The use of acoustic analyses to evaluate ecological and social impacts of habitat degradation in contemporary conservation biology

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DECLARATION

The thesis conforms to an 'article format' in which the middle chapters consist of discrete articles written in a style that is appropriate for publication in peer-reviewed journals in the field. The first and final chapters present synthetic overviews and discussions of the field and the research undertaken.

Chapter 1 is submitted to PeerJ journal as "Systematic literature review on the association soundscape and ecological/human wellbeing" in a PeerJ Preprint version.

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Chapter 2 is written in the style of an article appropriate for Ecological Indicators journal.

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:……………………………………

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ABSTRACT

Overexploitation of the earth's resources is causing concern for ecosystem health globally and demands clear strategies for biodiversity conservation. The development of non-invasive and cost-effective tools for ecosystem assessment is an urgent global imperative. In this context, the nascent discipline of ecoacoustics provides a new framework to assess the effects of habitat degradation on human and non-human populations. Sound is considered as a core component and indicator of ecological processes and therefore can be investigated to infer ecological information about populations, communities and landscapes. A subfield of this discipline, soundscape ecology, provides fresh perspectives on understanding coupled natural-human dynamics. Despite the contributions of ecoacoustic methods in biodiversity assessment, landscape ecology and conservation biology some factors are constraining their full potential. This is principally due to challenges in interpreting the acoustic community through current acoustic metrics. Moreover, research gaps in understanding coupled natural-human dynamics through soundscape analysis have been identified, which could make significant further contributions to conservation biology in the near future.

This thesis contributes to ecoacoustics from the perspective of conservation biology. The relevance and potential use of acoustic methods for assessing biodiversity and exploring social dimensions within conservation biology are presented throughout. Chapters include both *Ecological* and *Social* research components. A systematic review of publications on soundscape and its association with ecological and human wellbeing contextualizes the following empirical work, in chapter 1. Chapter 2 provides an evaluation into how effectively current acoustic metrics (*ACI*, *BI*, *AE* and *H*) reflect the status of wildlife populations along a gradient of forest disturbance. A novel approach to rapidly assess habitat status using automatic detection of indicator species (IS) is presented in chapter 3. Empirical studies are complemented by an analysis of the cost-effectiveness of acoustic sensors for assessing biodiversity, in chapter 4.

Finally, social factors are addressed in chapter 5, which presents a novel approach for evaluating the human and environment relationship through soundscape perception analysis.

The acoustic analyses explored show potential in analysis of ecological and social research dimensions in conservation biology. The systematic review shows that soundscape, and its association with wellbeing, evolved from an interest in sounds, and their influence on health, into a multidimensional and integrative concept incorporating multiple domains of wellbeing (Health, Social and Cultural Wellness and Ecological Integrity). Within the *Ecological* component in chapter 2, although significant differences in acoustic biodiversity metrics along sites were found, relevant qualitative biodiversity values that describe the status of wildlife populations were not reflected through the acoustic indices. To tackle this issue, I observed that the tool for automatic detection of IS was effective for rapid evaluation of habitat status; however, it should only be used for obtaining data of presence/absence of species. The combination of community level (acoustic indices) and individual level (automatic detection of indicator species) acoustic analysis showed a great potential as a tool for rapid evaluation of habitats. Moreover, I found that use of acoustic sensors was effective for registering high number of birds and indicator species; however, it is best applied in conducting multiple surveys or long term monitoring due to expensive equipment costs. Within the *Social* component I observed that soundscape perception analysis generated insights into human-environment relationships and highlighted the implications of habitat degradation on humans. Sounds of social relevance were also identified, which could be used for determining priority areas for conservation. Great potential for investigating social implications of habitat degradation through acoustic methods was revealed.

The acoustic approaches investigated proved to be useful tools in understanding the dynamics of ecosystems, by exploring both ecological and social dimensions, and contribute to knowledge in conservation biology. Further research on the application of acoustic methods in conservation biology is recommended.

GENERAL INTRODUCTION

Current global economic and political systems demand extensive and intensive exploitation of multiple natural resources, which has led to rapid habitat change and caused catastrophic consequences globally. For example, current species extinction rates are elevated to at least a thousand times the natural background rate (Mittermeier et al., 2011), and highly important ecosystem functions and services, such as nutrient recycling, bee pollination and pest control, are being altered (Oliver et al., 2015). This generates a situation where rapid decisions and measures at all societal levels (political, cultural, and financial) need to be taken. In this context, world leaders have agreed that biodiversity and resource conservation are essential elements of sustainable livelihoods at local scales (DFIC 2002) and must be integrated into strategies for economic development. Numerous multilateral initiatives such as the Strategic Plan for Biodiversity 2011-2020 (CBD, 2010), the UN Conference on Sustainable Development Rio + 20 (Assembly, 2012), the Millennium Development Goals (Poverty, 2015) emphasize the need to address the underlying causes of biodiversity loss and maximise ecosystem resilience and functioning. In parallel, the contribution of natural ecosystems to essential "non-market services", such as human wellbeing is increasingly recognised (Milner-Gulland et al., 2014b). These political and policy trends and developments are informed by and stimulate the emergence of new academic subfields that offer integrative transdisciplinary insights into social-ecological systems (Berkes, 2004).

In line with these changes, conservation biology is evolving into a transdisciplinary field with increasing influence on wider fields such as environmental design, planning, and decision-making (Curt, 2010). Conservation biology has been transformed from a "mission-oriented" field based on the biological sciences and incorporating a few perspectives from the social sciences, humanities, and ethics, into a much more integrated field with expanded aims and research focus and an increasing role for social sciences in its framework (Curt, 2010, Mascia et al., 2003). The new generation of conservation scientists recognize the importance of incorporating social perspectives into the field in order to both enrich perspectives and overcome current limitations (e.g. conflicts of interests between stakeholders, land management issues, conservation projects failure); moreover, the desire to move beyond monetized approaches to the evaluation of conservation costs and benefits has been acknowledged (Mascia et al., 2003, McCauley, 2006, Bottrill et al., 2014b, Milner-Gulland et al., 2014a, Rands et al., 2010). Similarly, interest in the human dimensions of conservation have increased significantly since the turn of the new millennium (McKinnon et al., 2016) and several hypotheses about the effects of conservation interventions on tangible (e.g. economic and material living standards) and intangible domains of human wellbeing (e.g. culture, spirituality, psychological health) have been raised (Dodge et al., 2012, Milner-Gulland et al., 2014a, McKinnon et al., 2016, Bottrill et al., 2014b).

In addition to the integration of new perspectives into conservation research and practices, the assessment of biodiversity has been identified as one of the main priorities and challenges in conservation biology (Magurran, 2013, Groves et al., 2002), especially, considering that one of the goals of the Strategic Plan for Biodiversity 2011-2020 (CBD, 2010) is to address the causes of biodiversity loss and to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity. A plethora of biodiversity indices have been proposed, mainly since the 1950s and 1960s, to describe biodiversity patterns and dynamics occurring in wildlife (Magurran, 2004), ranging from traditional metrics of species richness to novel indices based on functionality/quality biodiversity metrics (e.g. Southwood and Henderson, 2000, Magurran, 2013). However, there is little agreement on which is the most effective tool (Purvis and Hector, 2000, Morris et al., 2014). Other challenges within biodiversity monitoring relate to sampling methods, which tend to be time consuming, expensive, logistically difficult and/or inefficient, as they often rely on species inventories of diverse taxonomic groups (Sueur et al., 2012, Gardner et al., 2008). As a response to this situation, new methodologies for biodiversity monitoring and ecological assessment are being proposed (Magurran, 2004) with the purpose of improving the efficacy and reducing the costs and time involved during field work. The concept of rapid biodiversity assessment, for example, was developed as an alternative methodology for rapid exploration of tropical habitats, by selecting a representative group of species or taxa that act as surrogate of the biodiversity of the area (Oliver and Beattie, 1993, Oliver and Beattie, 1996, Oliver et al., 2000).

A promising acoustic approach, which responds to current concerns in ecology and conservation biology, emerged over the last few years and has become established as the discipline of *ecoacoustics*. This novel approach, extends bioacoustics beyond the individual, to higher evolutionary units (community, population, landscape) and considers sounds as both a component in and an indicator of ecological processes occurring in an ecosystem (Sueur and Farina, 2015). Acoustic signals are the material from which a range of ecological processes can be inferred to investigate the ecology of populations, communities and landscapes (Sueur and Farina, 2015). This discipline harbours the field of soundscape ecology, which focuses on studying how sounds of different sources (biological, anthropogenic and geophysical) can be used to understand coupled natural-human dynamics across different spatial and temporal scales (Pijanowski et al., 2011b). The soundscape is broken down into components according to the source of the sounds, including biophony (biological sounds), geophony (geological sounds) and anthrophony (anthropological sound), and the interaction between those components is explored (Pijanowski et al., 2011b, Farina, 2014b). Soundscape ecology is also concerned with soundscape conservation, which aims to identify ecological and social values provided by soundscapes, and to treat soundscapes as resources that need to be properly managed and conserved (Dumyahn and Pijanowski, 2011).

Some of the main ecological contributions of ecoacoustics include: methods to measure and quantify sound such as the development of a range of acoustic indices; comprehension of spatial and temporal dynamics across scales; comprehension of the effect of environmental covariates on sound; assessment of human impacts on wildlife; and assessment of the impact of soundscapes on humans (e.g. Villanueva-Rivera et al., 2011, Pijanowski et al., 2011b, Krause et al., 2011, Sueur et al., 2014b, Krause and Farina, 2016, Dumyahn and Pijanowski, 2011). Ecoacoustics has great potential to address tasks linked to biodiversity assessment, habitat assessment, population ecology, community ecology, landscape ecology and conservation biology, with the aim of better understanding ecological processes and patterns (Sueur and Farina, 2015).

The use of acoustic indices, which aim to characterize animal acoustic communities and soundscape, is receiving increased attention by ecologists over the last few years (Sueur et al., 2014b, Sueur and Farina, 2015). Up to 28 acoustic indices have been developed, mainly based on classic biodiversity indices, which estimate biodiversity patterns of the acoustic community (e.g. richness, evenness, amplitude)(Sueur et al., 2014a). In spite of multiple efforts undertaken over recent years within this discipline some fundamental factors are still constraining the outcomes. These relate to technical and procedural problems, such as biases by non-biotic sounds in recordings or bad interpretation of the sonic environment through acoustic metrics (Towsey et al., Sueur et al., 2014b, Fairbrass et al., 2017); moreover, there is no agreement over which index -or combination of indices- is more effective for assessing biodiversity. It is a major challenge to evaluate these factors and improve methodological analysis of soundscapes (Sueur et al., 2014). Furthermore, research into identified gaps in research within the discipline, could also contribute to current concerns in conservation biology. For example, the understanding of the ecological and social values of soundscapes with the aim of identifying priority areas of conservation is a relevant, yet poorly understood field (Dumyahn and Pijanowski, 2011).

The main question addressed in this thesis is:

- How can acoustic analysis be applied to ecological and social assessment in conservation biology?

The sub-questions raised are:

- What is known about the relationship between sounds and ecological and human wellbeing?
- Do current analytical methods in ecoacoustics, through the use of acoustic indices, effectively address biodiversity assessment?
- How could the current acoustic approach be improved to assess effectively biodiversity?
- How cost-effective is the use of acoustic methods for assessing biodiversity?
- Which social values of soundscape are relevant to conservation biology?

1.1. Aims & Dissertation Structure

Given the current concerns and priorities of research within conservation biology, this thesis investigates the relevance of, and potential for, acoustic methods in assessing both ecosystem and human factors in contemporary conservation biology. A range of distinct but interrelated research topics are investigated and presented, which aim to contribute to current gaps of knowledge within ecoacoustics, from the perspective of conservation biology.

The dissertation is comprised of five chapters with an additional Introduction (i.e. the current chapter) and Conclusion. The structure of the thesis is presented in Figure 1. Chapters are separated into *Ecological* and *Social* research components, according to their focus of study (i.e. non-human and human organisms, respectively), and are based on the *evaluation of current or new acoustic approaches* within conservation biology.

Chapter 1, focuses on both components of research and provides a systematic review of the literature on soundscape and its association with ecological and human wellbeing. Results are examined using visual network maps, and a novel use of supervised classifier to generate conceptual maps of the research terrain.

Chapter 2, the first chapter of the *Ecological* component, evaluates the efficacy of current acoustic indices for describing biodiversity patterns occurring in wildlife communities along a gradient of habitat degradation and shows how relevant ecological information is missing with the use of these indices.

Chapter 3 continues within the *Ecological* component with a novel methodology suggested by Chapter 2, for the identification and automatic acoustic detection of indicator species to rapidly evaluate the ecological integrity of an area.

Chapter 4 combines both components of research, and provides a detailed description of the cost-effectiveness of acoustic monitoring for rapid ecological evaluations in comparison with traditional point count surveys.

Chapter 5 focuses on the *Social* component, presenting a tool for gaining understanding human-environment relationship by analysing the influences of soundscape on human emotions across social groups living across a gradient of industrialization; an analysis of how this information can be used for conservation plans and actions is presented.

Finally, the conclusion provides an outline of the main contributions of the thesis and an overall discussion.

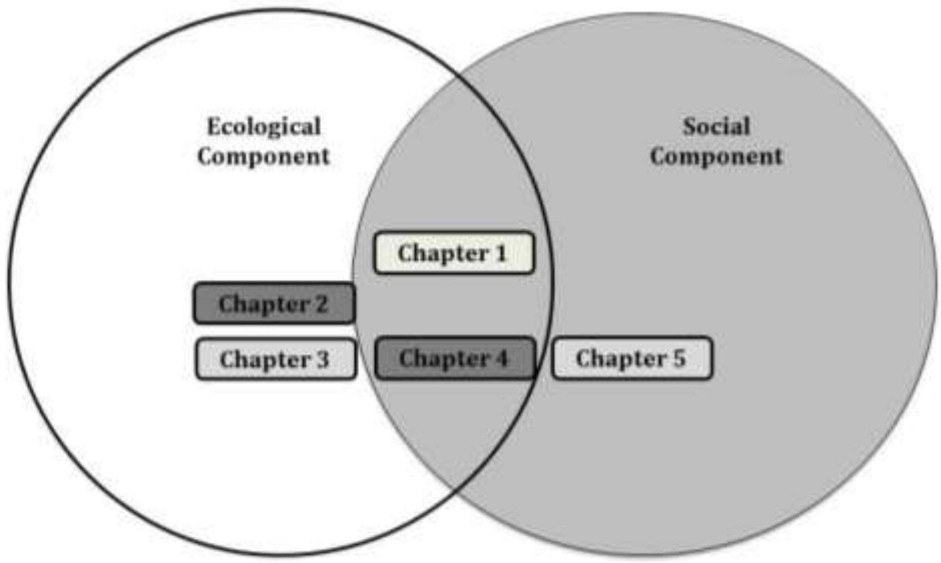

Figure 1. Conceptual diagram showing the structure of the dissertation. Chapters presenting "current acoustic approaches" are shown in dark grey and "new acoustic approaches" are shown in light grey.

CHAPTER 1

Systematic literature review on the association between soundscape and ecological/human wellbeing

ABSTRACT

Wellbeing issues are increasingly incorporated within conservation biology and environmental sciences, both in academic research and in applied policies such as the global sustainable development plans. The role of landscape on human wellbeing has been widely reported, but a comprehensive understanding of the role of *soundscape* has yet to be explicated. Research on the influences of sound on wellbeing has been conducted across a range of disciplines, but integration of findings is impeded by linguistic and cultural differences across disciplinary boundaries. This study presents the largest systematic literature review (2499 publications) of research to date, addressing the association between soundscape and human/ecological wellbeing. It is divided into two components: 1. rapid visualisation of publication metrics using the software VOS Viewer, and 2. analysis of the categories of wellbeing associated with soundscape using the natural language processing platform, Method52. The first component presents network diagrams created from keyword searches and cited references (*lexical, temporal, spatial and source networks*) that explain the origin and evolution of the field, the influences between disciplines and the main contributors to the field. Research on the topic, occurring mostly between 2004 and 2016, evolved from a medical/physiological focus, into technological and psychological/social considerations, and finally into ecological/social research. The evolution of the field was associated with the diversification of terminology and the evolution of new branches of research. Moreover, research appears to have evolved from the study of particular associations between sound and health, to an integrative multidimensional field addressing soundscape and wellbeing, across human and non-human species, including ecologically based studies. The second component includes a trained classifier that categorizes publications, based on keywords analysis, into three frameworks for understanding the association between soundscape and wellbeing: 'Human health', 'Social and Cultural wellness' and

‘Ecological integrity’. This novel methodology is shown to be an effective tool for analysing large collections of data in short periods of time. In order to address the gaps found during the study, it is recommended to increase research conducted in and by non-western societies and in non-English languages, and the exploration of ecological and sociocultural aspects of wellbeing associated with soundscape.

Keywords: health, sounds, welfare, ecological health, noise, wellbeing, machine learning, bibliometric networks

1. INTRODUCTION

1.1. The study of Human Wellbeing in Conservation and Environmental Sciences

The importance of addressing wellbeing issues as part of global strategies and action plans for sustainable development and biodiversity conservation is increasingly recognized. For example, the Intergovernmental Panel on Climate Change (2014) and the Millennium Ecosystem Assessment (2015) reports highlight consequences of global environmental change on human wellbeing and the importance of considering it a priority. In addition, the Sustainable Development Goals (SDGs) include the promotion of human wellbeing and healthy lives as part of their 2030 Agenda. Within conservation and other environmental sciences, there is an increasing trend for studies which incorporate social and ecological concerns, and consider the impact of landscape disturbance or nature conservation on human wellbeing (e.g. McKinnon et al., 2016, Mascia et al., 2014, Milner-Gulland et al., 2014a). With the study of the impact of environmental change on human wellbeing, new perspectives in academic research are emerging. For example, most studies in ecology and conservation sciences describe humans as a ‘negative influence’ on ecosystem integrity (e.g. Bennett and Robinson, 2000, Peres, 2000, Goudie, 2013, Halpern et al., 2008, Nyssen et al., 2004) and not as an ‘affected component’ of the ecosystem. This change in paradigm, from conceiving humans as detrimental to nature, to an affected part of the ecosystem, is likely to have repercussions for future decisions, practices and management plans. For example, it has been reported that the loss of ecosystems, species, populations, and genetic diversity has implications for human health by altering the goods and services provided by natural ecosystems, such as: decreasing global food productivity, eliminating species important for medical use, increasing the rate of infection diseases, and others (Chivian, 2002). Hence, the integration of human perspectives in ecological/conservation sciences might stimulate the generation of strategies and action plans that aim to maintain ecosystem integrity, of which humans are an integral part.

The study of the role of the natural environment on human wellbeing is complex. Not least because definitions of wellbeing vary; however, even though there is a current lack of consensus on how to quantify wellbeing, a few promising approaches have been proposed (e.g. Dodge et al., 2012, Milner-Gulland et al., 2014a, Bottrill et al., 2014b). A review by McKinnon et al. (2016), found that nature conservation was associated with 9 aspects of wellbeing and recommended further research to better understand these relationships: *Economic living standards*, *Material living standards, Health, Education, Social relations, Security and Safety, Governance, Subjective wellbeing, Culture and Spirituality* and *Freedom of choice and action.*

1.2. Evaluating the associations between Soundscape and Wellbeing

In addition to the role of landscape, the role of soundscape in human wellbeing is now recognised (Sattar et al., 2016). Soundscape has been defined as all the sounds emanating from a landscape, including multiple sonic sources: geophony (geophysically produced sounds), biophony (biologically produced sounds) and anthrophony (sounds produced by humans)(Pijanowski et al., 2011b). The study of the effects of soundscape, or of specific sonic sources, on wellbeing has been of interest in a wide range of fields such as psychoacoustics, medical sciences, acoustic ecology, soundscape ecology, ethnomusicology, bioacoustics, engineering, and others. However, information is scattered across disciplines and integration across them is difficult, as specialist academic language can sometimes be a barrier (Nielsen-Pincus et al. (2007) and Klein (1984). Furthermore, most of the work has been centred around quite specific facets of sound, and human wellbeing: the effects of noise and quietness on health (Gidlof-Gunnarsson and Ohrstrom, 2007, Münzel et al., 2014, Booi and van den Berg, 2012, Van Der Eerden et al., 2013, Van Renterghem and Botteldooren, 2012), comfort and annoyance (Gidlof-Gunnarsson and Ohrstrom, 2007, Gidlof-Gunnarsson and Ohrstrom, 2010, Van Kempen et al., 2009, Yang and Kang, 2005) and productivity (Hume, 2010, Mak and Lui, 2012, Sakuma and Kaminao, 2010).

Research has also been carried out on the influence of sounds at individual, social and cultural levels. For example, the pioneers of soundscape studies, Barry Truax (Truax, 1978) and Murray Schafer (Schafer, 1994), started by studying the relationship and interactions between humans and the sonic environment, including musical orchestration, aural awareness, and acoustic design (Pijanowski et al., 2011b). They brought new concepts to the field that highlighted the consequences of industrialization (and of noise pollution) on the quality of a sonic environment. Since then, it has been recognized that not only humans, but also the natural environment, has been impacted by habitat modification (Schafer, 1994).

More recently, the field of *ecoacoustics* has emerged, which considers sound as a component and an indicator of ecological processes occurring in an ecosystem (Sueur and Farina, 2015). Sounds are the material from which different ecological processes can be inferred to investigate the ecology of populations, communities and landscapes (Sueur and Farina, 2015). This discipline harbours the field of soundscape ecology, which investigates how sound in landscapes can be used to understand coupled natural-human dynamics across different spatial and temporal scales (Pijanowski et al., 2011b). Several ecological hypotheses underpin this research, such as the Acoustic Niche Hypothesis[1] (ANH)(Krause, 1987), the Acoustic Adaptation Hypothesis[2] (AAH)(Daniel and Blumstein, 1998) and the

[1] The ANH describes how acoustic signals are shaped in an interspecific arrangement, according to the competition model, in which each species occupies a specific space in the auditory spectrum in order to minimize spectral or temporal overlaps.

[2] The AAH explains how animal signals are moulded according to their intrinsic physical features (e.g. length of trachea) and also by the influence of environment properties.

Morphological Adaptation Hypothesis[3] (MAH)(Podos, 2001). These postulations explain how the soundscape becomes structured through the evolutionary pressures that occur within natural acoustic communities according to physical structure, the adaptive mechanisms of sound production and transmission, the reduction of acoustic competition, and the behavioural processes associated with vocalizing species (Farina, 2014b). By studying these mechanisms and impacts due to environmental changes, ecological research has started to explore associations between soundscape and environmental health. Soundscape ecology promotes research not only of the ecological but also the social associations of soundscape with wellbeing (Pijanowski, 2011).

An important contribution highlighting the ecological and social importance of preserving soundscapes was provided in a review by Dumyahn and Pijanowski (2011). They recognized 5 soundscape values and benefits of 'quality soundscapes': *Human wellbeing, Wildlife wellbeing, Sense of place, Landscape interactions,* and *Ecological integrity*. However, this proposal was based on a reduced number of publications (<100) and might not cover all knowledge generated across all disciplines. For example, Devadoss (2017) examines additional roles of soundscape in human identity, sense of belonging and community, which are not mentioned in the list. The need for more research on the ecological and social values associated with soundscapes has been identified (Dumyahn and Pijanowski, 2011).

The purpose of this study was to synthesise current cross-disciplinary knowledge around the associations between soundscape and wellbeing by integrating existing research into human and ecological wellbeing. The aim was to generate a corpus of synthethised information on the topic that facilitates comprehension of what has been done to date, circumventing the barriers of academic language. This study aims to contribute to soundscape ecology or ecoacoustics, to promote the integrated study of soundscape, wellbeing and soundscape conservation.

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[3] The MAH refers to the role of the body size as a constraint of the vocalization organs and their acoustic performance.

The main questions addressed by the analysis were:

1. What is the state of knowledge in the field of soundscape and wellbeing? How was the field born and how has it evolved over time?

2. Which types of associations between soundscape and wellbeing have been described to date? What are the most relevant concepts and linkages?

3. Which areas are untouched or under-researched and require future investigation?

2. METHODS

A systematic literature review was carried out based on data compiled from academic literature on the topic of 'soundscape and its associations with wellbeing'. This is comprised of two components: 1. analysis of publication metrics; 2. analysis of categories of wellbeing associated with soundscape.

2.1. Corpus construction

In order to compile publications on the topic of research, it was necessary to identify a set of words ('topic words') that were used to conduct a search within abstracts, titles or keywords of online publication databases. In order to compile a comprehensive list of topic words for conducting the literature search, synonyms of the words 'soundscape' and 'wellbeing' were identified. The latter search strategy has also been used in Woodhouse et al. (2015) and Coralie et al. (2015) for conducting systematic literature reviews on similar topics. In the case of 'wellbeing', 12 synonyms (listed on page 13) were found in online dictionaries (Thesaurus.com and WordReference.com). These terms were considered appropriate for the search as they include broader definitions of 'wellbeing' (Šprah et al., 2014) and are not restrictive, considering the diversified use of 'wellbeing' across disciplines (Dodge et al., 2012, Milner-Gulland et al., 2014a). 'Soundscape' synonyms were searched for in the same online dictionaries. However, these synonyms were not included as they were considered inappropriate for the search strategy (e.g. they included terms such as 'landscape', 'sound wave' and others which diverged from the focus of this study). In order to find more suitable synonyms, a brief review of related terms used in relevant publications on the topic was carried out: 'soundscape' appeared as a term in the late 1970s (by Murray Schafer), but it also has been referred to in literature as 'sonic environment' (Truax, 1978) or 'acoustic environment' (International Organization for Standardization SO 12913-1:2014). Therefore, the three last mentioned terms were selected for the search.

A search string comprising the following terms was used to query SciVerse's *Scopus* and Tomson Reuters *Web of Science*, both peer-reviewed publication databases: "'soundscape' OR 'sonic environment' OR 'acoustic environment' AND 'wellbeing' OR 'well-being' OR 'comfort' OR 'happiness' OR 'health' OR 'prosperity' OR 'welfare' OR 'advantage' OR 'benefit' OR 'ease' OR 'good' OR 'wealth' OR 'pleasure'". The search string in SCOPUS and Web of Science was based on the database titles, abstracts and keywords. The results from both bibliographic databases were combined into one database. In order to evaluate whether the search strategy was effective, the compilation was compared to a comprehensive personal database of publications compiled by the author on the same topic. As most of publications from the personal compilation were present in the combined database used for this study, the search strategy was considered appropriate for the analysis.

2.2. Evaluation of publication metrics

In order to provide an overview of the linkages between research across disciplines, bibliometric networks were constructed and viewed using VOS Viewer (version 1.6.5) source. Four maps were generated: 1. A Lexical network, 2. A Temporal network, 3. A Spatial network, and 4. A Source network:

The lexical network was generated in order to evaluate how the field of research has grown, and what the concepts most associated between soundscape and wellbeing are. This was conducted by analysing the 'keyword co-occurrence' among the database publications. 'Co-occurrence' refers to the number of times one keyword appears in close relation with another. In this network, map terms are located at different coordinates in 2D space, according to the number of co-occurrences of a term (keyword) and its relationship with other terms. Objects are located close to their 'ideal coordinates'. The ideal coordinates of an object *i* are defined as a weighted average of the coordinates of all other objects, where the coordinates of objects more similar to object *i* are given higher weight in the calculation of the weighted average (van Eck and Waltman, 2007). Hence, the distance between two terms can be interpreted as an indication of the relatedness of the terms: the smaller the distance between them, the more strongly they are likely to be related to each other (Van Eck and Waltman, 2011). Each term has a specific label and circle size depending on a measured weight, which is obtained by calculating the number of links of an item and the total strength of the links of an item (Van Eck and Waltman, 2013). Terms are grouped in clusters - shown in different colours - of closely-related terms, based on the weighted and parameterized variant modularity function of Newman and Girvan (2004). A minimum number of co-occurrences of a keyword was used as a threshold, as recommended in Van Eck and Waltman (2013) (≥10).

A Temporal network was created in order to explore the temporal dynamics of the field, using the same clustered network but presented within a time period, based on the average number of publications per year. A Spatial network, was created in order to evaluate geographical patterns in contributions to the field, based on the average number of publications per country. A minimum number of publications per country (≥5) was used as a threshold, as recommended in Van Eck and Waltman (2013). Finally a Source network was created in order to analyse the sources (i.e. publication types) that have contributed to the evolution of the field, through an analysis of source citations. A minimum number of documents/citations of a source (≥5) were used as a threshold for creating the map of source citation and linkages between them. Additionally, a temporal analysis was integrated in order to visualize contributions from each source over time (based on the average number of publications per year).

2.3. Definition of categories of wellbeing associated with soundscape

To further explore lexical associations between soundscape and wellbeing, a supervised classifier was built with Method52 (version6.1.)(Wibberley et al., 2014). Method52 is a tool for collecting, processing and exploring large collections of text documents. It uses natural language processing, which allows pattern inference from a trained dataset created by the analyst, and enable general predictions about the whole dataset to be made (Nadkarni et al., 2011). For this study a classifier was built in order to automatically categorize the compiled publications into defined categories of wellbeing. A training process was used to create the classifier which consisted of: 1. Defining categories of wellbeing, 2. Manual labelling of a random subset (300 samples) of publications into categories of wellbeing (called correct answers or 'gold-standard dataset'), 2. Training the classifier by labelling a smaller subset of samples (200 samples) and measuring the model performance against the gold-standard dataset (see Section 3.4. for details), and 3. Aggregating more samples to the training data to enhance the performance of the model.

Wellbeing categories were initially pre-defined based on domains of wellbeing reported in similar works (Woodhouse et al., 2015, Bottrill et al., 2014a), and refined during the interactive-learning process (details in results). 'Author-keywords' or 'index-keywords' (when the latter were missing) were used for the classification of each publication into a category. When the keywords of a publication were not clear enough to categorize it, the whole abstract was read. The addition of more samples to the training data was decided based on classifier performance scores; if the performance scores of the model were poor, more training data was added until the model reached acceptable performance scores. The performance of the classifier was evaluated using the F-Score of each category and overall classifier Accuracy, with the training dataset. F-Score is derived from the harmonic mean of *Precision* and *Recall* proportions (2 x ((*Precision* x *Recall*) / (*Precision* + *Recall*)). Precision evaluates the proportion of documents assigned to a category which are that category (*True Positive*/*True Positive* + *True False*); Recall measures the the proportion of documents in a category which were assigned that category. (*True Positive/True Positive + False Negative*); Accuracy assesses the proportion of documents assigned to a correct category (*True Positive/True Positive +True Negative+ False Positive+ False Negative*). Scores with a performance higher than 50%, were considered good, following the criteria of Wibberley et al. (2014).

Classification of the compiled dataset was evaluated in a temporal domain (number of documents per year) in order to visualize how much each topic has been studied over time. Finally, a conceptual map of the association between 'soundscape' and 'wellbeing' was built by using the 'author-keywords' or 'index-keywords' list obtained during the classification of the compiled dataset. Terms that were duplicates or not self-explanatory, non-adjectives and/or not descriptive were removed from the list.

3. RESULTS

3.1. Lexical network

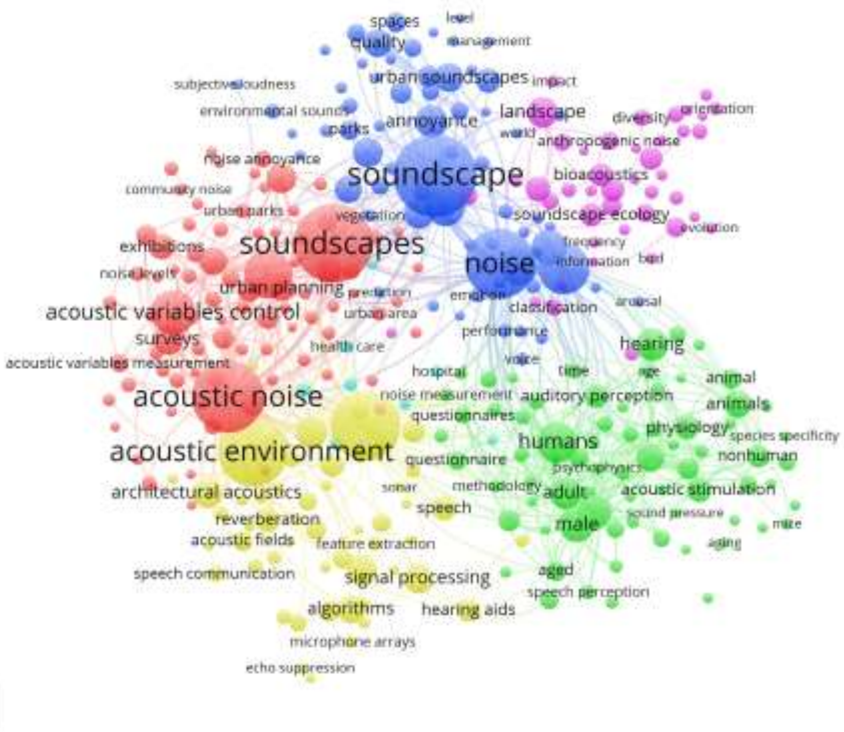
The final corpus consisted of 2499 articles (SCOPUS=1153; Web of Science=1346). The keyword co-occurrence analysis found 331 terms that met the threshold (number of co-occurrences of a keyword ≥10). Figure 1a shows a network of terms grouped into 6 clusters (see bibliographic metrics in Annex 1). Each cluster comprised a list of terms that were classified into general subjects, categorized as:

1. (Green) Medical/Physiological research: groups words which are lexically related to sense of hearing, and human/animal physiology research
2. (Yellow) Technological/Medical applications: comprises terms associated with the development of acoustic technologies and research into the properties of sound.
3. (Red) Acoustic perception research I: gathers terms related to acoustic assessment and sound measurement based on psychological research, especially focusing on 'noise' and 'urban' areas.

4. (Blue) Acoustic perception research II: includes terms that reflect broader research on soundscape perception and integrates a range of cultural/social aspects (e.g. tranquillity, identity, memory). This category differentiates from ´Acoustic perception research I´ because it is more focused on community, rather than individual levels, and include perspectives not only related to psychological research.

5. (Purple) Ecological research: gathers terms based on ecological research, especially in ecologically relevant descriptive patterns and noise

6. (Light Blue) Health care: contains terms associated with the application of research in health care practices.



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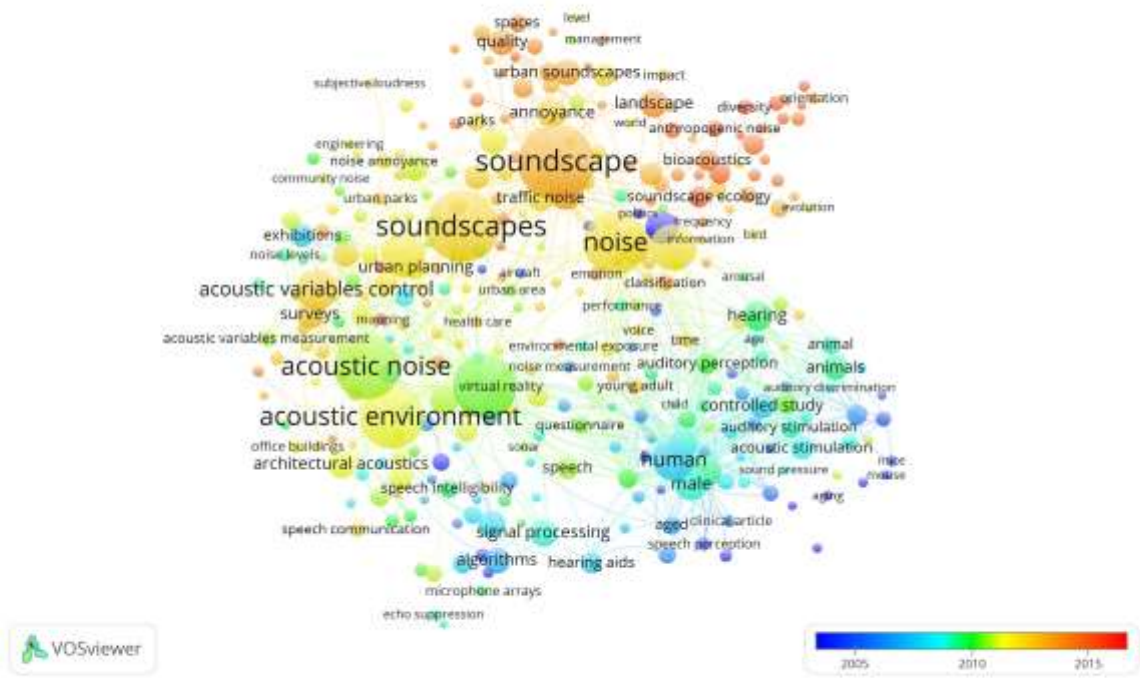


b

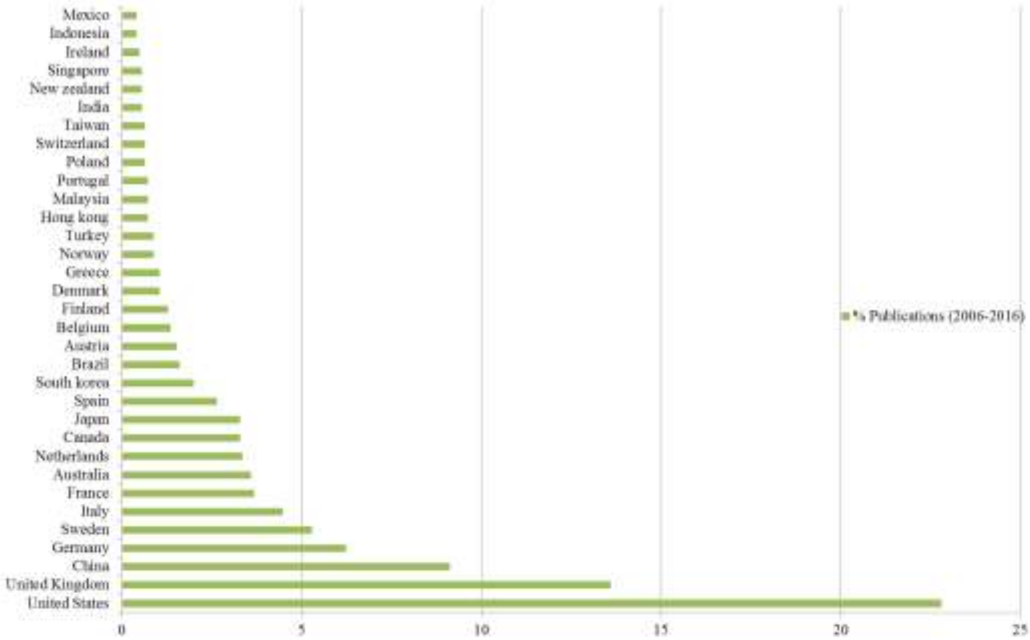
Figure 1. Network of the co-occurrence of keywords (items) in literature based on the association between ‘soundscape’ and ‘wellbeing’. a) coloured by clusters, b) coloured by year of publication (2004-2016).

3.2. Temporal network

As shown in Figure 1b, most research on the topic has occurred over a period of 15 years, between 2004 and 2016. Terminology associated initially with the field suggests how research was mostly focused within the medical/physiological realm and the sense of hearing (i.e. physical health). At the same time, vocabulary seems to have evolved within the branch of acoustic technology – especially hearing/speech research, and other acoustic sciences from 2005-2009. From 2010, a new lexicon associated with the study of human perception of sound within psychological research emerges. This is followed by the evolution of other terms that develop a deeper understanding of the perception and influence of sound and soundscape for humans in 2013-2014 (e.g. soundscape, quality, urban planning). Finally, the development of soundscape ecology within biological sciences can be observed, with terms describing the fields of research involving environmental patterns and ecological impacts of noise (2014-2015).

