehensive prior sensitivity analysis, comparing our main model's assumptions (normal [0, 1.5]) with both tighter (normal [0, 1]) and broader (normal [0, 3]) alternatives.

## Results

#### Study Selection

We identified 3040 records from the three databases and search engines in our initial search (Fig. 1). We eliminated 119 duplicate records in DistillerSR. First, we manually screened the titles and abstracts of 2921 records, excluding 2729 articles. Second, we read 192 articles in their entirety and eliminated 95. Ultimately, we included 97 papers that satisfied the eligibility-inclusion criteria. Our additional searches identified 1671 papers. We eliminated 101 duplicates and applied the same rigorous screening process as above, eliminating 1479 papers that did not meet the criteria. We included 90 additional studies that met our criteria (Fig. 1). The final set comprises 187 papers spanning from 2003 to May 2025 (Table S1). The meta-analysis, which included 299 observations from 187 studies, was consistent across prior specifications, with key effects maintaining direction and statistical credibility, supporting the reliability of our conclusions. The analysis detected substantial between-study heterogeneity, with random intercept standard deviations ($\tau$) of 2.04 (95% credible intervals [CrI]: 0.97–3.25) for *Decrease* responses and 2.09 (95% CrI: 0.89–3.46) for *Increase* responses. The heterogeneity translated to an intraclass correlation coefficient (ICC) of 0.55 (95% CrI: 0.38–0.70), indicating that 55% of the total variance in response direction was attributable to between-study differences. Sensitivity analyses confirmed the robustness of these findings: the direction and statistical credibility of key effects remained consistent across prior specifications.

Over this period, there has been a rise in the use of ecoacoustics in research related to ecosystem change (Fig. 2). The current year (2025) was excluded from the trend analysis to avoid bias from incomplete data, as only a few months were available.

The 187 studies included were geographically diverse, covering all continents but Antarctica. Most research work was conducted in North America ($n = 67$), followed by Europe ($n = 40$), South America ($n = 32$), Asia ($n = 19$), Africa ($n = 15$), and Australia ($n = 14$). Forty-eight countries contributed to the studies reviewed, with the United States ($n = 41$), Brazil ($n = 19$), and the United Kingdom ($n = 12$) leading in terms of the number of published studies (Fig. S1).

Furthermore, this evaluation found a near balance in the distribution of studies across climatic zones, though temperate

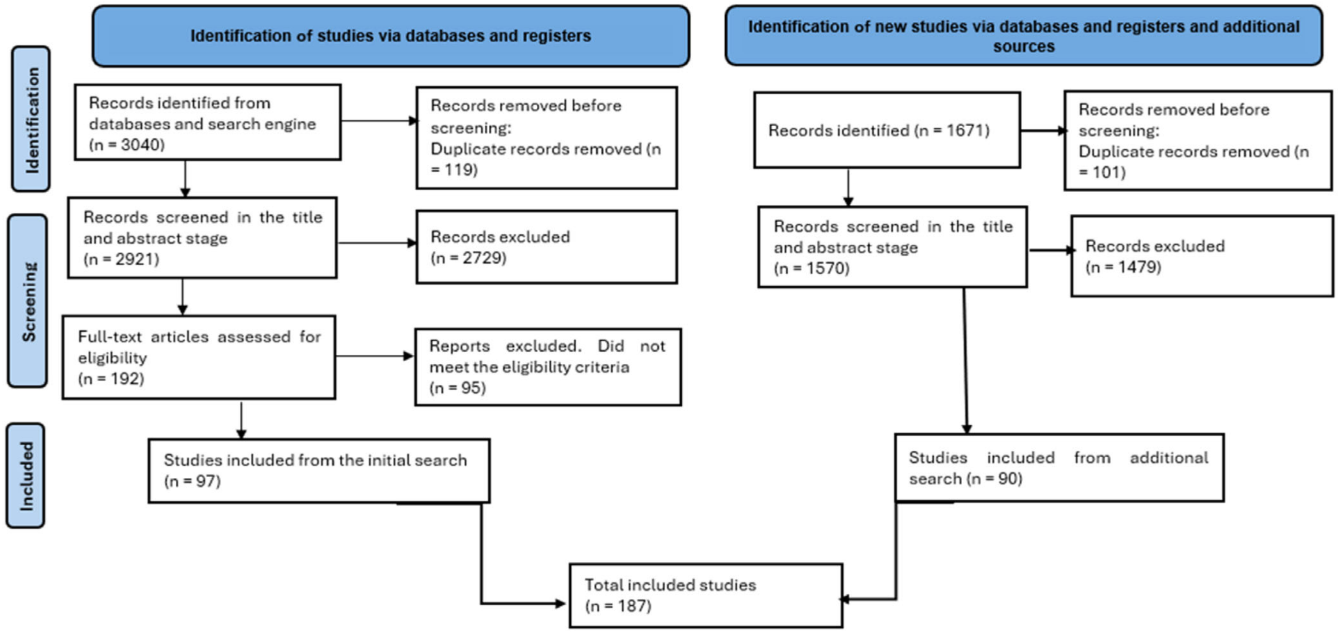


Figure 1. A flow diagram showing the study selection process based on PRISMA 2020 guidelines (Page et al. 2021).

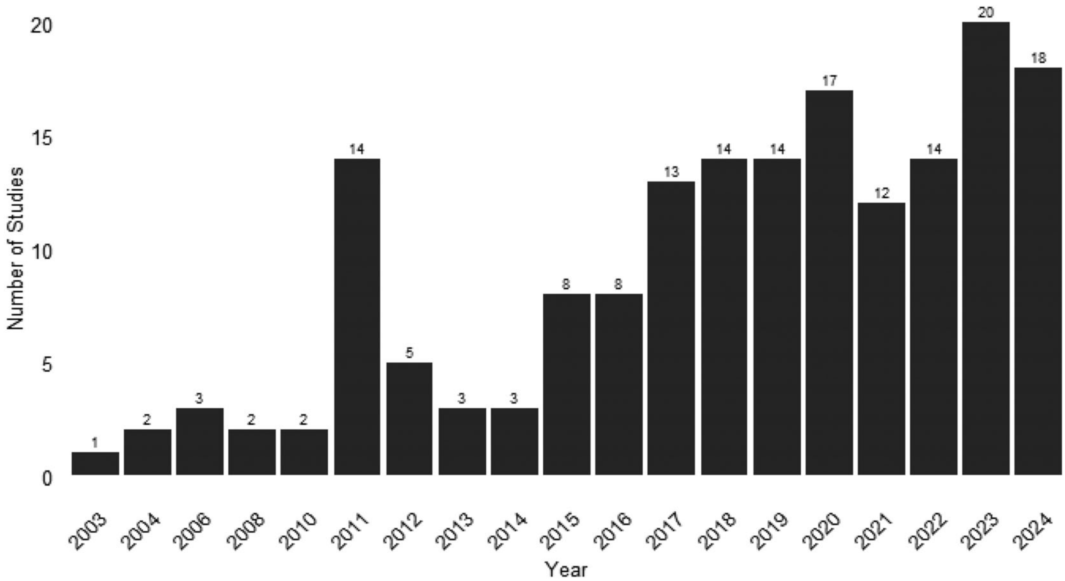


Figure 2. Number of studies using ecoacoustics in monitoring ecosystem change from 2003 to 2024.

regions accounted for marginally more (102 studies, 55%) compared to 85 studies (45%) in tropical regions (Fig. S2).

