Title: A systematized spatial review of global protected area soundscape research

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Abstract: Protected areas (PA) represent the primary mechanism to protect global ecosystems; yet current capacities often lead to geographic imbalances for PA management around the world. PA soundscapes have proved a valuable element to inform effective management, as natural sounds are important for healthy natural systems and rewarding visitor experiences. This article employed a systematized literature review of PA soundscape research, matching the areas of study described for the 218 articles, with PA from the World Database on Protected Areas (WDPA). The studies took place in 372 PA, which were cataloged by geographic location and size where possible, country, and continent. Data charting included extracted keywords, research objectives, methods, outcomes and future research needs. Numeric and geographic analysis focused on understanding the nature, extent, and distribution of the studies, while thematic analysis was applied to identify trends with respect to methods, outcomes, and future research. Study results identified content and geographic imbalances between studies in tropical and temperate zones, terrestrial and marine environments, and the Global South and North. Discussion considers how global initiatives may support information and resource sharing that facilitates knowledge and capacity transfer between the two regions.

Keywords: systematized literature review; soundscapes; protected area; human-natural systems; soundscape ecology; World Database on Protected Areas (WDPA); socio-ecological systems

1. Introduction

Recent research has identified gaps in the global study of soundscapes that may have important implications for biodiversity and conservation. Scarpelli et al. (2020) identified a bias in 'Web of Science' and 'Scopus' scientific literature toward research focused on humans and anthropogenic noise, in urban areas within global temperate regions. They called for greater focus on soundscapes in nature and a purposeful effort to prioritize biodiversity hotspots, like tropical and marine environments. They also emphasized the importance of natural area soundscape

research within developing countries, and the potential for soundscape research to help conservation management efforts by providing efficient acoustic monitoring across large geographies (Scarpelli et al. 2020). The research presented in this paper expands on Scarpelli et al. (2020), through focused geographic analysis of trends within the subset of soundscape research that occurs within protected areas (PA), in order to help evolve a global soundscape research agenda for natural areas that can further conservation objectives.

The International Union for Conservation of Nature (IUCN) defines a PA as being, "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008, p. 8). On a global level, PA represent the most prominent strategy for the conservation of ecosystems and biodiversity (Loos 2021) and are increasingly charged with providing humans opportunities to experience nature through recreation and tourism. Management effectiveness of the world's PA has become a major area of focus over the past two decades, as it plays a primary role in determining the capacity of a PA to effectively protect biodiversity, provide ecosystem services, and stem anthropogenic pressures (Oldekop et al. 2016; Tapia-Armijos et al. 2017; Meijles et al. 2021).

The utility of PA in countries located in the 'Global South' (GS) has undergone criticism, as PA restrictions and exclusions have produced negative social impacts for many local communities, and biodiversity conservation results remain unclear (Oldekop et al. 2016; Loos 2021). This debate is particularly concerning for conservation, as GS countries are largely concentrated within tropical ecosystems (Uddin 2017), where the majority of biodiversity exists (Lewis et al. 2015). Thus, understanding relationships between PA, biodiversity conservation results, and human experiences within tropical GS regions of the world seems imperative. 'Southern Theory' suggests that science, development, and conservation manifest differently in parts of the world that were formerly colonized and/or considered as peripheral (Collyer 2018; Frimpong Boamah et al. 2021). Loos (2021) linked the contested nature of PA in the GS with tensions that arise between conservation and development, and a tendency to view the natural systems of PA as being separate from the social systems within a territory.

PA acoustic environments, or 'soundscapes', are an important element influencing both natural and human systems, and the study of how natural and human systems interrelate through sound can potentially lead to greater management effectiveness for PA around the world (Smith and Pijanowski 2014; Francis et al. 2017; Levenhagen et al. 2020). A major area of soundscape research focuses on natural systems and bioacoustics to understand how animals use acoustic and vibrational abilities to communicate, and to detect the presence of predators and prey (Francis 2015; Mason et al. 2016; Deichmann et al. 2018). In parallel, perceptual soundscape studies have been used in PA research focused on human-systems to evaluate the sounds visitors hear in PA, develop indicators of soundscape quality, and improve visitor experiences (Miller et al. 2018; Ednie et al. 2020; Gale and Ednie 2020; Gale et al. 2020). Typically, different methods are used to study natural systems and human systems (visitor experiences) within PA. PA natural systems acoustic monitoring and research has normally focused on characterization and measurement of the sound environment in combination with behavioral observation of populations of interest (Francis 2015; Mason et al. 2016; Deichmann et al. 2018). For example, the United States National Park Service (USNPS) protocols include objective measures of sound, such as duration and dBA, to measure the extent of specific sounds (USNPS 2013). However, PA visitor experience research has typically relied on perceptual measures, incorporating physical measurement of the sound environment with much less frequency.

Growing recognition of the impacts of anthropogenic noise on biodiversity and natural system health has led researchers, like Smith and Pijanowski (2014), to prioritize the need for a better understanding of acoustic ecology and the intertwining of human sounds and noise within nature and PA. Soundscape research contributes to better management of PA. For example, ecoacoustic methods have been shown to provide an efficient method of large-scale biodiversity monitoring within PA (Krause and Farina 2016; Scarpelli et al. 2020). PA managers also use perceptual research to maintain high quality visitor experiences (Ferrero et al. 2020; Gale et al. 2020, 2021), which have been associated with greater connections to nature and pro-conservation behaviors (Dumyahn and Pijanowski 2011; Ednie and Gale 2021). And, soundscapes may help build community involvement in PA management, e.g., recent research conducted in the GS has suggested citizen science and crowd-sourcing monitoring to assist with shared learning and governance efforts (Gale and Ednie 2020; Gale et al. 2021).

Increasingly, researchers have identified that effective PA management requires an efficient understanding of the interrelationships and feedback loops within complex and rapidly changing social-ecological systems (Dudley 2008; Tapia-Armijos et al. 2017; UNEP-WCMC et al. 2018; Levenhagen et al. 2020; Loos 2021; Meijles et al. 2021). In parallel, some PA soundscape ecology research has evolved beyond single discipline approaches focused on natural

or human systems toward coupled human-nature approaches that consider the interrelationships between human experiences in nature and how humans affect biodiversity and ecological processes. For example, Francis et al. (2017), proposed that acoustic conditions be considered as a vital ecosystem service, emphasizing that natural sounds play a critical role in ecological processes and the quality of human experiences in natural environments; while the health and quality of natural systems also affect human behaviors and experiences causing conservation implications. They identified the need for PA soundscape research to help understand the impact of changing soundscapes on ecological systems and visitors to reduce conflicts between conservation and public use (Francis et al. 2017).

