HABITATS: DEVELOPMENTS IN MANAGING THE ECOLOGICAL IMPACTS OF NOISE ON WILDLIFE HABITATS FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

The Habitats project integrates research in the fields of ecological impacts and environmental noise to facilitate development of management tools and processes needed for sustainable development. This conference paper summarises the content and outcomes of a workshop at the University of Salford on 15th December 2022, focused on the development of a UK network on anthropogenic noise impact assessment in wildlife. Topics covered included biodiversity assessment using acoustic techniques, behavioural changes in different systems, industrial and consultancy best practices, and the formation of a network for support and funding for subsequent workshops and projects. Participants discussed the difficulty of methods standardisation, the importance of characterising anthropogenic noise exposure of wildlife, and the potential use and improvement of sensors and robotics in producing reliable datasets. The workshop identified topics for further discussion, including the repeatability and reproducibility of research on noise impact assessment in wildlife, linking stressors to end points, and the potential to use evolutionary changes in anatomy to predict species differences in hearing. The summary perspectives from industry, academia and government provided an important step in defining the knowledge gap between the state-of-the-art and societal need. Overall, the workshop concluded that the creation of an international, collaborative, multi-disciplinary network of experts is a key step in developing a comprehensive framework for assessing

Keywords: Anthropogenic noise, Environmental noise, Ecological impacts, Wildlife impact assessment, Biodiversity assessment

1 INTRODUCTION

In 2015, the United Nations (UN) adopted a 2030 Agenda for Sustainable Development, which includes a vision for a world in which humanity lives in harmony with nature and wildlife is protected. In the UK, the 25-year Environment Plan aims to improve air and animal welfare, and reduce all forms of pollution, including noise. Similarly, the EU Biodiversity Strategy for 2030 states that global wildlife populations have fallen by 60% in the last four decades due to human activities.

1.1 Explanation of ecological and sustainability terms

This paper uses some terms that may not be familiar to some acousticians. Table 1 presents a short explanation of these ecological and sustainability terms.

Table 1: Ecological and sustainability terms used in this paper

Term	Definition
Acoustic biodiversity	The diversity of sounds in an ecosystem.
Anthropogenic noise	Noise caused by human activities, such as road traffic, aircraft noise, and industrial noise.

Assessment methods	Methods used to assess the impact of anthropogenic noise on wildlife.
Biodiversity	The variety of life on Earth, including all plants, animals, and microorganisms.
Bioacoustics	The study of the production, transmission, and reception of sound by animals. Bioacoustics is typically focused on the individual animal.
Biophysics	The application of physics to the study of biological phenomena.
Classifiers and indicators	Tools and metrics used to identify and measure different types of sounds.
Ecoacoustics	The study of how sound is used and perceived by animals in their environment. Ecoacoustics is focused on the soundscape, or the totality of sounds in an ecosystem, including not only the sounds produced by animals, but also the sounds of wind, water, and human activity.
End-points	The biological response observed/measured.
Environmental noise	The accumulation of noise pollutants in outdoor areas caused by transportation, industrial, and recreational activities.
Impact assessment	The process of identifying, predicting, and evaluating the potential impacts of a project or policy on the environment.
Psychophysics	The interdisciplinary study of the relationship between the physical characteristics of stimuli and the resulting psychological or behavioural response.
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[Brundtland]
Wildlife	All living organisms that are not domesticated or cultivated.

1.2 Summary of research on the ecological impacts of environmental noise

There is a growing body of research on the ecological impacts of environmental noise, but there are still many gaps in our knowledge. Some of the key findings (Jerem and Mathews, 2020, Scarpelli et al. 2020, Kok et al. 2023) are summarised below.

Anthropogenic noise can have a variety of negative effects on wild animals, including:

- Masking communication signals
- Disrupting breeding and foraging behaviour
- Causing hearing loss and other physiological damage
- Increasing stress levels
- Reducing population sizes and diversity

While birds and mammals have been the focus of most research on the ecological impacts of environmental noise, other groups, such as fish and invertebrates, also need to be studied more thoroughly. Most studies on the effects of noise on wildlife are short-term and do not fully consider how noise affects different seasons or life stages. This is a limitation of our current knowledge, as it is important to understand how noise affects wildlife throughout their lives and across different environmental conditions.

New methods and tools are needed to study the soundscapes of wildlife habitats and assess the impacts of anthropogenic noise (Sharma et al., 2023). This research will help us to better understand how noise affects wildlife populations and communities. More research is needed on the hearing capacity of different species and how this affects their response to noise. This research is important because hearing is a critical sense for many wildlife species, and noise can have a variety of negative effects on hearing, including masking communication signals and potentially hearing loss.