### Use of Ecoacoustics in Assessing Ecosystem Degradation and Restoration

More studies in this review used ecoacoustics to monitor the impacts of various drivers of ecosystem degradation ($n = 124$, 66%) than ecosystem restoration ($n = 63$, 34%) on biodiversity. Studies that focused on monitoring ecosystem degradation employed ecoacoustic monitoring to assess the impacts of the following drivers of habitat change: wildfire/accidental fires (e.g. Wood et al. 2024), logging/deforestation (e.g. Law et al. 2011), agricultural/pasture expansion (e.g. Vilches-Piñones et al. 2022), urbanization (e.g. Holgate et al. 2021), infrastructure development (e.g. Alvarez-Berríos et al. 2016), non-native invasive species (Mark et al. 2024), and natural phenomena (i.e. typhoons, [Buxton et al. 2016]) on biodiversity and ecosystem health. The meta-analysis showed an increased odds of a decrease in animal response with urbanization (Table 1).

**Table 1.** Bayesian multinomial regression results for decreased outcome on animal responses to habitat change.

| | *Log−odds* | | *Odds ratio* | | |
|---|---|---|---|---|---|
| *Parameter* | *Estimate* | *LogOdds_CI* | *OR* | *OR_CI* | *Significance* |
| Decrease: intercept | 0.66842392 | [−1.92, 3.12] | 1.95 | [0.15, 22.67] | |
| Decrease: habitat loss | 2.13363697 | [−0.08, 4.39] | 8.45 | [0.93, 80.32] | |
| Decrease: birds | 0.23199747 | [−1.86, 2.33] | 1.26 | [0.16, 10.26] | |
| Decrease: other (insects, mammals, amphibians) | −0.31513626 | [−2.72, 2.08] | 0.73 | [0.07, 7.99] | |
| Decrease: soundscape | 0.51695437 | [−1.62, 2.64] | 1.68 | [0.20, 14.00] | |
| Decrease: (forest management, removal of invasive species and reforestation) | −1.11629294 | [−3.46, 1.11] | 0.33 | [0.03, 3.02] | |
| Decrease: Fragmentation | −0.09535978 | [−2.00, 1.88] | 0.91 | [0.13, 6.54] | |
| Decrease: other (logging and deforestation) | −0.08093251 | [−1.81, 1.77] | 0.92 | [0.16, 5.88] | |
| Decrease: other (natural phenomena, growth of invasive species, industrial disturbance) | −0.59179493 | [−2.74, 1.60] | 0.55 | [0.06, 4.93] | |
| Decrease: other (restoration of mines, regrowth/regeneration) | −0.58351298 | [−3.31, 2.14] | 0.56 | [0.04, 8.47] | |
| Decrease: Prescribed fire | −0.41112226 | [−2.95, 2.09] | 0.66 | [0.05, 8.12] | |
| Decrease: urbanisation and infrastructure development | 1.10889090 | [−0.70, 3.02] | 3.03 | [0.50, 20.41] | |
| Decrease: wildfire | 0.10288541 | [−2.05, 2.21] | 1.11 | [0.13, 9.15] | |
| Decrease: ACI and complexity | −0.28783603 | [−2.71, 2.10] | 0.75 | [0.07, 8.20] | |
| Decrease: activity | 0.32518274 | [−1.29, 1.95] | 1.38 | [0.28, 7.06] | |
| Decrease: ADI, diversity and richness | 0.89553627 | [−0.67, 2.50] | 2.45 | [0.51, 12.24] | |
| Decrease: BI | 0.87796789 | [−1.40, 3.27] | 2.41 | [0.25, 26.18] | |
| Decrease: composition | −0.46295379 | [−2.85, 1.91] | 0.63 | [0.06, 6.76] | |
| Decrease: occupancy | −0.80822825 | [−2.85, 1.24] | 0.45 | [0.06, 3.47] | |
| Decrease: other (AEI, NDSI, H) | −0.34642195 | [−2.81, 2.07] | 0.71 | [0.06, 7.93] | |
| Decrease: soundscape saturation | −0.12465911 | [−2.57, 2.50] | 0.88 | [0.08, 12.16] | |
| Decrease: habitat loss: birds | 1.08428080 | [−1.09, 3.25] | 2.96 | [0.34, 25.73] | |
| Decrease: habitat loss: other (insects, mammals, amphibians) | 0.08785487 | [−2.32, 2.58] | 1.09 | [0.10, 13.15] | |
| Decrease: habitat loss: soundscape | 0.85665774 | [−1.41, 3.13] | 2.36 | [0.24, 22.85] | |

Conversely, there was less emphasis on studying drivers of ecosystem restoration, which included reforestation (e.g. Robinson et al. 2023), reclamation of mining sites (e.g. Wilson & Bayne 2018), removal of invasive plant species (e.g. Wright et al. 2018), prescribed burning (e.g. Jorge et al. 2022), forest and landscape management (e.g. Venier et al. 2024), ecological succession (Rowley et al. 2024) and non-assisted regrowth/regeneration (e.g. Ng et al. 2018). The meta-analysis showed that forest management practices, invasive species removal, and reforestation showed an increased odds of animal response increase (Table 2).

### Ecoacoustic Approaches Used in Monitoring the Impact of Ecosystem Change

Throughout the literature, researchers used various ecoacoustic techniques to monitor how animals respond to changes in their ecosystem. These approaches are divided into PAM and manual acoustic monitoring (MAM). PAM was employed in most studies ($n = 166$; 89%), whereas only 21 studies (11%) used MAM. Bats were the most extensively researched taxa using PAM and MAM approaches (Fig. 3).

Of the 187 studies, 82% ($n = 153$) focused on individual animal groups rather than soundscapes. In contrast, fewer studies examined more than one taxon, e.g. birds and invertebrates, or bats and birds ($n = 19$, 10%), or investigated soundscapes, capturing a broad range of sound sources ($n = 15$, 8%).

### Community and Population Characteristics

Many studies focused on animal community characteristics ($n = 123$, 66%) (Fig. 4). A small number of these studies employed more integrative biodiversity measures: three studies used beta diversity, two applied functional diversity metrics, and one incorporated taxonomic, functional, and phylogenetic diversity in combination.

Other studies ($n = 42$, 22%) investigated the relationship between population (individuals of the same species) and broader community (multiple species) patterns and ecosystem changes. The studies that exclusively examined population characteristics, like activity patterns, occupancy, occurrence, presence, overall abundance, and relative abundance of specific species, were the least common ($n = 22$, 12%, Fig. 4). Our meta-analysis showed a higher chance of detecting animal response decrease with habitat loss when using ADI, diversity, and richness metrics, but this was not statistically significant (Table 1).

To assess the impact of ecosystem changes on animal populations, most researchers used the Shannon–Weaver index, ecosystem suitability models, non-metric multidimensional