In this article we build on the work of Scarpelli et al. (2020), through a closer look at the regions and PA where soundscape research has occurred and the areas of research focus, to help to define future direction or advances in this field. We pioneer a new use of the World Database on Protected Areas (WDPA), that combines a systematized literature review with a spatial location component to understand the nature, extent, and distribution of studies. This exercise allows us to examine how PA soundscape research aligns with the concerning patterns identified in other conservation biology work regarding research gaps in tropical and marine areas (Wilson et al. 2016; Scarpelli et al. 2020). We examine how researchers around the world are approaching PA soundscape research by considering if their focus is on human experiences, natural systems, or coupled human-nature approaches (Francis et al. 2017; Levenhagen et al. 2020). We also consider the patterns of research within the GS and 'Global North' (GN), in accordance with the categories established by the Independent Commission on International Development Issues (ICIDI), referred to as the 'Brandt Line' (ICIDI 1980), to identify opportunities to improve knowledge flows and achieve better and more equitable integration with societal needs and concerns (Santangeli et al. 2019; Sonne et al. 2020). Thus, our main objectives with this research were to identify geographic tendencies with respect to: (a) where PA soundscape research has occurred; (b) the specific areas of focus for PA soundscape research; and (c) potential knowledge system inequalities for PA soundscape research, based on geographic inequities within the GS and GN.

2. Materials and methods

This research employed a systematized literature review with a geographic component (Munn et al. 2018; Bourlon et al. 2021), following the study flow outlined in Figure 1. A systematized literature review uses clear protocols for searching and selecting papers that minimize bias and protect scientific rigor (Munn et al. 2018) but employs a manageable scope that does not require exhaustive collection of all available information (Moscoso et al. 2018; Borrie et al. 2020).

To develop the search strings, the following terms associated with soundscapes were used: 'acoustic', 'noise', 'soundscape', 'sound'; and the following terms associated with PA: 'protected area', 'park', 'wilderness', 'natural area', 'forest', 'national park', 'preserve', 'conservation', 'preservation' (Figure 1). Combining these terms, text strings were developed and entered into electronic databases specialized in scientific literature, including 'Academic Search Complete', 'JSTOR', 'Web of Science', 'EBSCO', 'BioOne Complete', 'ProQuest', 'SCOPUS', and 'SciELO'. Only peer reviewed, empirical research articles were sought, with a period of publication between January 1, 1975, and August 27, 2020, the day on which the search was carried out.

The search process resulted in an initial collection of 1,345 documents. A total of 113 duplicates were found and removed. Of the 1,232 articles that remained, 673 advanced through the title and keywords' review. Considering the study focus on PA soundscape studies, the abstracts and methods sections were reviewed to ensure that the research had been conducted within one or more PA. Full-text revision was employed for 280 articles, which resulted in the exclusion of 62 additional articles. Articles were excluded if they were not about soundscapes and/or not about PA, if they were not empirical studies, or if they contained insufficient information to georeference. The final sample for the structured literature review consisted of 218 documents.

The geographic component used in this study expanded the possibilities for data analysis, assisting the process to address the research questions (Bourlon et al. 2021). During the document selection process, we identified the PA where each study occurred and obtained their location, using the WDPA (UNEP-WCMC and UICN 2020). The WDPA was chosen for this study because it is the most complete repository of PA worldwide and is updated monthly to reflect the most current data available. The WDPA records the location of PA in the form of georeferenced points and polygons. The WDPA database was downloaded in geodatabase format (August 2020 version), to integrate with ArcMap, using ArcGIS 10.6. The geographic information was stored in a geodatabase. For the purposes of this article, a specific repository was created, and all PA were stored in point form. Those that

were in point form in the WDPA were selected and exported to the new repository. When PA were stored in polygon form within the WDPA, the 'feature to point' tool was used to convert them to points.

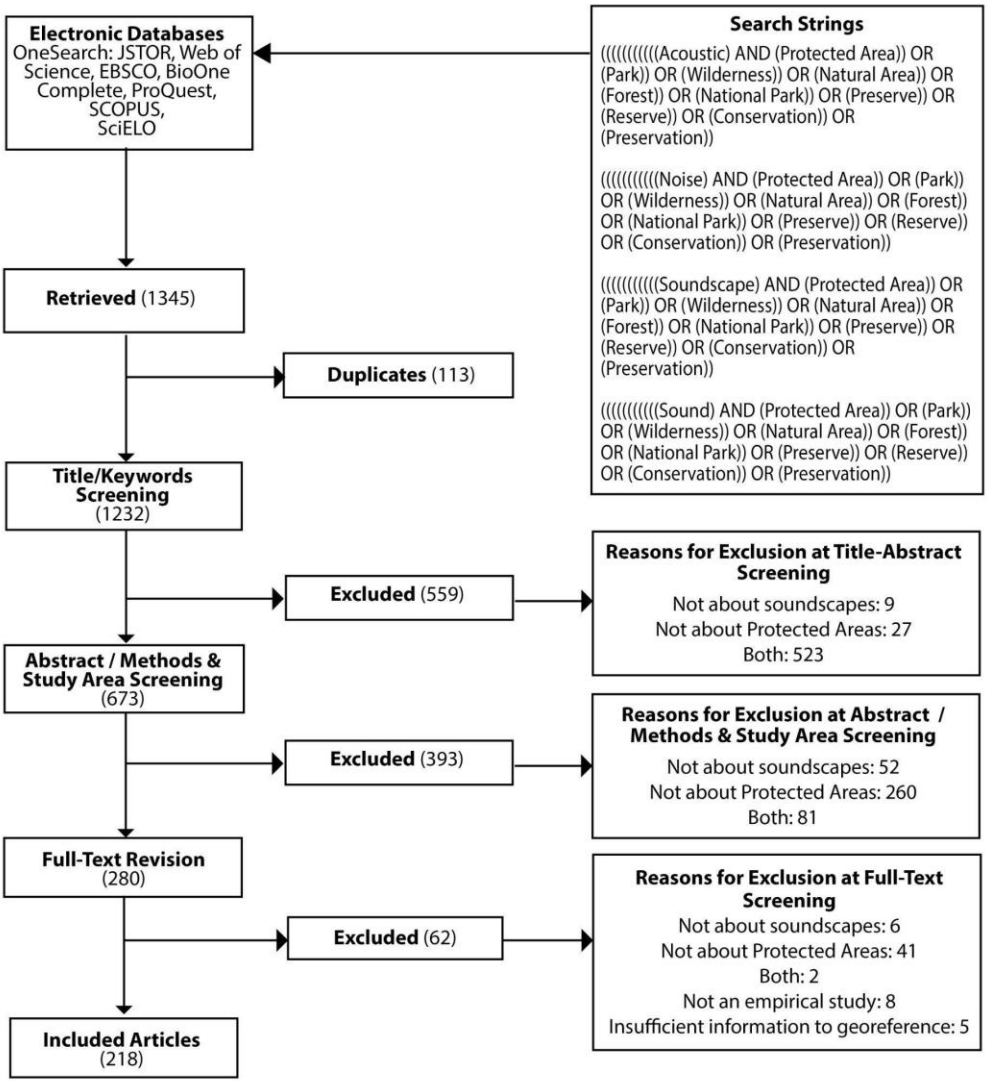

Fig. 1 Flow chart of the document selection process.