3.3. Spatial network

The 34 countries, out of a total 94, that met the threshold criterion (number of documents of a country ≥5) are shown in Figure 2a (see also Annex 2). According to the analysis, most of the research has been conducted in institutions from 'developed countries' (N=30, 88.23%), as defined in the Global Human Development Report (UNDP, 2016), during the period 2006-2016. The United States made the largest contribution (22.08%), followed by United Kingdom (13.6%), China (9.12%), Germany (6.24%) and other European countries (≤5% each). The temporal network, based on the average publications per year (figure 2b), shows that United States and Japan were the pioneers of the research (2006-2008), followed by other European countries (France, Belgium, Finland, Sweden and Portugal), United Kingdom, Hong Kong and Canada (2009-2011). Afterwards, other European countries (Germany, Switzerland, Netherlands, Poland, Austria, Italy, Spain, Norway, Denmark and Greece), Asiatic countries (China, South Korea, Turkey), and South American countries (Brazil and Mexico) contributed to the field (2011-2012). From 2013-2015 other Asiatic countries (Taiwan, Hong Kong, Indonesia, Singapore and India), New Zealand and Ireland have also conducted research on the topic.



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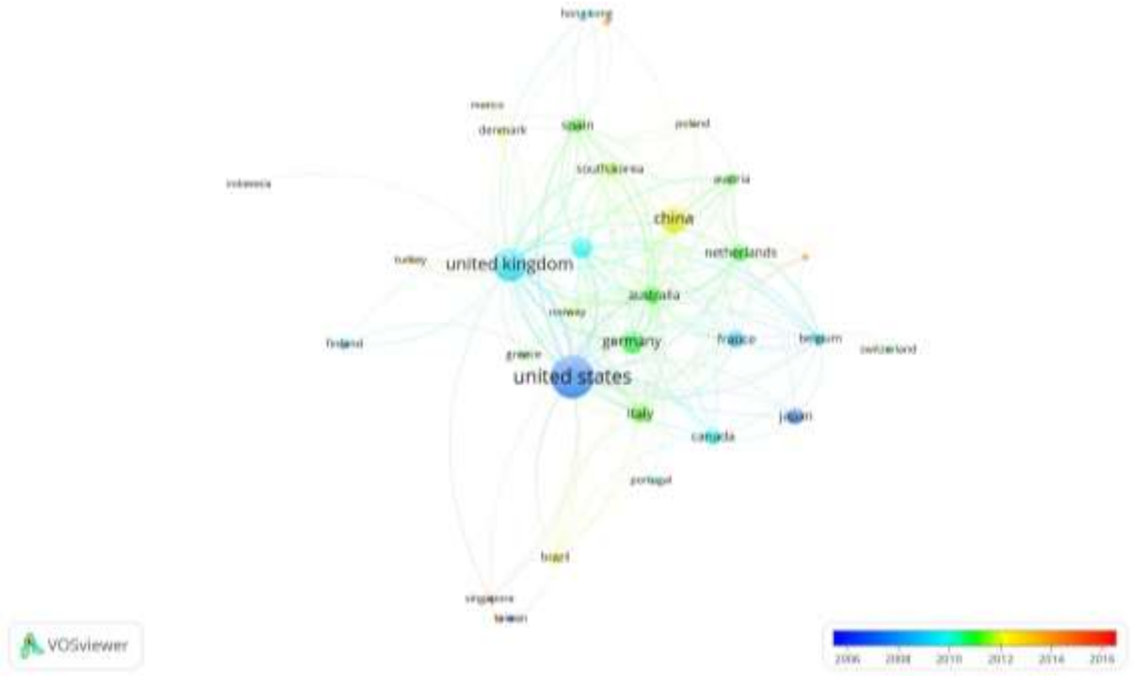


b

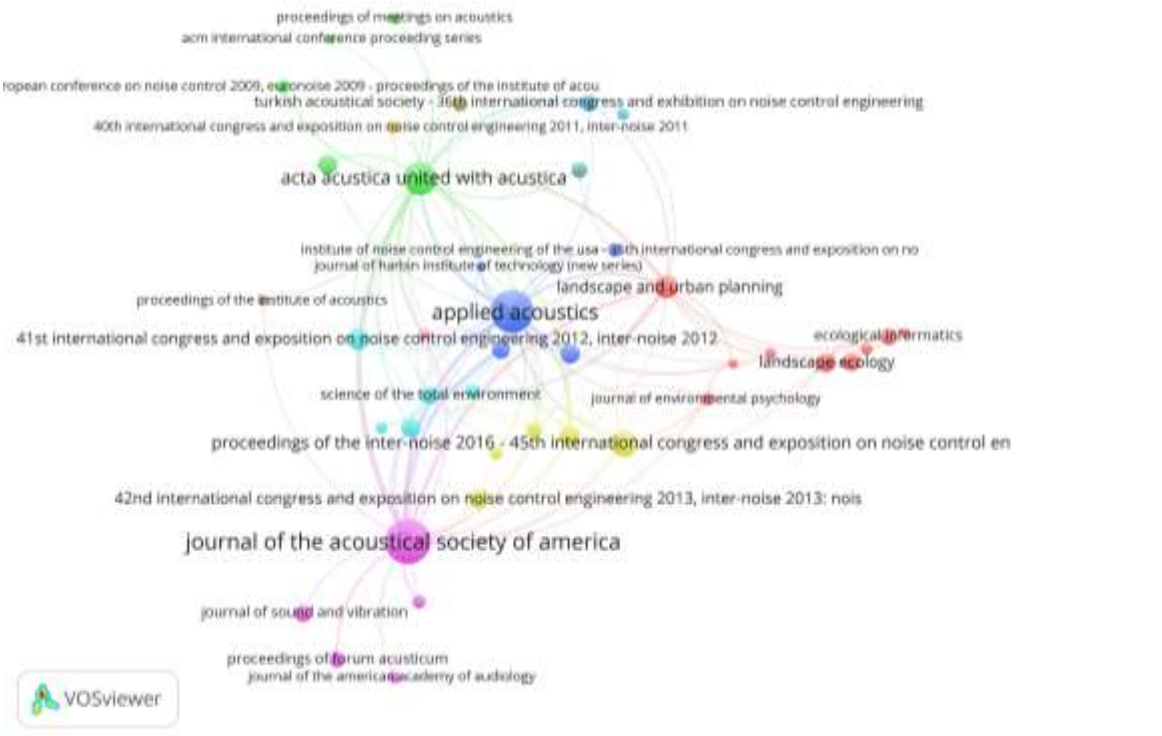
Figure 2. Countries that have contributed to literature based on the association between 'soundscape' and 'wellbeing', between 2004 and 2016: a) countries are displayed along the Y axis and number of publications along the X axis, b) spatial

network on number of documents cited by countries (average publications per year).

3.4. Citation Source network

Analysis of citation sources (figure 3a) illustrates that there are 5 main disciplinary clusters. Of 1180 sources found, 86 met the threshold (minimum number of document of a source ≥5) (Annex 3). Clusters were classified into the following categories: 1. Ecological and environmental sciences (red), 2. Engineering, noise control and acoustics (green), 2. Applied acoustics and engineering (blue), 3. Noise control and environmental research (yellow), 4. Acoustics and audiology (purple), and 5. Sound and noise control science research (light-blue). The most dominant publications in the field have been the Journal of the Acoustical Society of America (8.98%) and Applied Acoustics (7.90%), followed by Acta Acustica United with Acustica (4.68%), Proceedings of Inter-noise 2016 (3.12%) and Landscape and Urban Planning (2.34%).

Temporal analysis (Figure 3b) shows how research into soundscape has evolved through distinct research fields. Initial contributions to the field were conducted by journals on Acoustics and international meetings/conferences on Engineering, and were focused on noise control. This was followed by further contributions by other journals on Acoustics, but also by the incorporation of Environmental and Public Health literature (2006-2011). Following that period, there appears to be an integration of publications based on Applied Acoustics and Landscape Architecture. At the same time, other conference journals, focused on noise control, continued to contribute to the field. In recent years new sources based on Ecological and Landscape research have emerged (2012-2016).



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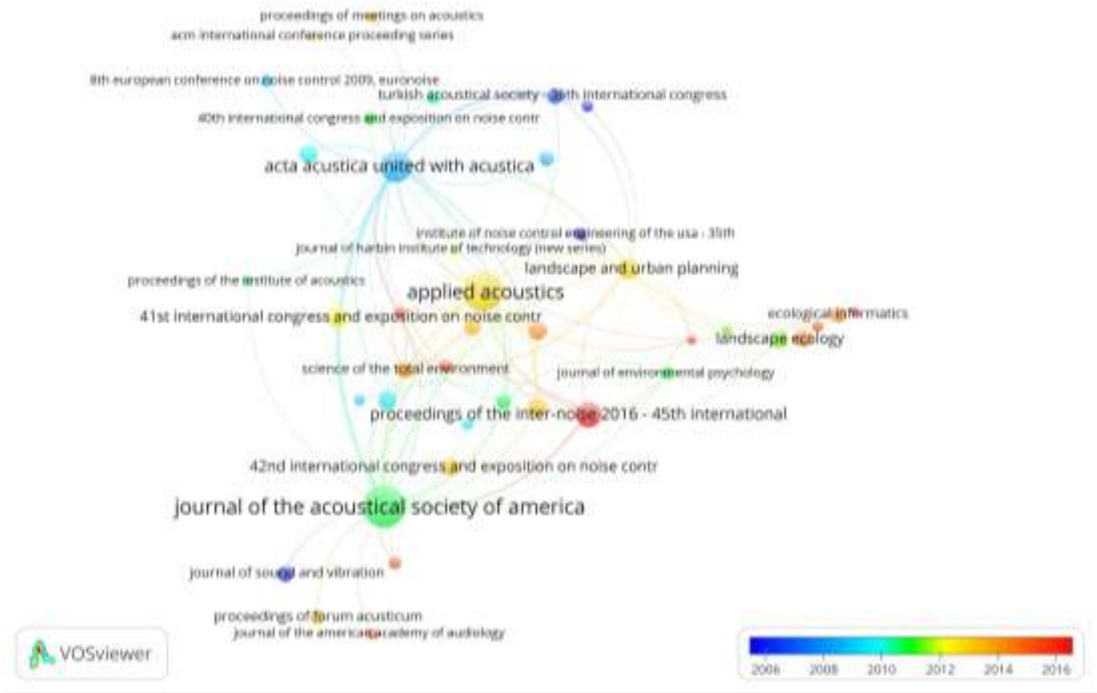

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Figure 3. Spatial network showing the main contributors to the field on the association between 'soundscape' and 'wellbeing,' based on number of documents by citation sources: a) coloured by clusters, b) coloured by year of publication.

3.4. Lexical classifier: Categories associated with 'wellbeing' and Conceptual Map

Five categories, or domains of wellbeing were initially included in the analysis, considering pre-defined domains reported in Woodhouse et al. (2015) and Bottrill et al. (2014a): 1. 'Health', 2. 'Spiritual and Cultural wellness', 3. 'Freedom and Social wellness', 4. 'Animal health' and 5. 'Ecological integrity'. Because the number of samples in 'Freedom and Social wellness' and 'Animal health' categories was low, and the evaluation of the classifier gave poor scores (i.e. low F-scores), these categories were combined into one category. The refined categories used for creating the classifier were: 1. 'Health', 2. 'Cultural and Social wellness', 3. 'Ecological integrity' and 4. 'Non-related' -this last category served as a 'trash category' where publications not contributing to the aims of this study were removed from the dataset (e.g. studies of speech, virtual reality, technology).

A dataset with 300 samples was manually labelled and used for evaluating the quality of the classifier (i.e. the 'gold-standard dataset'). In order to train the classifier, 200 samples were labelled and evaluated against the 'gold standard dataset'. Table 1 shows the F-Scores per category and of overall classifier accuracy . All categories showed good performance (F= 0.65-0.73), except 'Cultural and Social wellness', (F= 0.44). The overall accuracy of the model was good (66%).

Table 1. Evaluation of the quality of the classifier based on the gold-standard data set.

Categories	Precision	Recall	F-Score	Accuracy
Health Sample	0.8	0.547	0.649	
Cultural & Social wellness Sample	0.361	0.55	0.436	
Ecological integrity Sample	0.657	0.71	0.682	
Non-related Sample	0.673	0.796	0.729	
Overall				0.658

2008 publications were evaluated, which were automatically labelled under the following categories: Health, 520 (25.90%), Cultural and Social wellness, 295 (14.69%), Ecological integrity, 295 (14.69%) and 'Non-related' categories, 898 (44.72%). As illustrated in figure 4, 'Health' is the category that harbours the earliest research on 'soundscape' and 'wellbeing' (since the 80s), followed by several studies in the 'Ecological integrity' category (during the late 80s and 90s) and 'Cultural and Social wellness' (in the late 90s). There were few publications between 2002 and 2003. Since then, research has grown overall, with some periods of decreasing or non-increment (such as in 2004, 2007 and 2011). A noticeable growth in the investigation on the topic seems to have occurred since 2014.

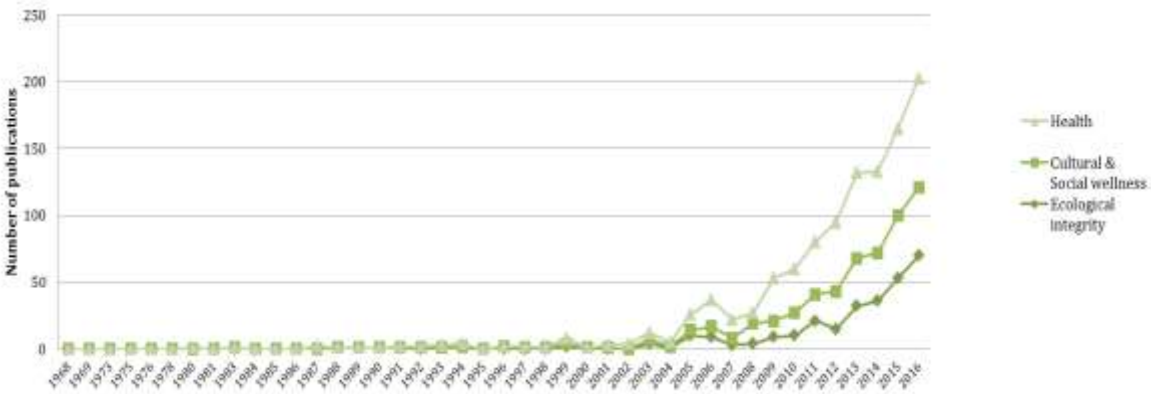


Figure 4. Number of publications reporting the association between soundscape and distinct domains of wellbeing: 1. Health, 2. Social and Cultural wellness, and 3. Ecological integrity, based on the analysis of 'author-keywords' or 'index-keywords'.

A conceptual map of the association between 'soundscape' and 'wellbeing', based on the publication-keywords list, is presented in figure 5. The map was separated into human and non-human species and divided into positive and negative associations, to facilitate comprehension. 'Health' associations with soundscape was the category with the highest number of keywords. The positive associations describe mainly psychological/mental states of wellbeing (e.g. tranquillity, comfort, welfare) and health benefits (e.g. attention restoration, stress recovery, rehabilitation); whereas the negative associations were based on noise and its consequences for psychological wellbeing (e.g. noise annoyance, stress, hypertension). ‘Cultural and Social wellness’ presented a range of positive associations that refer to individual and collective social processes (e.g. such as identity, collective memory, cultural heritage). Negative associations with wellbeing were scarce, and were related to the effects of noise, especially on communication (e.g. noise barrier, acoustic fragmentation, acoustic problems). ‘Ecological integrity’ was particularly associated with terms describing ecological patterns (e.g. acoustic heterogeneity, acoustic partitioning, biodiversity) and environmental status (e.g., acoustic quality, environmental health, soundscape indicator). Negative associations were describing impacts on the acoustic community (e.g. acoustic masking, acoustic niche overlap, acoustic disturbance).

HUMAN WELLBEING				**ECOLOGICAL WELLBEING**	
Cultural & Social Wellness		**Health**		**Ecological Integrity**	
Positive	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**
Acoustic comfort	Sound barrier	Aural health	Agitation	Acoustic diversity	Acoustic masking
Acoustic value	Acoustic fragmentati-on	Hearing impairment	Annoyance	Audio diversity	Biological noise
Identity	Acoustic problems	Psychological stress	Anxiety	Biodiversity	Nature deficit disorder
Place identity	Community noise	Rehabilitation	Environmental noise pollution	Habitat restoration	Acoustic competition
Popular Culture	Noise annoyance	Restoration	Health risk	Indicators	Acoustic disturbance
Acoustic memory	Noise barrier	Speech intelligibility	Health anxiety	Resource partitioning	Acoustic interference
Acoustic value	Noise disturbance	Acoustic comfort	Hearing loss	Urban environmental quality	Acoustic masking
Architectural heritage	Noise problems	Acoustic quality	Hypertension	Acoustic adaptation	Acoustic niche overlap
Collective memory	Social impact	Acoustic variable controls	Job stress	Acoustic heterogeneity	Acoustic noise

Communication	
Control measures	
Creativity	
Cultural heritage	
Cultural identity	
Environmental benefits	
Ecosystem services	
Efficency	
Indicators	
Intangible cultural heritage	
Memory	
Noise control	
Noise management	
Noise regulation	
Office satisfaction	
Place identity	
Quality of life	
Sense of place	
Social identity	

Amenity	Mental health
Attention restoration	Noise annoyance
Aural comfort	Noise disturbance
Environmental quality	Noise pollution
Healing environment	Physiological stress
Health	Road traffic noise
Human comfort	Subjective loudness
Mental restoration	Sound unpleasantness
Motivation	Sleep disturbance
Noise pollution control	Sound barrier
Patient rehabilitation	Stress
Pleasure	Traffic noise
Public health issues	Traffic noise pollution
Quality of life	Uncomfortable
Quietness	Urban noise
Restoration	
Restorativeness	
Satisfaction	
Speech production	

Acoustic niche	Ambient noise
Acoustic partitioning	Anthropogenic disturbance
Acoustic quality	Anthropogenic impact
Adaptation	Anthropogenic noise
Acoustic variables control	Community noise
Animal care	Environmental noise
Damage detection	Environmental pollution
Environmental health	Habitat degradation
Environmental quality	Masking
Environmental sound quality	Noise
Environmental values	Noise barriers
Restoration	Noise disturbance
Sonification	Noise pollution
Soundscape indicator	Ocean noise
Soundscape quality	Ship noise
Species evenness	Traffic noise
Species richness	Underwater noise
Sustainable land use	Urban noise
	Wind-dependent noise

Social life		Stress recovery			
Sound heritage		Tranquillity			
Urban identity		Welfare			
Use of Territory		Wellbeing			
		Work performance			

Figure 5. Conceptual map of the associations between 'soundscape' and 'wellbeing' in outcomes categories, based on keywords analysis of literature published on the topic.

4. DISCUSSION

This study analysed the largest collection of academic literature at the intersection of ecological and social research into soundscape and wellbeing to date. Based on a systematic review carried out using bibliographic software analyses tools, the origins and the evolution of research in soundscape and wellbeing are reviewed; temporal and spatial dynamics of the field were also characterized. Additionally, a classification model that describes the domains of wellbeing associated with soundscape was described.

4.1. Origin, Evolution and Dynamics of the field

Analyses reveal that research into soundscape and wellbeing has been of interest to a wide range of disciplines, as reported in Farina (2014b) and Sattar et al. (2016). Understanding of the associations between soundscape and wellbeing has changed and evolved over time: the initial term *association* reflects a research focus into the effects of sounds on the physical body and the mechanical processes associated with the senses in human and other non-human animals. This seems to be followed by the exploration of technological applications, based on acoustic research and sound measurement. Research on physical responses to sounds in humans, especially of the effects of noise, seems to have influenced the development of research in other disciplines, such as the psychological and the social/cultural implications of sounds. Furthermore, the appearance of new research perspectives led to the wider usage of concepts, such as 'soundscape'. Likewise, research in soundscape seems to have influenced the development of studies not centred on humans, but on ecological understanding and the implications of noise in the ecosystem.

The evolution of the field, evidenced by the appearance of differing terminology through time, has occurred over a relatively short period of time. Before the 21st century publications were scarce. The appearance of a new lexicon on the subject seems to be related to the emergence of new branches of research over time, as suggested by Pijanowski et al. (2011a). The usage of the term 'soundscape' could have had an effect on the evolution of the subject and its diversification into new research avenues: initially, the study of the influence of sounds was centred mainly on negative associations of sound (i.e. noise) in humans (Farina, 2014b), but the popularization of the term 'soundscape' might have influenced the integration of other studies explaining a range of linkages between soundscape and wellbeing. That is, 'soundscape', as a multidimensional concept that includes the integration of biological, geophysical and anthropogenic sounds (Pijanowski et al., 2011b) could have had an influence on other ways of understanding and studying sound and its associations with 'wellbeing'. As a consequence, new and more integrated branches of research that include social and ecological realms (such as soundscape ecology), appeared. On the other hand, terms such as 'noise' or related words, were already present in most branches of study. The impacts of noise on health and quality of life was already identified in the late 1960s (Ward and Fricke, 1969), nevertheless, it was only after some decades that its study became popular (Passchier-Vermeer and Passchier, 2000).

Spatial analysis highlighted the influence that some nations have had on the evolution of the field. Most of the contributions have been produced in industrialized or ´developed´ countries, which can be considered as a bias of knowledge with regard to data collection or within the field of research. The scarcity of publications from 'developing countries' could be explained by three possible reasons: 1. There is a generalized trend, observed in the countries that have contributed mostly to the field, of producing most of the world's published scientific research (EU-Commission, 2003). 2. For methodological reasons the current database did not include other sources of literature, such as 'grey' literature or other bibliographic databases, which would have increased the amount of work (and knowledge) coming from 'developing' countries, and 3. Data compilation is biased by the language given that it is comprised of publications only in English. Additionally, it could be inferred that most of the associations presented in this study are referring to industrialized environments, with research on natural environments settled within urban areas.

The analysis of contributors by citation source provides an overview of the main branches associated with the development of the field, and the associations between them. As reported in Sattar et al. (2016), sound engineering has been the primary contributor to the field, with publications on sound mechanics and noise assessment/control. Other influential contributors have been acoustics, focused on the development of technologies, sound measurement and noise control, as mentioned by Turner et al. (2013). Other contributing fields include acoustic ecology, psychology, landscape architecture and environmental sciences. Recent work, as shown by spatial and temporal analyses, include the branch of ecology and landscape ecology.

4.2. Defining categories of the association of Soundscape with Wellbeing

The analysis suggests that described associations between soundscape and wellbeing could be synthetized into three main domains ('Health', 'Cultural and Social wellness', and 'Ecological Integrity'). This classification is represented in the Lexical network, reporting academic linkages between soundscape and ecological and social wellbeing, based on the largest database of literature analysed to date. Most of the associations found in this analysis were human-based; as a consequence, and because the number of ecology-based publications was low, there was only one category proposed for the ecological realm.

It is important to consider that the increase in work published on the topic over time is also an observed trend for all academic publications: for example, the number of documents registered in SCOPUS from all documents published from 1974 to 2016 (i.e. period of time observed in the database of this study) has increased five times (from 557,315 to 2, 788, 202 publications).

Health

Of all the identified categories, the domain that has been better described in the scientific literature is ‘Health’. This might be explained by the great number of years that the topic has been studied in comparison with the rest of the categories. This study confirmed that there has been particular interest in research on ‘noise’, related terms (e.g. ‘noise-pollution’, ‘noise annoyance’, ‘traffic noise’) and its consequences on health. Good descriptions of the impact of noise on human health have been reported in Passchier-Vermeer and Passchier (2000), Stansfeld and Matheson (2003), Fritschi et al. (2011), and Farina (2014b), which describe negative effects on physical health (such as hearing impairment, hypertension, cardiovascular disturbance, immune effects and sleep disturbance) and on mental/psychological health (such as emotional instability, task performance, stress, neurosis, annoyance, long term memory). Most of these associations were illustrated by this analysis.

It was also observed that even though research on the positive linkages of sound with health appeared years later, there was a high variety of described positive associations. Some good examples of those associations are reported in similar work by Sattar et al. (2016), Oldoni et al. (2015), Gidlof-Gunnarsson and Ohrstrom (2010) and Farina (2014), which describe how soundscape of good quality influences physical and mental/psychological health. These influences include long-term annoyance reduction, stress prevalence reduction, restorative effects, rest, relaxation, welfare and mental health. The lists of associations obtained in this category were self-explanatory, which contributed to a general understanding of the existing relationships between soundscape and this category.

Cultural and Social wellness

The ‘Cultural and Social wellness’ category was comprised of a variety of aspects associated with wellbeing, which have been reviewed in similar studies (Sattar et al., 2016, Schafer, 1994, Farina, 2014b). The most relevant positive aspects considered in these reports were illustrated in this study and include sense of place (e.g. Fisher, 1999), cultural heritage (e.g. O'Connor, 2008), identity (e.g.

Harmon, 2003), and communication (e.g. Fritschi et al., 2011). Additionally, other variables might reflect association with soundscape as an environmental service. Negative associations in this study were scarce, and are related to the effects of noise on communication. For example, Brammer and Laroche (2012) report how noise interferes with communication within industrial and other workplaces (e.g. open-plan offices, construction) but also within buildings (e.g. schools, residences, arenas) and describe the social implications of this. It is important to mention that this category had the lowest F-Scores (especially of *Precision*), which may need further research in order to confirm the accuracy of the described associations with soundscape. The high variance of topics (i.e. type of terms) related to this category could explain the low precision in the classification analysis. Additionally, the scarcity of data (number of publications) analysed during the elaboration of the classifier could also be related to the low scores of the analysis and the lack of negative associations found in this analysis.

Ecological integrity

The category 'Ecological integrity' comprised of aspects that might be related to patterns occurring in natural ecosystems. These linkages highlight the basis of the fields of soundscape ecology and ecoacoustics, in which soundscape is studied as a proxy of biodiversity and of habitat status, by generating quantitative and qualitative measurements of sound or 'acoustic indices' (e.g. Sueur and Farina, 2015, Sueur et al., 2014b, Kendrick et al., 2016, Sattar et al., 2016). The negative associations observed were mostly descriptions of the impact that noise or anthropogenic activities have on the environment and on acoustic communities, including ocean noise, which has been well reported within bioacoustics (Au and Hastings, 2008). It is important to mention, given that the categories 'Ecological integrity' and 'Animal health' were combined into one category, that other associations with wellbeing might not have been highlighted. For example, work on the impact of underwater noise on the behaviour and hearing loss of whales (e.g. Moore and Clarke, 2002, Erbe, 2002, Aguilar Soto et al., 2006), would have been classified within the 'Animal Health' category, but now is classified within the category 'Ecological integrity' which is less specific. In general terms, it was difficult to define the positive associations within this category as the terms are not self-explanatory or not so evident, but after reviewing material on the topic (e.g. Dumyahn and Pijanowski, 2011, Farina, 2014b, Sueur and Farina, 2015) it was easier to classify them.

4.3. The use of technological tools for reviewing large collections of publications

The use of technological tools for conducting this systematic literature review allowed us to: 1. Analyse a large compilation of data in a short period of time with reduced research effort compared to a traditional literature review methodology, which may require longer periods of time and participation of multiple researchers (e.g. McKinnon et al., 2016), 2. Synthesise relevant information published on the topic such as key-concepts and relevant terminology. In particular, the use of keywords was confirmed as a useful means for extracting essential information from literature as they highlight relevant content in each publication (Wartena et al., 2010), 3. Understand the multiple dynamics of the field of research through bibliographic network maps, 4. Identify the lacunae/gaps in research. Furthermore, the visualization map made interpretation of the results easy. Additionally, the use of technological tools might facilitate comprehension of the topic for people with lack of expertise in the field, by extracting relevant concepts in a concise and precise way.

The limitations of the use of technological tools found during this study are the following: 1. The outcome (i.e. term extraction) sometimes could be ambiguous and depends on the interpretation of the analyst. For example, some terms have a different meaning, depending on the context of the topic. As a consequence, the probability of misinterpreting terms could be high; 2. The extraction of terms from each publication could limit the understanding of the field in depth. During the analyses, it was often necessary to read the whole abstract in order to better understand the definition of the keyword; 3. The analyses required a specific format of data compilation which is only provided by the SCOPUS and Web of Science, hence, data compilation from other published/unpublished sources is constrained; 4. In order to run the analysis, it was necessary to have a minimum amount of publications; as a consequence, specific topics with low numbers of publications (e.g. animal health) were considered within a bigger (or better studied) topic or research, obviating detailed analysis.

4.4. Gaps and limitation of the study

The systematic review presented in this study identified gaps in literature compilation which might reflect limited or lack of publications in particular research areas. In this study two main gaps or biases were observed: 1. Most of the studies were conducted by academic institutions from 'developed countries' and 2. Literature based in the ecological and social/cultural realms was scarce. These limitations may reflect the current status of knowledge of the field, but at the same time stimulates future investigation. Work in these areas may extend the understanding of the association between soundscape and wellbeing. It is important to also consider that gaps might be a consequence of a constrained search strategy. As discussed above, this study did not include information published in additional databases and in 'grey' literature, due to software requirements. Furthermore, it did not include other languages, which could be a bias particularly of publications conducted in non-western societies. Additionally, although keyword analysis provides relevant information on each publication, it does not cover all the theoretical thinking associated with this topic; as a consequence, important information published on the topic might not be considered within this framework.

This work should be taken as a general framework with which to understand the current status, with respect to academic material published on the field, of the associations between 'soundscape' and 'wellbeing'. Subsequent studies should be more exhaustive in terms of data compilation, and also consider delving more deeply into the content of the publications in order to improve the understanding of the proposed conceptual model of the linkages between 'soundscape' and 'wellbeing'.

5. CONCLUSION

This study characterized the status of knowledge on the field of soundscape and its associations with ecological and social wellbeing. In spite of the fact that research on sound and its impact on human health has had a long trajectory within academia (Ward and Fricke, 1969), it is only since the 21st Century that the topic has been studied in detail. The aim of this work was to bring together knowledge produced across disciplines that have contributed to the topic, in order to explain the origins and evolution of the field; and also understand the existing linkages, gaps and frontiers of knowledge. The outcome of this study illustrates how research on the topic originated from having a primarily medical/physiological focus, mainly oriented to human research, into a technological and psychological/social focus, and finally widening to include an ecological/social focus. Work published on the subject comprises a number of branches, which are related, and influence each other to differing degrees. Furthermore, the diversification of the field into branches seems to be related to the evolution of the topic which, at the same time, brought into use new concepts and terminology. It was clear how research evolved from studying particular associations between sound and health (mainly focused on noise and related topics), to multidimensional and integrative research on soundscape and its linkages with wellbeing. This development allowed the incorporation of a wider spectrum of topics, beyond the humanities driven focus, based on the concept of ecological wellbeing. The appearance of ecological-based research was influenced mostly by research from human-based disciplines (Pijanowski et al., 2011a).

The conceptual map presented comprises a range of associations between soundscape and wellbeing which are synthetized into three main categories: 'Human health', 'Social and Cultural wellness' and 'Ecological integrity'. The first category was the most representative, better understood and oldest topic explored over time; it is based on physical and physiological influences of soundscape on health. 'Social and Cultural wellness', is characterized by a range of associations, that describe individual and collective processes, based on aspects of identity, sense of place, memory, cultural heritage and social communication. Despite the high variety of associations found in this category, the number of publications on the topic was low. The category 'Ecological integrity' encompassed associations describing patterns of environmental communities and the influence of anthropogenic activities on them. Whilst these associations might be not so evident to comprehend in comparison with other categories, they suggested aspects of wellbeing influenced by 'high quality soundscapes', as reported in Dumyahn and Pijanowski (2011). More work on these associations should be addressed in the future in order to increase comprehension, as the study of 'ecological wellbeing' is relatively new. There is no clear concept of what 'ecological wellbeing' involves, yet scientists use a range of synonyms, such as 'biological/ecological/ecosystem integrity', or 'ecological/ecosystem health' to describe the ability of an ecosystem to support and maintain ecological processes and a diverse community of organisms (Karr, 1991). Moreover, there is no consensus of how to measure it, therefore results on the topic are scarce.

This work reports the largest analysis of the relationship between soundscape and ecological/human wellbeing to date. It could be considered as a reference for further work on the topic, especially within the field of soundscape ecology, which promotes research on the implications of soundscape conservation on wellbeing (Dumyahn and Pijanowski, 2011). The methodology used in this study is shown to be an effective tool for analysing large collections of data in short periods of time. With these tools the main questions of the study were addressed by extracting and synthesizing relevant concepts/terms generated by the topic; nevertheless, it was necessary to delve deeply into literature to understand the ambiguities or non-self-explanatory terminology. Further work is necessary in order to complete/improve the framework generated on the topic, in particular by including other sources of information (i.e. databases or 'grey literature') that were not considered in this study, and publications in other languages. Furthermore, several gaps in research were observed in the analyses; further research is recommended in order to develop a more comprehensive understanding of the associations between soundscape and wellbeing, such as information generated by non-western societies, and exploration of the ecological and sociocultural aspects of wellbeing.

CHAPTER 2

Ecological relevance of acoustic biodiversity monitoring: missing bits in the application of acoustic indices

ABSTRACT

Monitoring the dynamics and responses of wildlife populations to landscape modification is one of the main challenges in conservation science; however, it presents multiple constraints, not least the use of proper and efficient methodological tools. In recent years, passive acoustic monitoring has emerged as a promising method for biodiversity monitoring. In particular, the use of acoustic indices (AI) has been proposed as a potentially powerful tool for the evaluation of biodiversity at the community level, yet it still needs to be improved and effectively calibrated. It is important to understand the scope of AIs to describe biodiversity patterns occurring within wildlife populations. This study analyses whether current AIs (H, ACI, BI, AE) are describing relevant biodiversity patterns in avian and amphibian populations in an Ecuadorian Chocó rainforest. A temporal daily variation and a gradient of landscape modification were explored; fifteen recorders, set in three sites along the sampling area, were programmed to record the dawn and dusk/night chorus. Experts identified avian and amphibian species from resultant recordings, and estimated individuals per species for three days of recordings (5400 mins, 2700 for birds and 2700 for amphibians). The status of wildlife populations was evaluated using traditional biodiversity descriptors (e.g. Shannon, Simpson, Evenness, Jaccard indices) and biodiversity quality descriptors (e.g. species assemblage, species predominance, habitat use, species vulnerability). For comparisons, a range of acoustic indices (Shannon Index, Acoustic Evenness, Acoustic Complexity Index, and Bioacoustics Index) were calculated from the same database. The gradient of forest modification was evidenced in all biodiversity descriptors for amphibians. Birds showed the highest species richness for disturbed areas, yet biodiversity quality values were higher in the primary forest. No clear patterns were observed between the AIs and the biodiversity descriptors. Only the ACI was correlated with manual recorded species richness and abundance of birds. The sampling time, the properties of each AI, and confounding

anthropogenic sounds could have influenced the results for AI values. In order to fully understand the population status of communities, an acoustic approach that focuses also on qualitative values of biodiversity is recommended.

Keywords: acoustic indices, biodiversity measurement, Chocó rainforest, biodiversity quality, indicator species.

1. INTRODUCTION

Land use and forest cover are changing rapidly throughout the tropics. It is estimated that around half of the potential tropical closed-canopy forest has already been removed and the land converted to other uses, especially during the 1980s and 1990s, and the rate of deforestation has increased in some areas (Wright, 2005, Ramankutty and Foley, 1999). This rapid change is resulting in high rates of species extinction, which are currently cited to be elevated to at least a thousand times the natural background rate (Mittermeier et. al, 2011), and altering important ecosystem functions and services (Oliver et al.). Conservation of biodiversity is therefore considered a global priority and a major research agenda item (UNEP, 1992; Magurran, 2004), especially within *Hotspot* areas or areas of high diversity, endemism and threat (Myers et al., 2000). At the same time, biological knowledge-banks are sparse in these same regions, and new methods of biological diversity monitoring are needed in order to implement critical management plans and conservation action.

1.1. Measuring biodiversity and introduction to acoustic monitoring

Biodiversity assessment remains a challenging field: there are a range of diversity indices that have been developed in order to evaluate distinct components of biodiversity (Southwood and Henderson, 2000, Magurran, 2013). These include indices that attempt to express basic aspects of richness (e.g. Shannon (Pielou, 1966), Simpson (Peet, 1974) and Margalef (Margalef, 1958)), evenness metrics and dominance metrics (Magurran and McGill, 2011). Aspects of community structure have also been explored, such as compositional similarity and differentiation metrics (e.g. Jaccard and Sorensen (Sørensen, 1948)); species abundances distribution (e.g. commonness and rarity); and spatial placement of species (e.g. presence/absence of species)(Magurran and McGill, 2011). Functional diversity is also favoured as it has shown that ecosystem function is dependent not on the number of species itself, but on functional traits, and that it is considered more relevant to local-scale ecosystem functioning than taxonomic diversity (Hooper and Vitousek, 1997, Tilman, 2001, Naeem and Wright, 2003, Petchey et al., 2004, Hooper et al., 2005). Moreover it has been recognized that species are not equal in their effects on ecosystem functioning (Mason et al., 2005). Functional diversity describes a range of roles played by organisms in an ecosystem (Petchey and Gaston, 2002), and can reflect morphological, reproductive, physiological, or behavioural features of species (Bremner et al., 2003, Dumay et al., 2004). However, it is not clear how to quantify it (Mason et al., 2005). A relative new descriptor focuses on a range of qualitative values of biodiversity, such as species group characteristics/functionality that can be viewed in combination to create a picture of the biodiversity quality of an area (Feest, 2006, Feest et al., 2010). Despite the plethora of biodiversity measures which have been proposed to date, there is little agreement on which is the most effective tool to reflect biodiversity (Purvis and Hector, 2000, Morris et al., 2014).

Moreover, existing methods for surveying biodiversity are still being debated. Traditional methods of surveying wildlife populations can be invasive, time consuming, costly and logistically difficult, especially when they are conducted in remote habitats (Sueur et al., 2012); therefore, alternative techniques and methodologies have been proposed over the last 15 years (Magurran, 2004). One promising approach that quantifies ecological communities and their habitats, by the use of sound is ecoacoustics. Sound is considered both a component, and an indicator of ecological processes (Sueur and Farina, 2015, Towsey et al., 2014). Over the last 6 years, acoustic sensors have been introduced as a tool for assessing biodiversity of the entire community (e.g. Gasc et al., 2013b, Sueur et al., 2014a) as they are cheap, portable, reasonably accurate, non-invasive and can be applied at a range of different spatial and temporal scales (Sueur et al., 2012). Furthermore, rapid development of technology for passive acoustic monitoring makes this method promising. 28 acoustic metrics, mainly based on classic biodiversity indices, have been proposed in order to qualify and quantify environmental sounds (Sueur et al., 2014a). These metrics evaluate specific features of sound and are divided in α and β indices. Alpha indices estimate amplitude (intensity), evenness (relative abundance), richness (number of entities) and heterogeneity of the acoustic community; beta indices compare amplitude envelopes or frequency spectral profiles (i.e. similarities and dissimilarities) between acoustic communities or different dates of a focused community or landscape (Sueur et al., 2014a). Outcomes obtained to date have been promising, but mixed, showing that the current acoustic approach still needs to be improved and calibrated (Sueur and Farina, 2015). No clear consensus yet exists over which index - or combination of indices - is more effective for assessing biodiversity and its proper use (i.e. under which environmental/weather conditions). A number of constraints, especially related to technical and procedural problems, have been reported (Towsey et al.), causing misinterpretation of the sonic environment, such as: transitory or permanent background noise; variation in the distance of animals to the microphone; relative intensity and repetition in the calling of animals; time and/or frequency overlap between sounds arising from different sources (Sueur et al., 2014a).