**Table 2.** Bayesian multinomial regression results for increased outcome on animal responses to habitat change.

| | *Log−odds* | | *Odds ratio* | | |
|---|---|---|---|---|---|
| *Parameter* | *Estimate* | *LogOdds_CI* | *OR* | *OR_CI* | |
| Increase: intercept | 3.71470825 | [1.33, 6.26] | 41.05 | [3.80, 524.30] | * |
| Increase: habitat loss | −2.08420261 | [−4.28, −0.02] | 0.12 | [0.01, 0.98] | * |
| Increase: birds | 1.07234131 | [−0.94, 3.11] | 2.92 | [0.39, 22.52] | |
| Increase: other (insects, mammals, amphibians) | 0.52594645 | [−1.81, 2.91] | 1.69 | [0.16, 18.43] | |
| Increase: soundscape | 0.93322465 | [−1.11, 3.01] | 2.54 | [0.33, 20.33] | |
| Increase: (forest management, removal of invasive species and reforestation) | 1.16572381 | [−0.96, 3.36] | 3.21 | [0.38, 28.84] | |
| Increase: fragmentation | 0.32952514 | [−1.57, 2.28] | 1.39 | [0.21, 9.77] | |
| Increase: other (logging and deforestation) | −0.66473995 | [−2.60, 1.26] | 0.51 | [0.07, 3.53] | |
| Increase: other (natural phenomena, growth of invasive species, industrial disturbance) | −0.47453055 | [−2.61, 1.65] | 0.62 | [0.07, 5.22] | |
| Increase: Other (restoration of mines, regrowth/regeneration) | 0.86392699 | [−1.71, 3.47] | 2.37 | [0.18, 32.06] | |
| Increase: prescribed fire | 0.04267554 | [−2.33, 2.47] | 1.04 | [0.10, 11.86] | |
| Increase: urbanisation and infrastructure development | 0.49797854 | [−1.32, 2.34] | 1.65 | [0.27, 10.34] | |
| Increase: wildfire | −0.08185767 | [−2.21, 2.12] | 0.92 | [0.11, 8.32] | |
| Increase: ACI and complexity | 0.73744978 | [−1.58, 3.09] | 2.09 | [0.21, 22.01] | |
| Increase: activity | −0.56507853 | [−2.15, 1.04] | 0.57 | [0.12, 2.84] | |
| Increase: ADI, diversity and richness | −0.32924761 | [−1.95, 1.22] | 0.72 | [0.14, 3.38] | |
| Increase: BI | −0.37201629 | [−2.80, 2.04] | 0.69 | [0.06, 7.68] | |
| Increase: composition | −0.53276200 | [−2.69, 1.67] | 0.59 | [0.07, 5.29] | |
| Increase: occupancy | 0.07546923 | [−1.90, 2.05] | 1.08 | [0.15, 7.76] | |
| Increase: other (AEI, NDSI, H) | 0.83444630 | [−1.63, 3.34] | 2.30 | [0.20, 28.21] | |
| Increase: soundscape saturation | 0.57854042 | [−1.87, 3.13] | 1.78 | [0.15, 22.82] | |
| Increase: habitat loss: birds | −0.55794064 | [−2.73, 1.62] | 0.57 | [0.07, 5.04] | |
| Increase: habitat loss: other (insects, mammals, amphibians) | −0.17539497 | [−2.59, 2.33] | 0.84 | [0.07, 10.30] | |
| Increase: habitat loss: soundscape | −0.34907943 | [−2.52, 1.84] | 0.71 | [0.08, 6.31] | |

**Note:* indicates 95% credible interval excludes zero (log−odds) or one (OR).

scaling, principal component analysis, multi-species occupancy model, and acoustic space occupancy model ($n = 149$, 80%).

### Use of Acoustic Indices

Of the 187 studies, 29 (15%) used multiple acoustic indices to analyze the ecoacoustic data. Few studies ($n = 9$, 5%) only used a single type of acoustic index in their analysis.

Studies that used acoustic indices mostly used the ACI, followed by the ADI and NDSI (Fig. 5).

### Relationship Between Animal Communities and Ecosystem Alteration

Most studies ($n = 136$, 72.7%) evidenced an association between acoustic animal communities and ecosystem quality, whereby the communities were negatively impacted by a reduction in ecosystem quality (due to habitat loss) and positively impacted by an improvement in ecosystem quality (due to restoration). The meta-analysis revealed that habitat loss was associated with lower odds of an increase in animal response (Table 1), while habitat gain increased the likelihood of an increase in animal response (Table 2).

Thirty-five studies reported species-specific responses to habitat change; some species increased in response to habitat loss, while others declined (Fig. 6). However, our meta-analysis showed that soundscape responses exhibited marginally higher odds of decrease, suggesting increased vulnerability to habitat loss (Table 1), while birds showed slightly reduced odds of increase, indicating potential sensitivity (Table 2). These results were not statistically significant. Researchers observed no changes in the characteristics of animal communities in 14 studies conducted in various environments (Fig. 6). For example, researchers studied bats using ecoacoustic methodologies with no evidence of a difference between logged and non-logged forests (Cistrone et al. 2015) and in forested ecosystems with and without non-native plants (Mark et al. 2024).

## Discussion

This systematic review presents several critical findings regarding the current state of research in ecoacoustic monitoring of ecosystem degradation and restoration, highlighting the breadth of published studies and the significant gaps that warrant further investigation. Moreover, it underscores the increasing utilization of ecoacoustics in research, reflecting a growing interest and advancements in ecoacoustic techniques across multiple disciplines.

The geographic distribution of studies employing ecoacoustics illustrates their wide use and significance in various ecosystems, though it also reveals significant geographic biases tied to socioeconomic and geopolitical disparities (Petersen 2021).

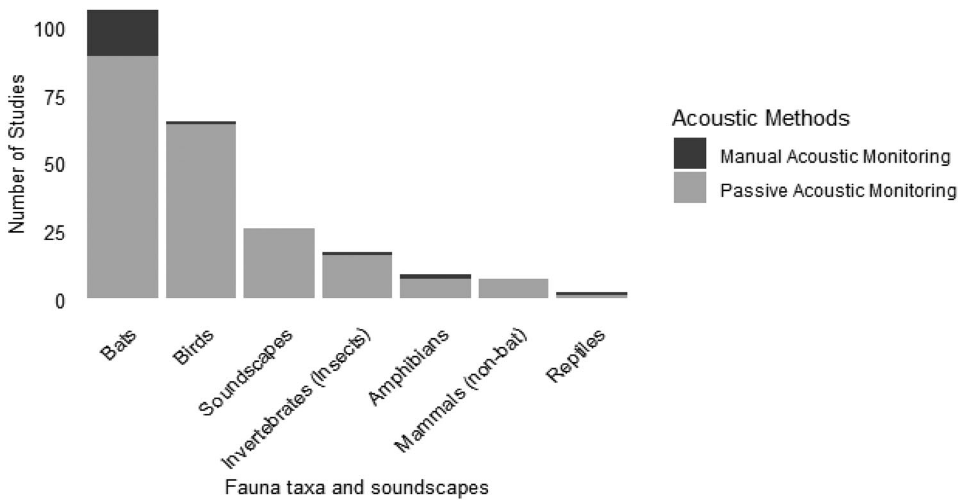


Figure 3. Animal taxa and soundscapes studied using different ecoacoustic methods.

Countries such as the United States and the United Kingdom demonstrate broad applicability and importance in research activity, reflecting their robust funding mechanisms, advanced technological infrastructure, and well-established scientific networks (Petersen 2021; Asubiaro et al. 2024). In contrast, while Brazil contributes substantially, driven by its exceptional biodiversity and historical research investment, its recent science budget cuts highlight how financial instability can threaten long-term research capacity (Magnusson et al. 2018; Quintans-Júnior et al. 2020).

The small number of African studies is concerning, as many nations face chronically low research investment, regional conflicts, and economic systems where local currency weakness multiplies equipment and collaboration costs (Abdulai & Issahaku 2024; Asubiaro et al. 2024; Fuseini et al. 2024). Many of these regions are biodiversity hotspots with high endemism (e.g. Madagascar), experiencing rapid ecosystem change, but often lack sufficient research resources, presenting an opportunity for targeted studies utilizing ecoacoustics (Dröge et al. 2021). Global research dynamics, where Northern Hemisphere institutions frequently set agendas and control funding streams, potentially divert attention from regionally urgent ecological questions, further amplify these disparities (Boampong et al. 2024; Fuseini et al. 2024).

The convergence of acute research gaps, exceptional biodiversity, and urgent threats makes Africa the highest-priority region for immediate ecoacoustic research investment. The secondary focus should address Asia and Australia to ensure comprehensive global coverage. Implementing these priorities will simultaneously advance ecological understanding, conservation efficacy, and equity in scientific practice. Addressing these inequities will require intentional strategies, including equitable funding partnerships, technology transfer programs, and cost-optimized methodologies tailored to low-resource research contexts (Bezeng et al. 2025).