For articles that explicitly stated the PA where the research was conducted, a search by attributes (name) was performed in the geodatabase downloaded from the WDPA. If the search resulted in record/s for the PA that was sought, the record/s were selected and saved in the repository created specifically for the study. If the search did not find the PA, a search for its location was carried out through the Internet and its coordinates were obtained through web-mapping applications. Then, the coordinates were entered into the ArcMap locator, with the WDPA geodatabase open. If that location did not have a PA in the WDPA, the document was excluded; however, if the location corresponded with an entry in the WDPA geodatabase, it was selected, and the record was saved within the study repository. This tended to happen when the name given in the paper did not exactly match the name registered in WDPA. When multiple listings existed for a WDPA site, these listings were compared with the site names within the text of the studies and registered accordingly. For example, many United States (U.S.) National Parks include records for the park unit and separate records for wilderness areas within the parks, and/or UNESCO World Heritage site designations. All three were noted within the metadata; yet the name used in the paper that best corresponded with the WDPA database was chosen. Some of the articles provided the geographic coordinates for their study areas or sampling sites. When this occurred, the coordinates were entered directly into the ArcMap

locator. As before, if the location did not correspond with a WDPA site, the document was excluded; however, if a WDPA site was found at that location, it was selected, and the record was saved in the study repository. When articles described studies within multiple PA, all the PA that were recognized within the WDPA database were selected and stored.

2.1. Analysis

Data charting was used to extract key information from the 218 studies (Arksey and O'Malley 2005; Bourlon et al. 2021). A total of 372 PA were extracted from the areas of study described in the 218 articles. Both the studies and the PA were classified according to their geographic distribution by country and continent and categorized according to their climate zone ("Tropical", "Temperate", or "Polar"), their ecosystem type ("Terrestrial", "Marine", or "Coastal", which included both terrestrial and marine zones), and international inequality levels, as captured by the "GS" and "GN" categories, according to the Brandt Line divisions (ICIDI 1980). In parallel, a data extraction form was developed, and pilot tested on five of the papers by members of the research team. Based on the pilot results, minor changes were made to the extraction grid to increase clarity. The final version charted the original demographic variables (e.g., author/s, year of publication, journal), categorization of research focus areas "Human experiences," "Natural systems", or "Coupled human-nature approaches"), and the manuscript keywords. Once consensus was achieved for the final form, three members of the research team charted the data for the remaining 213 papers, using an iterative triangulation process to ensure agreement. A combination of numerical, geographic, and thematic analysis was employed for data reporting (Arksey and O'Malley 2005). Numeric and geographic analysis was used to understand the nature, extent, and distribution of the studies; thematic analysis was used to characterize the research focus and common topics (Arksey and O'Malley 2005). Lastly, VOS viewer keyword co-occurrence network analysis was employed using VOSviewer Version 1.6.17(0), to understand geographic tendencies within the specific areas of focus for PA soundscape research, through identification of the top 10 keywords for each of the three focus areas, within the GS and GN.

3. Results

Full bibliographic information for the 218 documents comprising the systematized literature review, including keywords, geographic location (countries and continent), PA name(s) as specified in the WDPA, and the study focus categories, is included within Appendix A.

With respect to the general geographic tendencies for PA soundscape research, studies spanned 61 countries and six continents: Africa, Asia, Europe, North America, Oceania, and South America. Most studies focused on PA within a single continent (215; 98.6%); however, three studies spanned PA across more than one continent. One study included PA in Asia and North America (Appendix A: ID59), one study included Asia and South America (Appendix A: ID142), and one focused on PA in Europe and North America (Appendix A: ID88). North American PA were included in the largest number of studies (87; 39.9%); followed by PA in Europe (50 studies; 22.9%). The U.S. led North America with 57 PA soundscape studies (26.1%), followed by Canada (15, 6.9%), and several Central American countries that had one to five studies (e.g., Belize, the Caribbean Netherlands [Bonaire, Sint Eustatius, and Saba], Costa Rica, Dominican Republic, Guadeloupe, Honduras, Martinique, Mexico, Panama, Puerto Rico, Saint-Barthélemy, Saint-Martin, and Virgin Islands). In Europe, Italy, and the United Kingdom (UK) had the most studies within our sample (11, 5.0% and 13, 6.0%, respectively). Other countries with a concentration of PA soundscape studies included Australia (17, 7.8%), in Oceania, and Brazil (12, 5.5%), in South America.

The 218 PA soundscape studies were conducted within 372 PA, as several studies incorporated multiple PA (Figure 2). Sixty of the studies took place within two PA, and 17 studies included three or more PA. The PA with the heaviest concentration of soundscape studies included: Glacier Bay National Park and Preserve (U.S.) with seven studies, the Gerry E. Studds/Stellwagen Bank National Marine Sanctuary (U.S.) with six studies, and four PA with four studies each: Lagon de Moorea Ramsar Site (French Polynesia), Yosemite National Park (U.S.), and Yellowstone National Park (U.S.). Of the eleven PA that were included in three studies, eight were in the U.S. (Denali National Park and Preserve, Everglades National Park, Glacier National Park, Golden Gate National Recreation Area, Grand Canyon National Park, Great Smoky Mountains National Park, Muir Woods National Monument, Point Reyes National Seashore); two in Brazil (Parque Estadual Marinho Da Laje De Santos, Parque Estadual Xixová-Japuí); and one in Côte d'Ivoire (Taï National Park).

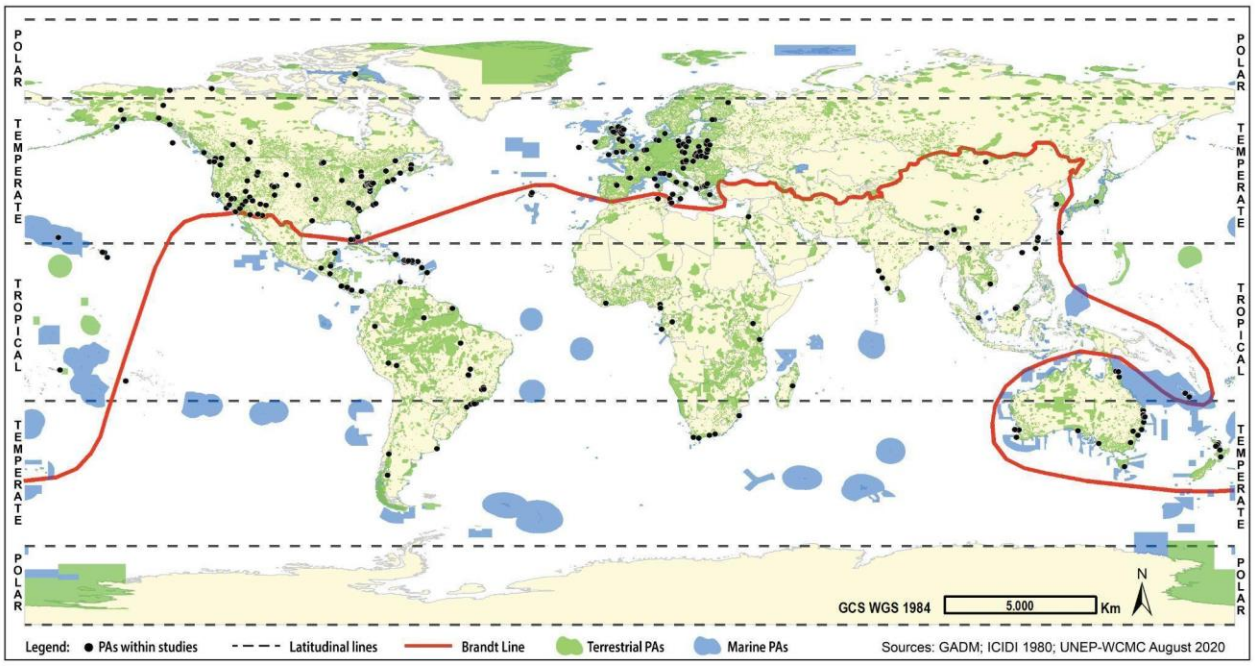

Fig. 2 Geographic distribution of PA within soundscape studies, including climate zones, WPAD-PA ecosystem type, and Brandt Line country divisions.