It is vital therefore to understand whether information obtained with the use of acoustic indices are accurately describing the ecological processes occurring within wildlife populations, in order to improve the current analytical tools, reduce bias and generate a proper understanding of the ecosystems. Research comparing the accuracy of the acoustic indices with manual quantification of wildlife populations has been principally focused on avian and aquatic communities, through the use of classic metrics of diversity. For example, Towsey et al. (2013) used a combination of acoustic indices to compare acoustic values against avian species richness during the dawn chorus within a tropical rainforest in Australia. Gasc et al. (2013a) applied several diversity metrics to evaluate functional and phylogenetic diversity in bird communities across France, and correlated with acoustic diversity values. Whereas, Bertucci et al. (2016) used two acoustic indices to correlate with characteristics of the substratum and fish diversity in a marine ecosystem in France.

The aim of this study is to evaluate whether current acoustic indices are describing relevant biodiversity patterns occurring in avian and amphibian populations along a gradient of tropical rainforest modification. This work aims to contribute to ecological understanding of the status of wildlife populations by verifying the efficacy of acoustic indices. The impact of temporal daily variation and gradients of landscape modification on acoustic indices and wildlife populations were also explored.

1. METHODS

1.1. Data collection

An acoustic survey undertaken over a short period of time, called in this study Rapid Acoustic Monitoring (RAM), was conducted at three sites located along a gradient of landscape modification in the Ecuadorian Chocó Biogeographic Region: 1) a primary forest (3000ha, N0° 32' 7.044''; W 79° 8' 28.751''); 2) a secondary forest (10ha, N0° 7' 11.136'' W 79° 16' 25.355''); and 3) a palm oil plantation (40ha, N 0° 7' 48.864''; W 79° 12' 59.543''). The primary forest (Site 1), Tesoro Escondido, is an evergreen lowland tropical forest (Sierra, 1999) of around 300ha, comprised mostly of pristine forest, with dispersed small farms of cocoa, mixed-fruits trees and pastures. The secondary forest (Site 2), Puerto Quito, is a reserve of 10ha, isolated around 40 years ago from the first site and surrounded by farms of mixed fruit trees, pastures and palmito trees (*Chamaerops humilis*). The palm oil plantation (Site 3) is a monocrop of around 40 ha, mainly of palm oil trees (*Elaeis guineensis*), a few hectares of palmito (*Chamaerops humilis*) and mixed fruit trees. It is surrounded by other oil palm plantations and pastures, and is situated on the outskirts of Puerto Quito. The sampling area was located between 130-390 metres of altitude.

Fifteen digital audio field recorders (Wildlife Acoustics Song Meter, 7 SM2+ and 8 SM3+) were placed in each sampling area, with a separation distance of around 150 m between each other, to avoid pseudo-replication. Fourteen consecutive days, between June and August 2015, were audio sampled during peak hours of wildlife vocalisation at each site. Sampling schedules were defined relative to sunrise and sunset in order to capture the progression of dawn and dusk choruses (ten 1 minute samples every 15 min, starting 15min before sunrise; 20 samples of 1 minute every 15min from 60mins before sunset). The sampling rate was set at 48 kHz with a resolution of 16 bits. Microphone gains, which is the level used to increase the power of the recorded signals, were adjusted to minimise differences between recorder models. Through experimentation and consultation with the WildLife Acoustics technical team, analogue gains were set at +36dB on SM2+ and +12dB on SM3+ which has inbuilt +12dB gain and more sensitive signal pathway than the SM2+. Accurate calibration between recorders is necessary to ensure that the same environmental acoustic event produces the same recorded signal in all equipment. Changing the gain also adjusts the sensitivity of the recording equipment to a given sound, providing a means to control the effective spatial range of sensors. In areas of high acoustic activity, gains can be relatively low to ensure vocalisations in close proximity do not distort; this also minimises the amplification of system noise, creating a higher quality over all signal.

1.2. Data analyses

Analysis was divided into two components: 1) *Manual Processing*, based on the identification of avian and amphibian species by experts, followed by the estimation of a range of biodiversity patterns; and 2) *Automated Processing*, based on the use of the most commonly used acoustic indices (AIs) to estimate biodiversity.

1.2.1. Manual Processing

Amphibian and bird species were identified from three days of recordings by a herpetologist and ornithologist with expertise in the local/endemic communities. For each of 5400 1 min files (2700, files for birds and 2700 files for amphibians), a list of species was obtained together with an abundance proxy (vocal abundance estimation, VAE), based on the maximum estimated number of simultaneously vocalising individuals of each species. VAE of each species from each 1 min file and the overall VAE per species were calculated. A range of biodiversity metrics and populations descriptors were calculated from the resultant species data sets.

Traditional biodiversity descriptors calculated were species richness (*SR*); and the most used biodiversity metrics (*Shannon* (Shannon and Weaver, 1949), *Simpson* (Simpson, 1949), *Evenness* (Gini, 1912) and *Jaccard* indices (Jaccard, 1912) and; *species-uniqueness* (i.e. non-shared species percentage among sites)).

In order to gain deeper understanding of the population status of birds and amphibians through biodiversity quality descriptors, four further population descriptors were calculated:

i) *Species assemblage* analysis, which includes a *non-metric multidimensional scaling* analysis (NMDS) to test dissimilarities in species composition between sites and provides a graphical representation of the relative differences; significant differences were then tested using a PERMANOVA test (Adonis function in *vegan* package (Oksanen et al., 2007), R software).

ii) *Predominance of species,* which identifies the most abundant species at each site, for percentage values higher than 5. This value was considered representative for comparing the overall percentage values of all species.

iii) *Habitat use* analysis was conducted in order to find how the assemblage of species across sites was structured, according to ecological requirements of the species. A baseline of habitat use per species was first created from amphibian (Ron *et al*. 2006) and ornithological (Cornwell Lab of Ornithology, 2006) databases. Species were classified as being either specialists of primary forests, secondary forests or intervened habitats (Sites 1, 2 and 3, of this study, respectively). This information was compared with the amphibian and avian species lists through a habitat-congruence analysis in order to confirm that observations from each site align with previous classifications.

iv) *Species* V*ulnerability,* which evaluates how fragile a community is to habitat intervention according to the number of sensitive-species on each site. Evaluation of species-sensitivity was conducted using a classification scheme of categories of threat, accordingly to the Ecuadorian Red List defined with the IUCN criteria[4] (IUCN, 2006).

1.2.2. Automated processing

All recordings were pre-processed with a high pass filter at 300 Hz (12 dB) to attenuate the impact of anthrophony and to minimise loss of low frequency biophony. Acoustic Indices were calculated from the same audio files used in manual identification. Four of the most commonly used AIs (*Shannon Index (H*), *Acoustic Evenness* (*AE*), *Acoustic Complexity Index* (*AC*I)(Sattar et al., 2016), and *Bioacoustic Index* (*BI*) (Boelman et al., 2007), were calculated using the *seewave* (Sueur et al., 2008a) and *soundecology (Villanueva-Rivera, 2015)* package in R software (Version 3.0.2: R Foundation for Statistical computing Vienna, Austria), and a mean value per audio file was computed:

1. *Shannon or Acoustic Entropy Index* (H)(Sueur et al., 2008b) is based on the Shannon Index (Shannon and Weaver, 1949), that measures heterogeneity from recordings based on a set of categories differing in frequencies (species distribution); and also evaluates the evenness of the amplitude envelope over the time units (distribution of sound energy). *H* is a result of multiplication of temporal and spectral entropies. The value increases with the evenness of the frequencies of the categories and with the number of categories.

[4] The categories defined by the IUCN are Low Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Not Evaluated (NE), Data Deficient (DD). In this analysis the categories NE and DD were not used.

2. *Acoustic Evenness* (AE)(Villanueva-Rivera et al., 2011) calculates the Gini coefficient (Gini, 1912) of occupancy at each frequency band (considered as a specific "species"), measuring the inequality among values of a frequency distribution. This value is obtained by dividing the spectrogram into frequency bands, and calculating the Gini coefficient on the proportion of the signals in each bin above a threshold (-50 dBFS).

3. *Acoustic Complexity Index* (ACI)(Farina et al., 2011) was designed to measure the spectral and temporal dynamics of a soundscape, especially in bird vocalisations, in order to highlight changes in behaviour and composition of a community. In a matrix of intensities extropolated from the spectogram, divided into temporal steps and frequency bins, the ACI calculates the absolute difference between two adjacent values of intensity in a single frequency bin and for a temporal subset.

4. *Bioacoustic Index* (BI)(Boelman et al., 2007) was designed to detect changes in the sound level and range of frequency bands of the overall avian community. It is calculated using the area under the mean spectrum minus the minimum frequency value of this mean spectrum across a specified range.

In order to compare AIs with all the biodiversity descriptors, derived from manual species identification, an overall mean value for each AI was calculated per site, using the same database used in the manual component. A Friedman Test was run to identify any significant differences between sites. Spearman's rank correlation test was computed to explore associations between the two population diversity descriptors (*species richness* and *VAE*) and all acoustic values (AIs).

All analyses were performed in R (Version 3.0.2: R Foundation for Statistical computing Vienna, Austria) and SPSS (IBM SPSS Statistics 22).

2. RESULTS

2.1. Manual Processing

2.1.1. Amphibian

Eighteen amphibian species were identified. VAE and percentage of abundance of each species across sites is shown in Annex 4. The richest (SR) amphibian community was found in Site 1, followed by Site 2 and Site 3. Nevertheless, VAE was higher in Site 3 than in Sites 2 and 1 (Table 1). Population diversity indices (*Simpson*, *Shannon* and *Evenness*) also showed the highest values for Site 1, followed by Sites 2 and 3 (Figure 1, Table 1). The percentage of shared species (*Jaccard*) between Sites 1 and 2 was higher than the percentage shared between Sites 1 and 3; and this first value was higher than the percentage shared between Sites 2 and 3.

Table 1. Traditional biodiversity descriptors of avian and amphibian communities registered during the RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). The values in parenthesis are showing the 95% confidence intervals.

	AMPHIBIANS			**AVIAN**		
SITE	**1**	**2**	**3**	**1**	**2**	**3**
SR (TOTAL NUMBER OF SPECIES)	**14**	12	10	92	**106**	96
VAE (VOCAL ABUNDANCE ESTIMATE)	1130	538	**2889**	1943	**2554**	2400
SIMPSON	**0.72** (0.70 0.74)	0.31 (0.26 0.36)	0.57 (0.55 0.58)	0.93 (0.92 0.94)	**0.97** (0.96 0.97)	0.96 (0.95 0.96)
SHANNON	**1.65** (1.58 1.70)	0.74 (0.63 0.85)	1.05 (1.02 1.08)	3.48 (3.42 3.54)	**3.84** (3.80 3.88)	3.74 (3.70 3.79)
EVENNESS	**0.37** (0.34 0.39)	0.17 (0.16 0.19)	0.29 (0.28 0.30)	0.35 (0.33 0.37)	**0.44** (0.42 0.46)	0.44 (0.42 0.46)
NO. OF UNIQUE SPECIES	**3**	1	2	**22**	7	12
% OVERALL UNIQUENESS	**16.7**	5.6	11.1	**14.5**	4.6	7.9
JACCARD INDEX SITE 1-SITE 2		62.50			45.59	
JACCARD INDEX SITE 1-SITE 3		41.18			36.23	
JACCARD INDEX SITE 2-SITE 3		46.67			60.32	

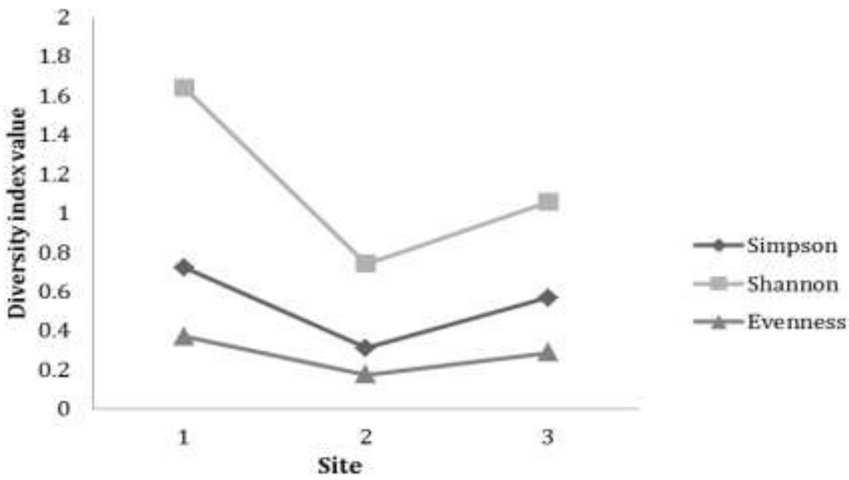


Figure 1. Traditional biodiversity indices Shannon (a), Evenness (b), and Simpson (c) of amphibian communities registered during the RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

The NMDS ordination (Figure 2) illustrates clear species assemblage differentiation across sites with few shared species. Site 1 is grouped further from Site 3; likewise, the distribution of species in Site 1 is more spread out in comparison with Sites 2 and 3, which show a clustered distribution. Significant differences are observed in the species assemblages across sites ($R=0.32$, $p \leq 0.001$).

It was noticeable that a few species were highly representative of each site, especially in Site 3 (Annex 4). The most dominant species, based on overall percentage higher than 5%, within Site 1 were *Pristimantis labiosus, Barycholos pulcher* and *Pristimantis subsigillatus*. In Site 2 dominant species were *Pristimantis achatinus* and *Pristimantis subsigillatus*. Whereas in Site 3 *Pristimantis achatinus*, *Hypsiboas boans* and *Rhinella marina* dominated.

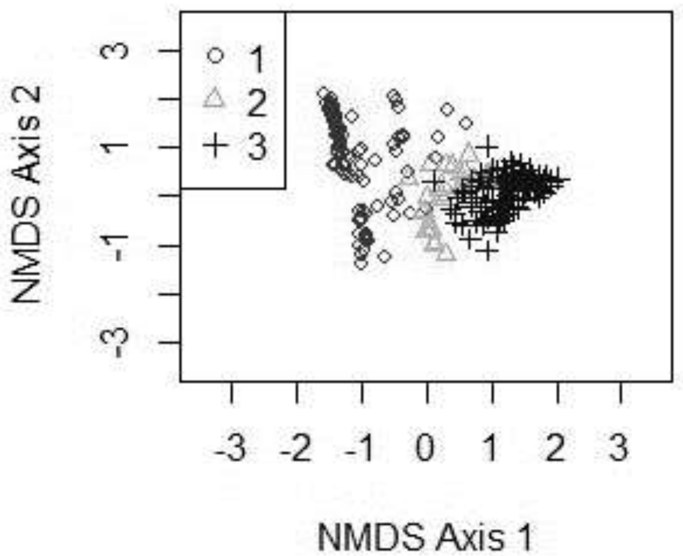


Figure 2. NMDS plot of total amphibian community composition in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

Species vulnerability evaluation (Table 2, Figure 3) suggests that the percentage of threatened species was higher in Site 1, followed by Sites 2 and 3. Furthermore, the most endangered species (VU and EN, according to the UICN classification in Ron et al. 2016), were found mainly within Site 1. Species-uniqueness analysis (Table 1) showed that Site 1 had the highest overall percentage, followed by the Site 3 and 2.

Table 2. Biodiversity quality descriptor, Species Vulnerability evaluation of amphibian communities registered during the RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). The overall percentage of threatened species per site is shown (%).

Site	**1**	**2**	**3**	**% 1**	**%2**	**%3**
No. frogs species	14	12	10			
VAE frogs	1130	538	2889			
Vulnerability-Conservation Status						
Least Concern	7	7	6	19	19	17
Near Threatened	2	2	2	6	6	6
Vulnerable	1	1	0	3	3	0
Endangered	1	0	0	3	0	0

No. threatened amphibian species	4	3	2
% threatened species per location	29	25	20
% threatened species all locations	11	8	6

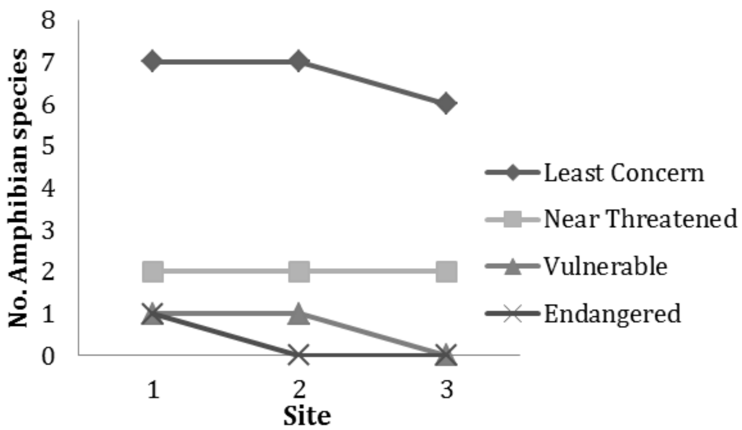


Figure 3. Biodiversity quality descriptor, Count of threatened species in the amphibian community registered during the RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

Habitat use analysis (Table 3) showed that observations aligned with previous classifications (Ron *et al.*, 2016), with some overlap between sites: 'species of primary forest' were more often registered in Site 1, followed by Site 2 and 3; 'species of secondary forest' were observed equally in Sites 1 and 2, followed by observations in Site 3; 'species of intervened areas' were mostly found in Site 2, followed equally by Site 3 and Site 1 (Figure 4).

Table 3. Biodiversity quality descriptor, Habitat use-congruence analysis in the classification of amphibian species, registered during the RAM at three sites of NW in Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3), by ecological requirements (´species specialists of primary forests´, ´species specialists of secondary forests´ or ´ species specialists of intervened habitats´).

	Amphibian species-congruence observed						
Habitat preference*	**Overall. species no.**	**1****	% 1***	**2**	% 2	**3**	% 3
Species of primary forest	14	11	79	9	64	7	50
Species of secondary forest	15	11	73	11	73	9	60
Species of intervened areas	8	6	75	7	88	6	75

* According to species information classification consulted on AmphibiaWeb (2016).

** Number of ´species of primary/secondary forest or intervened areas´ registered in the 1 Primary, 2 Secondary, 3 Oil Palm.
*** Overall percentage of number of ´species of primary/secondary forest or intervened areas´ registered in the 1 Primary, 2 Secondary, 3 Oil Palm

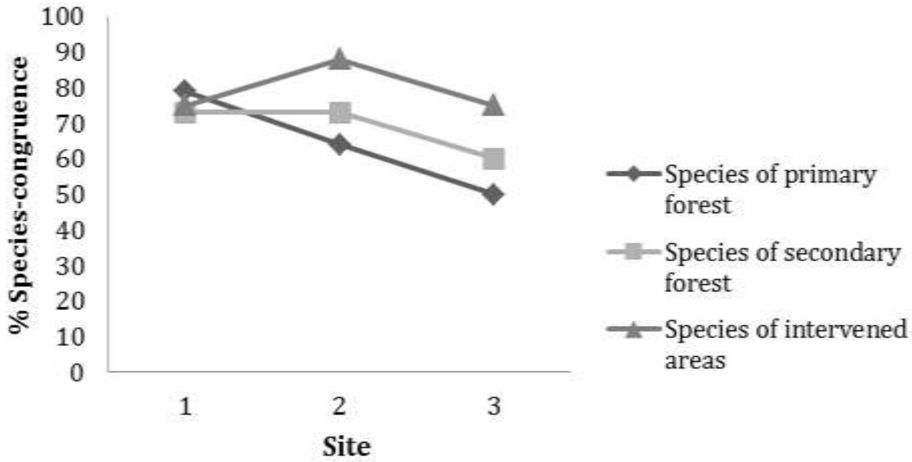


Figure 4. Biodiversity quality descriptor, Habitat use-congruence analysis. Overall percentage of species congruence in the classification of amphibian species, registered during the RAM at three sites in NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3), by ecological requirements.

2.1.2. Birds

156 avian species were registered by the ornithologist in the *Manual Component*. Results for VAE and percentage per species across sites is shown in Annex 5. Population diversity analyses are shown in Table 1: the highest species richness and most abundant avian acoustic community was found in Site 2, followed by Sites 3 and 1. Likewise, population diversity indices (*Simpson*, *Shannon* and *Evenness*) show the highest values in Site 2, followed by Sites 3 and 1 (Figure 5, Table 1). *Jaccard* showed that Site 2 shared more species in common with Site 3 than with Site 1, and that Site 3 and Site 1 shared the lowest percentage of species.

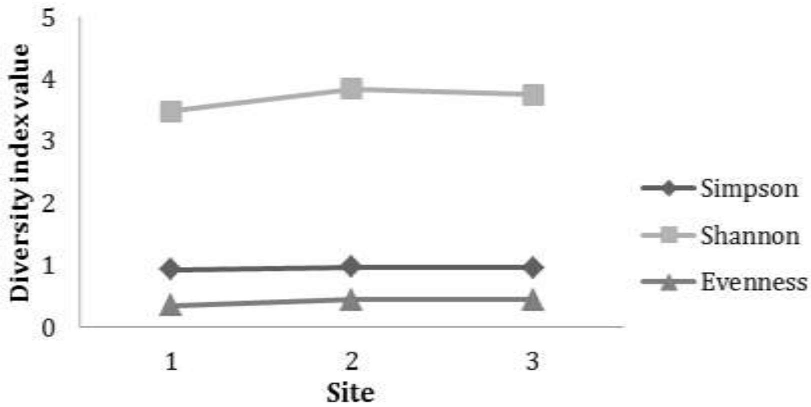


Figure 5. Traditional biodiversity indices Shannon (a), Evenness (b), and Simpson (c) of avian communities registered during the RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

The NMDS ordination (Figure 6) illustrates the split between sites. There was a differentiation in species assemblage across sites. Site 1 was clearly separated from Sites 2 and 3; whereas Site 3 was closer to Site 2 and included species within the cluster group of this last site. Furthermore, the PERMANOVA test revealed that there was a significant difference in species assemblage across sites ($R=0.18$, $p \leq 0.001$).

We found that some species were more representative than others for particular sites, based on their overall percentage (>5%)(Annex 5). For example, *Poliocrania exsul*, *Microbates cinereiventris* and *Amazona farinosa* were mostly dominant in Site 1; in Site 2 *Crypturellus soui*, *Leptotila pallida* and *Baryphthengus martii* dominated; whereas in Site 3 most abundant species were *Euphonia fulvicrissa* and *Myiozetetes cayanensis*.

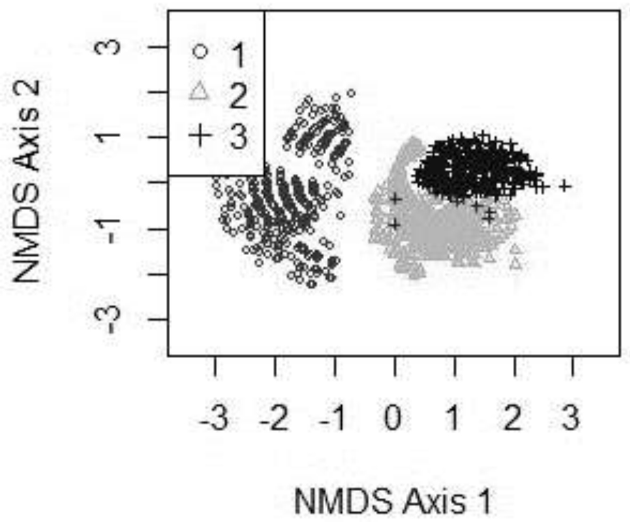


Figure 6. NMDS plot of total avian community composition at three sites in NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

Species vulnerability evaluation (Table 4, Figure 7) showed that the percentage of threatened species in Site 1 was more than twice that of Sites 2 and 3. Furthermore, the most endangered species (VU and EN, according to the IUCN classification), were found mainly within Site 1. The analysis of species-uniqueness (Table 1) also found that Site 1 had the highest overall percentage of unique species, followed by Sites 3 and 2.

Table 4. Biodiversity quality descriptor, Species Vulnerability evaluation of avian communities registered during the RAM at three sites in NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). The overall percentage value per site is shown.

	1	2	3	% 1	%2	%3
No. birds species	92	106	96			
VAE birds	1943	2554	2400			
Vulnerability -Conservation Status						
Least Concern	67	95	85	23	32	29
Near Threatened*	10	6	4	3	2	1
Vulnerable*	13	4	6	4	1	2
Endangered*	2	1	1	1	0	0
No. threatened birds species	25	11	11			

% threatened species per location	27	10	11
% threatened species all locations	9	4	4

***categories considered as 'threatened'**

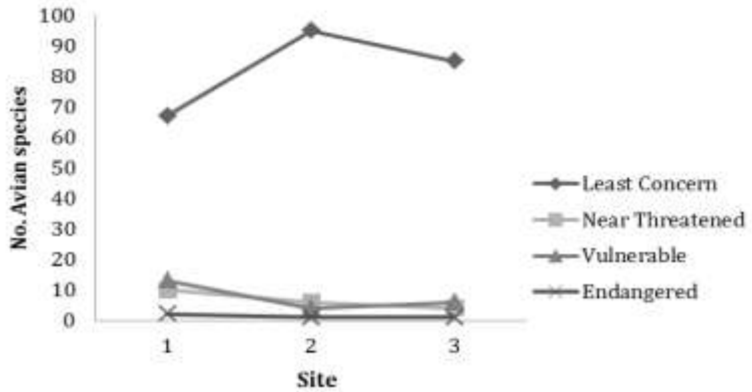


Figure 7. Biodiversity quality descriptor, count of threatened species in the avian community registered during the RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

Habitat preference evaluation (Table 5) showed that according to species classification (del Hoyo et al., 2016) 'species of primary forest' were mostly found in Site 1 and less often found in Site 3; 'species of secondary forest' were mostly present in Sites 2 and 1, but fewer registered in Site 3; whereas 'species of intervened areas' were found mainly in Site 3 and less so in Site 1 (Figure 8).

Table 5. Biodiversity quality descriptor, Habitat use-congruence analysis in the classification of avian species, registered during the RAM at NW Ecuadorian primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3), by ecological requirements (´species specialists of primary forests´, ´species specialists of secondary forests´ or ´ species specialists of intervened habitats´).

	Bird species-congruence observed						
Habitat preference*	**No. species**	**1**	% 1	**2**	% 2	**3**	% 3
Species of primary forest	104	78	75	71	68	59	57
Species of secondary forest	122	76	62	94	77	80	66
Species of intervened areas	83	41	49	67	81	68	82

* According to species information classification in The Cornell Lab of Ornithology (2016).

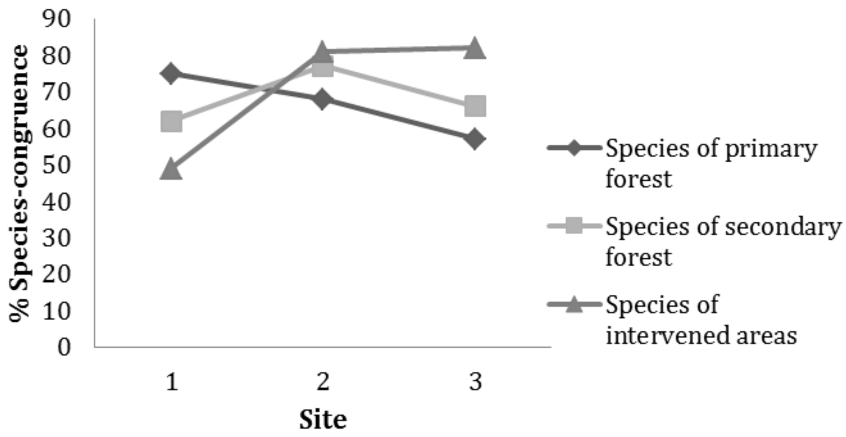


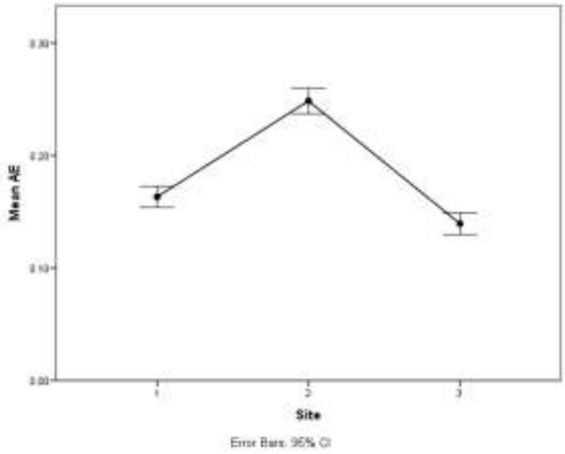
Figure 8. Biodiversity quality descriptor, habitat use-congruence analysis. Overall percentage of species congruence in the classification of avian species registered during the RAM at three sites in NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3), by ecological requirements.

3.2. Automated Processing

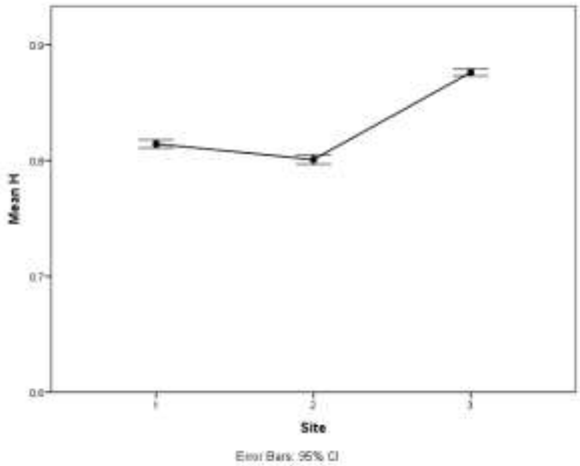
3.2.1. Amphibian dataset

The analysis revealed considerable variation in all acoustic indices across sites (Friedman Test, *ACI*, $\chi 2(2)$ =289,1, p < <0.0015; *H*, $\chi 2$ (2) =621.9, p <<0.0015; *BI* $\chi 2$ (2) =370,6, p < <0.0015; *AE*, $\chi 2$ (2) =185,7 p < <0.0015). Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons confirming the significant differences across sites (p <0.0015). Different values across AIs were found (Figure 9, Annex 6): ACI showed the highest mean value in Site 1, followed by Sites 2 and 3. H showed the highest mean value in Site 3, followed by Site 2 and 1; whereas BI and AE revealed the highest mean value in Site 2, followed by Site 1 and Site 3.

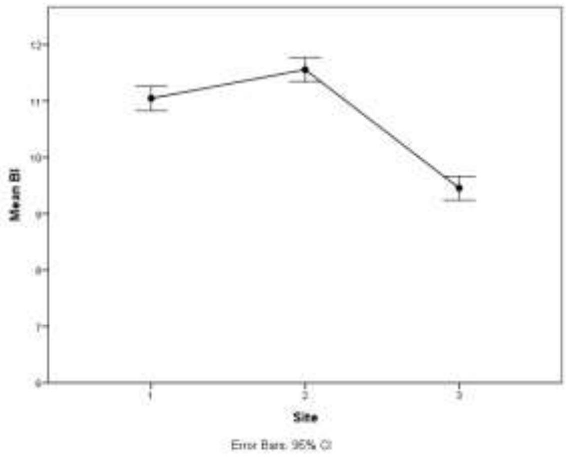
There was a weak association between all the acoustic values and the population descriptors, *VAE* and *SR,* as most of the correlation coefficients were close to 0 (Table 6). *ACI* was the only index that showed the highest, but still relatively low and negative association with these population descriptors.


0.30
0.20
0.10
0.00
Mean AE
1
2
3
Site
Error Bars: 95% CI

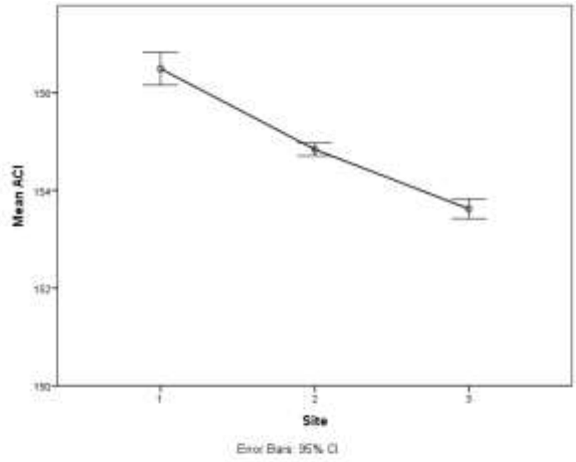
a


0.9
0.8
0.7
0.0
Mean H
1
2
3
Site
Error Bars: 95% CI

b


12
11
10
9
8
7
0
Mean BI
1
2
3
Site
Error Bars: 95% CI

c



d

Figure 9. Mean value of AIs within the amphibian dataset: a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index, BI; d) Acoustic complexity Index (ACI), computed for the amphibian dataset during the peak hours of activity in a RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Error bars represent 95% confidence intervals.

Table 6. Spearman correlation coefficients of the population descriptors, species richness (SR) and vocal abundance estimate (VAE), and the acoustic indices a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index, BI; d) Acoustic complexity Index (ACI), computed for peak hours of amphibian activity at a RAM in three sites in NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

		H	ACI	AE	BI
VAE	Correlation Coefficient	.088**	-.236**	.069**	.067**
	Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001
SR	Correlation Coefficient	.046*	-.175**	.046*	.078**
	Sig. (2-tailed)	.018	<0.001	.016	<0.001

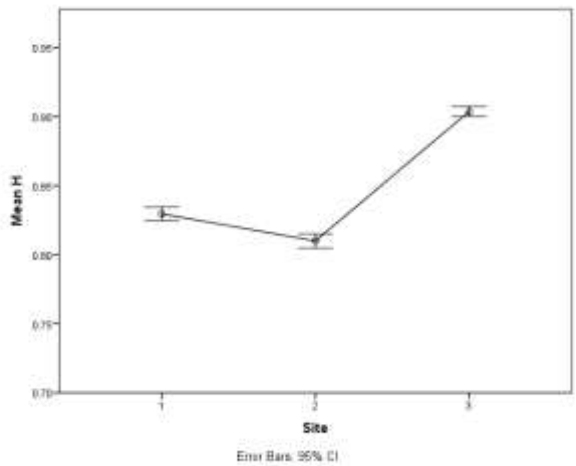
**. Correlation is significant at the 0.01 level (2-tailed).

3.2.2. Avian dataset

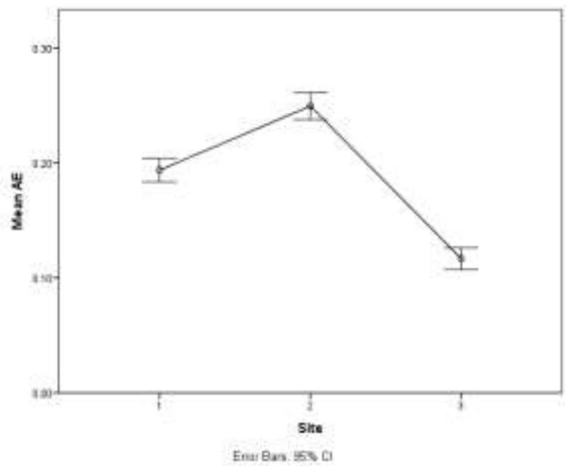
The analysis also revealed variation in all AIs across sites (Friedman Test, *ACI*, $\chi2(2)$ =105,2 p < <0.0015; *H*, $\chi2$ (2) =1580,4 p < <0.0015; *BI,* $\chi2$ (2) =495,6 p < <0.0015; *AE*, $\chi2$ (2) =358,2 p <0.0015). Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons confirming the significant differences across sites (*p* < <0.0015). Different values were found across the AIs

(Figure 10, Annex 7): *AE* was the only index that showed the highest mean value in Site 2, followed by Sites 1 and 3. *ACI* and *H* showed the highest mean values in Site 3, followed by Sites 1 and 2; whereas *BI* showed the highest mean value in Site 1, followed by Sites 2 and 3.

Correlation tests show that the only index that shows a stronger and a positive association with *VAE* and *SR*, was *ACI*. *BI* and *H* were weakly correlated, with *BI* related negatively (Table 7). *AE* showed a negligible correlation with *SR* and *VAE*.



a



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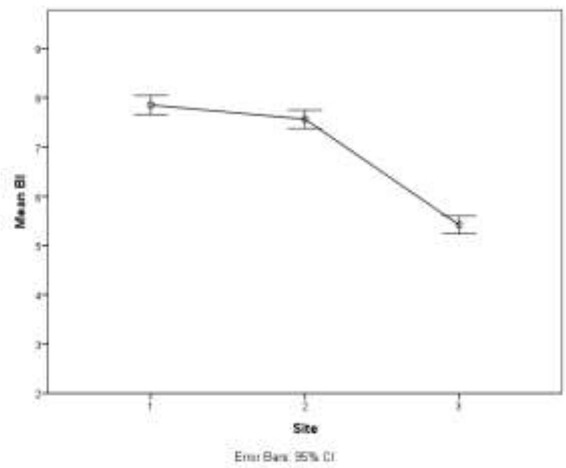

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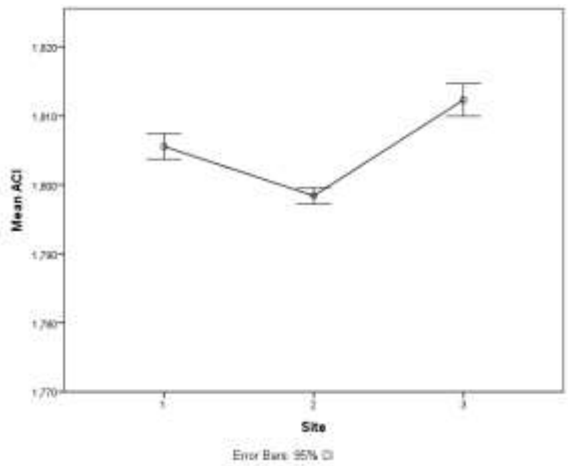


d

Figure 10. Mean value of AIs within the avian dataset: a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index, BI; d) Acoustic complexity Index (ACI), computed for the avian dataset recorded during the peak hours of activity in a RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Error bars represent 95% confidence intervals.

Table 7. Spearman correlation coefficients of the population descriptors, species richness (SR) and vocal abundance estimate (VAE), and the acoustic indices a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index, BI; d) Acoustic complexity Index (ACI), computed for peak hours of the avian activity in a RAM at three sites in NW Ecuador: primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

		H	BI	ACI	AE
VAE	Correlation Coefficient	.340**	-.363**	.420**	-.115**
	Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001

SR	Correlation Coefficient	.349**	-.377**	.423**	-.131**
	Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001

**. Correlation is significant at the 0.01 level (2-tailed).

3. DISCUSSION

In this study multiple analyses were used to assess the degree to which AIs reflect ecologically meaningfully processes, such as the status of wildlife populations for a gradient of forest degradation. In order to frame this evaluation, it is important firstly to consider the population status of each of the taxa observed in this study, and then compare it to the AI values.