The long-term effects of chronic noise exposure on wildlife populations and communities are not well understood. This is a significant gap in our knowledge, as chronic noise exposure can have a variety of negative impacts on wildlife, such as reduced population sizes and diversity. Most studies on the ecological impacts of environmental noise have focused on traffic noise. However, other noise

sources, such as industry, construction, and aircraft, also have the potential to impact wildlife. More research is needed on the effects of these different noise sources on wildlife.

1.3 Objectives of this study

This study aims to identify key knowledge gaps and so enable initiatives to advance assessment of the ecological impacts of anthropogenic noise on wildlife. To achieve this, a focus group was held at the first "Habitats workshop" at the University of Salford in December 2022. After the workshop, a feedback form was sent to participants to collate expert opinion on knowledge gaps and prioritise research questions to be addressed. This paper presents the gap analysis generated from the workshop and feedback.

2 METHODOLOGY

Data collection was conducted during the Habitats project workshop on "Anthropogenic noise impact assessment on wildlife" in mid-December 2022 at the University of Salford. Two data collection methods were used: a focus group and a feedback form.

2.1 Focus group

Focus groups are a type of collective interview in which a moderator facilitates a discussion on a specific topic. This method can capture detailed, unbiased opinions (Marry & Defrance, 2013; Bruce & Davies, 2014). Bjørner (2004) also noted that focus groups are a good way to gather technical solutions. The reflective state of mind of participants enhances the expression of ideas, and the technique helps to quickly reproduce group responses (Engel et al., 2018).

2.2 Feedback forms

Feedback forms typically provide a profile of planned improvements of activities, learning processes, events, or activities. They can also be used to assess reactions and provide a rich source of information on participant behaviours and thoughts (Philips & Stawanski, 2016). In this study, the feedback form was used to collect participants' thoughts on the information provided during the workshop about "anthropogenic noise impact assessment on wildlife".

2.3 Data collection and data analysis procedure

The workshop was held in a hybrid format, with 23 participants (12 on-site and 11 online) representing industry, academia and government. Of the on-site participants, four were female and eight were male. Of the online participants, five were female and six were male.
The workshop was divided into three main topics:

1. Biodiversity assessment using acoustic techniques
2. Behavioural changes in different systems
3. Industrial and consultancy best practices

During the topic sessions, some participants presented short overviews of the topic. At the end of each session, there was a Q&A session (50-60 minutes), allowing questions to be answered and a discussion of the topic to occur. One of the participants took notes of the answers and highlighted the identified knowledge gaps in each topic. At the end of the workshop, these answers, gaps, and research questions were summarized into a document. This document was then shared with the participants, along with an evaluation form and feedback request, allowing them to complement the information and highlight priority knowledge gaps in the development of "anthropogenic noise impact assessment for wildlife".

Data analysis combined the dataset from the workshop (Dataset 1) and the feedback form (Dataset 2). The data were classified, and the classes and frequency of each class were quantified. Descriptive statistics were used to give an overview of the main gaps and possible research questions that can

be investigated related to "anthropogenic noise impact assessment for wildlife" in different sectors and research fields.

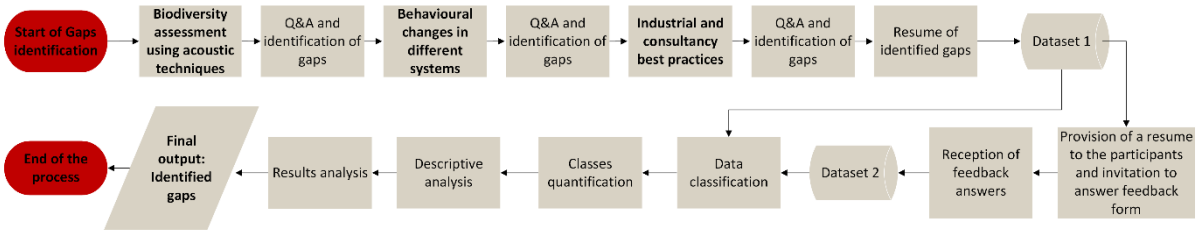

Figure 1. Habitats workshop, feedback data collection and data analysis flowchart

3 RESULTS

Focus groups and feedback forms collected at the first Habitats workshop at the University of Salford identified 46 gaps in anthropogenic noise impact assessment on wildlife. As shown in Figure 3, 72% of the gaps were identified through focus groups and 28% through feedback forms. Most of the gaps were identified in the Q&A after the "industrial and consultancy best practices" session (46%), followed by the "feedback form" (28%), Q&A periods after the "biodiversity assessment using acoustic techniques" (20%) and "behavioural changes in different systems" (7%) sessions.