With respect to climate zone and ecosystem tendencies, most studies (66.5%) were focused on PA located completely within the temperate climate zone, in comparison with studies of PA located completely within the tropical climate zone (28.9%). Seven studies (3.2%), focused on PA with both temperate and tropical climate zones (Appendix A: ID38, ID59, ID80, ID81, ID88, ID118, ID195), and only three studies (1.4%), focused on PA within the polar climate zone (Appendix A: ID75, ID76, ID122). The 301 temperate climate zone PA included in these studies were distributed within Europe (50.8%), North America (32.9%), Oceania (8.0%), Asia (3.7%), South America (2.7%), and Africa (2.0%). The 68 tropical climate zone PA were distributed within North America (41.2%), South America (20.6%), Asia (16.2%), Africa (13.2%), and Oceania (8.8%).

Generally, there was much greater focus on terrestrial ecosystems, with 140 studies (64.2%), focused within 100% terrestrial PA. In comparison, marine ecosystems were the focus of 27 studies (12.4%) within 100% marine PA, while the remaining 51 studies (23.4%) occurred within coastal PA that included both terrestrial and marine ecosystems. In addition to Glacier Bay National Park and Preserve (Appendix A: ID57, ID58, ID61, ID80, 128, ID129, ID134) and U.S. Everglades National Park (Appendix A: 16, ID118, ID203) in the U.S.; Parque Estadual Marinho Da Laje De Santos in Brazil (Appendix A: ID171, ID179, ID181), and Lizard Island National Park in Australia (Appendix 1: ID166, ID187, ID214, ID215), which were mentioned earlier, other coastal PA with multiple studies included Cape Rodney - Okakari Point PA in Australia (Appendix A: ID137, ID77), Cape Lookout National Seashore in the U.S. (Appendix A: ID47, ID118), Saguenay-St. Lawrence Marine Park in Canada (Appendix A: ID40, ID67), and two PA in Poland, Słowiński Park Narodowy and Woliński Park Narodowy (Appendix A: ID18, ID19).

With respect to PA soundscape research focus areas, the majority of studies (171) were classified with natural systems focus, as compared with 41 studies with a human experience focus and six with a coupled human-nature approach (Figure 3). Study keywords differed according to focus area; only the word ‘soundscape’ showed up within all three categories. Nevertheless, the coupled human-nature approach category shared words with both the human experience and natural systems categories, like ‘national park’ and ‘acoustics’.

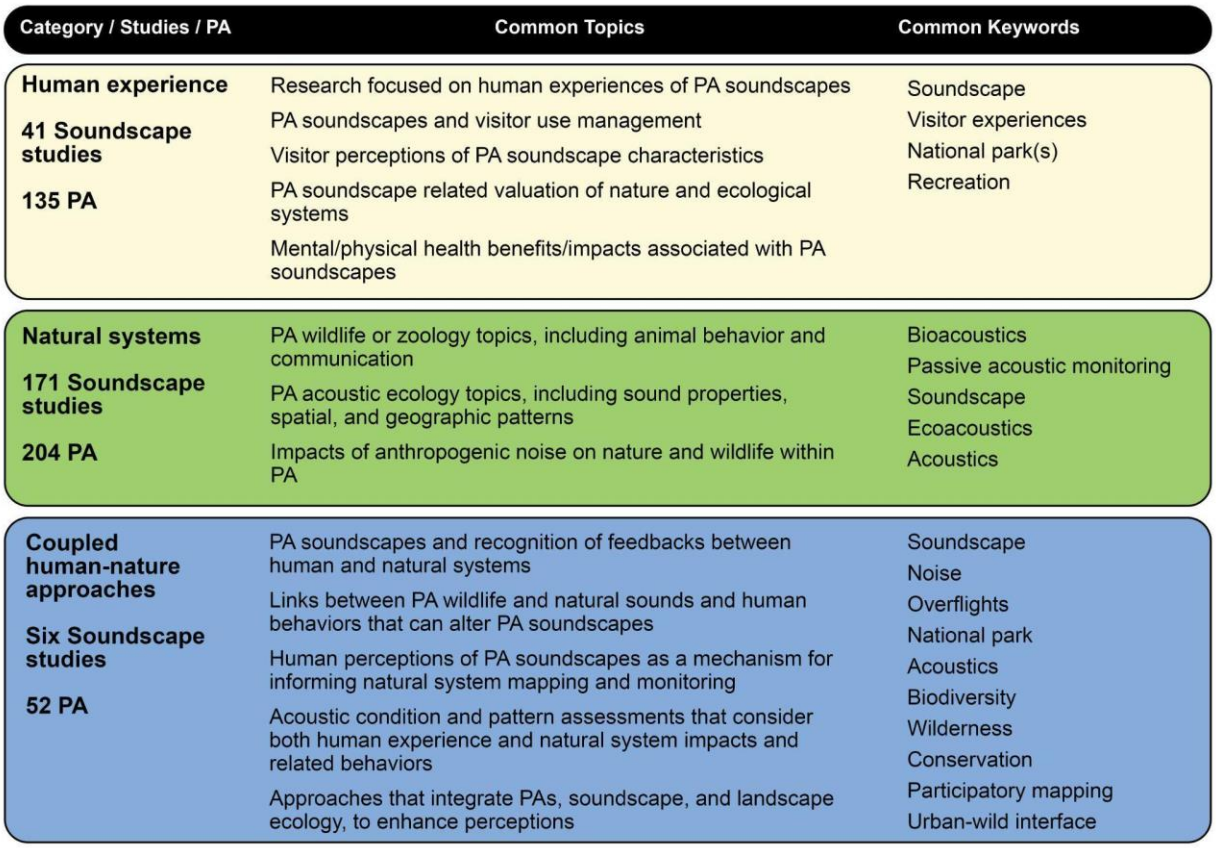

Fig 3. Comparison of human experience, natural systems, and coupled human-nature approaches research categories, detailing the numbers of studies and PA, as well as common keywords

Research relating to human experience was distributed within 15 of the 61 countries (24.6%; Figure 4A). North America had the largest number (19), which were distributed among three countries (U.S., 16; Canada, 2; Honduras, 1). Europe followed North America with 18 PA studies distributed across eight countries (Belgium, Croatia, Finland, Greece, Poland, Spain, and UK). Asia had three studies focused on human experiences (Appendix A: ID98, ID106, ID165), distributed within China (2) and South Korea (1). Africa, South America, and Oceania had one study each (Appendix A: ID11, ID62, ID150). These studies occurred within Cameroon, Australia, and Chile, respectively.