3.1. Manual processing

We found that the gradient of landscape degradation used in this study was reflected in the status of amphibian communities, as measured by all biodiversity descriptors. The primary forest harbours the healthiest community, not only in terms of biodiversity (e.g. species richness and evenness), but also in the high number of species that are disturbance-sensitive, unique (i.e. absent in other habitat types) and threatened. Results of both traditional biodiversity descriptors and quality biodiversity descriptors showed that amphibians are a susceptible taxon to habitat change, in line with research that reports that habitat loss and modification is one of the main causes of its declination (Cisneros-Heredia et al., 2010, Stuart et al., 2004). Similar population patterns were found in other studies in the Neotropics in amphibians (Gardner et al., 2007, Heinen, 1992). For example, in the Brazilian Amazon, Gardner et al. (2007) observed that the primary rainforest harboured more species than the degraded forests, but supported similar abundance when compared to secondary forest or plantations. Likewise, they reported that plantation forest was dominated by wide-ranging habitat generalists, which was also evident in the degraded areas of this study.

In the case of the avian communities, opposing responses were observed between traditional biodiversity descriptors and biodiversity quality descriptors. The highest patterns of species richness measured by traditional biodiversity descriptors were found in disturbed areas, especially in the secondary forest. Nevertheless, biodiversity quality descriptors, such as the number of sensitive species or species threatened, were higher within non-intervened areas. As in amphibians, we might expect to find healthiest/richest communities in undisturbed forest considering that one of the main sources of extinction in birds is habitat loss (Bennet and Owens, 2002); nevertheless, it is important to consider that patterns of extinction could vary according to lineage and that some families are more vulnerable than others (Bennet and Owens, 2002).

These observations highlight the value of subtler species assemblage analyses in ecological evaluations. As seen in amphibians, avian species assemblage also differed across habitats, and some population features such as presence/absence or abundance of certain species, aligned with the degree of habitat degradation. Blair (1996) has also found an increment in avian species richness along a gradient of urbanization, but he observed that it was a result of the addition of widely distributed species at the expense of native species, which was also observed in the communities in this study. This was also found in our study as secondary forest was composed of species that can be found in both extremes (i.e. old growth forests and cultivated lands). As reported in other second growth forests, such as in Costa Rica (Blake and Loiselle, 2001), high avian species richness could be explained due in part to the proximity of old-growth forest which serves as a source, and because second-growth habitats are considered an abundant source of resources, such as fruits and flowers. It is possible that the species assemblage of birds in the secondary forest has been influenced by the proximity of both extremes of habitat, given the spatial and temporal dynamics of landscape influence the initial establishment of secondary forest patches, their changing species composition, and their persistence (Chazdon et al., 2009).

It is important to consider that this study was based on the understanding of the status of two taxonomic groups that differ greatly in their biology and ecological behaviour. For example, the dispersion capacity in birds is greater than in amphibians; it is known that volant vertebrates are often highly adept at crossing wide gaps (Lees & Peres 2009) and typically show the highest rates of successional influx. Therefore, the responses to habitat change in each group might vary, and this could be reflected in the status of those communities. Here we observe that the amphibian communities seemed to be more affected by habitat intervention than birds (in terms of biodiversity richness), in line with previous reports suggesting that amphibians are more threatened and declining more rapidly than birds (Stuart et al., 2004).

3.2. Automated Processing: Acoustic Indices

Significant differences between all indices at each site for both taxa were observed; however there was no clear pattern between the acoustic indices and manually recorded species richness or abundance. In the case of the amphibian dataset, the results did not show the gradient of forest intervention revealed by the *Manual Component*. ACI was the only index that approximated to these findings when analysing mean values per site; nevertheless, this value does not seem to reflect population status of amphibians as the correlation between population descriptors and AIs was weak.

Likewise, in the avian dataset the AIs found differences in the acoustic patterns across sites; however, the gradient of forest intervention through the mean values calculation was not clear. A stronger correlation between the AIs and the patterns of species richness and abundance, in comparison with the amphibian dataset, was found-especially with the index ACI, and H and BI (negatively for the latter).

These differences found across AIs could be explained by some interrelated factors which are based on the: 1) the sampling time, 2) the properties of each acoustic index, and 3) anthropic activity.

The first factor refers to the sampling time variation used in this study based on the acoustic activity peaks of each taxon. For example, in the case of the amphibian dataset the recording periods were selected during dusk-night chorus when most of the insects (such as crickets and katydids) also became more acoustically active in comparison to the rest of the day (Alexander, 1960; Young, 1981). According to Young (1981), dusk cicada choruses occur after the burst activity of many insectivorous birds. Hence the differences of acoustic activity of other taxa, not considered in this research, could have influenced the acoustic values.

The second factor relates to the individual capacity of each acoustic index to process different signals within a soundscape. For example, constant vocalizations, such as those generated by cicada and Orthoptera are considered one of the main causes of biased values in the acoustic indices and has been highlighted in interpretation of H (Gasc et al., 2013a). In contrast, dawn chorus is considered the quietest and optimum time (in ecological terms) of the day for birds to sing most intensively (Farina, 2001); and their vocalizations are temporal segregated from the calling activity produced by nocturnal insects (Bittencourt et al., 2016) and frogs. The stronger correlation in the avian dataset, in comparison with the amphibian dataset, could be explained partly by this temporal partitioning in the calling activity of some species of insects and frogs during the dawn chorus (i.e. the avian dataset had less acoustic disturbance from other taxa, allowing AIs to better reflect avian communities). Furthermore, given that ACI was designed to track avian vocalizations (Sattar et al., 2016), it was strongly correlated with the patterns observed in the avian communities during the dawn chorus. Likewise, H showed a stronger association with those patterns in comparison to the other AIs, which also could be explained by the better acoustic conditions present during the dawn chorus, especially when considering that H is affected by background noise (Gasc et al., 2013a). The sensitivity to nocturnal biophony by H has also been mentioned in Ritts et al. (2016). As a result presence of other vocalising taxa appears to be an important factor in determining the efficacy of AIs in reflecting wildlife population status.

The third factor could be the variety of sounds produced from a range of anthropogenic activities that could not be removed from the audio files. This noise was mostly comprised of domestic animal vocalizations (such as dogs and roosters), registered in 14% of the files within the intervened sites; and sounds of human voice and music, registered in 9% of the files mostly within the intervened sites – especially during dusk (Annex 8). It is possible that these sounds lie within the frequency ranges in which the indices are calculated and would have influenced the results. An example of this situation has been found for ACI (Sattar et al., 2016), where they show that a variation of sound intensities of anthropic origin, as found in our study, can be registered by the index. Another similar observation was reported by Fairbrass et al. (2017) during biodiversity monitoring in an area dominated by anthrophony, where a number of anthropogenic sounds occupied similar frequencies to biotic sounds. Furthermore, a few sounds of machines (such as cars and chainsaws), registered in 12% of the files, were not completely removed from the files, which could also have affected the acoustic indices. It was also noted that the highest percentage of anthropogenic sounds was found mostly during the dusk chorus, so acoustic interpretation of wildlife communities would be better reflected during the dawn period than within the dusk-night periods. Biases in current acoustic indices (including ACI and BI) due to anthropogenic noise were reported during urban biodiversity monitoring in Greater London (UK)(Fairbrass et al., 2017).

ACI was the most effective index in reflecting population patterns of the taxa in this study, as its mean values were similar to the species richness and abundance values generated by observers listening in the Manual component. It was confirmed that this index is not sensitive to constant sounds, such as insect vocalization (Sattar et al., 2016, Gasc et al., 2013a, Ritts et al., 2016), but also that it registered intermittent anthropic sounds, generating reliable results. On the other hand, contrary to what has been reported for BI (Boelman et al., 2007, Ritts et al., 2016), population patterns, such as the abundance of avian and amphibian communities were not reflected in the analysis. Likewise, the AE index generated the highest mean value in secondary forest in all files, but if we consider that this index measures occupancy at each frequency band (Sattar et al., 2016), it could be possible that, as this site presented a high variation in frequencies of anthropic sounds (such as human voice, music, domestic animals), poor interpretation of the actual wildlife acoustic community could have resulted. It was also confirmed that H was not a reliable index when analysing soundscapes that present background or broadband noise (Ritts et al., 2016, Gasc et al., 2013b), as it confuses them with high values of acoustic energy, hence high acoustic diversity values.

4. CONCLUSIONS

This study evaluated the power of the acoustic indices to capture the population status of amphibian and avian communities along a gradient of tropical landscape intervention. The results showed that, from the selected automatic indices, only the ACI reflects the status of avian communities, as measured by their abundance and species richness. The factors that could have influenced this outcome seem to be related mainly to the dynamics of the acoustic community (i.e. dawn-dusk-night variation), properties of each acoustic index and the influence of a diverse range of anthropogenic sounds. This study suggests that tropical pre-urban farmland areas present a range of anthrophonic noises that could be biasing current AI values. Further research within similar ecological/habitat conditions should be undertaken to confirm this hypothesis. It is important to develop technologies capable of the automatic detection of anthropogenic sounds, during acoustic biodiversity monitoring in order to reduce biases caused by it.

Rapid acoustic monitoring was seen to be a time-effective tool for obtaining a preliminary understanding of community assemblage of amphibian and avian species within the study area; and also of species that describe the status of an ecosystem, or ‘indicator species’. The importance of taking into account additional ecologically meaningful information when conducting automatic acoustic analysis was highlighted. In order to fully understand the population status of communities, an acoustic approach that also focuses on qualitative values of biodiversity (i.e. species uniqueness, species vulnerability, community assemblage, habitat use, etc.), is recommended. Even though ecoacoustics addresses community, rather than individual level (Sueur and Farina, 2015) processes, this study showed that individual values of species could also be relevant in understanding ecological processes at higher levels of biological organization. Qualitative values of biodiversity were not captured by automatic acoustic analysis, which corroborates that a gain in computational efficiency could be a loss of ecological efficacy

(Eldridge et al., 2016). It is important here to acknowledge that high diversity does not ensure that a site has high ecological value (Dunn, 1994); and that species richness alone may not be sufficient to fully understand ecosystem resilience and functioning (Chillo et al.). In order to facilitate and complement the understanding of the health status of wildlife communities and the ecosystem through acoustic indices, it might be necessary to improve or develop additional tools, such as the implementation of indicator species detectors, especially in areas that confront complex natural-human systems (hence, present high variation of anthrophony). Conservationists have used the concept of 'indicator species' as an alternative to facilitate the understanding of the effects of habitat change in wildlife communities (Caro, 2010). For example, if a species is significantly more frequent in an undisturbed area, it could be considered a 'positive' indicator of ecological integrity, whereas if it is significantly more frequent in a disturbed area, it could be considered a 'negative' indicator of ecological integrity (Carignan and Villard, 2002).

Acoustic indices are a powerful tool for rapid evaluation of ecosystem health, and present a number of advantages over traditional methods of sampling (as mentioned in section 1), however some care must be taken, particularly when monitoring areas with a range of anthropogenic activity and when recording during the dusk-night period.

CHAPTER 3

Can automatic acoustic detection of ecological indicator species be used to rapidly evaluate ecosystem health?

ABSTRACT

Rapid Acoustic Survey (RAS) has been proposed as an efficient tool for rapid ecological exploration in tropical environments. To date it has generally been applied at the community level through the use of automatic acoustic indices that measure the diversity, heterogeneity or evenness of vocalisations at a site. Complementary to community level analysis, this study presents a practical tool for rapidly obtaining ecologically meaningful information about an area, through the automatic detection of indicator species of ecological integrity (IS). In order to identify IS of ecosystems with different grades of intervention, a gradient of landscape modification in the Ecuadorian Chocó rainforest was selected. Three days of recordings (5400 one min. files per site) during peak times of activity at three sites were analysed. The methodology involved: 1) avian and amphibian species identification by experts, 2) identification of "positive" indicator species (IS) through a multi-criteria analysis based on the Indicator Value (IndVal), and 3) design and performance evaluation of automatic recognizers for IS using Song Scope software. Three avian species (Black-headed Antthrush, Rufous Piha and Ocellated Antbird) and one amphibian (Labiated Rainfrog) were identified as IS. Recognizers for the avian species were built but resulted in low precision rates: Black-headed Antthrush (9.4%), Ocellated Antbird (3.1%) and Rufous Piha (1.2%). However, recall rates were higher: Ocellated Antbird (83.8%), Rufous Piha (73.1%) and Black-headed Antthrush (54.5%). Specific characteristics of vocalisations, such as high energy, broad frequency and distinctive spectral properties, are well recognized by the software. Even though the specific software tool used for automatic detection was problematic (high rate of misidentification), the proposed approach was effective to rapidly evaluate the ecosystem health of biodiversity rich environments, such as tropical forests. This application is

recommended to be combined with the RAS approach, in order to gain a rapid understanding of status of an ecosystem.

Keywords: rapid biodiversity assessment, acoustic monitoring, indicator species, automatic call recognition, Ecuadorian Chocó, birds

1. INTRODUCTION

1.1. Indicator species as ecological indicators

Given the increasing recognition of human impact on ecosystems, the development of tools that assess environmental conditions and trends is an urgent priority, not only in conservation biology and other environmental sciences, but also for landscape managers and governments (Niemi and McDonald 2004, Millennium Ecosystem Assessment 2005). A traditional ecological indicator, applied in ecology and related sciences, is the *indicator species*. The concept of the indicator species (IS) is based on field observations that specific habitats are often characterised by the presence or abundance of one or several particular species; based on this, Dufrene and Legendre (1997) defined indicator species as the most characteristic species of each group, found mostly in a single group of the typology and present in the majority of the sites belonging to that group. Furthermore, it has been recognized that cumulative effects of environmental change are reflected by trends in the diversity, abundance, reproductive success or growth rate of one or more species in a specific environment (Bartell, 2006, Burger, 2006). In light of these observations, IS have been used as ecological indicators of community types, habitat conditions or environmental change (Niemi and McDonald, 2004, Carignan and Villard, 2002, Siddig et al., 2016). A well-known example is the widespread decline of the peregrine falcon (*Falco peregrinus*) in the 1950s as an early warning system of environmental contamination by chlorinated hydrocarbons (Ratcliffe, 2010). Many other examples of IS have been well reported; these include a variety of taxonomical groups such as plants (e.g. De Boer, 1983, Keddy et al., 1993), birds (e.g. Bradford et al., 1998, Hutto, 1998), amphibians (e.g. Welsh et al., 1997, Adams, 1999), insects (e.g. Dufrene and Legendre, 1997, Rodríguez et al., 1998, Kremen, 1994), mammals (e.g. Soulé and Terborgh, 1999, Reunanen et al., 2000) and benthic invertebrates (Paine, 1969).

Whilst the criteria for selecting IS are debated, it has been proposed that IS should: 1) reflect the biotic or abiotic state of the environment; 2) provide evidence for the impacts of environmental change; or 3) predict the diversity of other species, taxa or communities within an area (McGeoch and Chown, 1998, Niemi and McDonald, 2004). Likewise, Carignan and Villard (2002) suggested, after a literature review on the topic, that selection of IS should consider: 1) the inclusion of various taxa and life histories; 2) the quantitative database on the focal region and; 3) a rigorous interpretation to distinguish actual signals from variations that may be unrelated to the deterioration of ecological integrity. In order to facilitate and strengthen the accuracy of the identification of IS, numerical tools have been developed. For example, Dufrene and Legendre (1997) introduced the indicator value (IndVal), which classifies species in groups according to their alliance to one habitat. The IndVal index is a product of two components: specificity and fidelity. The first component (or *positive predictive value*) is the degree to which a species is present at all sites of a group (i.e. abundance in a specific habitat), and the second component (or *sensitivity*) is the degree to which a species is found only in a given group of sites (i.e. predominance in this site). A good IS would be abundant and predominantly found in a specific site (De Cáceres, 2013); if a species is significantly more frequent in an undisturbed area, it is considered a 'positive' indicator of ecological integrity; whereas if it is found more frequently in a disturbed area, it is consider a 'negative' indicator of ecological integrity (Carignan and Villard, 2002). This tool has been widely used by ecologists to identify IS (Caro, 2010).

1.2. Monitoring biodiversity through Acoustic Surveys

Traditional methodologies for monitoring biodiversity and identifying indicator species, such as point counts or manual collections, are being complemented by the deployment of automatic and cost-effective tools (e.g. Sueur et al., 2008b, Sueur et al., 2012, Digby et al., 2013). Acoustic monitoring is considered a "portable, cheap, reasonably accurate and non-invasive" methodology to survey biodiversity (Sueur et al., 2012); and there is a rapidly growing body of research dedicated to developing and improving the efficacy of acoustic monitoring methods (e.g. Farina et al., 2016, Farina et al., 2014b, Pieretti and Farina, 2013, Towsey et al., 2014). The use of acoustic monitoring to detect specific species has been shown to generate results as accurate as traditional sampling techniques (e.g. Holmes et al., 2014, Acevedo and Villanueva-Rivera, 2006, Alquezar and Machado, 2015). In recent years, in order to optimize time and economic resources, other methodologies have been combined with acoustic monitoring approaches, such as rapid acoustic survey (RAS) (Sueur et al., 2009). RAS consists of recording all the sounds emanating from a landscape over a short period of time and analysing signals at the community level through acoustic indices. It was developed following the concept of rapid biodiversity assessment, as an alternative methodology for rapid exploration of tropical habitats (Oliver and Beattie, 1993, Oliver and Beattie, 1996, Oliver et al., 2000). RAS has been primarily conducted to evaluate species richness, heterogeneity and evenness at a particular site, and to measure ecosystem health through a range of community level indices (e.g. Gage et al., 2001, Sueur et al., 2009, Gasc et al., 2013b, Wimmer et al., 2013, Wooyeong et al., 2007). In spite of the great potential in reporting valuable information about the environment, these acoustic indices suffer challenges which currently limit their application (such as background noise, overlap between sounds arising from different sources, relative intensity and repetition in the calling of some species) (Towsey et al., Sueur et al., 2014b). Furthermore, these indices do not consider additional *qualitative* patterns associated with ecosystems, such as biodiversity quality (Feest, 2006, Feest et al., 2010) and functional diversity, which might provide a better overview of status of the environment and indicate trends and species responses to environmental changes (Butler et al., 2012).

1.3. Automatic species detection

In contrast to the community level approach of RAS, other automated tools have been developed in order to identify individual species. The development of automated species detection, from a set of audio files, has been proposed as an efficient and effective alternative to the manual identification of species (Waddle et al., 2009). Furthermore, its application results in significant gains in sample coverage, operating efficiency and cost savings (Agranat, 2009). Acoustic pattern recognition algorithms have been widely used, initially in bioacoustics, and more recently in soundscape ecology, with the aim of validating acoustic biodiversity indices (Farina, 2014a). Successful examples of the application of automatic species detection have been reported, for example, in the study of nocturnal migration of birds (Evans and Mellinger, 1999), the identification of endangered species (e.g. Bardeli et al., 2010), behavioural monitoring (Mellinger et al., 2007), estimation of population sizes (e.g. Buxton and Jones, 2012), the classification of constant-frequency vocalizations of crickets and amphibians (e.g. Brandes et al., 2006) and many others. Despite these successes, challenges remain, mainly because of the difficulties in developing appropriate pattern recognition algorithms that give reliable results in complex acoustic environments (Bardeli et al., 2010, Depraetere et al., 2012, Agranat, 2009).

In recent years, off-the-shelf free software has become available for studying sound in natural and human-modified landscapes such as the Song Scope Bioacoustics Monitoring package (Wildlife Acoustics, 2007-2011). Song Scope uses algorithms to build recognizers from training data containing labelled samples of a particular species' vocalizations (Holmes et al., 2014). This algorithm is based on Hidden Markov Models that considers not only spectral and temporal features of the individual vocalizations, but also the structure of vocalizations in complex songs (Agranat, 2009). The efficacy of the package has been investigated in anuran, primate and avian monitoring (Waddle et al., 2009, Spillmann et al., 2015, Wolfgang and Haines, 2016). It has been used to analyse the activity and status of nocturnal seabirds (Buxton and Jones, 2012) and detect bird species at risk (Holmes et al., 2014); the impact of different algorithm parameters and amounts of training data on performance have also been evaluated (Crump and Houlahan, 2017).

Given the current need for developing reliable cost-effective and time-efficient means to assess environmental conditions, especially in remote areas lacking biodiversity information, this study aims to evaluate the feasibility of using IS as a tool to determine environmental quality of an area using acoustic recording for a short period of time. The presented approach looks to contribute to understanding about how rapid acoustic monitoring could provide relevant information about processes occurring at ecosystem-level, by focusing on individual indicator species; and also how this approach could complement the information missing in the current RAS proposal, through the use of acoustic indices (as mentioned in Chapter 2), in order to evaluate the health of an ecosystem. The specific objectives were to: 1) identify, through a multi-criteria evaluation, the most suitable indicator species of environmental quality along a gradient of landscape degradation, and 2) evaluate the efficacy of using Song Scope software for automatically detecting IS.

2. METHODS

2.1. Data collection

Data collection is as described in Chapter 2, but it is repeated here to facilitate comprehension. A rapid acoustic monitoring was conducted at three sites located along a gradient of landscape modification in the Ecuadorian Chocó Biogeographic Region: 1) a primary forest (3000ha, N0° 32' 7.044''; W 79° 8' 28.751''); 2) a secondary forest (10ha, N0° 7' 11.136'' W 79° 16' 25.355''); and 3) a palm oil plantation (40ha, N 0° 7' 48.864''; W 79° 12' 59.543''). The primary forest, Tesoro Escondido, is an evergreen lowland tropical forest (Sierra, 1999) of around 300ha, comprised mostly of pristine forest, with dispersed small farms of cocoa, mixed-fruit trees and pastures. The secondary forest, Puerto Quito, is a reserve of 10ha, isolated around 40 years ago from the first site and surrounded by farms of mixed fruit trees, pastures and palmito trees (*Chamaerops humilis*). The palm oil plantation is a monocrop of around 40 ha, mainly of palm oil trees (*Elaeis guineensis*), a few hectares of palmito (*Chamaerops humilis*) and mixed fruit trees. It is surrounded by other oil palm plantations and pastures, and is situated on the outskirts of Puerto Quito. The sampling area was located between 130-390 meters of altitude.

Fifteen digital audio field recorders (Wildlife Acoustics Song Meter, 7 SM2+ and 8 SM3+) were located in the sampling area, with a separation distance of around 150 m from each other, to avoid pseudo replication. Fourteen consecutive days, between June and August in 2015, were audio sampled during peak hours of wildlife vocalisation at each site. Sampling schedules were defined relative to sunrise and sunset in order to capture the progression of dawn and dusk choruses (ten 1 minute samples every 15 minutes, starting 15min before sunrise; 20 samples of 1 minute every 15min from 60mins before sunset). Recording time was synchronized, so that the sound recordings were made simultaneously at each site. The sampling rate was set at 48 kHz with a resolution of 16 bits. Microphone gains, which is the level used to increase the power of the recorded signals, were adjusted to minimise differences between recorder models. Through experimentation and consultation with the WildLife Acoustics technical team, analogue gains were set at +36dB on SM2+ and +12dB on SM3+ which has inbuilt +12dB gain and more sensitive signal pathway than the SM2+. Accurate calibration between recorders is necessary to ensure that the same environmental acoustic event produces the same recorded signal in all equipment. Changing the gain also adjusts the sensitivity of the recording equipment to a given sound, providing a means to control the effective spatial range of sensors. In areas of high acoustic activity, gains can be relatively low to ensure vocalisations in close proximity do not distort; this also minimises the amplification of system noise, creating a higher quality over all signal.

2.2. Data analyses

Sound analysis comprised of three components: 1) avian and amphibian species identification by an ornithologist and a herpetologist, respectively, 2) identification of potential indicator species for both taxa, through a multi-criteria analysis, and 3) automatic vocalization detection of the identified indicator species. Three days of recordings were selected per site, based on a selection criteria of good sound quality and low acoustic interferences (e.g. from rain, electrical interference) generating 5400 1 min files across three sites. All recordings were pre-processed with a high pass filter at 300 Hz (12 dB) in order to attenuate the background noise (of motors and other machines), but minimizing loss of frequencies of sounds produced by non-human animals.

2.2.1. Avian and amphibian species identification

Species identification of amphibians and bird communities and a register of the number of individuals from the same species per sample (VAE or Vocal Abundance Estimate; N=5400 files/1 minute) were conducted by a herpetologist and an ornithologist.

2.2.2. Identification of potential indicator species

A multi-criteria evaluation was undertaken to identify potential indicator species of ecological integrity for each site. These criteria were based on work by Carignan and Villard (2002) and Hutto (1998) for identifying IS. Firstly, an Indicator Value (IndVal) was calculated with the 'Indicspecies' R software package (De Cáceres, 2013) using the VAE of each species. The selection of IS based on the frequency of occurrence of species could be influenced by transitory events occurring at the time of the acoustic survey (e.g. increase in rain, temperature, wind), therefore a second criterion was added following the recommendations of Carignan and Villard (2002) and Hutto (1998): habitat specialization. Hence, the multi-criteria for identifying potential indicator species comprised of a) specificity, b) fidelity and c) habitat specialization. This last criterion was assessed by consulting life-history databases (The Cornell Lab of Ornithology: Neotropical Birds, available at: https://neotropical.birds.cornell.edu/ and AmphibiaWeb Ecuador, available at: https://zoologia.puce.edu.ec.aspx) and consultation with ornithologists and herpetologists. It was used to confirm the accuracy of the observations found in this study. Once the overall IndVal value were obtained, the highest scores of specificity and fidelity (from 0 to 1) were considered to define the minimum values for the multi-criteria analysis (see results for more details). Species with the highest score values were then assessed in the following analysis:

2.2.3. Automatic vocalization detection of indicator species

In order to assess whether the IS identified were suitable for automatic vocalization recognition, an evaluation was conducted using Song Scope Software (version 4.1.5. Wildlife Acoustics Inc.). Only 'positive' indicator species of ecological integrity were selected for this analysis (3 birds and 1 amphibian, see results for details). In order to create a 'recognizer' for each IS, recordings of each species were compiled from online databases (Xeno-canto, XC, available at: www.xeno-canto.org). Each recording was auditioned and visualized in Song Scope and noisy samples (i.e. files with audio damage or poor audio quality) were removed. Clear examples of vocalizations of each species from the database were isolated and labelled. These examples were saved as separated files, called 'annotations', which are used as training data to build a recognizer in Song Scope. Annotations were adjusted to each species vocalizing pattern, following the software designers' guidelines, in order to build a recognizer (Wildlife Acoustics Inc. 2007-2011). The variables adjusted in the annotations were background filter, frequency range, minimum frequency, and maximum durations for syllable, syllable gap, and vocalization length. These adjustments tune a model, which is then used to isolate samples with similar characteristics, in order to identify the target vocalizations (Waddle et al., 2009). Short/mono-syllabic calls were excluded from the model, as they were found to increase the number of false positives, and had no effect on positive identifications. Once the recognizer was built, default minimum values for quality and score were used for filtering the results. Quality (from 0.00 to 9.99) represents a statistical distribution of parameters from the training data used to build the recognizer; whereas score (from 0 to 100%) represents the statistical fit of the candidate vocalization to the recognizer model. The default values (0.2 minimum quality and 50% minimum score) were considered appropriate for the aim of this research given that they are low enough to include as many target vocalizations as possible. The recogniser reports candidate vocalizations which match the corresponding model for each species. Each candidate vocalization was evaluated manually, as 'true positive' or 'false positive', by observing the spectrogram and/or listening to the vocalization. The performance of each recognizer was evaluated through: 1) the cross-training value, 2) batch scanning the training files, and 3) batch scanning the field recordings. In the first case, the value shows the average and standard deviation of the 'fit' of the samples when building the model. Low score (e.g. < 50%) or a large standard deviation (e.g. > 15%) indicate that the generated model is not expected to perform well (Wildlife Acoustics Inc. 2007-2011). In the second case, the accuracy of the model was evaluated by calculating the rate of true positives (no. confirmed candidate vocalizations/no. detections*100) and false positive detections (no. not confirmed candidate vocalizations/no. detections*100), and the file detection rate (no. files detected/no. files scanned*100). Rates with scores higher than 50% were considered appropriate for application of the recognizer in the survey data. In the third case, all field recordings were scanned by each recognizer separately. The accuracy of each recognizer was calculated by calculating the precision rate (no. true positives/no. true positives+ no. false positives*100) and the recall rate (no. true positives/no. false negatives+ no. true positives*100). Precision, also called positive predictive value (Fawcett,2006 cited in Crump), provides an estimate of the probability of the recognizer match actually being the target vocalization; whereas recall, or sensitivity, provides an estimate of the proportion of vocalizations detected by the recognizer (Crump and Houlahan, 2017).

3. RESULTS

3.1. Avian and amphibian species identification

A species list of bird and amphibian species, with its respective VAE values per species, is shown in Annex 4 and 5. A total of 156 avian species and 18 amphibian species were identified. In the primary forest 14 species of amphibian and 96 species of birds were detected; in the secondary forest 12 species of amphibian and 106 species of birds; and in the palm oil plantation 10 species of amphibian and 96 species of birds.

3.2. Identification of suitable acoustic indicator species

Annex 9 shows the results of the IndVal index analysis. For birds, 33 significant IS were identified in the primary forest, 21 species in the secondary forest and 28 in the palm oil plantation. Whereas for amphibians, 9 significant IS were identified in the primary forest and 6 species in the palm oil plantation. No significant IS of this taxonomic group were found in the secondary forest. Annex 10 illustrates the IS selected following the multi-criteria analysis of specificity, fidelity and habitat specialization. The highest scores of specificity and fidelity of the overall indicator values (IndVal) were used to define the minimum values criteria (as described in section 2.2.2.): 0.9 (90%) for specificity and 0.04 (4%) for fidelity, which were the highest values in the list but, at the same time, ensured inclusion of sufficient species for the aim of the study. This resulted in 3 avian IS for the primary forest: Black-headed Antthrush (*Formicarius nigricapillus*), Rufous Piha (*Lipaugus unirufus*) and Ocellated Antbird (*Phaenostictus mcleannani*). Three IS species were also identified for the palm oil: Pacific Antwren (*Myrmotherula pacifica*), Social Flycatcher (*Myiozetetes similis*) and House Wren (*Troglodytes aedon*). According to the chosen criterion, no bird species from the secondary forest was considered as a suitable IS. For amphibians, only the Labiated Rainfrog (*Pristimantis labiosus*) was identified as a suitable IS of the primary forest.

3.3. Automatic vocalization detection of multiple indicator species of the primary forest

Recognizers were built for each of the selected IS: Black-headed Ant Thrush (26 files, 63 vocalisations), Rufous Piha (22 files, 18 vocalizations) and Ocellated Antbird (36 files, 42 vocalisations). The first evaluation of the accuracy of the recognizers through the 'cross-training' scores and the standard deviation showed that all models represented vocalizations of each species accurately (Black-headed Antthrush, 77.15±10.36%; Rufous Piha, 72.11±7.10%; and Ocellated Antbird, 72.80 ±11.69%). The second evaluation of the performance of the recognizers, through batch scanning of all training files, is illustrated in Table 1. High rates of true positive files (95%, for Black-headed Antthrush; 95% for Rufous Piha; and 98% for Ocellated Antbird) and low rates of false positive files (5%, for Black-headed Antthrush; 5% for Rufous Piha; and 2% for Ocellated Antbird) were observed. The rate of file detection was higher for Rufous Piha (100%), followed by Ocellated Antbird (75%) and then Black-headed Antthrush (62%).

The results of the scans of field audio files (900 files, 1 min) are presented in Table 2. Song Scope software detected 386 Black-headed Antthrush vocalizations, 36 true positive detections and 348 false positive detections. 3287 Rufous Piha vocalizations were detected with 38 true positive detections and 3213 false positive detections. 994 Ocellated Antbird vocalizations were detected, with 31 true positive detections and 960 false positive detections.

The accuracy of the models explained by the precision and recall rates are: the Ocellated Antbird's recognizer presented the highest recall rate of all species (83.8%) but the rate of precision was low (3.1%). The second highest recall rate was for the Rufous Piha´s recognizer (73.1%), yet it showed the lowest precision rate (1.2%) of all recognizers. The Black-headed Antthrush's recognizer showed the lowest recall rate (54.5%) of all, but the precision rate was the highest from the three recognizers (9.4%).

Table 1. Evaluation of the performance of the automatic recognizers with the training audio files.

	Black-headed Antthrush	**Rufous Piha**	**Ocellated Antbird**
No. of files used	26	22	36
No. Annotations	63	18	42
Detections	60	99	98
True positive	56	94	96
True Positive Rate (%)	95	95	98
False Positive	3	5	2
False Positive Rate (%)	5	5	2
No. files with detection	16	22	27
Rate file detection	62	100	75

Table 2. Evaluation of the performance of the automatic recognizers with the field audio files.

	Black-headed Antthrush	**Rufous Piha**	**Ocellated Antbird**
Detections	384	3287	994
True positive	36	38	31
False Positive	348	3213	960
False Negative	30	14	6
Unknown	0	36	3

4. DISCUSSION

4.1. Identification of suitable acoustic indicator species through rapid acoustic monitoring

The multi-criteria evaluation for identifying IS highlighted a combination of species that accurately represent each habitat type. In particular, the inclusion of the additional criterion (i.e. habitat specialization) within the IndVal components (i.e. specificity and fidelity) eliminated species that, according to expert consultation and ecological knowledge from previous research, were not good candidates for an IS, as recommended by Carignan and Villard (2002). This has to be considered, especially when conducting acoustic surveys over short periods of time, as the information collected might be biased by transitory natural events (e.g. rain, temperature) and not necessarily reflect the ecological integrity of an area.

The initial aim of this study was to combine birds and amphibian communities into the selection of suitable IS, however, most amphibians (except the Labiated Rainfrog) were eliminated during the multi-criteria evaluation. Therefore, the idea of using multi-taxonomic IS as recommended by Carignan and Villard (2002) and De Cáceres et al. (2010), was not possible. The reason might be related to the low number of amphibian species registered during the survey, in comparison to the avian registers. It was also noticeable that the amphibian species that were identified as IS by the IndVal components were eliminated by the third criterion (i.e. habitat specialization). This could be explained because most acoustically active amphibian species were distributed among all habitat types, whereas the rare species or species more representative of a specific habitat type (e.g. *Hyloxalus toachi* or *Teratohyla spinosa*) were not so active acoustically during the monitoring. As a consequence, those species were not considered as significant by the IndVal analysis either. Further investigation is needed to determine reasons why rare species were less active during the acoustic survey. Similar research has identified bird species as good ecological-disturbance indicator species of the Andean tropical forest in Ecuador (Peck et al., 2014) and in the Brazilian Amazon (Gardner et al., 2008), using a range of taxonomical groups (bats, lizards and small mammals), although they did not use acoustic monitoring methods. Other research also confirms the suitability of the use of bird species as indicators of the ecological status of an area (Roberge and Angelstam, 2006, Croonquist and Brooks, 1991, Temple and Wiens, 1989, Koskimies, 1989).

It is also recommended to conduct acoustic monitoring for longer periods of time in order to increase the effectivity of the survey, by including the range of diversity conditions existing in an ecosystem.

4.2. Using automatic vocalization detection for identifying indicator species

The use of automatic detection of IS in this study presented pros and cons that should be considered for future research. All recognizers identified the target species from the field recordings, yet the performance of the models was not good: there was an elevated number of false positives with all recognizers (see detailed discussion in paragraph four); furthermore the model did not detect all files where the target species was registered by the ornithologist. The lack of precision in registering all the vocalizations could be considered a constraint when using this software, especially when the aim is to monitor the activity of single species or estimate population sizes (Buxton and Jones, 2012). Nevertheless, this research aimed to determine presence of several target species, which was accomplished. Hence, this fact might be considered as a trade-off between the information obtained with the software and the number of days employed for the acoustic monitoring (i.e. the outcome was valuable considering the low sampling effort). Moreover, the time taken in the examination of all detections was acceptable (~1 hour per 1000 detections). For example, three and half hours were taken to examine the recognizer that presented the highest number of false positive detections. Another aspect to be considered is that Song Scope is a free software package, which makes it easy to access, especially for researchers with limited financial means. It is important also to mention that there are other commercially available options for automatic detection with high detection capability. For example, Digby et al. (2013) presented a comparison between manual and automatic examination of recordings of a nocturnal bird (*Apteryx owenii*) through a custom software written in C#, obtaining high precision rates (98%). In contrast, Potamitis et al. (2014) reported that automatic species recognition reduced by 98%, the listened effort for a human observer. Likewise, Wa Maina (2016) used an open source machine learning tool kit, called Bob, in order to successfully detect a bird species (*Tauraco hartlaubi*) with a highly efficient classifier (93% true positive rate and 7% false positive rate). Furthermore, rapid developments in machine listening and machine learning are likely to improve the efficacy of automated detection tools, and to create more options commercially available and easy to use for researches (e.g. Katz et al., 2016). In this way, the use of automatic detection of indicator species shows great potential for effective biodiversity evaluations, especially to determine presence or absence of a species in remote areas, as mentioned in Digby et al. (2013).

The highest recall rate seen in the Ocellated Antbird model, could be explained by the characteristic calls of this species that are well suited to automated recognition: they have high energy and broad frequency range (from 1 to 10kHz), both features have been reported to be well recognized by Song Scope (Agranat, 2009). Likewise, the training vocalizations for the Rufus Piha have loud and distinctive spectral properties, with frequencies ranging from low (1kHz) to high frequencies (8kHz), which worked well with the software. This was noticeable when comparing with the Black-headed Antthrush's recognizer, which has a narrowband call (1-3kHz), and presented the worst recall rate of all recognizers. It was also noticeable that the number of training samples used to create the model for the Black-headed Antthrush was the highest of all species. Conversely, the training data used for the other recognizers was lower; this might suggest that the performance of the software is dependent on features of the vocalizations itself, rather than in the quantity of vocalizations used in the training process. Nevertheless, more research is necessary to confirm this hypothesis. Crump and Houlahan (2017) found a small improvement in the performance of the recognizer for the Wood frog (*Lithobates sylvaticus*) by adding additional training data, even though this data came from different sites. In this case, annotations from other recordings were added and did not improve the vocalization detection rate. Moreover, a high number of vocalization of the Black-headed Antthrush were not even shown in the spectrogram viewer which could be explained by the low amplitude signals and overlap of other sounds within the same frequency range as suggested by (Buxton and Jones, 2012).

One important constraint observed in all the models was the high number of misidentifications (false positives), especially in the case of the Rufus Piha's recognizer, which explain the low precision rates in all the recognizers. Despite the difficulties in determining the occurrence of these errors with the software (Crump and Houlahan, 2017), it was observed that the model misidentified calls by selecting similar features in the vocalization of other species. For example, the Rufus Piha recognizer detected vocalizations from bird species such as the Chestnut-backed Antbird, Tawny-faced Gnatwren, Stripe-throated Wren and Zeledon Antbird, but also of some species of frogs and insects. Likewise, the rate of misidentification in the Ocellated Antbird model was high. In both cases, the calls are well distributed throughout the frequency spectrum where the vocalizations of other species occur, which might have increased the model error rates. Conversely, the Black-headed Antthrush's recognizer had the lowest rate of misidentification (hence, the highest precision rate), possibly due to its narrower frequency range distribution. Additionally, the software presented some technical issues during the scanning of the spreadsheet of call detections, with sudden closures and repetitions of a number of detections (i.e. the programme counted a number of detections twice). This fact influenced the total counting of the number of detections (true positives and false positives), which has to be considered for future research.

Another factor that should be considered before using automatic vocalization detection is the selection of the taxonomical groups: one advantage of using birds as indicator species is that there are free-online databases with vocalizations of a range of species, which might be used for building the recognizers. For other taxonomical groups, like the amphibians, comparably large databases of vocalizations are not yet publicly available, which means building a recognizer would have to be preceded by manually annotating a large number of files.