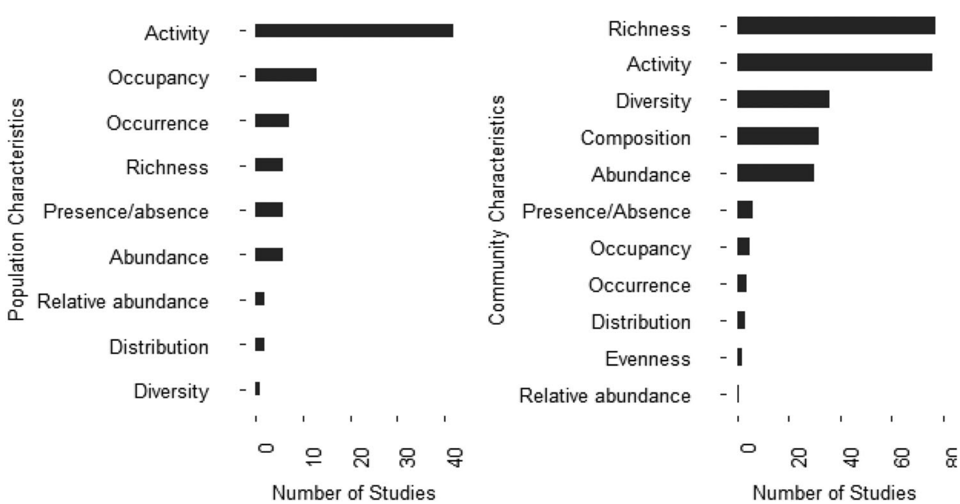


Figure 4. Number of ecoacoustic studies assessing community and population-level characteristics.

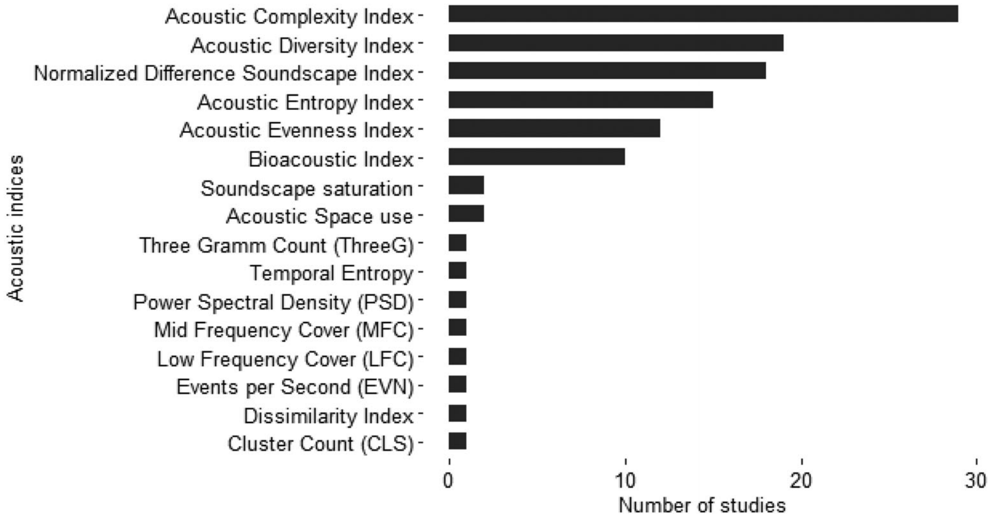


Figure 5. Types of acoustic indices used in different studies.

#### Use of Ecoacoustics in Assessing Ecosystem Degradation and Restoration

This review underscores the pivotal role of ecoacoustic approaches in monitoring changes in ecosystem health and biodiversity. While context-dependent, the results show soundscapes' composition and dynamics are sensitive to ecosystem changes and provide an early warning system for ecosystem degradation and hence biodiversity loss, as well as track the restoration of biodiversity and ecosystem function over time (Robinson et al. 2023; Venier et al. 2024). This sensitivity allows researchers to detect biodiversity and ecosystem functionality, providing insights into the impacts of ecosystem change on wildlife populations, hence tools for conservationists and ecologists (Rappaport et al. 2022; Teixeira et al. 2024). The ability of ecoacoustic methods to capture ecological interactions and species presence makes them valuable tools for conservationists and ecologists (Napier et al. 2024).

Our findings demonstrate that ecoacoustic monitoring can effectively track restoration. Yet, existing literature heavily favors habitat loss over restoration. This highlights a critical need for more ecoacoustic research on ecosystem restoration and its biodiversity impacts.

#### Ecoacoustic Approaches Used in Monitoring the Impact of Ecosystem Change on Animals

Ecoacoustic monitoring, specifically PAM, has grown significantly in the past two decades as a primary approach for evaluating animal characteristics. MAMs allow researchers to link the acoustic recordings to visual data from the surveys, enabling direct linking of sounds to taxa identity (Fuentes-Montemayor et al. 2011; Li & Kalcounis-Rueppell 2018). However, its precision depends on the taxa: while effective for visually identifiable species like birds, it faces challenges for neotropical bats, amphibians, and some birds due to overlapping call characteristics in field conditions (Russo et al. 2018; van Merriënboer et al. 2024). For these groups, combining MAM with methods like environmental DNA and mist-net trapping improves accuracy (Mancini et al. 2022; Mulvaney et al. 2023). Although MAM enables direct observation, common limitations include human effort, shorter deployment times, and potential biases in sampling and identification due to call overlap and flight patterns (Yoh et al. 2020). The limitations may lead to misinterpreting ecological data, reinforcing the significance of PAM as a robust alternative. Integrating PAM into ecological studies has significantly simplified collecting large amounts of ecoacoustic data, which can be analyzed to infer biodiversity patterns and species interactions within and across different ecosystems (Sueur et al. 2014; Buxton et al. 2018). This capability is valuable in monitoring ecosystem degradation and restoration, as PAM provides insights into the temporal and spatial variations of sounds in an ecosystem (Gibb et al. 2019).

With the ongoing advancement of technological innovations, the adoption of PAM is likely to grow significantly, potentially replacing traditional methods of species monitoring, especially in remote areas where implementing traditional monitoring methods can be more challenging. Automated sound recognition techniques present significant potential for improving the efficiency of PAM; however, their effective application largely depends upon the existence of extensive and regionally tailored acoustic libraries (Sugai et al. 2018; Gibb et al. 2019). In biodiverse regions like the Neotropics, reliable automated identification remains challenging due to insufficient reference data and overlapping vocal signatures among species (Walters et al. 2013). A foundational strategy involves building robust reference libraries through manual validation and taxonomic expertise, which is crucial before the effective application of automation can take place (de Jong et al. 2025). Integrating automated sound recognition and classification methods into PAM will streamline data analysis and facilitate real-time monitoring, allowing policymakers to respond more rapidly to ecological changes.