Natural systems studies were geographically distributed across 56 of the 61 countries (92%; Figure 4B). For 45 of the countries (73.8%), all the respective studies were focused on natural systems. North America had the largest number (72), which were distributed among 14 countries (U.S. 37; Canada, 13; Costa Rica, 5; Belize, 3; Puerto Rico, 3; Mexico, 2; Virgin Islands, 2; Bonaire, Sint Eustatius and Saba, 1; Dominican Republic, 1; Guadeloupe, 1; Martinique, 1; Panama, 1; Saint-Barthélemy, 1; Saint-Martin, 1). Again, Europe followed North America, with 36, distributed across 13 countries (Italy, 11; UK, 6; France, 3; Greece, 3; Spain, 3; Ireland, 2; Portugal, 2; Austria, 1; Denmark, 1; Germany, 1; Hungary, 1; Monaco, 1; Poland, 1). Oceania had the third highest concentration (25) distributed across Australia (16), French Polynesia (4), New Zealand (4), and New Caledonia (1). South America had 19 studies distributed within Brazil (12), French Guiana (2), Peru (2), Argentina (1), Chile (1), and Ecuador (1). Asia had 18 studies distributed across 11 countries (India, 3; Brunei, 2; China 2; Japan, 2; Malaysia, 2; Taiwan, 2; and Bangladesh, Israel, Mongolia, Singapore, and Vietnam, with one study each. Africa had the least number of natural systems focused PA soundscape studies, with 16 works distributed across seven countries (South Africa, 5; Côte d'Ivoire, 3; Cameroon, 2; Tanzania, 2; Algeria, 1; Gabon, 1; Kenya, 1; Madagascar, 1).

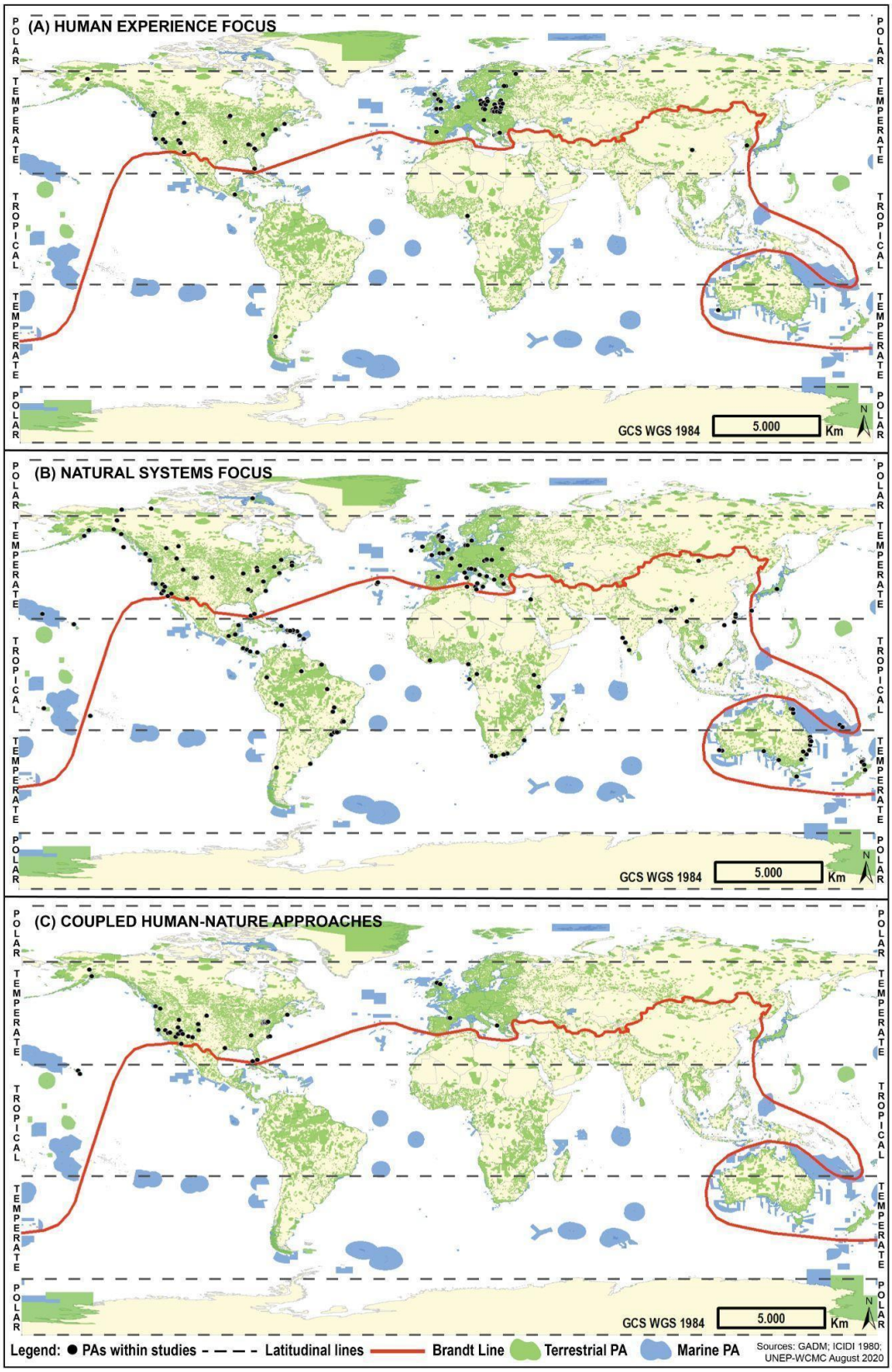

Fig. 4 Geographic distribution of PA within soundscape studies, by research focus category [(A) Human experience focus, (B) Natural systems focus, (C) Coupled human-nature approaches.

PA soundscape studies with a coupled human-nature approach were only observed within four of the 61 countries (6.6%; Figure 4C): Greece (Appendix A: ID127), France and the UK (Appendix A: ID34), and the U.S. (Appendix A: ID118, ID135, ID144, ID186). Some of these studies involved numerous PA within their sample; thus, a total of 52 PA were represented, all of which were located within Europe and North America (Figure 3, Part C). The vast majority (47) of the PA were in the U.S., with the remaining located in France (2), Greece (1), and Scotland (2). Hawaii's Haleakalā National Park and its wilderness were included in two of the studies employing a coupled human-nature approach (Appendix A: ID118, ID135), and two others focused on adjacent Alaskan PA: Kenai Fjords National Park and Kenai National Wildlife Refuge (Appendix A: ID118, ID144).