5. CONCLUSION

This study evaluated the feasibility of using automatic detection of indicator species using acoustic monitoring in a short period of time as a tool for evaluating the environmental quality of an area. The rapid acoustic monitoring was useful for surveying an elevated number of species, including IS, particularly of birds. Automatic detection of IS can be recommended for rapid ecological evaluations in remote areas with high diversity, replacing expensive and time consuming methods of biodiversity monitoring. This approach might also provide a tool to understand the composition/trends of wildlife communities and the effects of habitat modification on the ecosystem. Although there are some constraints associated with the use of acoustic surveys, such as extraneous sounds which may bias acoustic analyses, the multi-criteria evaluation applied in this study was a useful tool for overcoming these, by filtering the most suitable indicator species and eliminating the species that were not representative of a specific area.

The employment of an automatic acoustic detector, such as Song Scope, presented advantages (e.g. detection of target species over short periods of time) as well as disadvantages (e.g. high rate of false positives) that need to be addressed in further research, especially when the aim is the evaluation of patterns of activity or estimating population sizes. The extraction and isolation of specific calls within a complex chorus is still computationally challenging, and yet to be solved (Agranat, 2009). Nevertheless, the rapid development of new technology focused on improving the tools of acoustic analysis and devices for wildlife monitoring might overcome the current constrains. For example, the development of *in situ* automatic detector of IS might overcome the challenge of missing vocalizations during the survey.

As shown in this study, it is important to consider in further work that the characteristics of certain species' vocalisations are more suitable for automatic vocalization detection than others; hence, identifying the characteristics of calls which are better suited to particular automated species detection (e.g. acoustic distinctness, particular acoustic niche distribution, broad frequency) might be important. It is also recommended in future research to consider a number of potential IS occurring in an area, prior to conducting the survey, so the possibilities of finding at least one of them might increase.

The automatic detection of IS that reflect the ecological integrity of an area could be a powerful tool to be combined with the RAS approach, as relevant information about the processes occurring within an ecosystem, currently missing with the use of acoustic indices (see Chapter 2), can easily be obtained. For example, it could be a complementary tool of the Acoustic Complexity Index (Pieretti et al., 2011), that reflects density of avian vocalizations (Pieretti et al., 2011)) or the Normalized Difference Soundscape Index (Kasten et al., 2012), which determines the level of anthropogenic disturbance of a habitat. The inclusion of the automatic detection of IS in rapid evaluations of the ecological integrity of an area might contribute by identifying patterns of communities that are not identified by the RAS approach. It seems very likely that by combining species recognition and community level indices we will be able to make even more accurate evaluations of ecological integrity, utilising acoustic monitoring as a reliable cost-effective tool that produces useful data for conservationists and decision makers.

CHAPTER 4

Essential matters for your pocket: cost-effectiveness of the use of rapid acoustic monitoring for ecological evaluation in the Ecuadorian Chocó forest

ABSTRACT

Cost-effective methods for biodiversity monitoring are considered a necessity, especially for areas with biodiversity data shortage and lacking of financial means. Passive acoustic monitoring using autonomous recorders has been proposed as a promising approach to monitor areas rich in diversity over short periods of time. This study presents an evaluation of the cost-effectiveness of using short time scale acoustic surveys, or Rapid Acoustic Monitoring (RAM) to evaluate the habitat status of a biodiversity *hotspot* in NW tropical rainforest of Ecuador. Fifteen field recorders were located in three sites with distinct gradients of landscape modification; three days of recordings during peak hours of wildlife activity were analysed. Avian and amphibian species were recognized by experts, and ecological indicator species of each taxon were identified. The cost effectiveness of using RAM with the aim of species identification and habitat evaluation was compared against traditional in situ point counts (PC). Avian and amphibian PCs were conducted for eight and three days respectively within one of the sites of the study area. Analyses comprised: 1) Evaluation of the survey costs involved in registering both taxa, and ecological indicator species, using the RAM and PC methods, and 2) Cost-Effectiveness Analysis (CEA) that identified the most suitable options for biodiversity monitoring, in terms of costs and outcomes (*number of species* and *number of indicator species*). Results showed that RAM was an effective method to survey high numbers of avian species and of IS in a short period of time; amphibians were identified as good ecological indicator species in terms of proportion of indicator species per species richness. Avian PC was the most cost-effective option of all surveys, followed by avian RAM, only when excluding equipment costs. RAM is a suitable solution for rapidly evaluating the habitat status when the aim is to survey multiple areas or to conduct long term studies. Rapid development of technology, focused on improving wildlife acoustic devices

and monitoring tools, would increase the cost-efficacy of the RAM approach. This study was focused only on one type of device (Song Meter, SM2 and SM3), therefore, research comparing other available options is recommended.

Keywords: survey cost, acoustic monitoring, tropical rainforest, indicator species, habitat status

1. INTRODUCTION

Targets under the Strategic Plan for Biodiversity 2011-2020 are focused on addressing the causes of biodiversity loss and improving the status of biodiversity (CBD Secretariat 2014), therefore understanding the status of wildlife populations, especially in areas with shortage of biodiversity data, is a priority. The challenge is that in areas with the highest percentage of threatened biodiversity (Myers et al., 2000) biological assessments tend to be time-consuming and complex tasks, as they often rely on species inventories of diverse taxonomic groups. It is also logistically complicated to monitor biodiversity in areas that are difficult to access, such as tropical forest habitats. In addition to logistical constraints, there is widespread under-funding of conservation research in rainforest systems, which is the primary explanation for this biodiversity data shortage (Balmford and Whitten, 2003). Most biodiversity monitoring programmes in less wealthy countries are unrealistically large, complicated and impossible to sustain with the locally available funds and human resources (Danida 2000). Moreover, the financial cost of multi-taxa field studies usually exceed the limits of the budget for biodiversity research (Lawton et al., 1998).

New methodologies for biodiversity assessment have been developed with the aim of improving the cost-effectiveness of sampling biodiversity and facilitating the tasks involved in the process, such as reducing the total time and human effort invested and maximizing the sampling effort during fieldwork. Direct methods (such as ‘human sensor networks’ or ‘camera traps’) and indirect methods (such as ‘satellite monitoring’ or ‘remote sensing’) have been proposed as alternatives to traditional techniques of biodiversity monitoring. However, there is an unbalance between data quality (i.e. precision of the measurement system) and data quantity (i.e. level of accuracy reached along time and space scales) obtained with those methods (Sueur et al., 2012).

More recently, financial aspects of monitoring biodiversity have been assessed by incorporating cost-effectiveness analysis in identifying conservation priorities (e.g. (Tulloch et al., 2011, Sommerville et al., 2011, Halpern et al., 2013). A focus on cost-effectiveness analysis will help to ensure that funds are properly used, especially in areas requiring ecological evaluations that are lacking in financial means lacking (Gardner et al., 2008). Particular attention has been placed on evaluating the cost-effectiveness of sampling different taxa and detecting indicator species or taxonomic groups in high diversity ecosystems (e.g. Gardner et al., 2008, Peck et al., 2014), which act as a surrogate for the ecological integrity of an area or for wider patterns of biodiversity (Angermeier and Karr, 1994, Caro, 2010). Moreover, cost-effective indicator species/taxa are more easily sampled than other species/taxa. Hence, these species/taxa have practical applications in evaluating and monitoring biodiversity (Peck et al., 2014).

The use of microphones has been considered a promising method for capturing and assessing biodiversity. For example, acoustic sensors that monitor biodiversity through a biodiversity index has been reported as an approach that, in comparison with other methods, is cheap, portable, 'reasonably accurate', non-invasive and can be applied at a range of different spatial and temporal scales (Sueur et. al, 2012). Moreover, the use of recordings to identify species, such as birds, have the potential to produce more information, more rapidly than traditional methods (Parker, 1991, Acevedo and Villanueva-Rivera, 2006). However, there is a lack of information concerning the real cost and effectiveness of the use of multiple recorders for rapid biodiversity evaluations. This study aims to fill the gap by providing an analysis of the cost-effectiveness of employing rapid acoustic monitoring (RAM) to identify species and evaluating the ecological integrity of a tropical species-rich forest. A comparison of cost-effectiveness of RAM and traditional point counts (PC) is presented. Moreover, a strategic selection of high-performance indicator taxa was conducted, based on Gardner et al. (2008) and Peck et al. (2014), by comparing the cost and benefits (i.e. outcomes) of sampling different taxonomic groups. The main aims of the chapter are to:

1) Evaluate relative cost-effectiveness of RAM versus traditional PC for monitoring amphibian and avian communities, along a gradient of landscape modification, in comparison to traditional PC.

2) Assess the cost-effectiveness of the use of amphibians and avian taxa to evaluate the habitat status of an area.

2. METHODS

The evaluation was carried out using data collected at the sites and methods described in Chapter 2 and 3.

2.1. Data collection

Acoustic survey undertaken over a short period of time, defined in this study as "Rapid acoustic monitoring" (RAM), was carried out at three sites located along a gradient of landscape modification in the Ecuadorian Chocó Biogeographic Region: 1) a primary forest (3000ha, N0° 32' 7.044''; W 79° 8' 28.751''); 2) a secondary forest (10ha, N0° 7' 11.136'' W 79° 16' 25.355''); and 3) a palm oil plantation (40ha, N 0° 7' 48.864''; W 79° 12' 59.543''). The primary forest (Site 1), Tesoro Escondido, is an evergreen lowland tropical forest (Sierra, 1999) of around 300ha, comprised mostly of pristine forest, with dispersed small farms of cocoa, mixed-fruits trees and pastures. The secondary forest (Site 2), Puerto Quito, is a reserve of 10ha, isolated around 40 years ago from the first site and surrounded by farms of mixed fruit trees, pastures and palmito trees (*Chamaerops humilis*). The palm oil plantation (Site 3) is a monocrop of around 40 ha, mainly of palm oil trees (*Elaeis guineensis*), a few hectares of palmito (*Chamaerops humilis*) and mixed fruit trees. It is surrounded by other oil palm plantations and pastures, and is situated on the outskirts of Puerto Quito. The sampling area was located between 130-390 metres of altitude.

This study was focused on avian and amphibian acoustic communities, which are characterised by high acoustic activity. Two methodologies for sampling these taxa were used: RAM and PC. The last methodology was carried out only within the primary forest (Site 1) due to practical reasons.

2.1.1. RAM

Fifteen digital audio field recorders (Wildlife Acoustics Song Meter, 7 SM2+ and 8 SM3+) were located at each site, with a separation distance of around 150 m from each other, to avoid pseudo sampling. Fourteen consecutive days, between June and August in 2015, were audio sampled during peak hours of wildlife vocalisation at each site. Sampling schedules were defined relative to sunrise and sunset in order to capture the progression of dawn and dusk choruses (ten 1 minute samples every 15 minutes, starting 15min before sunrise; 20 samples of 1 minute every 15min from 60mins before sunset). Recording time was synchronized, so that the sound recordings were collected simultaneously. The sampling rate was set at 48 kHz with a resolution of 16 bits. Microphone gains, which is the level used to increase the power of the recorded signals, were adjusted to minimise differences between recorder models. Through experimentation and consultation with the WildLife Acoustics technical team, analogue gains were set at +36dB on SM2+ and +12dB on SM3+ which has inbuilt +12dB gain and more sensitive signal pathway than the SM2+. Accurate calibration between recorders is necessary to ensure that the same environmental acoustic event produces the same recorded signal in all equipment. Changing the gain also adjusts the sensitivity of the recording equipment to a given sound, providing a means to control the effective spatial range of sensors. In areas of high acoustic activity, gains can be relatively low to ensure vocalisations in close proximity do not distort; this also minimises the amplification of system noise, creating a higher quality over all signal. Three days were selected per site, based on low rain and audio problems (1800mins x 3 sites= 5400 files). All recordings were pre-processed with a high pass filter at 300 Hz (12 dB) in order to attenuate the background noise (of motors and other machine), but minimizing loss of frequencies of biophony.

Amphibian and bird species were identified from three days of recordings by a herpetologist and ornithologist with expertise in the local/ endemic communities. For each of 5400 1 min files (2700, birds and 2700, amphibians), a list of species was obtained together with an abundance proxy (vocal abundance estimation, VAE), based on the maximum estimated number of simultaneously vocalising individuals of each species.

2.1.2. PC

Four transects of 1.2km, previously established by the local community, were selected within Site 1. Each transect was separated by a minimum distance of 100m from each other. In the case of the avian register, each transect was surveyed during the peak time of activity at morning (from 6.00am to 10.00am) for eight consecutive days. Along each transect 12 points sites were established with distance intervals of 100m. Due to weather conditions not all point counts could be surveyed, therefore, some transects only have 10-11 point counts. At each survey point a 2 minute initial adjustment period was allowed, followed by a 10 minute period during which all birds, observed or heard within a maximum distance of 40m, were registered. Visual and auditory bird identification was performed by an experienced local guide. Species identification was conducted using criteria indicated in the field guide of birds of Ecuador (Ridgely and Greenfield, 2001). For the amphibian register, each transect was surveyed during the peak time of activity at night (from 18.00pm to 22.30pm). Two herpetologists, with headlights walked slowly (~2m/min) along each transect, spotlighting for frogs within 3 m of the each transect line. The number of frogs of each species seen or heard was registered. Individuals seen were photographed in order to confirm the identification of each species. Species identification was confirmed with AmphibiaWebEcuador (online database, available at: https://zoologia.puce.edu.ec.aspx). Data was collected during the same months than the RAM, between June and July, in 2017. As mentioned in Karp et al. (2011) guilds of birds are more stable in abundance in low-intensity land, such as the area of this study, over time. Therefore, one year of separation of both surveys (RAM and PC) was not considered an inconvenience for comparing methods.

2.1.1. Quantifying the costs of monitoring avian and amphibian communities

In order to quantify the monetary costs associated with sampling biodiversity through the RAM and the PC methods, the following budgets were calculated: 1) field work for the minimum staff required to undertake the fieldwork, 2) field survey equipment, and 3) data management and species identification. The analysis was separated according to each taxon. This procedure was based on similar studies of cost-effectiveness of biodiversity sampling in other tropical rainforests (Gardner et al., 2008, Kessler et al., 2011, Peck et al., 2014); in addition, in-country transportation expenses were included as part of the field work budget, in order to better reflect the *in-situ* costs of the survey. The monetary analysis was split into absolute costs with/without non-perishable field equipment. Non-perishable field equipment includes devices/tools than can be used more than once (e.g. recorders, GPS, rechargeable batteries. Please refer to Annex 11 for detailed list of field equipment used).

2.2.2. Cost-effectiveness analysis

The following evaluations were conducted: 1) comparisons of cost-effectiveness between RAM and PC methods and 2) cross-taxa comparisons of cost-effectiveness.

In order to evaluate the relationship between species richness and the costs involved in each survey, individual-based rarefaction curves were constructed for each taxon using the analytical formula available in EstimateS 9.10 (Colwell and Estimate, 2009). The y-axis was recalibrated to represent the expected number of species in t pooled samples, given the reference sample (abundance per species). The x-axis was recalibrated to represent the cumulative costs of surveying each taxon, with and without non-perishable field equipment costs, by method. The cumulative costs were calculated based on the number of sampling days per method, considering the overall expenses of the survey (i.e. proportional surveyed costs were obtained according to the number of species/encounters per sampling day). Furthermore, the number of indicator species for each taxon, was represented in the y-axis and was standardized by total number of species per taxa. Identification of the number of indicator species for each taxon with the RAM follows that described in Chapter 3 (section 2.2.2). In order to identify avian and amphibian indicator species (IS) for the primary forest, the IndVal metric was used. IndVal computes an indicator value for each species by multiplying measures of habitat specificity (based on the acoustic abundance estimation) and habitat fidelity (based on registers of presence/absence). All significant IS were considered for the analysis. Indicator values were calculated with the 'Indicspecies' R software package (De Cáceres, 2013). IndVal analysis was not carried out for the PC method due to the fact that sampling area was conducted only in Site 1.

A cost-effectiveness analysis (CEA) was conducted in order to evaluate which taxon and method (RAM vs PC) is most cost-effective, based on the outcome and costs involved. This technique has been applied particularly in medical studies for estimating the costs and effectiveness of different interventions (Edejer, 2003). CEA is a measure that compares natural units (Robinson, 1993) from an economic evaluation against the outcomes (effects) of two or more courses of action. It is based on two equations: CE ratio (or *costs ratio*) = C1/E1 and EC ratio (or *effectiveness ratio*)= E1/C1, where C1= is the cost of option 1 (in USD); and E1= the effectiveness of option 1. The first equation represents the cost per unit of effectiveness, whereas the second equation is the effectiveness per unit of cost. Options can be rank ordered by CE ratio from lowest to highest, and from highest to lowest EC ratio. As the aim of this study was to analyse the effectiveness of monitoring biodiversity, the units of outcome were defined as the *number of species* sampled and the *numbers of indicator spe*cies. The latter unit was used only for comparing the cost-effectiveness by taxon sampled with the RAM method.

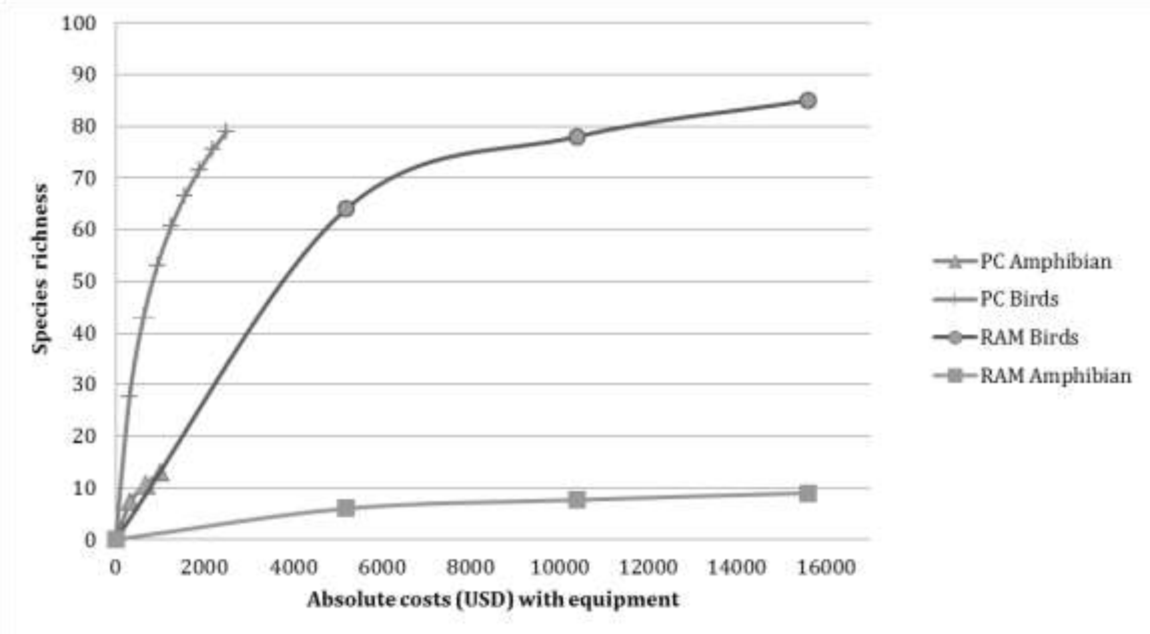
3. RESULTS

85 species of birds and 9 species of amphibian were registered with the RAM method, and 79 species of birds and 13 species of amphibian with the PC method. A list of species is shown in Annex 4 and 5. A total of 33 species of birds and 9 species of amphibian were identified as significant IS of Site 1 with IndVal (Annex 9).

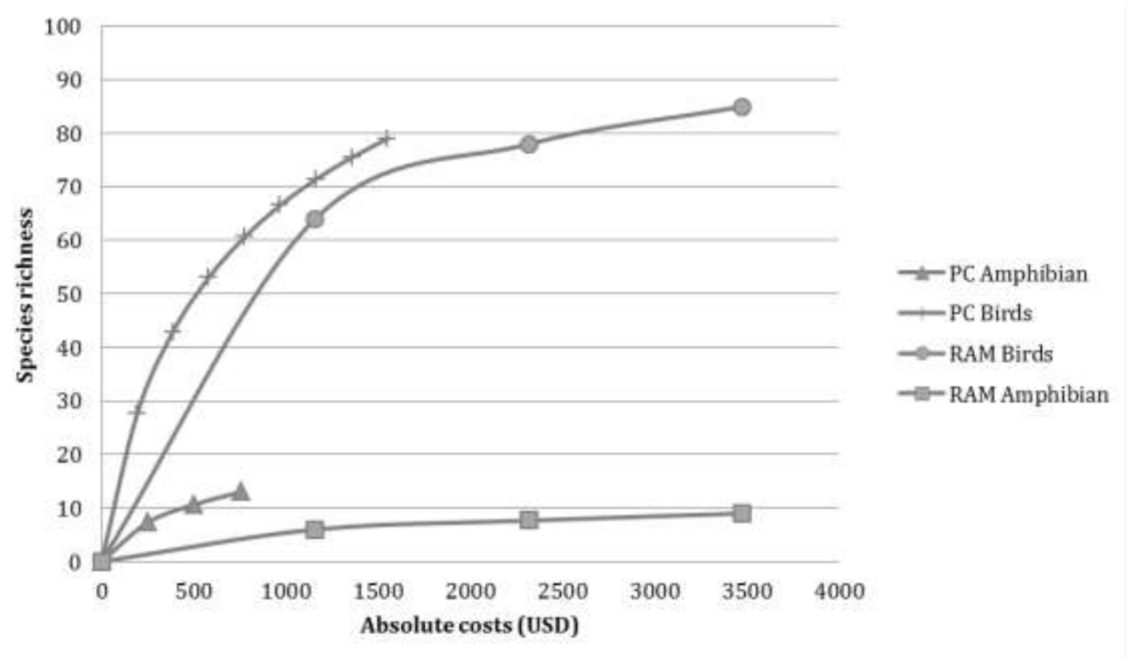
3.1. Cost effectiveness analysis

The total costs of surveying birds and amphibians with the RAM was USD 15 582, including non-perishable equipment costs, and USD 3 472 (22.28% of the original cost), excluding non-perishable equipment. The cost of surveying birds with the PC method was USD 2 504 and USD 1 011 for amphibian, including non-perishable equipment; and USD 1 552 for birds (61.98% of the total cost) and USD 756 for amphibian (74.77% of the total cost), without non-perishable equipment. A detailed description of the costs of each survey can be seen in Annex 11.

Birds were the taxon best surveyed with both methods (90.42% of the total number of species surveyed with the RAM, considering the total number of species registered for both taxa with RAM (N=94), and 85.86%, considering the total number of species registered for both taxa with the PC (N=92)), when compared to amphibian surveys (9.58% with the RAM and 14.13% with the PC, considering the total number of species registered for both taxa/method). Comparisons between taxa and costs of surveys are presented in Figures 1 (a,b). According to the rarefaction curves, birds showed the highest species richness in proportion to the costs of surveying in both methods. For birds, there was a noticeable increment in species richness as survey cost increased in the case of the RAM. The greatest number of species detected was on day one of three days of survey. Furthermore, avian species richness acummulated by the fifth sampling day of the PC was already reached in the first sampling day using RAM; yet, the highest species richness was found for the most expensive survey costs using RAM. For amphibians, there was a weaker increment in species richness as costs of surveys increased in both methods in comparison with birds, however, the highest species richness was obtained with the PC, for cheaper survey costs than the RAM.



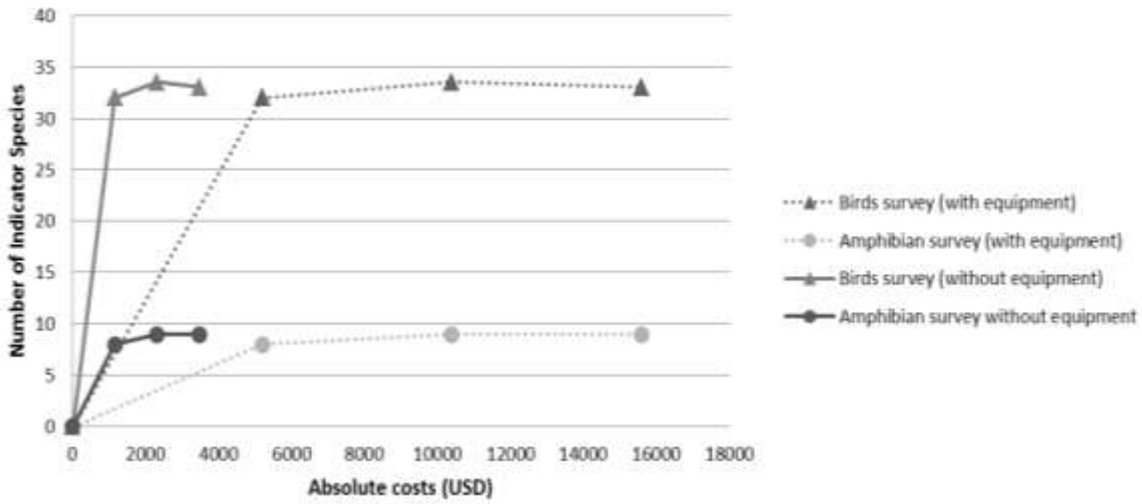
a



b

Figure 1. Rarefaction curves for total species richness sampled against total costs of sampling birds and amphibian communities using the RAM and PC methods. a) Including non-perishable equipment costs, b) Without including non-perishable equipment costs. Data points along each of the curves are showing the sampling day.

As shown in Figure 2a, b, compared to amphibians, birds generated the highest number of IS for the cheapest sampling costs (USD 1158 and USD 5195, without and with non-perishable equipment costs, respectively). However, amphibian IS represented 64.29% of the total species richness of this group at absolute survey costs, whereas bird IS represented 35.87% of total species richness of this group.



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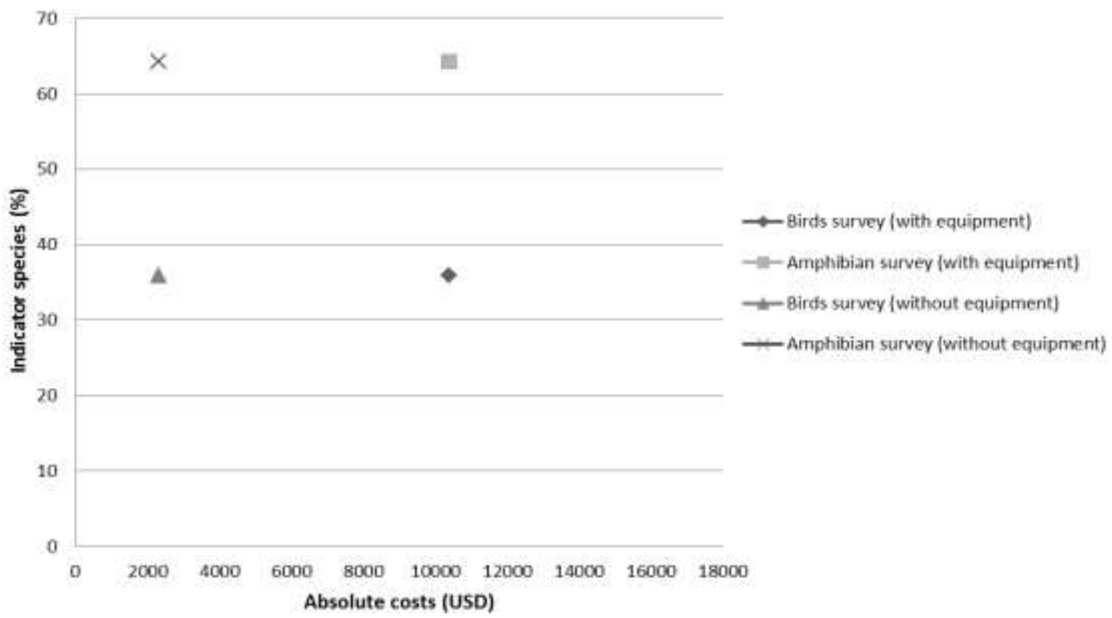


b

Figure 2. a) Number of indicator species against total costs of survey for birds and amphibians surveyed through the RAM method, b) Percentage of indicator species against total costs of survey for avian and amphibian taxa surveyed through the RAM method.

CEA analysis is shown in Table 1. For the RAM, the avian survey presented the lowest CE and the highest EC values of the CE1-CE4 ratio options, when considering the numbers of species and excluding field equipment costs. This was followed by the avian survey, considering IS as an outcome and excluding field equipment costs; and the avian survey with equipment costs, taking the number of species as the outcome. For the PC, the avian survey presented the lowest CE and the highest EC of all CE1-CE4 ratio options (both with and without non-perishable equipment costs) and considering the number of species as the outcome.

Combining sampling methods, the avian survey for the PC presented the lowest CE and the highest EC considering the number of species as the outcome (excluding non-perishable equipment costs); followed by the avian survey for the RAM, considering the number of species (excluding non-perishable equipment costs).

Table 1. Cost-effectiveness analysis (CEA) comparing the relative costs (C) to the outcomes (E) for RAM and PC used to survey avian and amphibian communities in a tropical primary forest. Cost per unit of effectiveness (CE ratio= C1/E1) and Effectiveness per unit of cost (EC ratio= E1/C1, where C1= is the cost of option 1 (in USD) are calculated. C1 and C2= cost of survey with and without non-perishable equipment, respectively. E1 and E2 outcomes measured by the number of indicator species and number of species, respectively.

	Acoustic Surveys		**Point Counts**	
	Birds	**Amphibian**	**Birds**	**Amphibian**
C1 (with equip, $)	15582	15582	2504	1011
C2 (without equip, $)	3472	3472	1552	756
E1(No. IS)	33	9	-	-
E2 (No. species)	85	9	79	13
CE1 ratio (C1/E1)	472.182	1731.333	-	-
EC1 ratio (E1/C1)	0.002	0.001	-	-
CE2 ratio (C1/E2)	183.318	1731.333	31.696	77.769
EC2 ratio (E2/C1)	0.005	0.001	0.032	0.013
CE3 ratio (C2/E1)	105.212	385.778	-	-
EC3 ratio (E1/C2)	0.010	0.003	-	-
CE4 ratio (C2/E2)	40.847	385.778	19.646	58.154
EC4ratio (E2/C2)	0.024	0.003	0.051	0.017

4. DISCUSSION

This study provides information to better inform decisions for future biodiversity monitoring and ecological evaluations, by presenting an analysis of the monetary costs and outcomes involved in the use of different sampling methods. In particular, it contributes to understanding the benefits and costs of integrating new approaches such as the RAM into biodiversity monitoring plans.

4.1. Cross-taxon comparisons for sampling biodiversity

Birds were the taxonomic group better represented, in terms of diversity and abundance, across sampling methods and for the lowest financial investment. The dominance of birds within the soundscapes of a wide range of environments (Gasc et al., 2016) might explain the high numbers registered, especially with the acoustic approach. In the case of the PC method, bird acoustic registers were complemented with visual scanning, which increases the probability of capturing species with low acoustic activity or those rarely heard (Haselmayer and Quinn, 2000); moreover, birds are easy to detect (Bardeli et al., 2010), which makes registering presence feasible. However, this study showed a higher efficacy for surveying birds with the RAM method. Another aspect revealed in the analysis is that the rarefaction curves showed greatest increments in the avian species richness per survey costs with the RAM, which suggests a higher efficacy of biodiversity sampling (per day of sampling) in comparison with the PC method. Similar work compared results of bird registers in a forest in Queensland (Australia) using acoustic sensors surveys with traditional field surveys, and also showed the power of the acoustic approach to capture a much elevated number of species against traditional methods (Wimmer, 2015). As found in this chapter, the latter study reported that the greatest difference in number of species was recorded on day one of a five day survey. Celis-Murillo et al. (2009) also report the efficacy of species ID from listening to field recordings over in-situ point counts for bird monitoring.

Conversely, amphibians are characterized by having irregular periods of acoustic activity and short dispersion movements, which resulted in lower detection rates for both sampling methods than for birds. Amphibian vocalizations are energetically costly to produce (Gerhardt, 1994) and are highly influenced by external factors and biotic conditions (e.g. presence of predators, humidity rates, breeding patterns (Akmentins et al., 2014)), which, as observed in this study, makes acoustic registers less effective than avian species registers. Even though acoustic monitoring has been considered an effective method for amphibian monitoring (Weir and Mossman, 2005, Weir et al., 2005), this study showed slightly better results for the PC method, in terms of diversity. Nevertheless, the difference was minimal. In the same way, the combination of aural and visual scanning with the PC increased probabilities of frog encounter, influencing the total diversity of species registered.

It is important to consider that the number of days of sampling and the area sampled varied in both methods and might have influenced results: in the case of the RAM, only three days were considered for the identification of both taxa, and less than 60 mins per day were recorded, per recorder. In the case of the PC, birds were surveyed during eight consecutive days for 240 mins per day, and frogs for three consecutive days for 240 mins per day; hence, relatively RAM can be seen to be very effective when considering the high diversity of birds sampled in the short period of time used for analysis. The advantage of using recordings over field point counts to estimate avian species richness, as mentioned in Celis-Murillo et al. (2009), Wimmer (2015), Haselmayer and Quinn (2000), is the possibility of listening to them multiple times, which also could explain the higher species richness captured with the RAM. It is important also to mention that one limitation of this study is that the RAM and the PC surveys were conducted in the same month, but in different years, which could have influenced the outcomes (i.e. in the abundance and species number), as reported in long term bird surveys in Panama (Robinson, 2001).

The IndVal metric identified more IS of birds than amphibians, yet when comparing the total percentage of species per taxon, the amphibian value was higher at lower sampling costs. Amphibians are considered a good indicator of the environmental conditions of an area due to their susceptibility to habitat change

(Blaustein and Wake, 1990) and to their high reliance on specific features of the ecosystem (e.g. discrete breeding sites)(Hecnar and Robert, 1996). The high levels of representation of amphibian as IS of the primary forest might reflect a sensitivity of the taxon to habitat transformation, which shows its suitability as ecological indicator species. However, it is important to consider that the number of amphibian species registered in this study was very low, which suggest that more research is needed in order to confirm those observations.

Gardner et al. (2008) identified in a cost-effectiveness analysis within three forest types in the Brazilian Amazon that, from a range of taxa that included birds and amphibians, dung beetles and birds were the most suitable taxa for evaluating habitat status. In the same way, Peck et al. (2014) reported that birds were the most cost-effective taxa, of four taxa -excluding amphibians- within an Andean cloud forest in NW Ecuador. However, the latter study also showed that small mammals were the most cost-effective taxa, in terms of number of indicator species as a proportion of species richness. This study did not include a range of taxa as in previous studies; however, it confirms that birds are a suitable taxon for ecological evaluations due to their ecological values as indicator species and their feasibility to be registered for low cost. The inclusion of other taxa, such as highly acoustic mammals (e.g. primates) and insects (e.g. cicadas), might be recommended for further work with the RAM method.

4.2. Cost-effective analysis

The CEA revealed that the avian survey using the PC method was the best option considering the outcomes generated and overall costs (without including equipment costs). The avian survey using RAM was a better cost-effective option than the PC only excluding equipment costs, which suggests that it should be considered with the aim of long term monitoring or to conduct multiple surveys. As mentioned in Wimmer et al. (2013), the cost of sensor surveys reduces as the deployment length increases. Apart from field equipment costs, posterior analysis (i.e. species identification by experts) raised considerably the overall RAM survey costs. The PC overall budget was lower than the RAM, due to its lack of expensive equipment and non-posterior identification analysis, which resulted in higher cost-efficacy values.

An aspect to consider is that the analysis presented in this study did not include other variables that might be important to acknowledge, such as the human fieldwork effort: RAM reduced the amount of fieldwork necessary for conducting the surveys, in comparison with the PC, with a similar final outcome (number of species). Furthermore, it is also important to acknowledge the potential that the RAM offers for post–fieldwork analysis, not only for species identification but for the automatic measurement of diversity, heterogeneity or evenness (Sueur et al., 2014b).

Considering the rapid development of new technology, focused on improving the quality of wildlife acoustic recording (Brandes, 2005) (e.g. microphones resistance, reduction of mechanical noise, battery duration), the generation of new effective devices, made of cheaper materials, will also reduce the total sampling cost and make this approach a more cost-effective option for biodiversity monitoring and accessible to smaller budgets. In recent years, a number of other options have been proposed in order to reduce equipment costs. For example, Farina et al. (2014a) demonstrates the effectiveness of the use of a low cost recorder (LCRs) to monitor biodiversity, that can be used in the same way as professional devices, such as the Song Meter SM1. Another example of a cheap and efficient device for biodiversity monitoring is presented in Aide et al. (2013), which includes an iPod Touch with a pre-amplifier, solar panel, voltage converter, a router, a car battery and a water/shock proof case. This study was focused on the analysis of only one well-known device (Song Meter, SM2 and SM3); hence, research investigating cost-effectiveness of the full range of available devices would be recommended in order to increase understanding on the topic.

5. CONCLUSIONS

The integration of new approaches for monitoring biodiversity and evaluating habitat status is considered a priority in ecology, conservation biology and related fields. Nevertheless, it is also important to fully understand the implications of the use of new methodologies. This study examined the understanding of the cost and benefits of the use of the RAM approach in a species-rich tropical environment, in comparison to traditional point count methods. Some of the benefits of the use of RAM explored in this study were its efficacy in registering high numbers of bird species over short periods of time, with less human sampling effort. As a result, the identification of IS that described the ecological integrity of the area sampled was also possible. Relevant aspects to consider when applying the RAM method were the high investment per survey, especially due to non-perishable equipment expenses. Nevertheless, the cost-efficacy of the use of the RAM method increased over the traditional PC excluding those costs, when the methodology is applied more than once. From this point of view, this methodology might be recommended when the aim of the research is to conduct multiple or long term studies/surveys. Otherwise, there is an imbalance between the total economical investment and the outcomes obtained. This study reports the cost-efficacy of the use of only one type of device; therefore, further research other equipment options also available in the market, is necessary in order to gain understanding.

The development of new technology focused on the improvement of acoustic devices, recording quality and the use of alternative and cheaper materials are necessary in order to increase the cost-efficacy of the RAM approach. Also, the deployment of automatic acoustic analysis might increase its cost-efficacy, by eliminating the expenses of manual identification by experts (e.g. acoustic indices analyse biodiversity patterns at community level, considering the ecosystem as a whole, and do not need individual species identification (Sueur and Farina, 2015)).

Birds were shown to be the better cost-effective taxon for monitoring biodiversity and evaluating ecological integrity of an area compared to amphibians, due to high species richness and ease of register using the RAM and traditional PC methods. Nevertheless, amphibians were seen to be high performance indicator taxa. Identification of priorities of research and clear aims need to be taken prior to any investment in biodiversity monitoring projects in order to reach a trade-off between the cost and outcomes generated, especially in areas with critical shortage of biodiversity data and lack of funding for conservation activities.