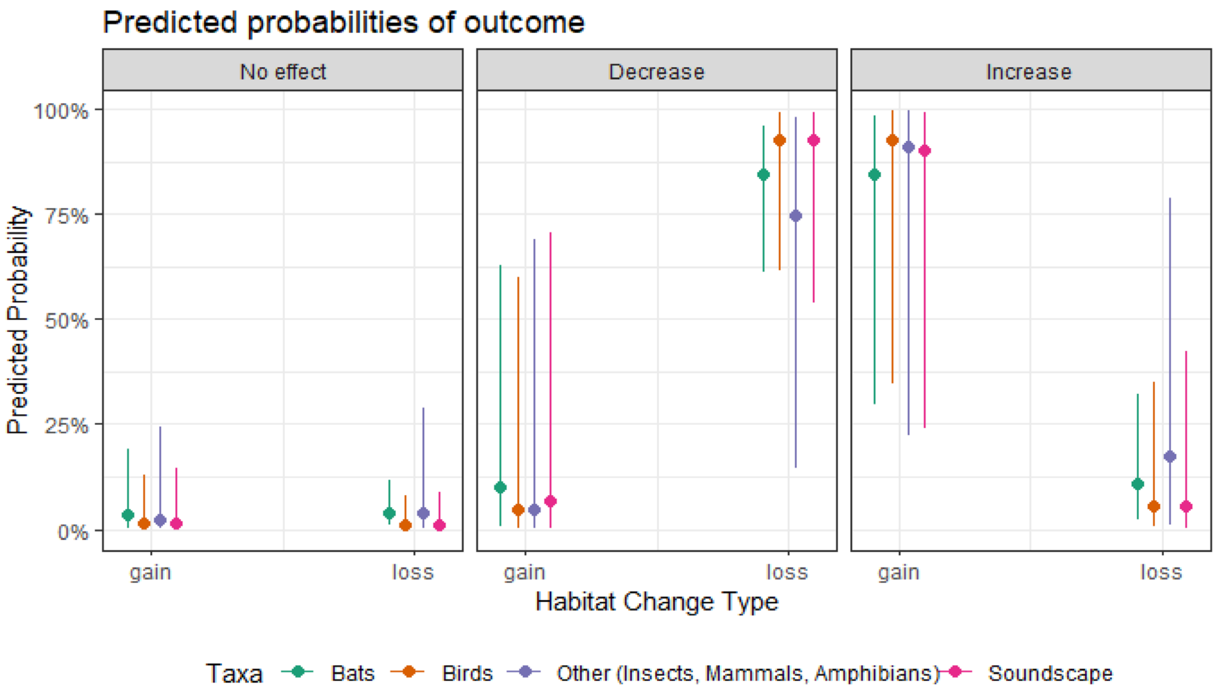


Figure 6. Predicted probability of animal response by habitat change and taxa.

#### Use of Ecoacoustic Tools in Characterizing Animal Communities in Changing Ecosystems

The findings here provide insights into the methodologies for assessing animal populations, particularly in changing ecosystems. While most taxa exhibited similar responses to habitat loss (decline with habitat loss), soundscapes and birds showed tentative signs of differential effects. Soundscapes and birds appeared more vulnerable to habitat loss. These nuances underscore the importance of taxonomic variation in habitat impact assessments, as not all species respond uniformly to ecosystem alterations. For example, ecosystem degradation affects taxa and species differently, with some species experiencing severe declines while others may adapt or thrive (Alvarez-Berríos et al. 2016; Steel et al. 2019). Integrating diverse taxa and their acoustic environments provides a more comprehensive approach to understanding ecological relationships and community dynamics in changing ecosystems (Holgate et al. 2021; Lisboa et al. 2021). The increasing awareness of the necessity to combine community and population perspectives in studying ecosystem dynamics reflects a growing acceptance of holistic approaches in ecological research (Vilches-Piñones et al. 2022).

The review suggests that different responses to varied taxa can be effectively detected by ecoacoustic methods, enabling a nuanced approach to understanding the effects of ecosystem degradation (Alvarez-Berríos et al. 2016; Shonfield & Bayne 2023). This review shows that the primary focus of ecoacoustic ecosystem monitoring has been comprehending ecological changes at the community level rather than assessing specific species. Expanding the use of these approaches in future research endeavors, e.g. by incorporating soil ecoacoustics, is critical to closing the knowledge gap about how ecosystem changes affect belowground biodiversity and ecosystem function (Robinson et al. 2024).

#### The Use of Acoustic Indices to Characterize Populations and Communities

Integrating acoustic indices into ecological assessments offers a cost-effective method for monitoring biodiversity changes over time (Metcalf et al. 2021; Bradfer-Lawrence et al. 2024). Yet their application in degradation and restoration studies remains limited, likely due to methodological unfamiliarity or interpretability concerns. While a single index provides valuable insights, relying solely on one can limit the scope of ecological assessments. This review demonstrates that studies commonly employ multiple indices, offering a deeper understanding of soundscape dynamics and ecosystem complexity, underscoring the need for researchers to embrace this complexity and address inconsistencies (Buxton et al. 2018; Gómez et al. 2018). To keep up with advancements in ecoacoustic monitoring, researchers must acknowledge metric complexity and address current inconsistencies.

Our review highlights a lack of consistency in using acoustic indices. The use of the ACI in most studies indicates that the index serves as a dependable indicator for biodiversity and may efficiently track changes in the ecosystem (Holgate et al. 2021; Bateman & Uzal 2022). Conflicting findings (Alcocer et al. 2022) highlight a critical need for standardized ecoacoustic analysis to improve ecological research reliability and comparability (Bradfer-Lawrence et al. 2019; Metcalf et al. 2023). To advance ecoacoustics and enhance biodiversity assessments, adopting a multi-index approach can help address the complexity and variability of acoustic metrics, improving the reliability and comparability of ecological research.

Despite the growing use of acoustic indices, they face significant limitations in reliability and ecological interpretation (Alcocer et al. 2022). Their oversimplification of soundscapes into single metrics often fails to capture meaningful ecological patterns (Eldridge 2021; Bradfer-Lawrence et al. 2023). For example, Bradfer-Lawrence et al. (2023) isolated technical (e.g. audio compression) and biological biases (e.g. dominant vocal species) that distort indices independently of true diversity. Environmental noise, such as broadband rainfall, can further mimic biotic activity, risking misinterpretation without proper validation (Fuller et al. 2015; Bradfer-Lawrence et al. 2024). Further, widespread pseudoreplication issues and observed declines in effect sizes over time suggest that many studies may have overestimated these indices' effectiveness (Alcocer et al. 2022). Collectively, these findings highlight the need for validation, standardization, and complementary methods for reliable results.

### Limitations of the Evidence Included in the Review

Several limitations in the included studies may significantly impact the validity and applicability of their findings. Short study duration and ineffective recording of temporal fluctuations in species' presence and behavior limit the ability to capture seasonal variability and responses to habitat loss (López-Bosch et al. 2022). While single-season sampling designs are methodologically valid for studies targeting specific research questions (e.g. peak breeding activity; Pillay et al. 2019), they inherently limit the detection of temporal ecological dynamics. Where temporal resolution is critical but logistically challenging, PAM with intermittent deployment (e.g. 1 week per season) can offer a feasible compromise (Metcalf et al. 2023).

Short-term studies can still provide valuable information, particularly for immediate responses to disturbances such as fires or local anthropogenic impacts (Sugai et al. 2018; Rowley et al. 2024). However, longer monitoring periods—spanning seasons or years—are essential to assess ecosystem recovery fully (Bradfer-Lawrence et al. 2023). Aligning study duration with research objectives and resource constraints enhances the reliability of findings and supports more effective restoration and management strategies.

Ecoacoustic monitoring records vocal species, potentially underrepresenting non-vocal species or those with limited vocal activity, hence skewing biodiversity assessment (Alvarez-Berríos et al. 2016). The absence of baseline data for comparison further complicates interpretation, as increases in species richness or abundance could stem from natural fluctuations rather than restoration success (Green et al. 2020). In such cases, comparisons with nearby control areas, which are ecologically similar, unrestored sites can provide useful context by allowing for strong causal inference (Ramesh et al. 2023; Reading et al. 2025).

### Limitations of Our Review

Systematic reviews have noticeable limitations. Publication bias, where studies with positive or significant results are more likely to be published than those with negative or inconclusive findings. In our review, few publications reported no influence of ecosystem degradation or restoration on animal species. This bias can skew the overall understanding of the effectiveness of ecoacoustic monitoring and its applications in different ecosystems, leading to misguided conservation strategies and policy decisions.