A summary of the results associated with each of the six studies with a coupled human-nature approach is presented as Appendix B for this paper. Four of the papers presented U.S. research, focused almost exclusively on the impacts of anthropogenic noise (e.g., aircraft, snowmobiles, infrastructure, and other human-caused noise) in PA. The remaining two studies were European and focused on the potential for acoustic characteristics and soundscape perceptions to inform zoning and land-use planning, along an urban-to-wild continuum. The six papers employed a range of methods, involving visitor and expert listening and perceptual data, soundwalks, passive acoustic monitoring, acoustic metrics, off-site listening, visual analysis of spectrograms, and mapping (see Appendix B). Outcomes were study specific; yet several common themes arose. For example, results contributed to better understanding of spatial and temporal soundscape dimensions, the appropriateness of specific sounds and noise within PA classifications and zones, and interrelationships between noise and natural quiet. Three common themes arose with respect to future research needs: (1) finding ways to better approach coupled human-nature considerations; (2) expanding scope to larger territorial settings; and (3) continued methodological evolution.

To understand the potential for PA soundscape research inequalities, we evaluated geographic tendencies with respect to research within the GS and GN. There were 73 studies (33.2% of total studies), with data from 81 PA within the countries of the GS. In comparison, 147 studies (66.8% of total studies) were conducted within countries of the GN, focused within 291 PA (Figures 2 and 3). Two studies (0.9%), focused on PA in both GS and GN (Appendix A: ID59, ID88). The 81 GS PA were distributed within North America (25.9%), South America (27.2%), Asia (24.7%), Africa (18.5%), and Oceania (3.7%). The 291 GN PA included in these studies were distributed within Europe (52.6%), North America (37.5%), Oceania (9.3%), and Asia (0.7%). Within the GS, there were six studies (2.8% of total studies) focused on human experiences (Appendix A: ID11, ID62, ID98, ID106, ID131, ID165) and the rest (67, 30.7% of total studies) were focused on natural systems. Within the GN, there were 35, 106, and six studies (16.1%, 48.6%, and 2.8% of total studies), focused on human experiences, natural systems, and coupled human-nature approaches, respectively. The six papers that surfaced in this study with a coupled human-nature approach were all within the GN.

4. Discussion

The majority (63%) of PA soundscape studies within the current study were developed within PA of North America and Europe; our geographical analysis identified a comparative lack of PA soundscape research within the PA of other continents. Over the last 12 years, significant effort has focused on developing PA management effectiveness within the world's PA to meet the Convention on Biological Diversity (CBD) Aichi Biodiversity Target 11, especially in continents outside of North America and Europe (Coad et al. 2013; CBD et al. 2016; Meehan et al. 2020). In recent years, increasing attention has been placed on the potential for acoustic data to contribute to these efforts, especially considering the cost efficiencies that have been realized for recording equipment and storage technologies (Deichmann et al. 2018). The lack of PA soundscape research outside of North America and Europe prevents agencies in other continents from incorporating acoustic parameters and tools within management protocols for localized, relevant issues. Legal protections, methods, and research agendas drawn from North America and Europe often do not represent options that are fiscally achievable or desireable for other regions of the world. Moreover, if the available soundscape management examples come from countries within different regions of the world (environmentally, economically, and culturally), those in early stages of natural soundscape protection are less likely to have pertinent solutions and options available to address the conservation challenges they face. This is particularly concerning considering gaps in research conducted within tropical and marine areas identified within the current study and previous work (Wilson et al. 2016; Scarpelli et al. 2020).

In general, soundscape research has tended to focus on terrestrial ecosystems within temperate climate zones (Scarpelli et al. 2020). Similarly, our results indicated that approximately two-thirds of PA soundscapes studies focused on temperate zones, while less than one-third focused on tropical zones. While this may be partly due to

there simply being a larger number of PA in temperate areas (81.2% vs. 18.2% in tropical areas), it nonetheless raises a concern (UNEP-WCMC and UICN, 2020). Given the estimation that tropical zones contain more than two-thirds of the world's overall biodiversity (Lewis et al. 2015), more research should focus here. Relating the findings of this study to previous research can demonstrate specific gaps, concerns, and implications associated with a relative lack of studies within the world's more biodiverse zones. For example, Wilson et al. (2011) identified 'high conservation importance' (HCI) countries for conservation based on a prioritization analysis that considered habitat loss, resources required for risk abatement, and the likelihood of success. They identified 10 countries as having particularly high importance for mammal conservation (i.e., Indonesia, Madagascar, Peru, Mexico, and Australia) and broader conservation considering vascular plant richness, endemic species, etc. (i.e., Ecuador, Costa Rica, Panama, the Dominican Republic, and Papua New Guinea). Later, Wilson et al. (2016) examined publishing trends and noted the relatively small proportion of conservation research in HCI countries, as compared to non-HCI countries within North America and Europe.

The search used for our study identified 28 soundscape articles focused on PA within eight of the 10 HCI countries (Figure 5). Most of the studies within these countries were conducted within PA in tropical zones; the exceptions were 10 studies within Australia. A closer examination of these 28 studies focused on the countries where the research occurred, the conservation elements involved, anthropogenic impacts/conservation concerns mentioned, and future research needs demonstrated knowledge gaps within these HCI countries that warrant a more robust PA soundscape research agenda. For example, the bulk (60.7%) of these studies were conducted in Australia, and included 13 different conservation elements (i.e., organisms, species, and/or their natural habitats), which ranged from specific species such as Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) to more general conservation concerns about natural habitats like fragmented forest remnants. Overall, the lack of replication of studies raises concerns over the depth of knowledge, while the low number of conservation elements (13) raises concerns about the breadth of knowledge for this biodiverse region. For Costa Rica, another HCI country, our study identified four PA soundscape articles, focusing on a total of five conservation elements that ranged from habitat concerns (e.g., lianas, neotropical rainforest canopies), and species, like birds and bottlenose dolphins (*Tursiops truncatus*), to general biodiversity loss. Here, as with study results related to the other six HCI countries, the research focused on a very limited number of conservation elements, demonstrating the depth and breadth of knowledge gaps to an even greater degree than in Australia.

An examination of HCI studies in tropical zones within our sample demonstrates the importance of soundscape research for biodiversity conservation, and the need for more soundscape research in these areas. For example, Pearson and Clarke (2019) examined the adaptive capabilities of the vulnerable grey-headed flying-fox (*Pteropus poliocephalus*) in New South Wales, Australia, who are increasingly moving from rural to urban landscapes. Although their vocalizations and habits appear to allow them to continue to communicate in a louder environment, Pearson and Clarke (2019) determined that the flying foxes became quiet during low aircraft overflights, and they coined the term 'silentium effect' to describe this tendency. This finding was an unexpected observation within their study, and led to many questions regarding physiological, morphological, and selective considerations, as well as questions about how this behavior may affect reproductive success.