CHAPTER 5

Emotional associations with soundscape reflect human-environment relationships

ABSTRACT

In line with the development of socio-ecological perspectives in conservation science, there is increasing interest in the role of soundscape perception in understanding human-environment interactions; the impact of natural soundscapes on human wellbeing is also increasingly recognized. However, research to date has focused on preferences and attitudes to western, urban locations. This study investigated individual emotional associations with local soundscape for three social groups living in areas with distinct degrees of urbanization, from pristine forest and pre-urban landscapes in Ecuador, to urban environments in UK and USA. Participants described sounds that they associated with a range of emotions, both positive and negative, which were categorized according to an adapted version of Schafer's sound classification scheme. Analyses included a description of the sound types occurring in each environment, an evaluation of the associations between sound types and emotions across social groups, and the elaboration of a soundscape perception map. Statistical analyses revealed that the distribution of sound types differed between groups, reflecting essential traits of each soundscape and tracing the gradient of urbanization. However, some associations were universal: Natural Sounds were primarily associated with positive emotions, whereas Mechanical and Industrial Sounds were linked to negative emotions. Within non-urban environments, natural sounds were associated with a much wider range of emotions. Our analyses suggest that Natural Sounds could be considered as valuable natural resources that promotes human wellbeing. Special attention is required within these endangered forest locations, which should be classified as a 'threatened soundscapes', as well as 'threatened ecosystems', as we begin to understand the role of soundscape for the wellbeing of the local communities. The methodology presented in this paper offers a fast, cheap tool for identifying reactions towards landscape modification and identifying sounds of social relevance. The potential contribution of soundscape perception within the current conservation approaches is discussed.

Keywords: emotions, wellbeing, soundscape conservation, sense of place, landscape modification, human perception

1. INTRODUCTION

Over the last few decades conservation biology has developed into an interdisciplinary field that incorporates social and economic development processes (see Berkes, 2004; Hobbs et al, 2011; Milner-Gulland et al, 2014; Rands et al, 2010). The primary concern of conservation has evolved from a focus on protecting endangered species and natural areas, to considering nature as a complex system in which humans are inherently implicated. In doing so, the importance of links between economic development and biodiversity emerge (Meine, 2010). The concept of 'ecosystem services', for example reframes the function of natural ecosystems in economic terms. Although widely adopted internationally, this tendency has been criticized for prioritizing money over nature and, in some cases, generating greater (economic as well as biological) losses than gains (e.g. McAfee, 1999; McCauley, 2006). There is a new direction in conservation that looks beyond a monetized approach, focusing on the assessment of the intrinsic benefits and costs of conservation (Milner-Gulland et al. 2014). At the same time, the definition of environment and conservation are in flux. For example, in Western societies environment has been considered as 'external' to the human realm, placing humans outside nature (e.g. Berkes, 2004; Eriksson, 2014) which creates an obvious challenge for integrated accounts. Furthermore, conservation has focused on the negative role of humans, and civilizations on their environment (Widgren, 2012). Hence, a challenge for conservationists is to integrate new concepts, beyond the traditional understanding of conservation, that incorporate a wider spectrum of current thoughts and understanding of humans in order to enhance and enrich the field and its applications in the social realm. One example is the recent inclusion of community and indigenous interests in an integrated model of conservation and governance (Berkes 2000; Rands et al. 2010).

In the last ten years, a new generation of conservationists have begun to explore the role of biodiversity in human wellbeing (Milner-Gulland et al, 2014; Palmer Fry et al, 2015; Rands et al, 2010; Woodhouse et al, 2015). A focus on human wellbeing may have ethical weight when conservation efforts involve and impact communities, but frameworks for measuring human wellbeing in relation to conservation are undeveloped. Wellbeing can be described along 3 axes: meeting needs, pursuing goals, and experiencing a satisfactory quality of life (Milner-Gulland et al. 2014). Therefore, changes in human wellbeing can be used as one indicator of conservation impact, which incorporates the participation of local communities and contribute to solutions that enable them to live sustainably alongside nature (Milner-Gulland et al. 2014). As a consequence, more conservation practitioners are talking about the importance of taking a holistic approach to people's relationships with nature, managing biodiversity as a global public good, and understanding ecosystems as complex adaptive systems in which humans are an integral part (Berkes, 2004; MEA, 2005; Milner-Gulland et al, 2014; Rands et al, 2010). For these reasons, new and interdisciplinary approaches are being proposed within conservation science, with an integration of the human realm into the field and a focus on the impacts of conservation on human wellbeing.

1.1. Understanding social-ecological interactions through soundscape analysis

Many environmental problems are a consequence of human behavioral choices, and addressing those problems will require understanding and changing those patterns of behavior (Clayton & Myers, 2009). An understanding of the main influences of behavior can allow for positive interventions, such as promoting healthy human-nature relationships, which go hand-in-hand with conservation efforts. One approach that has contributed to the understanding of human-nature interactions, and that has been studied in related fields such as conservation psychology, is the analysis of human perception of natural environments. For example, a number of studies have shown that prevalence and contact with nature is positively associated with human health and wellbeing (Hartig et al, 1991; Kaplan, 2003; Keniger et al, 2013; Mayer & Frantz, 2004). These studies have focused on the effect of natural landscapes on humans; a different branch has explored the effects of soundscape on humans, as soundscapes are a direct connection between natural systems and humans (Gobster et al, 2007).

Soundscape ecology studies the effects of the acoustic environment, or soundscape, on the physical responses or behavioral characteristics of those living within it (Truax 1999). A few studies within this field, based on human perception of soundscape, have contributed to the comprehension of interactions between soundscape and humans. The focus has been mainly on responses to sounds, by assigning subjective labels to soundscape - such as preference or pleasantness. For example, Axelsson et al (2010) proposed a model of reduced attribute dimensions (unpleasant-pleasant, uneventful-eventful, chaotic-quiet and boring-exciting) as a framework for soundscape perception analysis. Working with a group of European students, they showed that sound excerpts dominated by technological sounds were perceived as unpleasant, natural sounds were pleasant and human sounds were perceived as eventful. Similar results were found in visitors to the countryside of Hong Kong, where human preference was correlated with the absence or presence of wanted or unwanted sounds (Lam et al, 2010). In this case, most natural sounds were 'liked' whereas human-generated sounds, such as transportation noise, were 'disliked'. Other examples of soundscape perception that showed similar responses can be found in Kang & Zhang (2010), Payne (2008), Szeremeta & Zannin (2009), Ren et al (2015) and Tse et al (2012).

Research to date has predominantly been conducted in urban areas or areas where anthrophony, or sounds made by humans, dominates. With respect to natural areas, research on soundscape has focused on open urban-public spaces, such as parks and green areas, and has been conducted with primarily westernized groups. The only sound perception research within ethnic groups, living in natural landscapes, has been restricted to ethnographic descriptions, such as the study of

Feld (1990) with the Kaluli people of Papua New Guinea, which highlights the influence of 'sounds of the forest' (e.g. birds or water) in a cultural realm (e.g. language, spiritual knowledge, hunting). There is a lack of research exploring the relationships between forests communities and environment through soundscape studies.

Soundscape perception analysis has been applied in other disciplines such as landscape design. For example, it has been reported that soundscape values and perceptions can be valuably incorporated into landscape planning and soundscape conservation efforts, or can influence individuals to change their behaviour toward the soundscape, by highlighting the relevance of preserving it (Harmon, 2003). Soundscape perception is considered a personal process that can depend on the experience and cultural background of individuals (Farina, 2014); whether there are patterns at the societal level is not yet understood.

The aim of the current study is to develop understanding of human perceptions of soundscape in a variety of environments, based on emotional associations with everyday sounds. We present an approach that provides an overview of a range of soundscapes, from forest communities in Ecuador to western urban groups in the USA and the UK. We explore whether the relationships between human emotions and sounds varies according to the degree of urbanization. The consequences of local environmental impacts on human relationships with soundscape are also analyzed. Three questions motivate this study:

1. Which types of every day sounds characterize each environment?

2. How does each social group relate to those sounds? Are there any observable patterns in this emotional association across groups?

3. What are implications of these relationships for the present and future of each environment?

2. METHODS

Three participant groups were selected from communities living along a non-continuous environmental gradient, from pristine forest to inner city: 'forest group', 'intermediate group' and 'urban group'. The forest group comprised of three communities that live within distinct forested areas in Ecuador: 1. Indigenous Waorani (Wa), 2. Colonos-Mestizo of Santa Lucia Cloud Forest Reserve (SL) and 3. Colonos-Mestizo of Tesoro Escondido Cooperative (TE) (see section 2.1). 'Mestizos' or 'half-blood' are descendant from native communities (indigenous or afro-Ecuadorian) and white people. 'Colonos' refers to migrants who found a new ecological and social space, where they rebuild their identity and their processes of production (Alca, 2003). The intermediate group was a community of Colonos-Mestizo in Puerto Quito town (PQ), Ecuador (see section 2.2). The urban group was composed of three communities that live in urban areas: 1. Parker city, Colorado in USA (Pa), 2. Coventry City (Co), and 3. Birmingham City (Bi), the last two situated in the UK (see section 2.3).

2.1. Forest group (Wa,SL,TE)

The forest group participants lived within undisturbed or minimally disturbed forests and included 56 participants: 42 indigenous Waorani and 14 Colonos-Mestizo farmers. Waoranis are native indigenous people of a lowland rainforest in the Ecuadorian Amazon who have been in contact with western cultures since 1956. The size of their territory, the Waorani Ethnic Reserve, extends to 679,130 ha (Macía, 2001). Areas of their ancestral homelands are threatened by oil exploration and illegal logging. In the last 40 years, they have shifted from being hunting-gathering societies to societies that live mostly in permanent forest settlements. Some groups have rejected all contact with the 'exterior' world and continue to move into more isolated areas; others are adopting the westernized model based on a monetized economy and society. Individuals from the Tiguino, Nenkepare and Qehueirono communities were interviewed (see section 2.4. for method).

The communities that live within the cloud forest, Santa Lucía (730 ha), and the lowland tropical forest of Tesoro Escondido (3000 ha) are families of farmers who migrated to this region, situated in the NW Ecuador (in Pichincha and Esmeraldas Provinces, respectively), no more than 40 years ago. They settled in forested land that has now been transformed into a matrix of forest and pastures with small plantations of fruit and vegetables. The Santa Lucía community lives within the forest, but also spend part of their time in a small town, adjacent to the reserve. Nevertheless, they were considered part of the forest group as they have lived for many years within the forest in the past and spend half of their time within the forest today.

2.2. Intermediate group (PQ)

The intermediate group participants live in a recently founded town, which still harbors patches of forest. It can be considered an 'intermediate point' between a non-industrialized and an industrialized society. It was comprised of 77 participants from Puerto Quito (PQ), a small town in NW Ecuador (Pichincha Province). Most of the participants (79%) were not born in PQ but in surrounding areas. PQ is a 'new' town founded in 1996, and has a population of 19,728 inhabitants (AME, 2015). One of the principal incomes of the town is from ecotourism due to its close proximity to patches of forest and river systems. Agriculture and livestock farming also contribute to the economy of town.

2.3. Urban group (Pa,Co,Bi)

Participants belonging to the urban communities live within well-established cities and urban areas, and included 42 participants. The first community (N = 14) is from Parker, a small city in USA, Colorado, and surrounding areas. It was founded in 1864 and has 47,823 inhabitants. The second community (N=15) is from Coventry, the 10th largest city in England with 337,400 inhabitants. The last community (N=13) is from Birmingham, the 3rd most populous built-up city in the UK (ONS, 2014) with 1,101,360 residents. It is important to consider that these urban areas also maintain green or open areas, especially Parker which is the smallest city; Birmingham also reports to have 600 parks and open spaces (BCC, 2015).

2.4. Procedure

The research was conducted in Ecuador between June-July 2014 and July-August 2015. At all sites the participants (n=177, men and women, >17 years old) were gathered together and a structured interview was conducted. Participants were recruited via chain sampling, selecting informants until a saturation of participants appropriate for the approach of this investigation was obtained (Garson, 2008), following the sample size suggestions of Nastasi (2004). The interview consisted of associating sounds with five emotional states: 'Thinking of your home town, name 3 sounds which you associate with: 1) happiness, 2) sadness, 3) tranquility, 4) fear, and 5) irritation.' This study included all the range of emotions that influence human life and were considered as universal responses. Participants provided written responses of up to 15 sounds. In order to avoid biases during the recruitment of participants, a previous meeting with all informants, where the purposes and methods of the study were presented, was conducted.

Responses were labelled according to Schafer's classification of everyday sounds (Schafer, 1994). Originally created as a framework to study the functions and meanings of sound, sounds were drawn from anthropological and historical documents. The sources of everyday sounds are grouped into 'sound types' – such as bird song, human voice or machine and also arranged hierarchically into 'sound categories' – such as natural sounds, human sounds and mechanical sounds. Schafer's scheme was modified for this study by adding sound types that included the observed responses, such as sound of felines, music, leaves or wind (see Annex 12). The table consisted of 6 main categories or 'sound categories' and 53 subcategories or 'sound types'. The sound categories were Natural Sounds (such as birds, air and water), Human Sounds (such as voice, screams and body), Sounds and Society (such as domestic, digital and music), Mechanical Sounds (such as machines, guns and transportation machinery), Sounds as Indicators (such as bells, horns and explosions) and Other (such as silence, noise, unknown things).

The data obtained (1313 responses; forest group=229, intermediate group=517, urban group=567) was analyzed using Statistical Package for Social Sciences (SPSS) version 22. In order to explore differences between sound categories (n=6), sound types (n=53) and their relationship with emotions (n=5), comparisons within and between groups were conducted using a Kruskal-Wallis H Test.

A Multiple Correspondence Analysis (MCA) was conducted in order to detect and represent the structure of the dataset and to elucidate any association between sound types. Within the MCA, each sound type was represented in multidimensional space based on the response to emotions of all social groups. The distance between points reflects the relationship between sound types, the shorter the distance, the stronger the relationship (Sourial et al, 2010). The visualization of cloud points projected permitted the classification of sound types into clusters that represent combinations that best describe the differences amongst social groups.

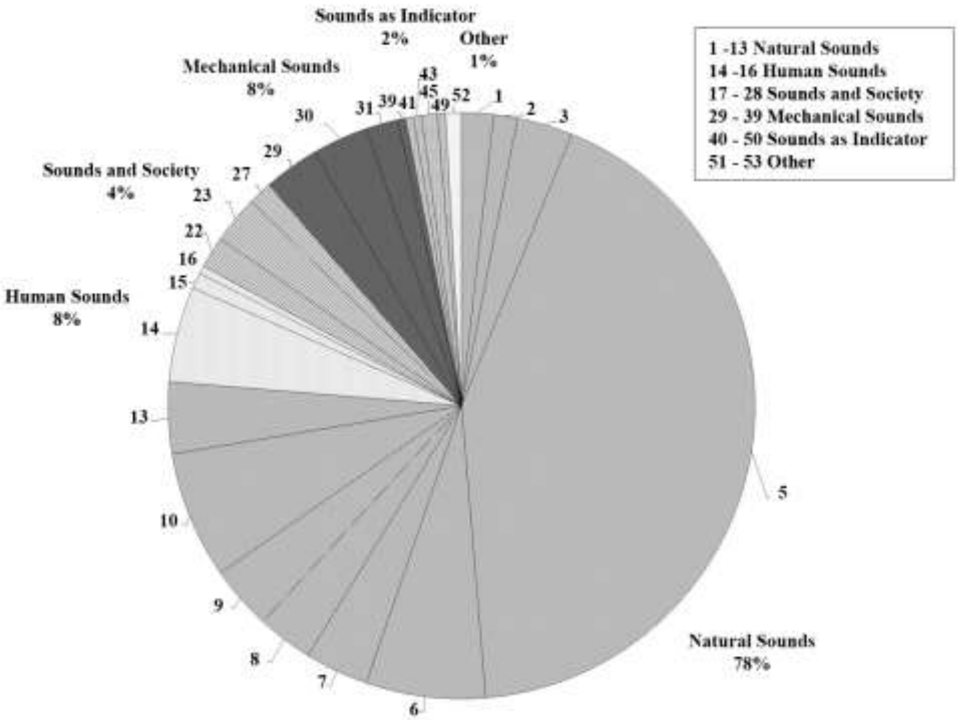
Previous to the field work period, all the activities and procedure conducted during this study were approved by the Social Sciences & Arts Research Ethics Committee of the University of Sussex

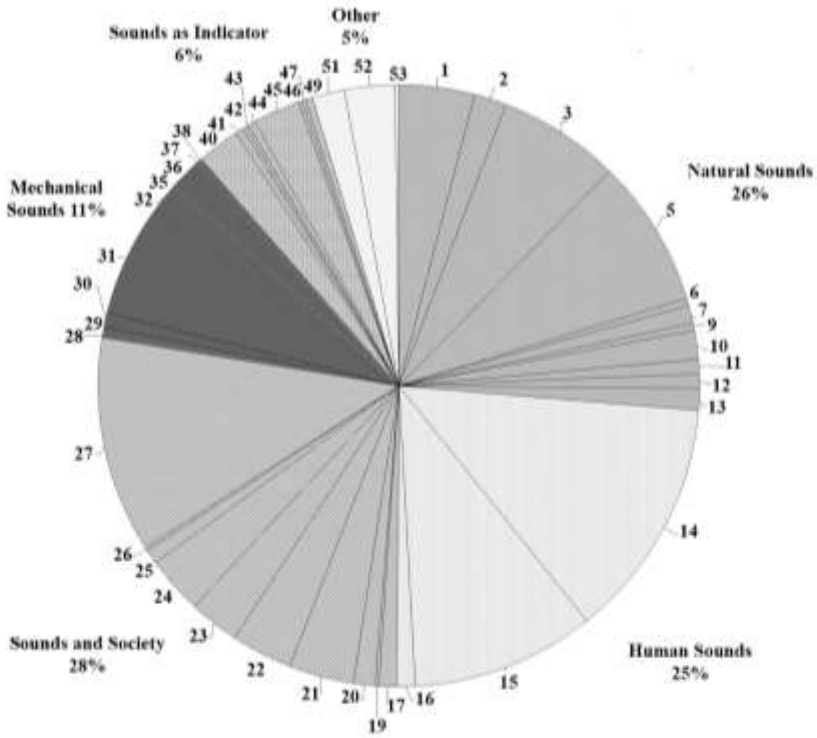
3. RESULTS

3.1. Distribution of responses across sound source categories

As shown in figure 1, the distribution of responses amongst sound categories varied across groups. Significant differences between the forest group and both the intermediate group (PQ), $\chi2$ (1) = 125,3 $p < 0.05$) and the urban group (Pa,Co,Bi), $\chi2$ (1) = 147,2 $p < 0.05$) were found; however we found no significant difference between the intermediate group and the urban group ($\chi2(1) = 1.61$ $p = 0.204$).

The modal category for the forest group was Natural Sounds, followed by low percentages of Human Sounds, Mechanical Sounds, Sounds & Society, Sounds of indicators and Other. In contrast, no sound category dominated the intermediate group: the main categories in order of importance were Sound & Society, Natural Sounds and Human Sounds, followed by lower percentages of Mechanical Sounds, Sounds as indicators and Other. The urban group responses followed a similar pattern: the main categories were Human Sounds, Sound & Society, Natural Sounds, followed by Sound as Indicators, Mechanical Sounds and Other.





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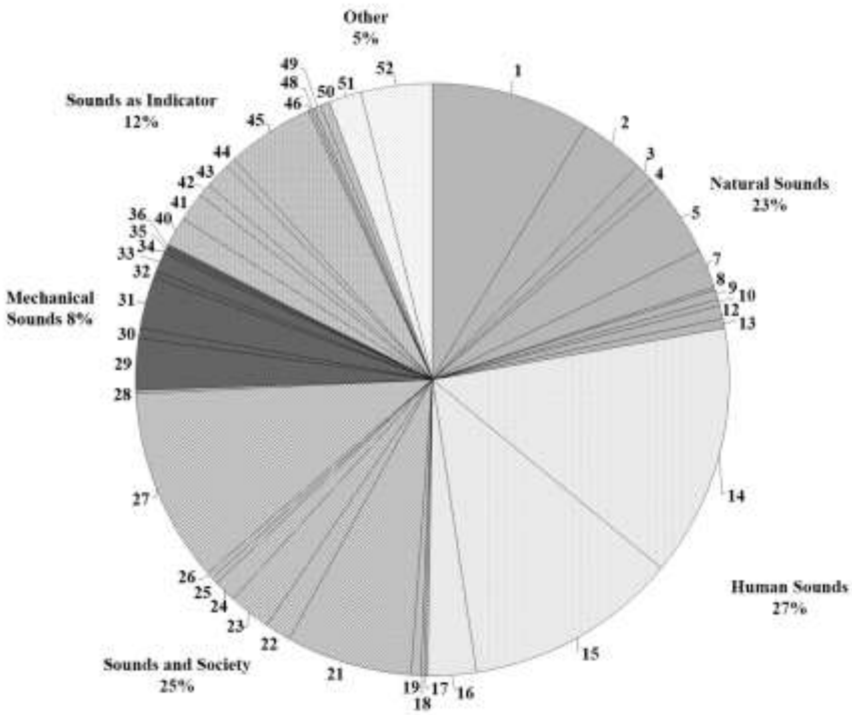

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Figure 1. Overall classification of sound categories (n=6) and count distribution of sound types (n=53) in a forest group (a), and intermediate group (b) and a urban group (c).The sound types comprise the sound categories classification: Natural Sounds (1-13), Human Sounds (14-16), Sounds & Society (17-28), Mechanical Sounds (29-39), Sounds as Indicators (40-50), Other Sounds (51-53). Each number corresponds to sound type defined by the soundscape classification table (see Annex 12 for more detail).

3.2. Emotional associations of sound source categories

The association between sound categories and emotions are illustrated in figure 2: The distribution of associations between sound categories and emotions differed between groups: (forest group, $\chi2$ (5) = 12,52 p <.05; intermediate group, $\chi2$ (5) = 69,30 p <.05; urban group, $\chi2$ (5) = 57,88 p <.05).

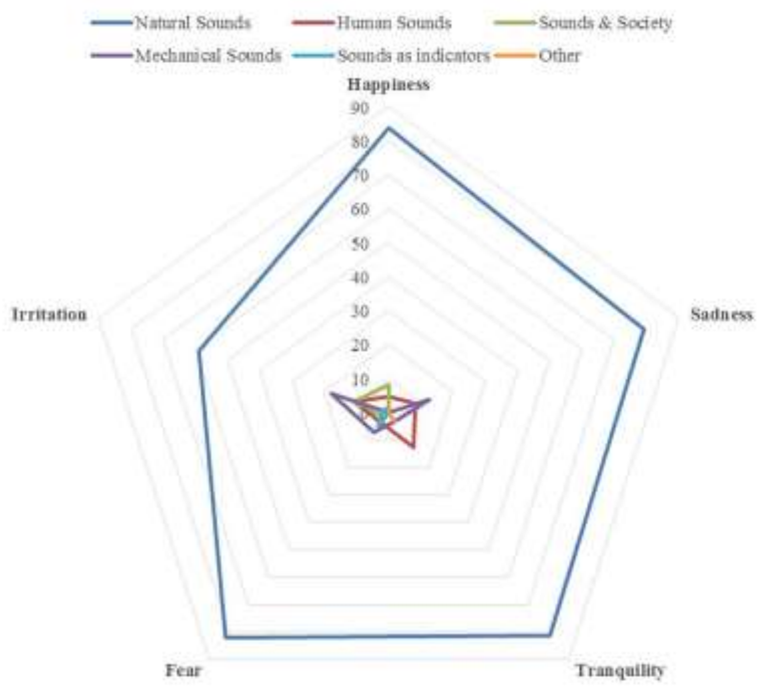
In the forest group (see figure 2a), Happiness was mostly associated with Natural Sounds (83.9%), followed by Sounds & Society (8.1%), Human Sounds (4.8%) and, with low association, with Sounds as indicators (1.6%) and Other (1.6%). Sadness was also associated primarily with Natural Sounds (79.2%), Mechanical Sounds (12.5%) and Human Sounds (8.3%). Tranquillity was related mainly to Natural

Sounds (81.3%), followed by Human Sounds (12.5%), Mechanical Sounds (3.2%) and Other (3.2%). Fear was related mainly to Natural Sounds (81.8%) and then Mechanical Sounds (7.3%), Sounds as indicators (5.5%), Human Sounds (3.6%) and Sounds & Society (1.8%). Finally, Irritation was also primarily associated with Natural Sounds (58.9%), and to a lesser degree with Mechanical Sounds (17.9%), Human Sounds (10.7%), Sounds & Society (10.7%), and Sounds as indicators (1.8%).

In comparison, the intermediate group responses (figure 2 b) suggested that Happiness was associated with Sounds & Society (35.3%), Natural Sounds (30.2%), Human Sounds (22.4%), and to a lesser degree with Sounds as indicators (7.8%) and Mechanical Sounds (4.3%). Sadness was related mainly to Human Sounds (44%), followed by Sounds & Society (25%), Sounds as indicators (11%), Natural Sounds (7%), Mechanical Sounds (7%) and Other (6%). Tranquility was associated primarily with Natural Sounds (54%), followed by Sounds & Society (20%), Human Sounds (18%), Other (5%), Mechanical Sounds (2%) and Sounds as indicators (1%). Fear was related mainly to Sounds & Society (39.8%) and Natural Sounds (32.4%), and to a lesser degree to Human Sounds (9.3%), Mechanical Sounds (9.3%), Sounds as indicators (5.6%) and Other (3.7%). Lastly, Irritation was associated with Human Sounds (33.3%) and Mechanical Sounds (33.3%), followed by Sounds & Society (15%), Other (9.7%), Sounds as indicators (6.5%) and Natural Sounds (2.2%).

The urban group results (figure 2 c) suggested that Happiness related mainly to Sounds & Society (42.9%), Human Sounds (39.6%) and Natural Sounds (17.5%), followed by Mechanical Sounds (5.3%), Other (1.8%) and Sounds as indicators (1%). Sadness was associated primarily with Human Sounds (39.7%) and Sounds & Society (27.4%), and to a lesser degree with Natural Sounds (12.3%), Sounds as indicator (12.3%), Mechanical sounds (4.7%) and Other (3.7%). Tranquillity was related mainly to Natural Sounds (58.8%), followed by Sounds & Society (18.5%), Other (9.4%), Human Sounds (6.7%), Mechanical Sounds (4.2%) and Sounds as indicators (2.5%). Fear was associated especially with Human Sounds (30%), Sounds & Society (23.9%) and Sounds as indicators (20.4%), followed by Natural

Sounds (13.3%), Mechanical Sounds (6.2%) and Other (6.2%). Finally, Irritation was related particularly to Human Sounds (30.4%) and Sounds as indicators (26%), and to a lesser degree to Mechanical Sounds (19.1%), Sounds & Society (13%), Natural Sounds (8.7%) and Other (2.6%).



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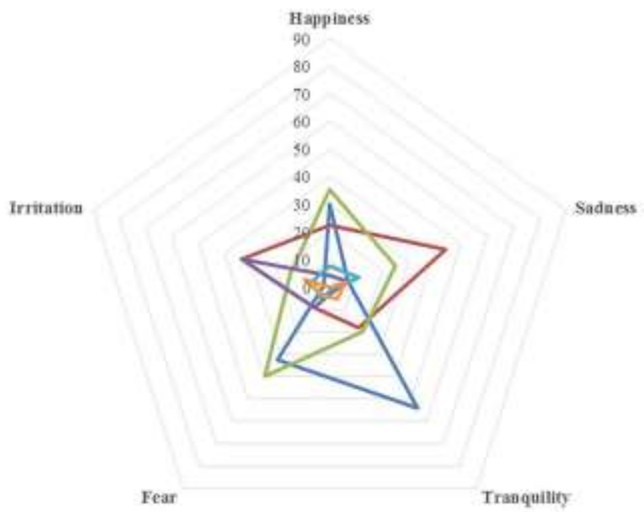

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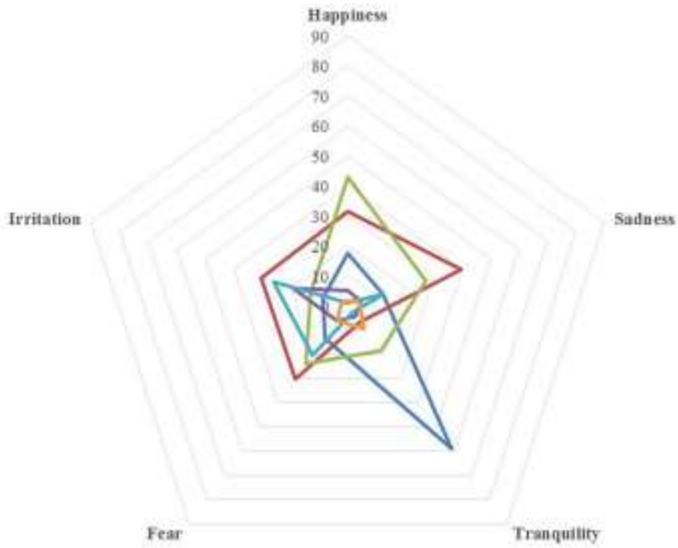

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Figure 2. Distribution of emotions (n=5) across sound categories (n=5) for a) the forest group, b) the intermediate group and c) the urban group.

3.3. Distribution of sound source types: soundscape projections

There were significant differences in the distribution of response across sound sources types reported among all social groups ($\chi2$ (5) = 108.75 p <.05). Figure 1 presents the distribution of sound types reported by each group (see Annex 12 for the list of recorded sound types).

With MCA, the analysis reduced the data to two dimensions that accounted for 50.4% of the variance. The variables of Dimension 1 have the highest inertia (0.390) and accounts for most of the variance between sound sources types among groups, whilst the variables of Dimension 2 show lower inertia (0.114). The contribution of each sound type in both dimensions and its scores are shown in Annex 13. Hierarchically, the most discriminant variables for Dimension 1 were, sounds of birds, felines, reptiles and mammals; and for Dimension 2 were marine soundscape, sounds of water, construction and demolition equipment, and transportation machines.

Figure 3 maps sound types within the two dimensional space. The relative distance of the points from the origin along each dimension indicate which dimension each variable was best represented by and which variables loaded onto the same dimension. The position of each social group shows which sound types and sound type combinations are strongly associated with them. For example, the forest group was closely related to Dimension 1, and the sound of 'birds', 'other animals', 'reptiles', 'industrial and factory equipment', 'thunder and storms', 'felines', and 'mammals'. The intermediate group was mostly related with the negative axis of Dimension 2 and sounds of 'social media programs', 'transportation machines', 'trades, professions and livelihood', 'radio', 'films and TV', 'bells, domestic animals', 'leaves and trees', 'forest', 'guns', and 'rural soundscape'. The urban group was equally related to both Dimensions (with the negative axis in case of Dimension 1 and sounds of 'water', 'air', 'warning systems and alarms', 'other entertainment', 'domestic soundscape', 'body', 'silence', 'whistles', 'horns', 'telephone', and 'sound of screaming and crying').

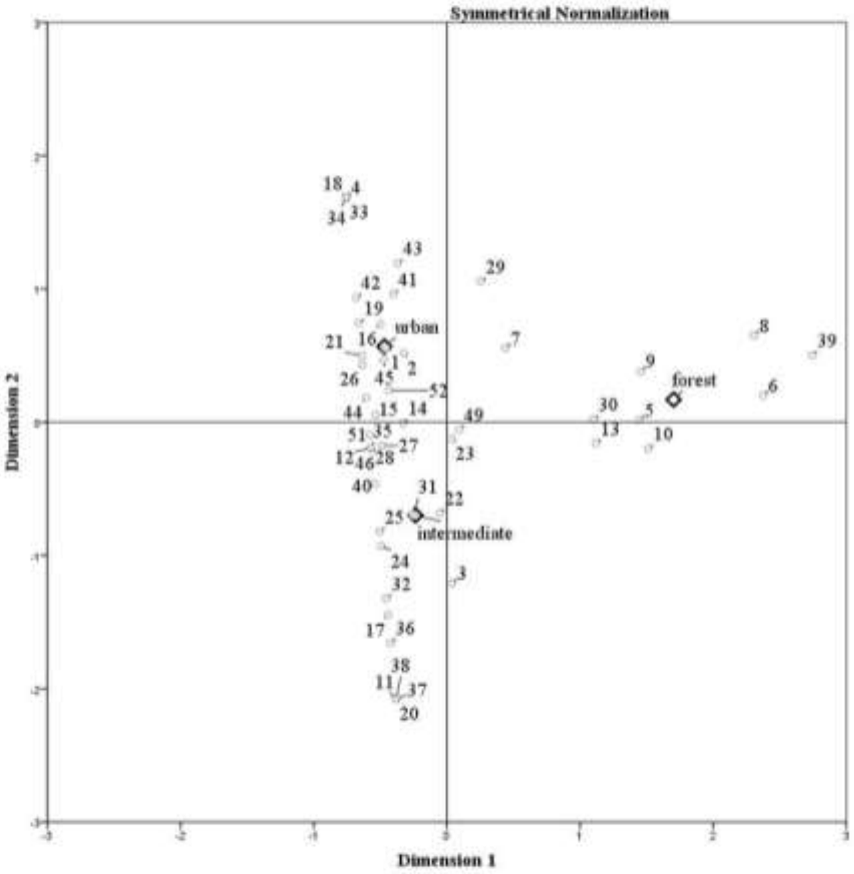

Figure 3. Multiple Correspondence Analysis. Projections on two dimensions of sound types among social groups. The X axis represents the first dimension of the data variation, whilst the Y axis represents the second dimension in the MCA.Each number corresponds to a sound type (N=53) defined by the soundscape classification table (see Annex 12). The social groups are: 1) the forest group, 2) the intermediate group and 3) the urban group.

4. DISCUSSION

4.1. Emotional association with sound source categories

Results suggest that, as expected, the soundscapes of forest, pre-urban and urban communities differed in the distribution and composition of sound categories and/or sound types, yet some similarities in patterns were observed in the association of sounds with particular emotions. We also found that the relationship between sounds and emotions was not necessarily related to the dominance of sounds. This was particularly clear for natural and mechanical/industrial sounds.

In the case of social sounds, the relationship was different: the Sound of Humans and Sound & Society were associated with the full range of emotions in all groups. According to Stocker (2013) this could be considered a predictable response which expresses human nature and 'something about the common experience of safety or vulnerability in humans' (p. 27). For example, the sounds of the voice, such as screams and crying of children, were related to negative emotions (sadness and irritation), whilst laughter and singing were related to positive emotions (happiness and tranquillity). These results therefore could suggest that the relationship between 'social sounds' and emotions was consistent across groups.

The relationship between Natural Sounds and emotions was different. In the forest group Natural Sounds dominated and were associated with the full range of emotions, including 'negative' attributes (sadness, fear, irritation) although less frequently. The breadth of emotional associations of natural sounds for the forest group tarries with Schafer's (1994) account of a survey of sound preference in Port Antonio, Jamaica, where most of the interviewees described animal and insect sounds as unpleasant. Even though living within a forest landscape could be a confounding factor, or a factor that influenced the high response rate of Natural Sounds, it could also have reflected the high level of integration of the forest communities within their natural environment. The fact that people are living within the forest and depending on it (especially in the Waorani community) could have created a stronger emotional affinity with nature, as the exposure level to the natural environment is greater, as suggested in Kals et al (1999). In contrast, in the intermediate and urban groups, natural sounds were most strongly associated with tranquility, which aligns with recent research pointing to the calming effect (Kaplan, 2003; Kaplan & Kaplan, 2011; Keniger et al, 2013) and preference for natural sounds (Kang & Zhang, 2010; Lam et al, 2010), rather than non-natural sounds. The 'positive' association with natural sounds within urbanized groups could suggest that these sound sources are providing them a 'stillness state' that perhaps other sound sources do not provide in their daily acoustic environment. This observation is supported by the Attention Restoration Theory (Kaplan, 1995) which postulates that exposure to natural environment has positive effect on humans, reducing stress and enhancing cognitive capabilities. Furthermore, studies conducted in urban areas revealed preferences for natural settings (Clayton, 2000; Newell, 1997), and its effects on people, such as heightened sensations of restorativeness, tranquility, and lowered sense of danger, and transcendence experiences in comparison to urban settings (Herzog et al, 2002; Herzog & Chernick, 2000; Williams & Harvey, 2001). According to the 'biophilia hypothesis' (Kellert & Wilson, 1995), humans have a biologically based need to affiliate with and feel connected to the broader natural world. The response of urbanized groups supports this hypothesis by showing that natural sounds might function as a 'link' between the natural world and the senses of affiliation and connection to it, within an urbanized environment.

The relationship between mechanical/industrial sounds and emotions shows a similar pattern among groups and were mostly associated with 'negative' emotions. Given that this study did not take the amplitude of each sound source into consideration, we cannot confirm that loudness, and not other qualities of mechanical/industrial sounds, explained this emotional association. Nevertheless, it has been widely reported that the effect of loudness/noise cause discomfort in humans (e.g. Axelsson et al, 2010; Lam et al, 2010; Szeremeta & Zannin, 2009) and even that it is associated with health problems (Farina, 2014; Passchier-Vermeer & Passchier, 2000; Stansfeld & Matheson, 2003). The relevance of identifying 'negative sounds', especially in forest communities is discussed further below.

As shown in our analyses, the relationship between sounds and specific emotions reflected similarities across groups, which could suggest that there are patterns occurring at societal level. Furthermore, we found that the shift from forests to urban landscapes is associated with shifts in the distribution (or abundance) of sound sources, which has an effect (negative or positive) on human emotions. General patterns observed, such as the positive association with natural sounds, or the negative association with industrial sounds, could help to gain understanding of the consequences of landscape change on human emotional responses. Nevertheless, further research is needed; especially within forest societies, in order to better understand their unique relationships with natural soundscapes and the consequences of environmental impact on their lives.

It should be noted that our samples confound urbanization and cultural background (urban groups were non-Ecuadorian); in future research we recommend the study be conducted with a single ethnic group living along a gradient of landscape modification.

It is also important to consider that one of the sites of the urban group (Parker) presented similar frequencies of sound categories to Puerto Quito town (intermediate group) (e.g. higher percentages of Natural Sounds and lower percentages of Sound as Indicators'). This similarity could explain some similarities found between the intermediate and urban groups. This shows also that the difference between the definition of a city and a town is not necessarily related to population density (i.e. high population density could be combined with rural ways of living). Furthermore, this study did not make any distinction between age, gender, level of education, etc. and the responses could be influenced by this as well. For example, most of the participants in the forest group were adults (between 20-50 years old), whilst in the other groups all the participants were young adults (around 18 years old). We recommend consideration of these factors in further studies.

4.2. Sound source types and soundscapes projection: a new tool for understanding human-environment relations

The analysis of sound source types, composition and frequencies in each group allowed us to better interpret and understand emotional associations with particular sound categories. For example, the strong association between fear and Sounds & Society observed in the intermediate group was related to the presence of sounds of 'police and guns,' revealed in the soundscape projection; whereas in the forest group, the presence of 'feline' (jaguar) and 'reptile' (snake), for example, explains the negative association with the Natural Sounds category. Furthermore, sound type composition showed that the diversity of natural sounds, explained as the numbers of words comprising the Natural Sounds category, decreased with landscape disturbance level (i.e. a greater diversity of natural sound types was reported from the forest group). This highlights the differences among groups, which could reflect not only the cultural proximity to nature but also the 'landscape state' in terms of biodiversity. Links between biodiversity richness and psychological wellbeing have been shown in a study of urban green spaces by Fuller et al (2007). They found that people are able to perceive areas with higher species richness (in plants, butterflies and birds), and that those areas produced more restorative effects on them than areas with lower biodiversity. This aspect was not tested in this study but our results contribute to understanding the relationship between human perception, emotion and biodiversity.