Our review excluded non-English publications and gray literature (e.g. theses), potentially omitting regionally important data (Hannah et al. 2024). Future studies should incorporate multilingual sources and institutional repositories to reduce bias.

### Recommendations

This review highlights several critical considerations and actionable recommendations for practitioners in ecosystem monitoring and restoration:

- Implement further investigation into how ecoacoustic monitoring can evaluate ecosystem restoration and its implications for biodiversity crucial for guiding practical restoration efforts.
- Creating and strengthening acoustic libraries and sharing acoustic data among researchers to improve autonomous identification.
- Integrate automated sound recognition and classification into PAM, as this is key to enhancing data analysis, enabling real-time monitoring, and facilitating more timely responses to ecological changes by policymakers.
- Consider a multi-taxa approach when monitoring ecosystems using ecoacoustic methodologies to provide a more complete picture of ecosystem health.
- Use multiple acoustic indices and adapt methods to capture the complexity of biological systems, improve ecological assessments, and gain a better understanding of the soundscape and its ecological implications.
- Use consistent temporal and spatial sampling to improve comparability of ecoacoustic assessments and ensure more reliable conclusions on ecosystem management and restoration. Complement ecoacoustic monitoring with other methods to account for non-vocal species or those with limited vocal activity to reduce taxonomic bias and provide a more accurate measure of biodiversity.
- Integrate soil and freshwater ecoacoustics alongside traditional aboveground monitoring to understand ecosystem health holistically.
- Develop standardized methods in ecoacoustic analysis to ensure that ecological research is reliable and comparable across different studies, enhancing the overall credibility of monitoring efforts.

## LITERATURE CITED

Abdulai MG, Issahaku H (2024) The effect of financial development and legal institutions on financial inclusion in sub-Saharan Africa. Journal of Open

Innovation: Technology, Market, and Complexity 10:100255. https://doi.org/10.1016/j.joitmc.2024.100255

Alcocer I, Lima H, Sugai LSM, Llusia D (2022) Acoustic indices as proxies for biodiversity: a meta-analysis. Biological Reviews 97:2209–2236. https://doi.org/10.1111/brv.12890

Alvarez-Berríos N, Campos-Cerqueira M, Hernández-Serna A, Delgado CJA, Román-Dañobeytia F, Aide TM (2016) Impacts of small-scale gold mining on birds and anurans near the Tambopata Natural Reserve, Peru, assessed using passive acoustic monitoring. Tropical Conservation Science 9:832–851. https://doi.org/10.1177/194008291600900216

Asubiaro T, Onaolapo S, Mills D (2024) Regional disparities in Web of Science and Scopus journal coverage. Scientometrics 129:1469–1491. https://doi.org/10.1007/s11192-024-04948-x

Bateman J, Uzal A (2022) The relationship between the acoustic complexity index and avian species richness and diversity: a review. Bioacoustics 31:614–627. https://doi.org/10.1080/09524622.2021.2010598

Becker FK, Shabangu FW, Gridley T, Wittmer HU, Marsland S (2022) Sounding out a continent: seven decades of bioacoustics research in Africa. Bioacoustics 31:646–667. https://doi.org/10.1080/09524622.2021.2021987

Bezeng BS, Ameka G, Angui CMV, Atuah L, Azihou F, Bouchenak-Khelladi Y, et al. (2025) An African perspective to biodiversity conservation in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences 380:20230443. https://doi.org/10.1098/rstb.2023.0443

Boampong MS, Boakye-Danquah J, Boafo YA, Appiagyei K, Tweneboah-Koduah D, Antwi EK (2024) Experiences of inequality in international collaborative research – perspectives from environmental and sustainability scholars from Ghana, West Africa. Environmental Science & Policy 152:103661. https://doi.org/10.1016/j.envsci.2023.103661

Borker AL, Buxton RT, Jones IL, Major HL, Williams JC, Tershy BR, Croll DA (2020) Do soundscape indices predict landscape-scale restoration outcomes? A comparative study of restored seabird Island soundscapes. Restoration Ecology 28:252–260. https://doi.org/10.1111/rec.13038

Bradfer-Lawrence T, Desjonqueres C, Eldridge A, Johnston A, Metcalf O (2023) Using acoustic indices in ecology: guidance on study design, analyses and interpretation. Methods in Ecology and Evolution 14:2192–2204. https://doi.org/10.1111/2041-210X.14194

Bradfer-Lawrence T, Duthie B, Abrahams C, Adam M, Barnett RJ, Beeston A, et al. (2024) The acoustic index user's guide: a practical manual for defining, generating and understanding current and future acoustic indices. Methods in Ecology and Evolution 169:112954. https://doi.org/10.1111/2041-210X.14357

Bradfer-Lawrence T, Gardner N, Bunnefeld L, Bunnefeld N, Willis SG, Dent DH (2019) Guidelines for the use of acoustic indices in environmental research. Methods in Ecology and Evolution 10:1796–1807. https://doi.org/10.1111/2041-210X.13254

Bürkner P-C (2017) Brms: an R package for Bayesian multilevel models using Stan. Journal of Statistical Software 80:1–28. https://doi.org/10.18637/jss.v080.i01

Buxton RT, Agnihotri S, Robin V, Goel A, Balakrishnan R (2018) Acoustic indices as rapid indicators of avian diversity in different land-use types in an Indian biodiversity hotspot. Journal of Ecoacoustics 2:8. https://doi.org/10.22261/jea.gwpzvd

Buxton R, Brown E, Sharman L, Gabriele C, McKenna M (2016) Using bioacoustics to examine shifts in songbird phenology. Ecology and Evolution 6:4697–4710. https://doi.org/10.1002/ece3.2242

Choksi P, Kotian M, Biniwale S, Mourya P, Korche D, Agarwala M, Khanwilkar S, Ramesh V, DeFries R (2023) Listening for change: quantifying the impact of ecological restoration on soundscapes in a tropical dry forest. Restoration Ecology 31:e13864. https://doi.org/10.1111/rec.13864

Cistrone L, Altea T, Matteucci G, Posillico M, De Cinti B, Rosson D (2015) The effect of thinning on bat activity in Italian high forests: the LIFE plus "ManFor C.BD." experience. Hystrix, the Italian Journal of Mammalogy 26:125–131

Conn PB, Johnson DS, Williams PJ, Melin SR, Hooten MB (2018) A guide to Bayesian model checking for ecologists. Ecological Monographs 88:526–542. https://doi.org/10.1002/ecm.1314

de Jong GJ, Melville HIAS, Richards LR (2025) The insectivorous bat assemblage in Telperion Nature Reserve, Mpumalanga, South Africa: species inventory and call library. Acta Chiropterologica 26:315–327. https://doi.org/10.3161/15081109ACC2024.26.2.012

DistillerSR Inc. (2024) DistillerSR. Version 2024.5. https://www.distillersr.com (accessed May–August 2024)

Dröge S, Martin DA, Andriafanomezantsoa R, Burivalova Z, Fulgence TR, Osen K, et al. (2021) Listening to a changing landscape: acoustic indices reflect bird species richness and plot-scale vegetation structure across different land-use types in north-eastern Madagascar. Ecological Indicators 120:106929. https://doi.org/10.1016/j.ecolind.2020.106929

Ducrettet M, Linossier J, Sueur J, Mathevon N, Sèbe F, Haupert S (2025) Bridging passive acoustic monitoring and essential biodiversity variables with detectability. https://doi.org/10.22541/au.174308491.17489353/v1

Eldridge A (2021) Listening to ecosystems as complex adaptive systems: toward acoustic early warning signals. In: ALIFE 2022: The 2022 Conference on Artificial Life.