Country / Appendix A	Conservation Elements	Anthropogenic impacts / Conservation Concerns	Future Research Needs
Australia ID12, ID100, ID124, ID125, ID136, ID145, ID150, ID154, ID158, ID163, ID166, ID200, ID205	Gondwanan relict insect, Silvereyes (Zosterops lateralis), ofgrey-headed flying-foxes, coral reef fish/larvae, crustaceans, snapping shrimp, Indo-Pacific bottlenose dolphins (Tursiops aduncus), Sperm whales (Physeter macrocephalus), Antarctic blue whale (Balaenoptera musculus intermedia), baleen and toothed whales, permian moss forests, fragmented forest remnants, Queenland rainforest	Underwater anthropogenic noise; anthropogenic noise disturbance; motor boat noise; construction noise; urban noise levels; high noise levels from airline traffic; global disturbance events; coral bleaching; anthropogenic pressure; habitat fragmentation; habitat degradation and restoration; pollution levels; anthropogenic factors; cultural heritage significance.	Increase knowledge of acoustic abilities during ontogeny; masking due to anthropogenic noise; relationships between behavioural and electro- physiological measures of hearing ability in the species and life history stages of interest; further research into the impact of anthropogenic noise throughout marine ecosystems; distinguish the acoustic orientation cues used by fish for orientation and identify behavioural and ecological significance; further exploration on how to describe and evaluate the acoustic dimension of these important places; better understanding of automated signal recognition and source identification; understanding the effect motorboat disturbance could have on the vulnerability of fish nests; importance of repertoire size and length of dawn chorus in different habitats to clearly understand the benefits/costs of behavioral changes in urban environments; overlaying maps of dolphin distribution with noise maps to identify areas of risk and opportunity; determine the influence of temporal patterns on aquatic fauna; test passive acoustic monitoring for sperm whales to measure and mitigate effects of anthropogenic activities and their impacts on cetaceans; how vessel characteristics (physical, behavioral, acoustical) elicit responses in Swan River dolphins beyond changes in animal occupancy; determine the level at which dolphin communications are being masked at anthropogenically noisy sites; determine how the structure of Swan River dolphin whistles may change in different contextual scenarios; clarify the occurrence and distribution of critically endangered species; determine the extent that clustering results obtained from one site can be used to classify acoustic data from an unrelated site; develop new acoustic features/indices that highlight various soundscape features; further monitoring and experiments in controlled conditions to measure precisely the flying-foxes' responses to variations in anthropogenic noise; studies to identify if other species temporarily cease to vocalize when subjected to extremely high anthropogenic noise levels (termed here the *silentium* effect), and the physiological, morphological and selective factors contributing to this response; identify if critical life history aspects of these species (e.g. reproductive success), may be impacted by vocalization cessation from anthropogenic noise pollution
Costa Rica ID59, ID87, ID130, ID155	Common bottlenose dolphins (Tursiops truncatus), lianas, birds, general biodiversity loss, neotropical rainforest canopies	Ambient noise levels; number of boats present; forest disturbance; climate change; intensifying human attempts to rectify the biodiversity crisis	Improving recording methods and consistency across geographic scales; more landscape level assessment of acoustic conservation values for forested environments
Dominican Republic ID82	Humpback whales, fish choruses, sperm whales, dolphin, and minke whales	Vessel traffic; noise, anthropogenic footprint; masking of marine mammal sounds, potentially changing typical animal behavior and raising the risk of ship strike	Continue data collection to support the capacity to track changes in species presence and increases or decreases in anthropogenic noise; provide an index for evaluating the health of underwater environments over time.
Ecuador ID142	Forest ecosystems	Habitat quality and landscape modification	None mentioned.
Indonesia	No studies identified.		
Madagascar ID197	Indri lemurs	Background noise masking	Fine tuning acoustic methods, through greater focus on frequency variation durring collective vocal displays, to provide tools for monitor chorusing mammals.
Mexico ID108	Bats	Vegetational clutter (i.e. deterioration, flooding, sinkholes, forest loss, fragmentation) are changing the structural and acoustic environments for bats.	Need for additional clutter-based acoustic characterization and species monitoring.
Panama ID70	Nocturnal birds: Great Potoo, (Nyctibius grandi); Crested Owls (Lophostrix cristata); Black-and- White Owls (Ciccaba nigrolineata); Vermiculated Screech-Owls (Megasops guatemalae); Tropical forests	Not mentioned.	Feasibility and cost-effectiveness of using synchronous audio data from multiple recorders to estimate presence, density, and relative abundance of nocturnal bird species.
Papua New Guinea	No studies identified.		
Peru ID623, ID1126	Indri lemurs	Background noise masking	Fine tuning acoustic methods through greater focus on frequency variation during collective vocal displays, to provide tools for monitor chorusing mammals.

Fig. 5. Countries, conservation elements, anthropogenic impact concerns, and future research needs for articles within the current study from the ten HCI countries identified by Wilson et al. (2011).

The authors also questioned whether other species may exhibit the same 'silentium effect'. This is an example of how the study of fauna sounds, combined with monitoring of foreground and background anthropogenic sounds, are needed to better understand at minimum the conservation of one vulnerable species and likely more. Another HCI

example study demonstrates how soundscape research can be used to evaluate the impacts caused by known environmental threats such as mining, and how further research on this topic in tropical zones is necessary. In this case, Alvarez-Berriós et al. (2016) demonstrated how soundscape research can be used to monitor vocalizing avian and anuran communities as part of rapid environmental impact assessments in small-scale gold mining communities. They found different patterns between populations, where avian activity decreased within the periphery of active mines, and anuran activity increased in those areas. This finding led to postulations and questions regarding avian and anuran responses to anthropogenic disturbances and the work demonstrates the possibility for a more robust soundscape research program in tropical regions to serve as rapid biodiversity assessments and environmental impact evaluations in the face of mining and other anthropogenic activities.

In addition to the predominance of research conducted in temperate over tropical regions observed within our study, results demonstrated a majority of terrestrial (64.2%) over marine (12.4%) studies. The rest of the studies (23.4%) focused on coastal environments, with a combination of terrestrial and marine environments. A larger focus on coastal environments seems fitting, given that these regions may experience dramatic upcoming alterations due to climate change, and soundscape research may provide invaluable, timely insights. Although 86% of all life exists in terrestrial environments, 78% of animal life is concentrated in marine environments (Bar-On et al. 2018). Thus, a global conservation focus warrants more soundscape research in marine environments. For example, in Chilean Patagonia, managers of the Laguna San Rafael (LSR) National Park, which forms the nucleus for the UNESCO LSR Man and the Biosphere Reserve, have prioritized the need for acoustic data within their visitor management plans. The acoustic data are used to inform tourism visitation parameters and thresholds to limit negative impacts of anthropogenic boat noise in the areas of the glaciers; both for marine life, and for the negative experiential impacts these motor sounds have on visitors (Chilean National Forestry Corporation 2018).

The Scarpelli et al. (2020) review found humans to be the primary focus of soundscape research, generally; yet our findings indicate that natural systems are the overwhelming focus for soundscape research taking place in PA around the world. In fact, for 45 of the 61 countries with PA soundscape research in this study, consideration of humans was limited to the impacts of anthropogenic noise on nature and wildlife. Additionally, for the studies conducted within the HCI countries identified by Wilson et al. (2011), all had natural systems as their focus. Even though their primary focus was natural systems, 22 of our 28 studies within these regions discussed anthropogenic noise and its effect on the conservation elements (Figure 5). It is concerning that PA soundscape studies with a human experience focus, or a coupled human-nature approach, were not observed within the HCI countries, especially considering the importance of community and stakeholder support for conservation programs, and for PA conservation management effectiveness (Leverington et al. 2008).