As a tool, soundscape projections can provide a means for investigating which sound types best characterize particular soundscapes. For example, the sound type composition in the forest group is principally comprised of natural sounds that describe a biodiverse landscape (especially in fauna). It also revealed the presence of sounds associated with industry and machinery. In comparison, the intermediate group presented a 'mixed soundscape', with sounds of an industrialized society (e.g. transportation machinery), that is still influenced by a natural landscape (e.g. forest sound). The urban group was mostly described as a combination of human generated sounds, or 'lo-fi' soundscape (Schaffer, 1989), with natural sounds that do not necessarily reflect the existence of a natural landscape, (e.g. water and wind).

4.3. Soundscape perception in conservation science

This study highlights the potential for the inclusion of studies of human perception of the environment within the science of conservation, particularly where there is the explicit aim of incorporating the impacts of land use change/conservation on humans. Soundscape perception analyses could contribute to conservation science in the following ways:

1) As a tool for understanding the impacts of environmental disturbance on humans and its effect on people's wellbeing, considering that health and wellbeing are influenced by the sonic environment (Pijanowski & Farina, 2011);

2) By highlighting sounds that are considered relevant sources (of welfare or disturbance) and illustrating 'soundscape values' for human communities. These two aspects have been suggested within soundscape conservation strategies (Dumyahn & Pijanowski, 2011);

3) By providing insights into the relationship between humans and nature; and

4) By providing a proxy for the degree of industrialization of a given area, as landscape change has an immediate effect on soundscape (Farina 2014).

In this study we gained understanding of different aspects of human-nature relationships that could be considered in future conservation planning. Within the forest group, the presence of industrial machinery, such as those associated with the crude oil industry within the Waorani Ethnic Reserve (Finer et al, 2010), was evident in the analyses. Sounds generated by industrial and factory equipment were viewed negatively by the communities (i.e. associated with irritation). This information corroborates other research that reports that the presence of crude oil companies in the Ecuadorian Amazon has caused negative reactions in the communities (Vallejo et al, 2015) and has even had health consequences (San Sebastian & Hurtig, 2004). Other relevant aspects revealed by the forest communities was their close relationship with nature through natural sounds. This particular association is significant: For the indigenous Waorani for example, the distinction between the natural world and humans is blurred, as their language (huao terero) does not include any words that separate humans from the environment, such as the terms 'nature', 'ecology', 'animals', 'plants' (Rival, 2012). This suggests that the value of natural sounds includes broader aspects of human identity and sense of belonging. According to 'deep ecology', these findings are explained by the 'ecological self' concept which is described as a sense of identity that transcends the individual and encompasses one's position as part of a living ecosystem (Bragg, 1996; Matthews, 2006; Naess & Rothenberg, 1990). Hence, we could consider that changes in soundscape due to habitat intervention, apart from having a negative effect on people's emotional state, could also affect their self-development process, or as Borden (1986) called it, provoke a 'crisis of the self'.

Key aspects about the relationship between forests communities and specific organisms were evinced during this study, such as fear of snakes, and could be considered for future educational programmes or conservation strategies within those areas.

Furthermore, we were able to identify that according to the Soundscape Type classification proposed by Dumyahn & Pijanowski (2011), the forest group classifies as a 'Threatened' type of soundscape, which requires specific management goals, such as mitigation of excessive noise, improvement in technologies of sound producing object(s) and limits to additional noise intrusions.

We also found that people from urbanized environments associated natural sounds with a narrower range of emotions than the forest communities and that there was a strong positive emotional association with natural sounds, which can be understood in terms of the restorative, calming effects of these soundscapes. The value of natural sounds within the urbanized groups should also be considered in conservation, inspiring future research for urban design, for example by protecting, creating and/or restoring natural areas that are sources of natural sounds.

5. CONCLUSION

The key findings of this research are threefold: Firstly, key soundscape elements differ along a gradient of urbanization; our analyses highlight specific sounds which characterize each environment. Secondly, universal trends in emotional associations of natural versus industrial sounds were observed; analyses of emotional association with sounds enabled exploration of soundscape sensitivities and values amongst groups. Thirdly, sounds reported in response to emotional cues are likely to be those of high personal relevance: sounds that do not have an impact on individual's life are less likely to be mentioned given that sounds have qualities that permeate the subconscious, affecting emotional state in humans (Stocker, 2013). In this light, the soundscape projections created through the analysis can be read as a 'phenomenological impression' of the relationship of the social group to their local environment. This impression may also reflect the behavior of the community towards the sonic environment, the soundscape values and the state of industrialization at that location. Our results align with Schafer's (1994) description of soundscape transition from 'first soundscapes' to 'post-industrial soundscapes' and support the idea that soundscapes have a direct impact on human wellbeing. These findings highlight the need for a greater understanding of which sounds promote healthier environments and the importance of continuing to widen the scope of conservation science research by integrating human perspectives in order to enhance conservation strategies and efforts.

GENERAL CONCLUSIONS

Summary of Contributions

- *Association between soundscape & human/ecological wellbeing:* Chapter 1 synthesized key information and concepts generated to date in the literature. Research and understanding on the topic was associated with the evolution of new concepts and terminology: the term "soundscape" evolved from a narrower interest in sounds and their influence on physical health, into a multidimensional and integrative concept associated with a range of domains of human and ecological wellbeing. Contemporary research has begun to understand the influences of soundscape on broader aspects of wellbeing, such as social and cultural wellness and ecological integrity; therefore, further investigation on these topics is required.
- *Current use of acoustic indices for ecological evaluations*: Chapter 2 examined the response of four acoustic indices (*ACI*, *BI*, *AE* and *H*) along a gradient of landscape modification. Significant differences between habitats were observed, but no clear relationship of acoustic indices with explored biodiversity descriptors that reflected the population status of amphibians and birds, was found. A focus on qualitative values of biodiversity is recommended in order to improve understanding on ecosystem dynamics and responses to habitat degradation through the acoustic approach.
- *New methodology for rapid ecological evaluations:* Chapter 3 presented a method for accurately identifying species which are indicators of the ecological integrity of an area, and for detecting those species through automatic detectors within recordings. The approach proved an effective tool to quickly evaluate the habitat status of an area, without the need for conducting extensive inventories of multiple taxa. However, high rates of misidentifications suggest that this approach should be used for obtaining only data of presence/absence.
- C*ost-effectiveness of the use of acoustic monitoring for rapid ecological evaluations:* Chapter 4 assessed the costs and outcomes involved in using rapid acoustic monitoring for ecological evaluations. Results highlighted

that this sampling methodology is a suitable tool to register high number of species and indicator species, particularly of birds, in short periods of time. The high costs involved in the survey, especially of equipment, suggested that this approach should be consider with the aim of conducting multiple surveys or long term monitoring.

- *New proposal for evaluating human-environment relationship:* Chapter 5 described a tool for gaining understanding on the human-environment relationship, and identifying sounds of social importance. Common patterns in the association of natural sounds with positive emotions, and industrial/technological sounds with negative emotions, across social groups suggests that universal responses to specific sound sources exist. Natural sounds can be considered a natural resource that promotes wellbeing, therefore special attention is required in future actions and landscape management plans.

The range of acoustic analyses presented throughout this work were seen to be effective for evaluating ecological and social research priorities in conservation biology. Within the *Ecological* research component, the use of acoustic sensor networks showed great potential, especially as a tool for registering high number of species over short periods of time, which is a limitation of traditional sampling techniques (Chapter 4). Moreover, the information recorded over short period was enough to produce an overall understanding of the wildlife patterns in each habitat type (Chapter 2). However, no clear patterns were observed using automated indices when comparing to biodiversity descriptors explored in this study. Current community level acoustic indices for biodiversity assessment might be enhanced by the integration of analytical tools that highlight qualitative biodiversity patterns, such as the automatic detection of indicator species of ecological integrity (Chapter 3). The combination of community and individual level acoustic analysis could make the application of acoustic methods a powerful tool for rapid evaluation of habitats, particularly in complex environments such as tropical rainforests. The integration of individual level analytical tools into the current acoustic approach might ensure that biases caused by anthropogenic noise or misinterpretation of the acoustic community, will not affect the final outcome (i.e. the accurate evaluation of habitat status).

Within the *Social* research component, the methods explored in this study, based on soundscape analysis, afforded fresh perspectives on key topics of research in contemporary conservation biology: soundscape perception analysis allowed increasing comprehension of the human-environment relationship and the implications of landscape degradation on humans (Chapter 5). This work inspires future research into identifying sounds of social relevance as priority areas for conservation. Moreover, research on the association of soundscape with multiple domains of human wellbeing (Chapter 1), suggests that special attention to soundscapes and their management are needed. Given that the study of this association is relatively new, more research to fully comprehend the implications of habitat change on human, as well as non-human organisms, need to be carried out.

The rapid development of new technologies and of research focused on acoustic analysis, suggest that this is a promising approach that can contribute significantly to the understanding of the dynamics of ecosystems, by integrating ecological and social dimensions; its application presents a range of opportunities for future research that need to be further explored in conservation biology.

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ANNEXES

Annex 1. Bibliographic metrics of the analysis of co-occurrence of key-words

Label	x	y	Cluster	Weight Links	Weight<Total link strength>	Weight<Occurrences>	Score<Avg. pub. year>
acoustic	-0.1371	0.0075	5	38	56	11	2010.6364
acoustic comfort	-0.7677	0.204	1	147	506	58	2011.9138
acoustic communication	0.8069	0.471	5	44	70	17	2014.2941
acoustic design	-0.5369	-0.1446	1	55	90	13	2008.6154
acoustic echo cancellation	-0.4107	-1.1509	4	14	46	10	2009.2
acoustic ecology	0.3848	0.457	5	49	84	24	2013.0417
acoustic environment	-0.6004	-0.3908	4	243	1471	277	2011.1733
acoustic environments	-0.3602	-0.7816	4	47	67	13	2006.0769
acoustic fields	-0.6418	-0.6865	4	83	191	33	2010.7273
acoustic generators	-0.2851	-0.1779	6	74	108	16	2008.9375
acoustic measurements	-0.9046	-0.1326	1	85	162	18	2011.7778
acoustic noise	-0.6881	-0.2084	1	233	1952	292	2010.7432
acoustic noise	-	-	4	91	155	25	2006.8

measurement	0.4721	0.4172					
acoustic quality	-1.0835	0.0939	1	58	127	17	2009.4118
acoustic signal processing	-0.2665	-0.8985	4	48	86	19	2004.3158
acoustic stimulation	0.8982	-0.5055	2	143	683	46	2008.8043
acoustic variables control	-0.8738	0.0724	1	159	850	128	2012.1406
acoustic variables measurement	-1.0502	-0.1058	1	74	215	28	2010.75
acoustic wave absorption	-0.9859	-0.4189	1	44	72	12	2009.8333
acoustic wave propagation	-0.7041	-0.6042	4	51	92	17	2008.7647
acoustic wave transmission	-0.866	-0.5005	4	39	71	11	2011.8182
acoustic waves	-0.2403	-0.3912	4	92	147	22	2007.5
acoustics	-0.2595	-0.2808	4	287	2105	277	2010.3935
adaptation	0.8293	-0.1356	2	55	87	10	2011.5
adolescent	0.3095	-0.3892	2	123	327	20	2006.4
adult	0.4629	-0.4913	2	187	1062	70	2008.9714

age	0.7251	-0.1088	2	73	116	12	2008.6667
aged	0.4235	-0.7912	2	128	475	32	2006.9375
aging	0.9932	-0.6814	2	52	132	11	2002.1818
air quality	-0.8493	-0.1549	1	80	139	21	2012.2381
aircraft	-0.1283	0.1359	1	63	81	12	2004.9167
aircraft noise	0.0781	0.7585	3	63	126	25	2010.92
algorithm	0.2512	-0.7983	2	75	143	12	2007.5833
algorithms	-0.2143	-0.9194	4	96	284	56	2007.0536
ambient noise	0.7198	0.6063	5	54	136	40	2014.3
animal	1.0036	-0.1293	2	111	364	32	2009.0938
animal experiment	1.1926	-0.4016	2	77	269	22	2004.9091
animalia	0.6649	-0.05	5	71	109	17	2011.7647
animals	1.0205	-0.2147	2	135	623	53	2009.434
annoyance	-0.0148	0.7194	3	132	448	71	2012.1408
anthropogenic noise	0.58	0.665	5	68	145	28	2014.5

architectural acoustics	-0.7804	-0.5677	4	134	462	62	2011.1452
architectural design	-0.7782	-0.2427	1	36	69	11	2013.3636
areas	-0.2714	1.0117	3	61	163	27	2012.9259
arousal	0.6867	0.1204	3	54	94	11	2009.7273
artificial intelligence	-0.0705	-0.6876	4	50	67	11	2008.8182
attention	0.5479	0.172	3	52	98	11	2013.0909
audio acoustics	-0.3246	-0.4439	4	108	217	43	2011.0698
audio recordings	-0.5793	-0.6743	4	59	100	11	2013
audition	-0.4072	-0.3311	4	159	496	68	2010.7941
auditory cortex	1.0699	-0.4864	2	76	281	25	2008.88
auditory discrimination	1.0038	-0.2855	2	73	158	12	2008.25
auditory perception	0.5481	-0.1967	2	159	546	42	2010.0714
auditory stimulation	0.8561	-0.4329	2	136	536	37	2009.1622
auditory system	0.7794	-0.5094	2	58	86	10	1995.7
auditory threshold	0.78	-	2	105	326	24	2005.6667

	18	0.6722					
australia	0.633	0.3694	5	60	85	13	2012.0769
aves	0.869	0.4134	5	31	54	11	2013.0909
background noise	-0.5979	-0.7748	4	78	141	20	2009.9
beamforming	-0.4903	-0.9522	4	42	110	19	2010.2105
behavior	0.8131	0.3732	5	98	186	31	2012.9032
behavioral research	-0.532	0.3413	1	37	71	11	2011.4545
bioacoustics	0.5528	0.5486	5	87	215	41	2013.9512
biodiversity	0.5954	0.5001	5	94	253	40	2014.625
biophony	0.7255	0.4926	5	54	94	18	2014.2222
bird	0.7268	0.2736	5	67	110	12	2011.75
birds	0.7009	0.4226	5	81	188	28	2013.5357
buildings	-1.0851	-0.2265	1	48	102	14	2013.9286
child	0.4312	-0.3461	2	55	99	10	2009.7
cities	-0.1858	0.5018	3	120	298	27	2011.8519
city	-0.0433	0.4846	3	117	259	28	2011.6786
city parks	-0.36	0.6821	3	64	115	14	2014.1429

	81						
classification	0.4014	0.0999	5	81	144	25	2013.56
clinical article	0.6314	-0.7743	2	76	206	16	2006.375
cognition	0.21	-0.2433	2	101	202	18	2012.5556
communication	0.588	0.4444	5	72	135	31	2012.4194
community noise	-0.8541	0.4795	1	56	112	13	2011.3846
comparative study	0.5376	-0.3498	2	121	278	20	2009.4
computer simulation	-0.1705	-0.6264	4	95	153	30	2006.9333
conservation	0.4254	0.6552	5	52	115	24	2014.5417
controlled study	0.7514	-0.3536	2	171	759	55	2007.8727
cortex	0.3488	0.3956	3	19	27	11	2013.8182
cues	0.8855	-0.017	2	58	114	12	2012.25
decision making	-0.2096	-0.1499	1	75	109	12	2011.0833
design	-0.3488	0.2141	1	97	221	46	2011.1087
diversity	0.6881	0.7425	5	42	109	22	2015
echo suppression	-0.4393	-1.1154	4	21	58	12	2009

ecology	0.3451	0.497	5	109	270	45	2012.7111
emotion	0.1457	0.132	3	88	163	20	2013.6
energy utilization	-0.8167	-0.4736	1	26	47	10	2014
engineering	-0.7533	0.6056	1	29	57	12	2011.5833
environment	0.2851	0.2353	3	223	855	97	2011.9381
environmental conditions	-0.8756	-0.2636	1	42	57	11	2011.2727
environmental exposure	0.0979	-0.1324	2	90	183	14	2009.2143
environmental factor	0.3444	-0.2327	2	122	277	19	2009.5789
environmental health	-0.2693	0.1501	1	57	79	10	2000.8
environmental impact	-0.4071	0.0754	1	71	116	15	2009.2667
environmental management	-0.4959	0.0866	1	62	97	13	2011.3846
environmental monitoring	0.441	0.1694	5	79	106	13	2011.2308
environmental noise	-0.5155	0.5227	1	149	495	63	2010.9841
environmental protection	-0.0537	0.2319	1	68	94	11	2011
environmental quality	-0.6809	0.2028	1	112	215	26	2011.2308

environmental sounds	-0.5465	0.7472	3	45	81	19	2011.5789
environments	-0.0258	0.8705	3	65	168	35	2013.3714
evoked potentials, auditory	1.1409	-0.479	2	53	146	11	2010.8182
evolution	0.9226	0.3756	5	50	92	13	2010.9231
exhibitions	-0.9247	0.2726	1	94	302	48	2007.9167
experience	0.1222	0.305	3	59	77	14	1869.3571
experiments	-0.1775	-0.2273	1	77	139	14	2010.7857
exposure	0.1747	0.8589	3	87	250	47	2011.9149
feature extraction	-0.1855	-0.6998	4	36	75	18	2009.7778
female	0.5421	-0.5921	2	191	1248	81	2009.4198
field surveys	-0.9198	0.1837	1	71	124	11	2009.4545
finite element method	-0.7467	-0.7087	4	26	52	11	2008.3636
fish	0.7508	0.6637	5	40	65	13	2014.2308
fishes	0.8268	0.7	5	43	84	15	2014.5333
forecasting	-0.5732	-0.5449	4	51	81	16	2011.5625
frequency	0.53	0.32	5	41	53	13	2014.3077

	39	06					
frequency bands	-0.3599	-0.5043	4	37	58	11	2008
frequency domain analysis	-0.1257	-0.7811	4	41	61	10	2010.1
frequency modulation	0.8388	-0.2824	2	69	122	12	2007
green areas	-0.3195	0.8289	3	56	89	12	2012.75
green spaces	-0.4845	0.6757	3	34	60	10	2012.7
habitat	0.5217	0.4933	5	49	76	13	2014.1538
habitats	0.9056	0.8184	5	26	64	14	2014.6429
health	-0.2877	0.4873	3	135	370	55	2012.1273
health care	-0.2882	-0.0422	6	59	99	16	2012.3125
health care facility	0.2025	-0.3561	6	69	130	10	2009.5
health risks	-0.793	-0.1123	1	44	71	10	2011.1
healthcare	-0.2021	0.2323	6	53	85	11	2014.5455
hearing	0.7368	-0.0226	2	196	826	72	2009.6389
hearing aid	0.4066	-0.8978	2	86	278	29	2006.2414

hearing aids	0.1271	-0.9274	4	98	349	41	2007.8537
hearing impairment	0.6197	-0.901	2	71	175	16	2003.25
hearing loss	0.62	-0.6299	2	100	260	26	2008.3846
hearing loss, noise-induced	0.8615	-0.7178	2	57	120	10	2002.4
hospital	0.0144	-0.128	6	67	144	14	2014.4286
hospitals	-0.4307	-0.1907	6	73	154	18	2013.8889
housing	-0.4322	0.1485	1	82	130	14	2013.3571
human	0.4286	-0.552	2	210	1589	130	2007.8615
human computer interaction	-0.286	-0.6964	4	20	28	11	2007.7273
human experiment	0.912	-0.3937	2	87	246	16	2008.9375
human perception	-0.4477	0.5996	3	44	60	11	2013
identification	0.3331	0.1175	5	48	58	13	2012.4615
identity	0.3907	0.3716	3	9	12	11	2010.6364
impact	0.3927	0.8609	5	44	71	14	2012.8571
indoor air pollution	-1.06	-0.31	1	28	57	10	2012.8

	45	38					
industrial engineering	-0.7254	0.572	1	25	45	10	2011.7
industrial noise	0.031	-0.3518	2	96	187	17	2007.1176
information	0.5307	0.2562	5	53	63	10	2012.6
intensive care units	-0.3242	-0.3724	6	65	122	15	2012.8667
laboratory experiments	-0.3529	-0.1246	1	89	164	12	2011.9167
landscape	0.3577	0.7549	5	119	390	67	2013.5373
laws and legislation	-0.6973	0.0488	1	46	71	10	2011.6
learning	0.6742	-0.5383	2	75	130	11	2008.3636
learning systems	-0.2491	-0.6474	4	26	40	10	2011.4
level	0.0764	1.0696	3	24	41	10	2012
listening	0.0004	0.1012	3	21	36	13	2012.0769
loudness	0.0567	0.6194	3	67	115	18	2011.8333
loudspeakers	-0.517	-0.5196	4	46	73	14	2010.2857
male	0.4942	-0.6413	2	193	1292	85	2008.9765
management	0.1728	0.9901	3	38	50	10	2013.8
mapping	-	-	1	56	103	14	2015.3571

	0.6366	0.0354					
marine mammals	0.6705	0.6385	5	20	33	10	2014.6
mathematical models	-0.4169	-0.5592	4	69	135	29	2003.3448
memory	0.3385	0.1732	3	49	69	19	2012.3684
methodology	0.2182	-0.4999	2	94	213	16	2008.0625
mice	1.2243	-0.5538	2	59	179	12	2005.25
microphone	0.3809	-0.6584	2	55	102	10	2004.6
microphone arrays	-0.2701	-1.03	4	34	74	14	2009.5714
microphones	-0.3413	-0.9293	4	88	234	35	2007.8286
middle aged	0.2617	-0.6179	2	144	587	37	2010.0541
model	-0.1187	0.8118	3	65	170	36	2013.3056
monitoring	0.2685	0.5222	5	35	49	13	2014.0769
mouse	1.203	-0.6075	2	58	169	11	2004.7273
music	0.3872	0.2983	3	97	232	85	1987.8824
natural sounds	-0.1498	0.5586	3	79	116	16	2013.6875
nerve cell plasticity	1.02	-	2	61	138	11	2010.9091

	53	0.6064					
neural networks	-0.544	-0.3635	4	73	120	20	2008.05
neurons	1.1134	-0.2137	2	46	98	12	2007.8333
newborn	1.1212	-0.6348	2	51	111	11	2003.6364
noise	0.2187	0.2466	3	287	1930	274	2011.6752
noise abatement	-0.6057	-0.2296	1	95	234	40	2008.1
noise annoyance	-0.623	0.5439	1	78	174	25	2011.64
noise barriers	-0.8499	0.1895	1	38	78	10	2010.5
noise exposure	-0.3594	-0.0002	1	66	95	15	2010.9333
noise levels	-0.9903	0.2024	1	79	172	20	2009.45
noise mapping	-0.4724	0.4219	1	44	83	12	2010.6667
noise measurement	0.0468	-0.2075	2	88	182	15	2006.3333
noise pollution	-0.5562	0.2001	1	217	1113	144	2011.5417
noise reduction	-0.0613	-0.4589	4	106	176	18	2009.1111
noise source	-	-	1	73	114	15	2009.8667

	0.7907	0.0446						
noise, occupational	0.3251	-0.5402	2	71	150	14	2003.7857
nonhuman	1.0995	-0.3877	2	102	475	38	2006.2895
normal human	0.7244	-0.4149	2	107	296	20	2006.55
office buildings	-0.9466	-0.5007	1	69	158	19	2011.2105
open spaces	-0.1968	0.8671	3	35	66	10	2013.6
optimization	-0.6326	-0.5619	4	56	76	14	2008.2857
orientation	0.9357	0.7748	5	26	59	16	2013.1875
parks	-0.2889	0.6892	3	104	234	31	2012.0323
passive acoustics	0.8417	0.7651	5	19	32	11	2014.4545
patterns	0.8027	0.7555	5	35	91	22	2014.8182
perception	0.0358	0.4313	3	206	742	100	2013.11
perception deafness	0.9523	-0.8738	2	49	135	11	2002.6364
perceptual masking	0.3478	-0.4726	2	90	196	10	2007.3
performance	0.2385	0.0152	3	60	87	17	2009.4118
physiology	0.8413	-0.34	2	139	511	44	2010.3864

		29					
planning	-0.5906	0.3338	1	45	81	13	2011.5385
politics	0.3001	0.3521	3	20	32	13	1857.3077
pollution	-0.1934	0.3321	1	78	144	18	2013.9444
prediction	-0.1946	0.1179	3	72	98	11	2013.0909
preference	-0.0789	0.9667	3	60	179	27	2013.6667
principal component analysis	-0.0587	0.0112	1	60	81	12	2012.3333
psychoacoustics	0.1902	-0.143	2	116	255	25	2011.6
psychophysics	0.5535	-0.429	2	79	177	13	2010.8462
public health	-0.434	-0.0847	1	98	159	15	2011.7333
public space	-0.4628	0.2452	1	63	97	12	2010.75
quality	-0.1976	0.9787	3	82	323	57	2013.4386
quality control	-0.7327	-0.3041	1	111	223	23	2012.087
quality of life	-0.2755	0.2188	1	107	218	25	2010.44
questionnaire	0.0902	-0.42	2	125	400	29	2010.4483

		12					
questionnaire surveys	-0.9447	0.0582	1	74	138	15	2013.0667
questionnaires	0.1074	-0.2685	2	137	435	25	2010.64
quiet areas	-0.1856	0.702	3	47	79	12	2013.3333
radio	0.3416	0.2892	3	22	27	10	1811.3
recognition	0.4438	0.4955	5	54	79	19	2013.7368
regression analysis	-0.1657	-0.365	4	78	109	14	2011.5714
research	-0.7785	0.2605	1	75	161	25	2010.2
residential areas	-0.714	0.3445	1	78	152	19	2010.8947
responses	0.118	0.8889	3	41	69	12	2013.0833
restoration	-0.5726	0.4932	1	58	93	13	2012.3077
reverberation	-0.5639	-0.616	4	113	318	46	2011.1522
reverberation time	-0.5283	-0.7568	4	72	148	17	2009.9412
review	0.6808	-0.3075	2	81	184	21	2006.8571
road traffic	-0.3858	0.5051	1	71	120	15	2010.3333
road traffic noise	-	0.61	3	146	451	62	2011.4194

	0.2292	88						
road-traffic noise	-0.2449	0.9133	3	36	50	11	2013
roads and streets	-0.8524	0.2916	1	70	166	19	2013
room acoustics	-0.7418	-0.491	1	41	81	10	2011.6
science	0.4964	0.6289	5	34	46	10	2012.6
semantics	-0.0912	-0.2221	6	97	159	13	2012.1538
sensitivity	0.4149	0.7436	3	35	59	12	2012.8333
sensors	-0.4792	-0.6957	4	19	26	10	2007.2
sensory perception	-0.5552	-0.0567	1	67	112	14	2012.1429
signal detection	0.3018	-0.6859	4	63	92	15	2007.2
signal noise ratio	0.6852	-0.6328	2	88	210	16	2008.875
signal processing	-0.0456	-0.8177	4	131	408	63	2009.0159
signal to noise ratio	-0.3045	-0.75	4	64	162	31	2008.3226
simulation	-0.0934	-0.5588	4	34	39	11	2009.1818
sleep	0.156	0.575	3	68	139	21	2011.9524

sonar	-0.1147	-0.5034	4	23	43	11	2010.4545
song	0.668	0.5325	5	36	63	11	2011.9091
sonic environments	-0.4697	0.0247	1	42	64	10	2013.4
sound	0.4302	0.2272	3	254	1035	160	2011.6437
sound design	-0.1207	0.3516	1	24	31	11	2011.5455
sound detection	0.4807	-0.4004	2	143	473	31	2009.6774
sound environment	-0.6187	0.0964	1	137	330	44	2011.6364
sound intensity	0.7529	-0.1709	2	110	267	18	2009.2778
sound level	-0.552	0.0461	1	134	306	33	2008.7576
sound localization	0.6359	-0.4474	2	88	189	19	2008.3684
sound pressure	0.8326	-0.5875	2	64	134	10	2008.8
sound pressure level	-0.7095	-0.016	1	100	259	37	2011.1622
sound production	0.883	0.698	5	34	82	21	2014.1429
sound quality	-0.9635	0.3272	1	96	255	33	2011
sound reproduction	-1.01	-0.17	1	59	148	20	2012.2

	84	86					
sound source	-0.741	0.106	1	89	177	23	2010.4783
sound spectrography	0.5414	-0.5203	2	106	251	15	2006.9333
sound studies	0.1633	0.2407	3	17	27	14	2013.7143
sound transmission	0.6415	-0.2334	2	67	105	12	2005
sounds	0.1669	0.7513	3	26	35	10	2013.6
soundscape	-0.0012	0.5383	3	254	1625	372	2012.8844
soundscape ecology	0.5212	0.4143	5	79	185	42	2014.8095
soundscapes	-0.3395	0.3047	1	269	1912	343	2011.9563
space	0.238	0.4198	3	30	53	19	2009.4211
spacecraft	-0.4522	-0.6237	4	24	31	11	2006.0909
spaces	-0.1405	1.0493	3	50	166	32	2013.9375
species richness	0.7596	0.5512	5	29	51	12	2014.1667
species specificity	1.1879	-0.3144	2	55	137	10	2005
speech	0.0426	-0.5775	4	134	330	46	2010.7391
speech communication	-0.7244	-0.8048	4	57	130	23	2011.8261

speech enhancement	-0.4454	-0.9658	4	45	139	26	2010.8462
speech intelligibility	-0.3898	-0.6569	4	104	287	34	2009.5588
speech perception	0.5376	-0.8569	2	89	281	20	2005.4
speech processing	-0.2467	-0.9623	4	34	76	14	2004.0714
speech recognition	-0.2329	-0.7843	4	79	238	62	2008.1935
stress	0.1911	0.3131	3	51	65	15	2011.6667
stress recovery	-0.0112	1.0198	3	32	55	10	2013.6
subjective evaluations	-0.7315	-0.153	1	90	201	26	2011.7308
subjective loudness	-0.6744	0.8293	3	25	53	10	2012.7
surveys	-0.8936	-0.0182	1	140	502	64	2012.4688
sustainable development	-0.9189	-0.0698	1	54	104	17	2012.4118
teaching	-0.5702	-0.4589	1	54	101	11	2010.7273
technology	0.2911	0.023	3	45	53	14	2010.7143
time	0.4711	-0.1109	2	114	218	23	2011.8696
time factors	0.57	-	2	109	283	21	2009.3333

	87	0.2893					
traffic noise	-0.0546	0.4084	3	165	519	59	2011.7458
tranquillity	-0.2874	0.7668	3	68	152	21	2014.0476
transportation	-0.6415	0.1586	1	59	137	16	2014.375
transportation noise	0.0578	0.9892	3	32	64	11	2010.8182
underwater acoustics	-0.0661	-0.317	4	49	133	40	2011.05
underwater sound	0.894	0.7493	5	18	34	10	2014.8
united kingdom	0.2783	-0.1372	2	62	83	11	2006.8182
united states	0.086	0.0673	3	48	59	10	2011.7
urban	-0.017	0.8194	3	50	105	24	2012.625
urban area	-0.1643	0.0728	1	109	237	20	2010.45
urban areas	-0.7882	0.4366	1	57	99	13	2010.3846
urban design	-0.5692	0.5695	1	46	62	12	2011.9167
urban environments	-0.8832	0.5521	1	62	121	17	2010.1176
urban noise	0.1073	0.4714	5	120	256	32	2012.2188
urban open spaces	-	0.92	3	29	47	11	2014.6364

	0.147	32					
urban parks	-0.6449	0.4089	1	83	153	20	2012.4
urban planners	-0.807	0.0472	1	50	78	10	2011.7
urban planning	-0.5111	0.1535	1	156	417	49	2011.3265
urban population	-0.3272	0.0799	1	94	250	14	2011.5714
urban soundscape	-0.3579	0.379	1	117	233	32	2012.4062
urban soundscapes	0.0425	0.8692	3	93	291	59	2013.0847
urban spaces	-0.8131	0.3693	1	71	130	15	2011.4
vegetation	-0.2138	0.4021	3	85	132	14	2013.5
vibration	0.365	-0.0051	3	63	97	14	2005.5714
vibrations (mechanical)	-0.6084	-0.1073	4	24	32	10	2007.7
virtual reality	-0.2013	-0.2794	4	81	141	26	2011.6923
vision	0.2254	0.1793	3	60	79	11	2012.9091
vocalization	0.8175	0.0208	2	93	207	22	2010.7273
voice	0.3012	-0.0732	3	79	113	15	2012.0667

water sounds	-0.3692	0.953	3	30	54	11	2013.5455
wellbeing	-0.4381	0.3259	1	86	136	14	2010.2857
world	0.2742	0.6838	3	29	42	11	2011.1818
young adult	0.2908	-0.2775	2	135	421	22	2012.5909

Annex 2. Publication metrics by countries that contributes mostly to the field

Country	Number of Publications (2006-2016)	%	Citations	Total link strength	Number of Publications
United States	285	22.8	3849	145	285
United Kingdom	170	13.6	1829	305	170
China	114	9.12	237	80	114
Germany	78	6.24	527	90	78
Sweden	66	5.28	674	144	66
Italy	56	4.48	289	98	56
France	46	3.68	268	24	46
Australia	45	3.6	419	145	45
Netherlands	42	3.36	247	50	42
Canada	41	3.28	1431	45	41
Japan	41	3.28	189	8	41
Spain	33	2.64	325	69	33
South korea	25	2	260	94	25
Brazil	20	1.6	129	26	20
Austria	19	1.52	119	49	19
Belgium	17	1.36	547	55	17
Finland	16	1.28	140	5	16
Denmark	13	1.04	70	10	13
Greece	13	1.04	19	11	13
Norway	11	0.88	111	52	11
Turkey	11	0.88	2	15	11
Hong kong	9	0.72	94	8	9
Malaysia	9	0.72	0	4	9
Portugal	9	0.72	1	2	9
Poland	8	0.64	22	8	8
Switzerland	8	0.64	144	1	8
Taiwan	8	0.64	53	2	8

India	7	0.56	0	3	7
New Zealand	7	0.56	28	13	7
Singapore	7	0.56	31	9	7
Ireland	6	0.48	7	0	6
Indonesia	5	0.4	1	1	5
Mexico	5	0.4	24	3	5

Annex 3. Publication metrics by sources that contributes mostly to the field of research

Source	documents	citations	total link strength
journal of the acoustical society of America	92	649	80
applied acoustics	81	539	76
acta acustica united with acustica	48	456	97
proceedings of the inter-noise 2016 - 45th international congress and exposition on noise control engineering: towards a quieter future	32	0	22
landscape and urban planning	24	172	41
41st international congress and exposition on noise control engineering 2012, inter-noise 2012	23	2	5
organised sound	22	0	0
international journal of environmental research and public health	19	98	25
internoise 2014 - 43rd international congress on noise control engineering: improving the world through noise control	18	0	5
landscape ecology	18	41	8
noise control engineering journal	18	47	17
39th international congress on noise control engineering 2010, inter-noise 2010	17	0	4
42nd international congress and exposition on noise control engineering 2013, inter-noise 2013: noise control for quality of life	17	0	5
icassp, ieee international conference on acoustics, speech and signal processing - proceedings	17	215	1
building and environment	16	184	19
plos one	16	40	3
science of the total environment	16	77	20
effects of noise on aquatic life ii	14	0	0
studi musicali	14	0	0
Turkish acoustical society - 36th international congress and exhibition on noise control engineering, inter-noise 2007 istanbul	14	4	14
ecological informatics	13	55	6
journal of sound and vibration	13	199	1
leonardo music journal	13	0	0

38th international congress and exposition on noise control engineering 2009, inter-noise 2009	12	1	3
lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)	12	9	0
proceedings of forum acusticum	12	16	3
advanced materials research	11	1	0
hearing research	11	235	3
marine ecology progress series	11	8	0
noise and health	11	104	22
neue zeitschrift fur musik	10	0	0
proceedings - European conference on noise control	10	9	3
proceedings of spie - the international society for optical engineering	10	16	0
22nd international congress on sound and vibration, icsv 2015	9	0	7
40th international congress and exposition on noise control engineering 2011, inter-noise 2011	9	17	3
8th European conference on noise control 2009, euronoise 2009 - proceedings of the institute of acoustics	9	1	4
institute of noise control engineering of the USA - 35th international congress and exposition on noise control engineering, inter-noise 2006	9	25	4
inter-noise 2015 - 44th international congress and exposition on noise control engineering	9	3	4
journal of environmental psychology	9	70	9
leonardo	9	0	0
world of music	9	0	0
20th international congress on acoustics 2010, ica 2010 - incorporating proceedings of the 2010 annual conference of the Australian acoustical society	8	0	5
journal of neuroscience	8	403	0
journal of the audio engineering society	8	0	0
acta acustica (Stuttgart)	7	45	3
applied mechanics and materials	7	2	0
archives of acoustics	7	5	2
down beat	7	0	0
ecological indicators	7	12	5
ethnomusicology	7	0	0
inter-noise 99: proceedings of the 1999 international congress on noise control engineering, vols 1-3	7	0	0

journal of environmental engineering and landscape management	7	6	22
journal of the American academy of audiology	7	11	1
proceedings of meetings on acoustics	7	7	3
world archaeology	7	4	0
ear and hearing	6	44	3
environmental management	6	47	4
ethnomusicology forum	6	0	0
eurasip journal on advances in signal processing	6	12	0
European signal processing conference	6	2	0
journal of the society for American music	6	0	0
neuroimage	6	50	0
noise & health	6	0	0
oceans conference record (ieee)	6	14	0
proceedings of the annual conference of the international speech communication association, interspeech	6	8	1
proceedings of the institute of acoustics	6	1	3
speech communication	6	169	1
6th international building physics conference (ibpc 2015)	5	0	0
acm international conference proceeding series	5	3	1
animal behaviour	5	252	0
contemporary music review	5	0	0
digital creativity	5	0	0
frontiers in psychology	5	0	0
ieee transactions on audio, speech and language processing	5	121	1
ieee workshop on applications of signal processing to audio and acoustics	5	22	0
journal of experimental biology	5	14	0
journal of harbin institute of technology (new series)	5	3	5
landscape research	5	2	7
peerj	5	3	1
performance research	5	0	0
popular music and society	5	0	0
proceedings of the 10th audio mostly: a conference on interaction with sound, am'15	5	0	0
prostor	5	1	0
senses & society	5	0	0
teksty drugie	5	0	0

transportation research part d-transport and environment	5	0	0

Annex 4. Register of amphibian species during the RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Vocal Abundance Estimation (VAE) and overall percentage per site (%) are shown.

		VAE					
Common name	**Scientific name**	**Site 1**	**%**	**Site 2**	**%**	**Site 3**	**%**
Cane Toad	***Rhinella marina***	25	2.2	15	2.8	305	10.6
Cachabi Robber Frog	***Pristimantis achatinus***	37	3.3	444	82.5	1699	58.8
Rusty Treefrog	***Hypsiboas boans***	13	1.2	0	0.0	799	27.7
Engraved Rainfrog	***Pristimantis subsigillatus***	186	16.5	49	9.1	7	0.2
Labiated Rainfrog	***Pristimantis labiosus***	500	44.2	3	0.6	4	0.1
Chimbo Frog	***Barycholos pulcher***	257	22.7	0	0.0	0	0.0
Truando Toad	***Rhaebo haematiticus***	34	3.0	7	1.3	0	0.0
Rosenberg's Treefrog	***Hypsiboas rosenbergi***	0	0.0	1	0.2	34	1.2
New Granada Treefrog	***Smilisca phaeota***	0	0.0	0	0.0	21	0.7
Warbler Rainfrog	***Pristimantis walkeri***	8	0.7	3	0.6	0	0.0
Nicaragua Giant Glass Frog	***Espadarrana prosoblepon***	0	0.0	1	0.2	0	0.0
Atrato Glass Frog	***Hyalinobatrahium aureoguttatum***	0	0.0	0	0.0	1	0.0
Northern Glassfrog	***Hyalinobatrachium fleischmanni***	1	0.1	3	0.6	16	0.6
Suretka Glass Frog	***Hyalinobatrachium chirripoi***	1	0.1	1	0.2	0	0.0
Imbabura tree Frog	***Hypsiboas picturatus***	8	0.7	1	0.2	0	0.0
Marbled Poison Frog	***Epipedobates boulengeri***	26	2.3	10	1.9	3	0.1
Toachi Frog	***Hyloxalus toachi***	10	0.9	0	0.0	0	0.0
Spiny Cochran Frog	***Teratohyla spinosa***	24	2.1	0	0.0	0	0

Annex 5. Register of avian species during the RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Vocal Abundance Estimation (VAE) and overall percentage per site (%) are shown.