Fuentes-Montemayor E, Goulson D, Park KJ (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. Biological Conservation 144:2233–2246. https://doi.org/10.1016/j.biocon.2011.05.015

Fuller S, Axel AC, Tucker D, Gage SH (2015) Connecting soundscape to landscape: which acoustic index best describes landscape configuration? Ecological Indicators 58:207–215. https://doi.org/10.1016/j.ecolind.2015.05.057

Fuseini MN, Enu-Kwesi F, Abdulai IA, Sulemana M, Aasoglenang TA, Domapielle MK (2024) Poverty in the global south: does the geographical theory offer any new insight to understanding penury? Cogent Social Sciences 10:2321710. https://doi.org/10.1080/23311886.2024.2321710

Gibb R, Browning E, Glover-Kapfer P, Jones KE (2019) Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring. Methods in Ecology and Evolution 10:169–185. https://doi.org/10.1111/2041-210X.13101

Gómez WE, Isaza CV, Daza JM (2018) Identifying disturbed habitats: a new method from acoustic indices. Ecological Informatics 45:16–25. https://doi.org/10.1016/j.ecoinf.2018.03.001

Green NS, Wildhaber ML, Albers JL, Pettit TW, Hooper MJ (2020) Efficient mammal biodiversity surveys for ecological restoration monitoring. Integrated Environmental Assessment and Management 20:1969–1981. https://doi.org/10.1002/ieam.4324

Greenhalgh JA, Stone HJR, Fisher T, Sayer CD (2021) Ecoacoustics as a novel tool for assessing pond restoration success: results of a pilot study. Aquatic Conservation: Marine and Freshwater Ecosystems 31:2017–2028. https://doi.org/10.1002/aqc.3605

Hannah K, Haddaway NR, Fuller RA, Amano T (2024) Language inclusion in ecological systematic reviews and maps: barriers and perspectives. Research Synthesis Methods 15:466–482. https://doi.org/10.1002/jrsm.1699

Higgins J, Thomas J, Chandler J, Cumpston M, Li J, Page M, Welch V (2022) Cochrane handbook for systematic reviews of interventions (Version 6.3). London, United Kingdom: Cochrane. https://training.cochrane.org/handbook (accessed 4 Aug 2023)

Holgate B, Maggini R, Fuller S (2021) Mapping ecoacoustic hot spots and moments of biodiversity to inform conservation and urban planning. Ecological Indicators 126:107627. https://doi.org/10.1016/j.ecolind.2021.107627

Jorge M, Conner L, Garrison E, Cherry M (2022) Avian species richness in a frequently burned ecosystem: a link between pyrodiversity and biodiversity. Landscape Ecology 37:983–996. https://doi.org/10.1007/s10980-022-01399-8

Law BS, Chidel M, Penman T (2011) Do young eucalypt plantations benefit bats in an intensive agricultural landscape? Wildlife Research 38:173–187. https://doi.org/10.1071/WR10204

Lee CKF, Duncan C, Nicholson E, Fatoyinbo TE, Lagomasino D, Thomas N, Worthington TA, Murray NJ (2021) Mapping the extent of mangrove ecosystem degradation by integrating an ecological conceptual model with satellite data. Remote Sensing 13:2047. https://doi.org/10.3390/rs13112047

Li H, Kalcounis-Rueppell M (2018) Separating the effects of water quality and urbanization on temperate insectivorous bats at the landscape scale. Ecology and Evolution 8:667–678. https://doi.org/10.1002/ece3.3693

Lisboa CS, Vaz RI, Malagoli LR, Barbo FE, Venturini RC, Brasileiro CA (2021) Herpetofauna from an Atlantic forest fragment in São Paulo, Brazil. Herpetological Conservation and Biology 16:436–451

López-Bosch D, Rocha R, López-Baucells A, Wang Y, Si X, Ding P, Gibson L, Palmeirim AF (2022) Passive acoustic monitoring reveals the role of habitat affinity in sensitivity of sub-tropical east Asian bats to fragmentation. Remote Sensing in Ecology and Conservation 8:208–221. https://doi.org/10.1002/rse2.237

Magnusson WE, Grelle CEV, Marques MCM, Rocha CFD, Dias B, Fontana CS, et al. (2018) Effects of Brazil's political crisis on the science needed for biodiversity conservation. Frontiers in Ecology and Evolution 6:163. https://doi.org/10.3389/fevo.2018.00163

Mancini MCS, Hintze F, de Souza LR, de Macêdo MR, Gregorin R (2022) Tradition vs. innovation: comparing bioacoustics and mist-net results to bat sampling. Bioacoustics 31:575–593. https://doi.org/10.1080/09524622.2021.2008494

Mark M, Drake E, Kerwin K, Maslo B (2024) Non-native plants influence forest vegetative structure and the activity of eastern temperate insectivorous bats. Forests 15:711. https://doi.org/10.3390/f15040711

McHugh ML (2012) Interrater reliability: the kappa statistic. Biochemia Medica 22:276–282. https://doi.org/10.11613/BM.2012.031

Meroni M, Schucknecht A, Fasbender D, Rembold F, Fava F, Mauclaire M, Goffner D, Di Lucchio LM, Leonardi U (2017) Remote sensing monitoring of land restoration interventions in semi-arid environments with a before–after control-impact statistical design. International Journal of Applied Earth Observation and Geoinformation 59:42–52. https://doi.org/10.1016/j.jag.2017.02.016

Metcalf O, Abrahams C, Ashington B, Baker E, Bradfer-Lawrence T, Browning E, Carruthers-Jones J, Darby J, Dick J, Eldridge A (2023) Good practice guidelines for long-term ecoacoustic monitoring in the UK. https://drive.google.com/file/d/12ps-ldG4tlXB6VlujAQLWnw_PxopYvFs/view (accessed 22 Jun 2024)

Metcalf OC, Barlow J, Devenish C, Marsden S, Berenguer E, Lees AC (2021) Acoustic indices perform better when applied at ecologically meaningful time and frequency scales. Methods in Ecology and Evolution 12:421–431. https://doi.org/10.1111/2041-210X.13521

Mulvaney J, Moir M, Cherry MI (2023) DNA barcoding reveals cryptic diversification and taxonomic discordance among bats and birds within sub-Saharan Africa. Biodiversity and Conservation 32:4895–4914. https://doi.org/10.1007/s10531-023-02737-1

Murray NJ, Keith DA, Bland LM, Ferrari R, Lyons MB, Lucas R, Pettorelli N, Nicholson E (2018) The role of satellite remote sensing in structured ecosystem risk assessments. Science of the Total Environment 619–620: 249–257. https://doi.org/10.1016/j.scitotenv.2017.11.034

Napier T, Ahn E, Allen-Ankins S, Schwarzkopf L, Lee I (2024) Advancements in preprocessing, detection and classification techniques for ecoacoustic data: a comprehensive review for large-scale passive acoustic monitoring. Expert Systems with Applications 252:124220. https://doi.org/10.1016/j.eswa.2024.124220

Ng M, Butler N, Woods N (2018) Soundscapes as a surrogate measure of vegetation condition for biodiversity values: a pilot study. Ecological Indicators 93:1070–1080. https://doi.org/10.1016/j.ecolind.2018.06.003

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. https://doi.org/10.1136/bmj.n71

Page MJ, Shamseer L, Altman DG, Tetzlaff J, Sampson M, Tricco AC, et al. (2016) Epidemiology and reporting characteristics of systematic reviews of biomedical research: a cross-sectional study. PLoS Medicine 13: e1002028. https://doi.org/10.1371/journal.pmed.1002028

Petersen OH (2021) Inequality of research funding between different countries and regions is a serious problem for global science. Function 2:zqab060. https://doi.org/10.1093/function/zqab060

Pillay R, Fletcher R, Sieving K, Udell B, Bernard H (2019) Bioacoustic monitoring reveals shifts in breeding songbird populations and singing behaviour with selective logging in tropical forests. Journal of Applied Ecology 56: 2482–2492. https://doi.org/10.1111/1365-2664.13492