It seems germane to consider human experiences with (and values attached to) PA soundscapes, considering the interconnections between land-use decision-making and natural systems health (Smith and Pijanowski 2014; Francis et al. 2017). The past 60 years have experienced greater anthropogenic ecosystem alteration than in any other era of recorded history (Collins et al. 2011) and associated human-caused noise has negatively affected both human and natural systems (Francis et al. 2017). Ecosystem alterations have not only contributed to our current biodiversity crisis, they have also caused numerous reciprocal effects for human well-being (Collins et al. 2011; Moscoso 2018; Teixeira et al. 'Unpublished results'). To address increasing pressures within and around PA, effective management approaches are increasingly seeking interdisciplinary, and transdisciplinary, research foci and tools that can address PA challenges from the standpoint of interconnected sociological and ecological systems (Hockings et al. 2006; Gale et al. 2019, 2021). PA soundscape research provides an opportunity for learning through coupled human-nature approaches, helping managers understand the impact of changing soundscapes on both humans and ecological systems, as well as informing managers regarding conflict mitigation between conservation and public use (Smith and Pijanowski 2014; Francis et al. 2017).

However, our results suggest that a coupled human-nature approach is still limited within PA soundscape research. Only six of the total 218 studies in our research utilized this focus, and all were within the GN. Within the GN, however, the spatial impact and PA coverage for these studies was relatively broad, particularly as two studies in the U.S. considered numerous PA (Figure 4C). Two of the six studies focused on general management and territorial zoning in Europe (UK, France, and Greece), within PA that were integrated within existing communities. Four of the six studies focused on the coupled human-nature impacts of anthropogenic noise (aircraft engines and snowmobiles) within U.S. parks and wilderness areas. Longstanding U.S. concern about the impact of engine noise on wildlife and visitor experiences in PA has provoked a series of laws and mandates which have required ongoing

research funding, monitoring, and programming (Mace et al. 2013; Miller 2008). Effective natural soundscape protection may have catalyzed more rapid advancement of research, facilitating advances toward a holistic approach that supports a more complete view on the issue and its possible solutions.

Much has also been written about the unequal production of academic knowledge and research between GS and GN countries (Wilson et al. 2016; Collyer 2018; Santangeli et al. 2019; Sonne et al. 2020). For example, Santangeli et al. (2019) identified that effective biodiversity research in the GS can be hampered by poor forms of governance, high violence levels, and weak or unstable socio-political contexts. Increasingly, authors and institutions are calling for biodiversity research and policy to develop local capacity and become better integrated with societal needs and concerns (Collyer 2018; Santangeli et al. 2019; Sonne et al. 2020). For example, Kasprowicz et al. (2020) discussed the potential for African-led health research to help overcome cycles of brain-drain, leading to place-based improvements and economic transformations. They identified six key benefits of local-led capacity building that may also be relevant for protected area soundscape research and overall management effectiveness, including (1) better alignment between research and local scientific challenges, (2) more local ownership, (3) local scientific and management skills building, (4) increased publishing outputs, (5) better alignment with local policy makers, and (6) providing a role model for other local scientists. Meanwhile, global collaborations have led to the development of resources to support PA around the world by bridging and sharing region-specific approaches to integrative PA conservation practices (Dudley 2008; UNEP-WCMC et al. 2018). In parallel, a more purposeful geographic research agenda is needed to facilitate better global knowledge flow and reduce the inequalities associated with the current knowledge system (Collyer 2018; Sonne et al. 2020).

Understanding and addressing the geographic imbalances and dynamics that surfaced within this study merits additional research and action. For example, several soundscape and conservation authors have identified the need for more research in tropical zones conducted by local researchers (Wilson et al. 2016; Vanhove et al. 2017; Deichmann et al. 2018). Wilson et al. 2016 discussed the importance of this with respect to the CBD AICHI Biodiversity Target 19, which is about improving and sharing biodiversity knowledge and science (CBD et al. 2016). They discussed a lack of representation in international research groups, like the IUCN, by researchers from HCI countries, and found that less than a quarter of conservation studies in HCI countries were conducted by in-country researchers (Wilson et al. 2016). It seems important to understand tendencies with respect to local-led research and authorship in the GS, to understand if PA soundscape research is being driven by local GS scientists; if not, it seems imperative to develop strategies to ensure that knowledge gains are being transferred to local scientists and PA managers.

When aligning our data to the HCI countries, at least one author was local to the study country in 71% of studies (Figure 5). There was some variation within the list, where 88% of studies in Australia (GN) had at least one local author, while none of the four studies in Costa Rica (GS) had local authors. Of the other six countries (all GS), only Mexico had a local first author. Disparities appeared to play a role driving research needs within our sample, based on recognition of future research needs. Within our HCI country studies, disparities were also apparent, based on the richness of the apparent research agenda within Australia (GN), as compared with the other GS countries. Not only was more research conducted within Australia across more conservation elements, but a wealth of future research needs were identified within this country. These research needs ranged from developing better acoustic measurement and monitoring methods, to the way different conservation subjects utilize sounds in different contexts and situations, to the effect of anthropogenic noise on specific species within dynamic contexts. Australia's list of research needs as demonstrated in Figure 5 shows that this GN country desires more research even though it is within the most productive PA soundscape research countries in the world, and this need exists across the globe, especially within the GS.

5. Conclusions

This work bridges PA soundscape research with conservation biology and visitor experience management priorities by aligning where PA soundscape research tends to take place, with what the research tends to focus on. Through the integration of geographic, bibliometric, and thematic analysis, the current study moves PA soundscape research forward; both at a disciplinary level (e.g. contributions to the field of conservation biology), and at an interdisciplinary level, by identifying strengths and gaps in our current state of knowledge and compiling geographical and content trends to suggest a path forward. For example, our results supported the Scarpelli et al. (2020) identification of a soundscape research gap within tropical zones. Our integrated research approach enabled us to drill into tendencies and develop rich contextual information. Adding a geo-component to our systematized

review allowed us to capitalize on the rich metadata provided within the WDPA database and to examine in greater depth how the lack of soundscapes research in tropical zones affects conservation biology.

As research in tropical areas of the GS expands, researchers need to capitalize on growing technological efficiencies, and integrate with global monitoring initiatives so they can be more purposeful and strategic, capitalizing on the methodological and theoretical advances of the last decades and developing a smart research agenda. Nevertheless, this should be advanced using a place-based approach, involving local researchers and communities. Several authors have discussed the importance and benefits related with developing GS capacities. Understanding that there is a lack of coupled human-nature approaches within GS PA soundscape research may facilitate more purposeful future research development. For example, perhaps it would be strategic to focus PA soundscape research agendas in the GS toward coupled human-nature approaches from the onset, enabling them to learn from the gradual evolution that has taken place in the GN. Perhaps it is time for the IUCN to consider a best practices initiative to share processes for coupled human-nature approaches to PA soundscape science, with guidance on the types of legislation and mandates that can support effective management of PA soundscapes. A global effort may also help GN regions to learn from the efficient practices being explored within the GS, such as applying citizen science and more perception-based research when resources are insufficient to follow international monitoring and management standards (Gale and Ednie 2020).

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