		VAE					
Common name	Scientific name	Site 1	%	Site 2	%	Site 3	%
Bananaquit	*Coereba flaveola*	0	0.0	29	1.1	50	2.1
Bicolored Antbird	*Gymnopithys bicolor*	7	0.4	1	0.0	0	0.0
Boat-billed Flycatcher	*Megarynchus pitangua*	0	0.0	37	1.4	7	0.3
Blue-black Grosbeak	*Cyanocompsa cyanoides*	0	0.0	51	2.0	1	0.0
Broad-billed Motmot	*Electron platyrhynchum*	5	0.3	8	0.3	0	0.0
Black-crowned Antshrike	*Thamnophilus atrinucha*	6	0.3	39	1.5	15	0.6
Bran-colored Flycatcher	*Myiophobus fasciatus*	0	0.0	0	0.0	3	0.1
Blue-chested Hummingbird	*Amazilia amabilis*	0	0.0	1	0.0	5	0.2
Blue-crowned Manakin	*Lepidothrix coronata*	26	1.3	2	0.1	0	0.0
Black-capped Pygmy-Tyrant	*Myiornis atricapillus*	3	0.2	0	0.0	0	0.0
Brown-capped Tyrannulet	*Ornithion brunneicapillus*	2	0.1	23	0.9	1	0.0
Black-cheeked Woodpecker	*Melanerpes pucherani*	5	0.3	4	0.2	7	0.3
Blue Ground-Dove	*Claravis pretiosa*	0	0.0	48	1.9	37	1.5
Blue-grey Tanager	*Thraupis episcopus*	0	0.0	11	0.4	11	0.5
Black-headed Antthrush	*Formicarius nigricapillus*	67	3.4	1	0.0	0	0.0
Blue-headed Parrot	*Pionus menstruus*	3	0.2	14	0.	22	0.9

					5		
Bay-headed Tanager	*Tangara gyrola*	0	0.0	3	0.1	0	0.0
Black-headed Tody-Flycatcher	*Todirostrum nigriceps*	0	0.0	2	0.1	0	0.0
Barred Puffbird	*Nystalus radiatus*	0	0.0	1	0.0	13	0.5
Buff-rumped Warbler	*Myiothlypis fulvicauda*	0	0.0	1	0.0	47	2.0
Black-Striped Woodcreeper	*Xiphorhynchus lachrymosus*	26	1.3	0	0.0	1	0.0
Band-tailed Barbthroat	*Threnetes ruckeri*	0	0.0	0	0.0	1	0.0
Buff-throated Foliage-Gleaner	*Automolus ochrolaemus*	3	0.2	30	1.2	1	0.0
Black-throated Trogon	*Trogon rufus*	38	2.0	1	0.0	0	0.0
Bay Wren	*Cantorchilus nigricapillus*	5	0.3	92	3.6	16	0.7
Bronze-winged Parrot	*Pionus chalcopterus*	1	0.1	8	0.3	49	2.0
Black-winged Saltator	*Saltator atripennis*	0	0.0	2	0.1	0	0.0
Collared Araçari	*Pteroglossus torquatus*	0	0.0	2	0.1	0	0.0
Cinnamon Becard	*Pachyramphus cinnamomeus*	0	0.0	1	0.0	0	0.0
Chestnut-backed Antbird	*Poliocrania exsul*	405	20.8	67	2.6	4	0.2
Crested Guan	*Penelope purpurascens*	4	0.2	0	0.0	0	0.0
Chocó Poorwill	*Nyctiphrynus rosenbergi*	1	0.1	0	0.0	0	0.0
Chocó Tyrannulet	*Zimmerius albigularis*	35	1.8	11	0.4	11	0.5
Chocó Toucan	*Ramphastos brevis*	0	0.0	0	0.0	16	0.7
Chocó Trogon	*Trogon comptus*	20	1.0	2	0.	0	0.0

					1		
Cinnamon Woodpecker	*Celeus loricatus*	8	0.4	0	0.0	1	0.0
Common Potoo	*Nyctibius griseus*	0	0.0	1	0.0	0	0.0
Common Pauraque	*Nyctidromus albicollis*	2	0.1	3	0.1	13	0.5
Collared Trogon	*Trogon collaris*	1	0.1	23	0.9	0	0.0
Checker-throated Antwren	*Epinecrophylla fulviventris*	52	2.7	1	0.0	1	0.0
Common Tody-Flycatcher	*Todirostrum cinereum*	0	0.0	6	0.2	36	1.5
Dusky Antbird	*Cercomacroides tyrannina*	6	0.3	49	1.9	0	0.0
Dusky Pigeon	*Patagioenas goodsoni*	12	0.6	0	0.0	0	0.0
Dagua Thrush	*Turdus assimilis*	30	1.5	0	0.0	0	0.0
Dot-winged Antwren	*Microrhopias quixensis*	19	1.0	31	1.2	5	0.2
Ecuadorian Thrush	*Turdus maculirostris*	0	0.0	31	1.2	42	1.8
Fulvous-vented Euphonia	*Euphonia fulvicrissa*	2	0.1	62	2.4	348	14.5
Flame-rumped Tanager	*Ramphocelus flammigerus*	2	0.1	0	0.0	2	0.1
Great Antshrike	*Taraba major*	0	0.0	7	0.3	15	0.6
Golden-bellied Warbler	*Tangara larvata*	0	0.0	1	0.0	9	0.4
Green Manakin	*Cryptopipo holochlora*	2	0.1	0	0.0	1	0.0
Golden-olive Woodpecker	*Colaptes rubiginosus*	1	0.1	4	0.2	14	0.6
Gray-rumped Swift	*Chaetura cinereiventris*	0	0.0	0	0.0	1	0.0
Guayaquil Woodpecker	*Campephilus*	1	0.1	11	0.	0	0.0

	gayaquilensis				4		
House Wren	*Troglodytes aedon*	0	0.0	2	0.1	54	2.3
Indigo-crowned Quail-Dove	*Geotrygon saphirina*	0	0.0	0	0.0	0	0.0
Laughing Falcon	*Herpetotheres cachinnans*	7	0.4	13	0.5	55	2.3
Lita Woodpecker	*Piculus litae*	4	0.2	0	0.0	0	0.0
Little Tinamou	*Crypturellus soui*	3	0.2	152	6.0	62	2.6
Lineated Woodpecker	*Dryocopus lineatus*	3	0.2	37	1.4	17	0.7
Mottled Owl	*Ciccaba virgata*	6	0.3	18	0.7	0	0.0
Mealy Parrot	*Amazona farinosa*	158	8.1	0	0.0	2	0.1
Masked Tityra	*Tityra semifasciata*	2	0.1	6	0.2	6	0.3
Northern Barred-Woodcreeper	*Dendrocolaptes sanctithomae*	36	1.9	2	0.1	0	0.0
Ochraceous Attila	*Attila torridus*	0	0.0	0	0.0	3	0.1
Orange-bellied Euphonia	*Euphonia xanthogaster*	0	0.0	0	0.0	2	0.1
Ochre-bellied Flycatcher	*Mionectes oleagineus*	6	0.3	26	1.0	18	0.8
Orange-billed Sparrrow	*Arremon aurantiirostris*	2	0.1	11	0.4	4	0.2
Ocellated Antbird	*Phaenostictus mcleannani*	37	1.9	0	0.0	0	0.0
Orange-crowned Euphonia	*Euphonia saturata*	1	0.1	39	1.5	50	2.1
Olive-crowned Yellowthroat	*Geothlypis semiflava*	0	0.0	3	0.1	19	0.8
Orange-fronted Barbet	*Capito squamatus*	1	0.1	3	0.1	0	0.0
Olive-striped Flycatcher	*Mionectes olivaceus*	1	0.1	1	0.	0	0.0

					0		
Pacific Antwren	*Myrmotherula pacifica*	0	0.0	11	0.4	99	4.1
Plain-brown Woodcreeper	*Dendrocincla fuliginosa*	14	0.7	23	0.9	6	0.3
Purple-chested Hummingbird	*Amazilia rosenbergi*	5	0.3	0	0.0	5	0.2
Pallid Dove	*Leptotila pallida*	0	0.0	214	8.4	72	3.0
Piratic Flycatcher	*Legatus leucophaius*	0	0.0	0	0.0	1	0.0
Pale-legged Hornero	*Furnarius leucopus*	0	0.0	17	0.7	36	1.5
Peruvian Pygmy-Owl	*Glaucidium peruanum*	0	0.0	0	0.0	12	0.5
Palm Tanager	*Thraupis palmarum*	0	0.0	12	0.5	18	0.8
Purple-throated Fruitcrow	*Querula purpurata*	18	0.9	18	0.7	11	0.5
Pale-vented Pigeon	*Patagioenas cayennensis*	0	0.0	40	1.6	48	2.0
Russet Antshrike	*Thamnistes anabatinus*	1	0.1	0	0.0	0	0.0
Red-billed Scythebill	*Campylorhamphus trochilirostris*	0	0.0	6	0.2	0	0.0
Rufous-crowned Antpitta	*Pittasoma rufopileatum*	10	0.5	0	0.0	0	0.0
Red-capped Manakin	*Ceratopipra mentalis*	2	0.1	0	0.0	0	0.0
Ruddy Foliagle-Gleaner	*Clibanornis rubiginosus*	0	0.0	12	0.5	0	0.0
Rose-faced Parrot	*Pyrilia pulchra*	3	0.2	2	0.1	0	0.0
Red-faced Spinetail	*Cranioleuca erythrops*	0	0.0	0	0.0	1	0.0
Rufous-fronted Wood-Quail	*Odontophorus erythrops*	73	3.8	0	0.0	8	0.3
Roadside Hawk	*Rupornis magnirostris*	1	0.1	4	0.	20	0.8

					2		
Red-headed Barbet	*Eubucco bourcierii*	0	0.0	6	0.2	0	0.0
Rufous-headed Chachalaca	*Ortalis erythroptera*	4	0.2	79	3.1	30	1.3
Ringed Kingfisher	*Megaceryle torquata*	0	0.0	1	0.0	10	0.4
Red-lored Parrot	*Amazona autumnalis*	8	0.4	1	0.0	1	0.0
Rufous Motmot	*Baryphthengus martii*	55	2.8	189	7.4	7	0.3
Rusty-margined Flycatcher	*Myiozetetes cayanensis*	0	0.0	28	1.1	126	5.3
Rufous Mourner	*Rhytipterna holerythra*	1	0.1	0	0.0	0	0.0
Rufous Piha	*Lipaugus unirufus*	52	2.7	0	0.0	0	0.0
Ruddy Quail-Dove	*Geotrygon montana*	6	0.3	0	0.0	0	0.0
Red-rumped Woodpecker	*Veniliornis kirkii*	0	0.0	1	0.0	0	0.0
Ruddy-tailed Flycatcher	*Terenotriccus erythrurus*	0	0.0	1	0.0	0	0.0
Rufous-tailed Hummingbird	*Amazilia tzacatl*	0	0.0	11	0.4	73	3.0
Rufous-tailed Jacamar	*Galbula ruficauda*	0	0.0	8	0.3	14	0.6
Ruddy Pigeon	*Patagioenas subvinacea*	20	1.0	19	0.7	4	0.2
Rufous-winged Tyrannulet	*Mecocerculus calopterus*	0	0.0	0	0.0	0	0.0
Scarlet-and-white Tanager	*Chrysothlypis salmoni*	0	0.0	0	0.0	0	0.0
Scrub Blackbird	*Dives warczewiczi*	0	0.0	19	0.7	95	4.0
Smooth-billed Ani	*Crotophaga ani*	0	0.0	1	0.0	2	0.1
Southern-beardless Tyrannulet	*Camptostoma*	0	0.0	13	0.	114	4.8

	obsoletum				5		
Scaly-breasted Wren	*Microcerculus marginatus*	78	4.0	67	2.6	16	0.7
Striped Cuckoo	*Tapera naevia*	0	0.0	0	0.0	8	0.3
Spot-crowned Antvireo	*Dysithamnus puncticeps*	46	2.4	4	0.2	0	0.0
Slaty-capped Flycatcher	*Leptopogon superciliaris*	3	0.2	22	0.9	0	0.0
Slate-coloured Grosbeak	*Saltator grossus*	44	2.3	82	3.2	17	0.7
Streak-chested Antpitta	*Hylopezus perspicillatus*	26	1.3	0	0.0	0	0.0
Scale-crested Pygmy-Tyrant	*Lophotriccus pileatus*	12	0.6	136	5.3	37	1.5
Slaty-capped Shrike-Vireo	*Vireolanius leucotis*	2	0.1	2	0.1	0	0.0
Social Flycatcher	*Myiozetetes similis*	0	0.0	5	0.2	72	3.0
Sooty-headed Tyrannulet	*Phyllomyias griseiceps*	0	0.0	0	0.0	4	0.2
Streak-headed Woodcreeper	*Lepidocolaptes souleyetii*	5	0.3	55	2.2	37	1.5
Song Wren	*Cyphorhinus phaeocephalus*	4	0.2	1	0.0	1	0.0
Spotted Antbird	*Hylophylax naevioides*	8	0.4	0	0.0	0	0.0
Scarlet-rumped Cacique	*Cacicus microrhynchus*	11	0.6	68	2.7	2	0.1
Stripe-throated Hermit	*Phaethornis striigularis*	0	0.0	5	0.2	7	0.3
Scaly-throated Leaftoser	*Sclerurus guatemalensis*	5	0.3	0	0.0	0	0.0
Short-tailed Nighthawk	*Lurocalis semitorquatus*	5	0.3	1	0.0	2	0.1
Stripe-throated Wren	*Cantorchilus leucopogon*	47	2.4	1	0.0	2	0.1
Spotted Woodcreeper	*Xiphorhynchus*	12	0.6	10	0.	1	0.0

	erythropygius				4		
Striped Woodhaunter	*Automolus subulatus*	14	0.7	0	0.0	0	0.0
Streaked Xenops	*Xenops rutilans*	2	0.1	0	0.0	0	0.0
Thick-billed Euphonia	*Euphonia laniirostris*	0	0.0	10	0.4	16	0.7
Thick-billed Seed-Finch	*Sporophila funerea*	0	0.0	0	0.0	1	0.0
Tawny-crested Tanager	*Tachyphonus delatrii*	7	0.4	4	0.2	1	0.0
Tufted Flycatcher	*Mitrephanes phaeocercus*	1	0.1	0	0.0	0	0.0
Tawny-faced Gnatwren	*Microbates cinereiventris*	129	6.6	7	0.3	1	0.0
Tropical Gnatcatcher	*Polioptila plumbea*	3	0.2	8	0.3	24	1.0
Tropical Kingbird	*Tyrannus melancholicus*	0	0.0	10	0.4	57	2.4
Tawny-throated Leaftosser	*Sclerurus mexicanus*	8	0.4	0	0.0	0	0.0
Violet-bellied Hummingbird	*Damophila julie*	0	0.0	0	0.0	4	0.2
Vermiculated Screech-Owl	*Megascops guatemalae*	9	0.5	0	0.0	0	0.0
White-bearded Manakin	*Manacus manacus*	1	0.1	75	2.9	0	0.0
White-breasted Wood-Wren	*Henicorhina leucosticta*	6	0.3	8	0.3	3	0.1
White-flanked Antwren	*Myrmotherula axillaris*	35	1.8	0	0.0	0	0.0
White-tipped Dove	*Leptotila verreauxi*	0	0.0	125	4.9	80	3.3
White-tailed Trogon	*Trogon chionurus*	29	1.5	10	0.4	2	0.1
White-whiskered Hermit	*Phaethornis yaruqui*	23	1.2	43	1.7	6	0.3
White-whiskered Puffbird	*Malacoptila*	11	0.6	17	0.	0	0.0

	panamensis				7		
Yellow Tyrannulet	*Capsiempis flaveola*	0	0.0	2	0. 1	63	2.6
Yellow-tailed Oriole	*Icterus mesomelas*	0	0.0	5	0. 2	25	1.0
Zeledon's Antbird	*Hafferia zeledoni*	17	0.87	0	0	0	0

Annex 6. Mean values of the AIs within the amphibian dataset: a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index , BI; d) Acoustic complexity Index (ACI) computed during the peak hours of the amphibian activity in a RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Maximum and minimum values of each index are shown.

Site	**Site 1**	Min	Max	**Site 2**	Min	Max	**Site 3**	Min	Max
BI	**11.05**	3.60	18.24	**11.56**	3.49	19.61	**9.45**	2.75	19.06
ACI	**156.49**	151.42	224.12	**154.84**	146.74	175.00	**153.62**	137.13	167.72
AE	**0.16**	0.00	0.66	**0.25**	0.00	0.76	**0.14**	0.00	0.78
H	**0.81**	0.55	0.94	**0.80**	0.55	0.93	**0.88**	0.64	0.94

Annex 7. Mean values of the AIs within the avian dataset: a) Shannon, H; b) Acoustic Evenness, AE; c) Bio-acoustic Index, BI; d) Acoustic complexity Index (ACI) computed during the peak hours of the avian activity in a RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3). Maximum and minimum values of each index are shown.

Site	Site 1	Min	Max	Site 2	Min	Max	Site 3	Min	Max
BI	**7.85**	0.28	16.41	**7.56**	0.85	15.16	**5.42**	1.49	15.73
ACI	**1805.57**	1760.29	2085.50	**1798.42**	1723.26	1939.42	**1812.33**	1635.00	1957.43
AE	**0.19**	0.02	0.69	**0.25**	0.02	0.78	**0.12**	0.02	0.75
H	**0.83**	0.53	0.97	**0.81**	0.51	0.95	**0.90**	0.69	0.97

Annex 8. Count of anthropogenic sounds registered manually during the avian and the amphibian identification registered during the RAM in three sites of NW Ecuador primary forest (Site 1), secondary forest (Site 2) and palm oil plantation (Site 3).

	Avian dataset			Amphibian dataset		
Site	**1**	**2**	**3**	**1**	**2**	**3**
Dogs and other domestic animals	3	309	152	2	181	124
%	0	34	17	0	20	14
Humans voice & Music	17	161	208	0	65	44
%	2	18	23	0	7	5
Plane/Car/Motor	0	0	69	20	278	258
%	0	0	8	2	31	29
Falling branches & similar	41	50	14	0	2	0
%	5	6	2	0	0	0
Howlers	209	0	0	?	?	?
%	23	0	0	?	?	?
Insects	832	818	633	?	?	?
%	92	91	70	?	?	?
Frogs	643	601	789	?	?	?
%	71	67	88	?	?	?
Insects dawn	407	372	206	?	?	?
Insects dusk	425	446	427	?	?	?
Frogs dawn	239	59	56	?	?	?
Frogs dusk	403	335	348	?	?	?

Annex 9. IndVal of avian and amphibian species registered during the rapid acoustic monitoring along a gradient of landscape degradation.

AVIAN		A*	B*	IndVal	p.value	
Common name	**Scientific name**					
Primary forest						
Chestnut-backed Antbird	*Poliocrania exsul*	0.85084	0.32222	0.524	0.001	***
Tawny-faced Gnatwren	*Microbates cinereiventris*	0.94161	0.13667	0.359	0.001	***
Mealy Parrot	*Amazona farinosa*	0.9875	0.08111	0.283	0.001	***
Black-headed Antthrush	*Formicarius nigricapillus*	0.98529	0.07222	0.267	0.001	***
Rufous Piha	*Lipaugus unirufus*	1	0.05778	0.24	0.001	***
Checker-throated Antwren	*Epinecrophylla fulviventris*	0.96296	0.05778	0.236	0.001	***
Scaly-breasted Wren	*Microcerculus marginatus*	0.94	0.05111	0.219	0.001	***
Black-throated Trogon	*Trogon rufus*	0.97436	0.04111	0.2	0.001	***
Spot-crowned Antvireo	*Dysithamnus puncticeps*	0.92	0.04333	0.2	0.001	***
Northern Barred-Woodcreeper	*Dendrocolaptes sanctithomae*	0.94737	0.04	0.195	0.001	***
Ocellated Antbird	*Phaenostictus mcleannani*	1	0.03778	0.194	0.001	***
White-flanked Antwren	*Myrmotherula axillaris*	1	0.03444	0.186	0.001	***
Dagua Thrush	*Turdus assimilis*	1	0.03333	0.183	0.001	***
Rufous-fronted Wood-Quail	*Odontophorus erythrops*	0.90124	0.03667	0.182	0.001	***
Streak-chested Antpitta	*Hylopezus perspicillatus*	1	0.02778	0.167	0.001	***
Black-Striped Woodcreeper	*Xiphorhynchus lachrymosus*	0.96296	0.02778	0.164	0.001	***
Chocó Tyrannulet	*Zimmerius albigularis*	0.61404	0.03889	0.155	0.001	***

White-tailed Trogon	*Trogon chionurus*	0.70732	0.03	0.146	0.001	***
Blue-crowned Manakin	*Lepidothrix coronata*	0.92857	0.02111	0.14	0.001	***
Chocó Trogon	*Trogon comptus*	0.90909	0.01889	0.131	0.001	***
Zeledon's Antbird	*Hafferia zeledoni*	1	0.01667	0.129	0.001	***
Striped Woodhaunter	*Automolus subulatus*	1	0.01444	0.12	0.001	***
Dusky Pigeon	*Patagioenas goodsoni*	1	0.01222	0.111	0.001	***
Rufous-crowned Antpitta	*Pittasoma rufopileatum*	1	0.01111	0.105	0.001	***
Vermiculated Screech-Owl	*Megascops guatemalae*	1	0.01	0.1	0.001	***
Tawny-throated Leaftosser	*Sclerurus mexicanus*	1	0.00889	0.094	0.001	***
Cinnamon Woodpecker	*Celeus loricatus*	0.88889	0.00889	0.089	0.004	**
Bicolored Antbird	*Gymnopithys bicolor*	0.875	0.00778	0.082	0.012	*
Ruddy Quail-Dove	*Geotrygon montana*	1	0.00667	0.082	0.009	**
Spotted Antbird	*Hylophylax naevioides*	1	0.00667	0.082	0.003	**
Scaly-throated Leaftoser	*Sclerurus guatemalensis*	1	0.00556	0.075	0.008	**
Crested Guan	*Penelope purpurascens*	1	0.00444	0.067	0.03	*
Lita Woodpecker	*Piculus litae*	1	0.00444	0.067	0.042	*
Secondary forest						
Pallid Dove	*Leptotila pallida*	0.74825	0.2	0.387	0.001	***
Rufous Motmot	*Baryphthengus martii*	0.75299	0.16333	0.351	0.001	***
Little Tinamou	*Crypturellus soui*	0.70046	0.16667	0.342	0.001	***
Scale-crested Pygmy-Tyrant	*Lophotriccus pileatus*	0.73514	0.14556	0.327	0.001	***
Bay Wren	*Cantorchilus nigricapillus*	0.8141	0.1	0.285	0.001	**

		6				*
White-bearded Manakin	*Manacus manacus*	0.98684	0.07111	0.265	0.001	***
Scarlet-rumped Cacique	*Cacicus microrhynchus*	0.83951	0.06222	0.229	0.001	***
Blue-black Grosbeak	*Cyanocompsa cyanoides*	0.98077	0.05222	0.226	0.001	***
Dusky Antbird	*Cercomacroides tyrannina*	0.89091	0.05222	0.216	0.001	***
Boat-billed Flycatcher	*Megarynchus pitangua*	0.84091	0.03444	0.17	0.001	***
Buff-throated Foliage-Gleaner	*Automolus ochrolaemus*	0.88235	0.03222	0.169	0.001	***
Black-crowned Antshrike	*Thamnophilus atrinucha*	0.65	0.03778	0.157	0.001	***
Brown-capped Tyrannulet	*Ornithion brunneicapillus*	0.88462	0.02556	0.15	0.001	***
Collared Trogon	*Trogon collaris*	0.95833	0.02333	0.15	0.001	***
Slaty-capped Flycatcher	*Leptopogon superciliaris*	0.88	0.02333	0.143	0.001	***
Mottled Owl	*Ciccaba virgata*	0.75	0.02	0.122	0.001	***
Ruddy Foliagle-Gleaner	*Clibanornis rubiginosus*	1	0.01333	0.115	0.001	***
Great Antshrike	*Taraba major*	0.91667	0.01222	0.106	0.001	***
Orange-billed Sparrrow	*Arremon aurantiirostris*	0.64706	0.01222	0.089	0.049	*
Red-billed Scythebill	*Campylorhamphus trochilirostris*	1	0.00667	0.082	0.005	**
Red-headed Barbet	*Eubucco bourcierii*	1	0.00667	0.082	0.002	**
Palm Oil Plantation						
Fulvous-vented Euphonia	*Euphonia fulvicrissa*	0.84466	0.33444	0.531	0.001	***
Southern-beardless Tyrannulet	*Camptostoma obsoletum*	0.89764	0.12444	0.334	0.001	***
Rusty-margined Flycatcher	*Myiozetetes cayanensis*	0.81818	0.12444	0.319	0.001	***
Pacific Antwren	*Myrmotherula pacifica*	0.9	0.09111	0.286	0.001	***

Scrub Blackbird	*Dives warczewiczi*	0.83333	0.09778	0.285	0.001	***
Rufous-tailed Hummingbird	*Amazilia tzacatl*	0.86905	0.08	0.264	0.001	***
Yellow-tailed Oriole	*Icterus mesomelas*	0.96923	0.06667	0.254	0.001	***
Social Flycatcher+	*Myiozetetes similis*	0.93507	0.06444	0.245	0.001	***
House Wren	*Troglodytes aedon*	0.96429	0.05889	0.238	0.001	***
Tropical Kingbird	*Tyrannus melancholicus*	0.85075	0.06	0.226	0.001	***
Buff-rumped Warbler	*Myiothlypis fulvicauda*	0.97917	0.05	0.221	0.001	***
Laughing Falcon	*Herpetotheres cachinnans*	0.73333	0.05111	0.194	0.001	***
Common Tody-Flycatcher	*Todirostrum cinereum*	0.85714	0.03889	0.183	0.001	***
Yellow-tailed Oriole	*Icterus mesomelas*	0.83333	0.02778	0.152	0.001	***
Bronze-winged Parrot	*Pionus chalcopterus*	0.84483	0.02556	0.147	0.001	***
Tropical Gnatcatcher	*Polioptila plumbea*	0.68571	0.02667	0.135	0.002	**
Chocó Toucan	*Ramphastos brevis*	1	0.01778	0.133	0.001	***
Olive-crowned Yellowthroat	*Geothlypis semiflava*	0.86364	0.02	0.131	0.001	***
Roadside Hawk	*Rupornis magnirostris*	0.8	0.02111	0.13	0.001	***
Red-headed Barbet	*Eubucco bourcierii*	0.92857	0.01333	0.111	0.001	***
Peruvian Pygmy-Owl+	*Glaucidium peruanum*	1	0.01222	0.111	0.001	***
Golden-olive Woodpecker	*Colaptes rubiginosus*	0.73684	0.01556	0.107	0.004	**
Common Pauraque	*Nyctidromus albicollis*	0.72222	0.01444	0.102	0.002	**
Ringed Kingfisher	*Megaceryle torquata*	0.90909	0.01111	0.101	0.001	***
Golden-bellied Warbler	*Tangara larvata*	0.9	0.01	0.095	0.001	***

Striped Cuckoo	*Tapera naevia*	1	0.0088 9	0.094	0.001	** *
Sooty-headed Tyrannulet+	*Phyllomyias griseiceps*	1	0.0044 4	0.067	0.04	*
Violet-bellied Hummingbird	*Damophila julie*	1	0.0044 4	0.067	0.036	*

AMPHIBIANS		**A**	**B**	**IndVal**	**p.value**	
Common name	**Scientific name**					
	Primary forest					
Labiated Rainfrog	*Pristimantis labiosus*	0.98619	0.38889	0.619	0.001	***
Chimbo Frog	*Barycholos pulcher*	1	0.09	0.3	0.001	***
Engraved Rainfrog	*Pristimantis subsigillatus*	0.7686	0.11	0.291	0.001	***
Truando Toad	*Rhaebo haematiticus*	0.82927	0.02333	0.139	0.001	***
Marbled Poison Frog	*Epipedobates boulengeri*	0.66667	0.02	0.115	0.001	***
Spiny Cochran Frog	*Teratohyla spinosa*	1	0.00889	0.094	0.002	**
Toachi Frog	*Hyloxalus toachi*	1	0.00778	0.088	0.004	**
Imbabura tree Frog	*Hypsiboas picturatus*	0.88889	0.00778	0.083	0.008	**
Warbler Rainfrog	*Pristimantis walkeri*	0.72727	0.00778	0.075	0.05	*
	Palm Oil Plantation					
Cachabi Robber Frog	*Pristimantis achatinus*	0.77936	0.58778	0.677	0.001	***
Rusty Treefrog	*Hypsiboas boans*	0.98399	0.32111	0.562	0.001	***
Cane Toad	*Rhinella marina*	0.88406	0.17556	0.394	0.001	***
Rosenberg's Treefrog	*Hypsiboas rosenbergi*	0.97143	0.03111	0.174	0.001	***
New Granada Treefrog	*Smilisca phaeota*	1	0.01556	0.125	0.001	***
Northern Glassfrog	*Hyalinobatrachium fleischmanni*	0.8	0.01111	0.094	0.007	**

Signif. codes: Statistically significance; asterisk shows the level of significance of each p.value
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’

Annex 10. Multi-criteria analysis to identify potential indicator species of ecological integrity for each site based on Indicator Value (IndVal) analysis and life-history databases (The Cornell Lab of Ornithology and Amphibia Web Ecuador), and consultation with ornithologists and herpetologists.

Avian	**Species**	**Specificity**	**Fidelity**	**Habitat specialization**
Primary forest	Black-headed Antthrush	0.99	0.07	Primary forest
	Rufous Piha	1.00	0.06	Primary forest
	OcAn	1.00	0.04	Primary forest
Palm Oil plantation	Pacific Antwren	0.90	0.09	Secondary forest and Intervened areas
	Social Flycatcher	0.94	0.06	Seconday forest and Intervened areas
	House Wren	0.96	0.06	Intervened areas
Amphibians				
Primary forest	Labiated Rainfrog	0.99	0.39	Primary forest & Old growth secondary forest

Annex 11. Overall costs of avian and amphibian sampling with the RAM and the PC methods

ACOUSTIC SURVEY (BIRDS AND AMPHIBIANS)

	Cost	No person	Total/per day	No days	Total all days
Accommodation per day biologist	20	2	40	15	600
Accommodation per day assistant	20	2	40	5	200
Salary field assistant per day	20	2	40	5	200
Transportation & Others		4			275
Total field work					**1275**
Recordings SM3	650	650 USD * 8 recordings SM3			5200
Recordings SM4	825	825 USD * 7 recordings SM4			5775
Chargers	85	85 USD * 3 chargers			255
Batteries rechargable	30	30 USD * 16 pair of batteries			480
GPS	100	100 USD*2			200
Other field material (locks, tools)	200				200
Total equipment					**12110**
Salary expert ID of recordings	100	1	100	22	**2200**
Total all					15585

TRADITIONAL POINT COUNTS (BIRDS)

	Cost	No person	Total/per day	No days	Total all days
Accommodation per day biologist	20	2	40	8	320
Accommodation per day assistant	20	2	40	8	320

Salary field assistant per day	20	2	40	8	320
Salary ornithologist surveys per day	40	1	40	8	320
Transportation & Others		4			275
Total field work					**1555**
Binoculars 8x42	150		150 USD * 3		450
Small recorder	100				100
Others (field guide, folders, etc)	200				200
GPS	100		100 USD*2		200
Total equipment					950
Total all					**2505**

TRADITIONAL POINT COUNTS (AMPHIBIAN)

	Cost	No person	Total/per day	No days	Total all days
Accommodation per day biologist	20	2	40	3	120
Accommodation per day assistant	20	2	40	3	120
Salary field assistant per day	20	2	40	3	120
Salary ornithologist surveys per day	40	1	40	3	120
Transportation & Others		4			275
Total field work					**755**
Camera	550				550
Head torch	20		20 USD*3		60
Others (plastic bags, batteries, etc)	200				200
GPS	100		100 USD*2		200
Total equipment					1010
Total all					**1765**

Annex 12. Sound classification table created by Schafer (1999) showing basic sound types and sound categories. Highlighted sound types were added for this study in order to adequately classify the responses of participants. The X shows the responses among the three social groups. The sounds that were added for this research are highlighted.

	Sound Category		Type of Sound	Forest	Intermediate	Urban
1	Natural Sound	1	sound of water	x	x	x
		2	sound of air	x	x	x
		3	sound of forest, nature	x	x	x
		4	sound of fire			x
		5	sound of birds	x	x	x
		6	**sound of feline**	x	x	
		7	sound of insects	x	x	x
		8	**sound of mammals**	x		x
		9	sound of animals	x	x	x
		10	**sound of reptiles**	x	x	
		11	sound of season, day-night		x	x
		12	**sound of leaves or trees**		x	x
		13	sounds of thunders or storms	x	x	x
2	Human Sounds	14	sound of the voice	x	x	x
		15	**sound of screaming and crying**	x	x	x
		16	sound of the body	x	x	x
3	Sounds and Society	17	rural soundscape		x	x
		18	town soundscape			x
		19	city soundscape		x	x
		20	marine soundscape		x	
		21	domestic soundscape		x	x
		22	sound of trades, professions and livelihood	x	x	x
		23	**sound of domestic animals**	x	x	x
		24	**sounds of TV, radio, films**		x	x
		25	**sound of social media programs (FB, WhatsApp, Twitter, etc)**		x	x
		26	sound of other entertainment		x	x
		27	music	x	x	x

		28	ceremonies and festivals		x	x
4	Mechanical Sounds	29	machines	x	x	x
		30	industrial and factory equipment	x	x	x
		31	transportation machines	x	x	x
		32	guns		x	x
		33	trains and trolleys			x
		34	internal combustion engines			x
		35	aircraft		x	x
		36	construction and demolition equipment		x	
		37	mechanical tools		x	
		38	instruments of war and destruction		x	
		39	farm machinery	x		x
5	Sounds as indicators	40	bells and gongs		x	x
		41	horns	x	x	x
		42	whistles		x	x
		43	sound of time	x	x	x
		44	telephones		x	x
		45	warning systems, alarms	x	x	x
		46	indicators of future occurrences		x	
		47	**social media alerts**			
		48	**social alerts**			x
		49	**explosions and bombs**	x		x
		50	**social adverts**			x
6	Other	51	**loud noises**		x	x
		52	**silence**	x	x	
		53	**unknown things**		x	
			Total	25	43	43

Annex 13. MCA dimensions discrimination values.

Sound ⁱType	Mass	Score in Dimension		Inertia	Contribution				
					Of Point to Inertia of Dimension		Of Dimension to Inertia of Point		
		1	2		1	2	1	2	Total
1	.056	-.458	.558	.013	.019	.052	.555	.445	1.000
2	.024	-.320	.520	.004	.004	.020	.413	.587	1.000
3	.036	.034	-1.209	.018	.000	.155	.001	.999	1.000
4	.002	-.750	1.690	.003	.002	.019	.268	.732	1.000
5	.123	1.443	.012	.160	.409	.000	1.000	.000	1.000
6	.013	2.368	.192	.046	.116	.001	.996	.004	1.000
7	.019	.438	.555	.004	.006	.017	.536	.464	1.000
8	.006	2.299	.644	.021	.052	.007	.959	.041	1.000
9	.010	1.451	.375	.014	.033	.004	.965	.035	1.000
10	.020	1.507	-.203	.028	.072	.002	.990	.010	1.000
11	.003	-.383	-2.071	.005	.001	.039	.060	.940	1.000
12	.006	-.567	-.191	.001	.003	.001	.942	.058	1.000
13	.014	1.115	-.162	.011	.027	.001	.989	.011	1.000
14	.120	-.327	-.007	.008	.021	.000	1.000	.000	1.000
15	.091	-.534	.058	.016	.041	.001	.994	.006	1.000
16	.016	-.497	.737	.005	.006	.026	.457	.543	1.000
17	.005	-.445	-1.444	.004	.001	.028	.149	.851	1.000
18	.001	-.750	1.690	.001	.001	.006	.268	.732	1.000

19	.003	-.658	.749	.001	.002	.005	.589	.411	1.000
20	.005	-.383	-2.071	.007	.001	.058	.060	.940	1.000
21	.043	-.634	.502	.015	.028	.032	.747	.253	1.000
22	.022	-.054	-.680	.003	.000	.030	.012	.988	1.000
23	.024	-.135	-.163	.000	.001	.002	.559	.441	1.000
24	.018	-.495	-.926	.008	.007	.045	.346	.654	1.000
25	.005	-.506	-.817	.002	.002	.009	.415	.585	1.000
26	.002	-.628	.436	.001	.001	.001	.793	.207	1.000
27	.094	-.486	-.174	.015	.035	.008	.935	.065	1.000
28	.002	-.567	-.191	.000	.001	.000	.942	.058	1.000
29	.019	.255	1.054	.008	.002	.063	.098	.902	1.000
30	.012	1.302	.077	.013	.033	.000	.998	.002	1.000
31	.039	-.254	-.690	.008	.004	.055	.201	.799	1.000
32	.008	-.457	-1.319	.005	.003	.039	.182	.818	1.000
33	.005	-.750	1.690	.006	.004	.039	.268	.732	1.000
34	.001	-.750	1.690	.001	.001	.006	.268	.732	1.000
35	.002	-.567	-.191	.000	.001	.000	.942	.058	1.000
36	.007	-.424	-1.653	.007	.002	.056	.109	.891	1.000
37	.001	-.383	-2.071	.001	.000	.010	.060	.940	1.000
38	.001	-.383	-2.071	.001	.000	.010	.060	.940	1.000
39	.001	2.735	.494	.004	.009	.001	.983	.017	1.000
40	.016	-.541	-.459	.004	.007	.010	.720	.280	1.000
41	.009	-.399	.963	.004	.002	.025	.241	.759	1.000
42	.004	-.677	.937	.002	.003	.010	.491	.509	1.000
43	.008	-.365	1.194	.004	.002	.032	.148	.852	1.000

44	.004	-.603	.185	.001	.002	.000	.952	.048	1.000
45	.032	-.471	.469	.007	.011	.021	.651	.349	1.000
46	.002	-.567	-.191	.000	.001	.000	.942	.058	1.000
47	.001	-.383	-2.071	.001	.000	.010	.060	.940	1.000
48	.001	-.750	1.690	.001	.001	.006	.268	.732	1.000
49	.004	.094	-.054	.000	.000	.000	.849	.151	1.000
50	.002	-.750	1.690	.003	.002	.019	.268	.732	1.000
51	.014	-.576	-.092	.003	.008	.000	.987	.013	1.000
52	.029	-.432	.241	.004	.009	.005	.856	.144	1.000
53	.001	-.383	-2.071	.001	.000	.010	.060	.940	1.000
Active Total	1.000			.504	1.000	1.000			