Qiu Y, Tong J, Fu H, Lyu S, Rizky MYR, Wu J, Wei G, Xue M (2024) Refining ecoacoustic indices in aquatic and terrestrial ecosystems: a comprehensive review and bibliometric analysis. Ecological Indicators 166:112363. https://doi.org/10.1016/j.ecolind.2024.112363

Quinn CA, Burns P, Jantz P, Salas L, Goetz SJ, Clark ML (2024) Soundscape mapping: understanding regional spatial and temporal patterns of soundscapes incorporating remotely-sensed predictors and wildfire disturbance. Environmental Research: Ecology 3:025002. https://doi.org/10.1088/2752-664X/ad4bec

Quintans-Júnior LJ, Albuquerque GR, Oliveira SC, Silva RR (2020) Brazil's research budget: endless setbacks. EXCLI Journal 19:1322–1324. https://doi.org/10.17179/excli2020-2887

Ramesh V, Hariharan P, Akshay VA, Choksi P, Khanwilkar S, DeFries R, Robin VV (2023) Using passive acoustic monitoring to examine the impacts of ecological restoration on faunal biodiversity in the Western Ghats. Biological Conservation 282:110071. https://doi.org/10.1016/j.biocon.2023.110071

Rappaport DI, Swain A, Fagan WF, Dubayah R, Morton DC (2022) Animal soundscapes reveal key markers of Amazon forest degradation from fire and logging. Proceedings of the National Academy of Sciences U.S.A. 119:e2102878119. https://doi.org/10.1073/pnas.2102878119

Reading RP, Stevens S, McCallister L (2025) Comparison of invertebrates on restored and unrestored coastal dunes in northern California. Natural Areas Journal 45:76–86. https://doi.org/10.3375/2162-4399-45.2.3

Ren Y, Lü Y, Fu B (2016) Quantifying the impacts of grassland restoration on biodiversity and ecosystem services in China: a meta-analysis. Ecological Engineering 95:542–550. https://doi.org/10.1016/j.ecoleng.2016.06.082

Robinson JM, Annells A, Cavagnaro TR, Liddicoat C, Rogers H, Taylor A, Breed MF (2024) Monitoring soil fauna with ecoacoustics. Proceedings of the Royal Society B: Biological Sciences U.S.A. 291:20241595. https://doi.org/10.1098/rspb.2024.1595

Robinson JM, Breed MF, Abrahams C (2023) The sound of restored soil: using ecoacoustics to measure soil biodiversity in a temperate forest restoration context. Restoration Ecology 31:e13934. https://doi.org/10.1111/rec.13934

Rowley S, López-Baucells A, Rocha R, Bobrowiec P, Meyer C (2024) Secondary forest buffers the effects of fragmentation on aerial insectivorous bat species following 30 years of passive forest restoration. Restoration Ecology 32:e14093. https://doi.org/10.1111/rec.14093

Russo D, Ancillotto L, Jones G (2018) Bats are still not birds in the digital era: echolocation call variation and why it matters for bat species identification. Canadian Journal of Zoology 96:63–78. https://doi.org/10.1139/cjz-2017-0089

Shonfield J, Bayne E (2023) Weak support for cumulative effects of industrial disturbance on three owl species in Alberta's boreal forest. Avian Conservation and Ecology 18:9. https://doi.org/10.5751/ACE-02409-180109

Steel Z, Campos B, Frick W, Burnett R, Safford H (2019) The effects of wildfire severity and pyrodiversity on bat occupancy and diversity in fire-suppressed forests. Scientific Reports 9:16300. https://doi.org/10.1038/s41598-019-52875-2

Sueur J, Farina A, Gasc A, Pieretti N, Pavoine S (2014) Acoustic indices for biodiversity assessment and landscape investigation. Acta Acustica united with Acustica 100:772–781. https://doi.org/10.3813/AAA.918757

Sugai L, Silva T, Ribeiro J Jr, Llusia D (2018) Terrestrial passive acoustic monitoring: review and perspectives. Bioscience 69:15–25. https://doi.org/10.1093/biosci/biy147

Teixeira D, Roe P, Rensburg B, Linke S, Mcdonald P, Tucker D, Fuller S (2024) Effective ecological monitoring using passive acoustic sensors: recommendations for conservation practitioners. Conservation Science and Practice 6: e13132. https://doi.org/10.1111/csp2.13132

Turlington K, Suárez-Castro AF, Teixeira D, Linke S, Sheldon F (2024) Exploring the relationship between the soundscape and the environment: a systematic review. Ecological Indicators 166:112388. https://doi.org/10.1016/j.ecolind.2024.112388

Umuhoza J, Jiapaer G, Tao Y, Bai J, Hakorimana E, Zhang L, Liang H, Lin K, Ju T (2025) Impacts of climate extremes on vegetation health in the tropical savannas of Africa. Global Ecology and Conservation 61:e03649. https://doi.org/10.1016/j.gecco.2025.e03649

van Merriënboer B, Hamer J, Dumoulin V, Triantafillou E, Denton T (2024) Birds, bats and beyond: evaluating generalization in bioacoustics models. Frontiers in Bird Science 3:1369756. https://doi.org/10.3389/fbirs.2024.1369756

Venier LA, Porter K, Adams G, McIlwrick K, Smenderovac E (2024) Response of forest bird communities to managed landscapes in the Acadian forest. Forests 15:184. https://doi.org/10.3390/f15010184

Vilches-Piñones KI, Matus-Olivares C, Catalán G, Lisón F (2022) Effect of forest areas configuration on the community of insectivorous bats in agroforestry landscapes. Austral Ecology 49:e13268. https://doi.org/10.1111/aec.13268

Walters CA, Lucas T, Mroz K, Sayer C, Jones K (2013) Challenges of using bioacoustics to globally monitor bats. Pages 479–499. In: Bat evolution, ecology, and conservation. New York: Springer. https://doi.org/10.1007/978-1-4614-7397-8_23

Wilson SJ, Bayne EM (2018) Use of an acoustic location system to understand how presence of conspecifics and canopy cover influence ovenbird (*Seiurus aurocapilla*) space use near reclaimed wellsites in the boreal forest of Alberta. Avian Conservation and Ecology 13:4. https://doi.org/10.5751/ACE-01248-130204

Wood C, Socolar J, Kahl S, Peery M, Chaon P, Kelly K, Koch R, Sawyer S, Klinck H (2024) A scalable and transferable approach to combining emerging conservation technologies to identify biodiversity change after large disturbances. Journal of Applied Ecology 61:797–808. https://doi.org/10.1111/1365-2664.14579

Wright PE, Lambert KT, McDonald PG (2018) The role of *Lantana camara* in areas of bell miner (*Manorina melanophrys*) associated dieback and its implications for terrestrial mammal and insectivorous bat populations. Australian Mammalogy 41:49–56. https://doi.org/10.1071/AM17003

Xavier BS, Rainho A, Santos AMC, Vieira MV, Carvalho WD (2023) Global systematic map of research on bats in agricultural systems. Frontiers in Ecology and Evolution 11:1214176. https://doi.org/10.3389/fevo.2023.1214176

Yoh N, Azhar I, Fitzgerald K, Yu R, Smith-Butler T, Mahyudin A, Kingston T (2020) Bat ensembles differ in response to use zones in a tropical biosphere reserve. Diversity 12:60. https://doi.org/10.3390/d12020060

## Supporting Information

The following information may be found in the online version of this article:

**Supplement S1.** Word document showing the complete search terms.
**Figure S1.** Number of studies using ecoacoustics to monitor ecosystem change in different countries.
**Figure S2**. Distribution of studies across climatic zones.
**Table S1.** Table showing a summary of the characteristics of each study.

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