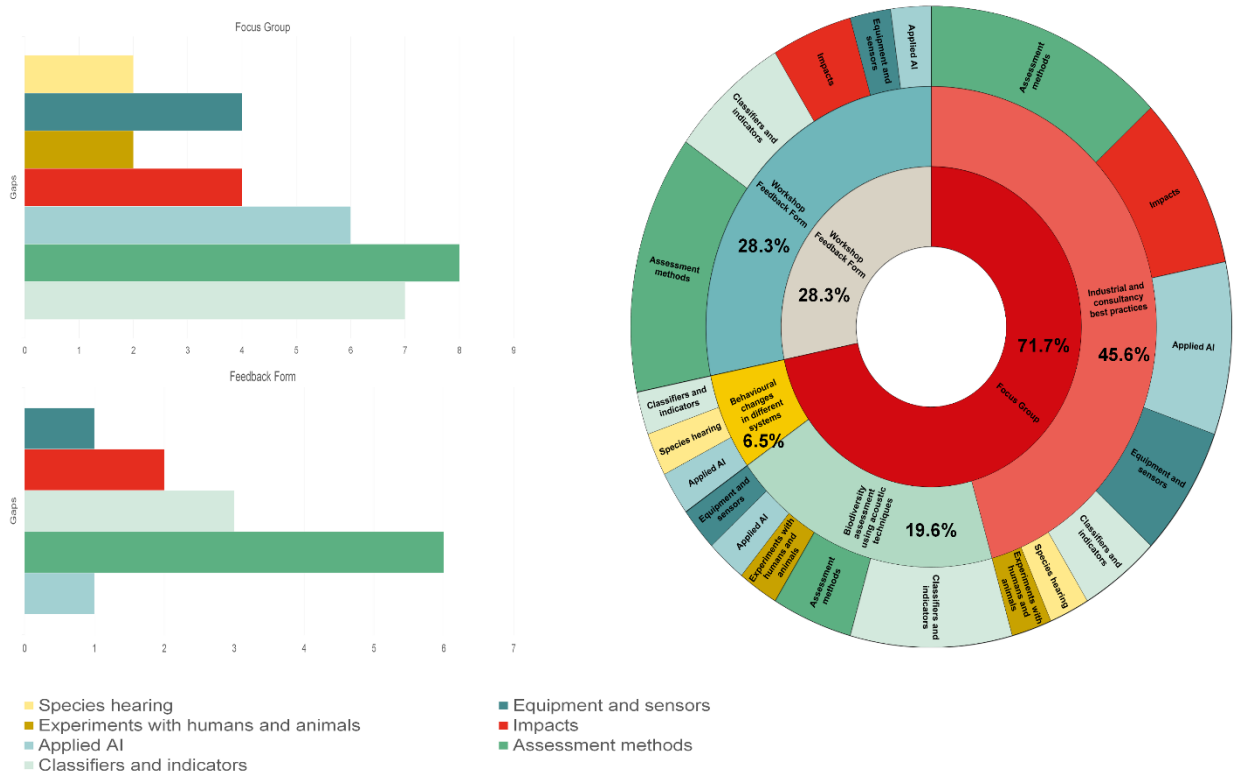

Figure 2. Results of the data collection division identified and classified gaps per the thematic workshop session.

The most reported gaps are related to:

- Assessment methods (15 reports): optimisation, comparability, usability, management, and robustness of assessment and methodologies, with quantification and reduction of uncertainties, aiming the quantification of noise and vibration regarding context, types of noise, duration, sensors position, survey, metrics, design, deliverables, discussion, and habituations.

- Classifiers and indicators (nine reports): lack of classifiers, parameters, and metrics for acoustic biodiversity, sound quality, and according to species. The difficulty of quantifying anthropogenic noise for wildlife was highlighted along with the challenges in defining suitable thresholds for biodiversity. Reports informed the difficulty of determining acoustic niche and audio configuration for spectral analysis.

Other gaps include:

- Applied Artificial Intelligence (AI) (seven reports): algorithms should improve scene, species, organisms, types of noise and animal behaviour classification and grouping.
- Impacts (six reports): researchers should investigate more about the differentiation between chronic, acute, direct and indirect impacts, their effects, main impacts, end-points and what to do about the problem.
- Equipment and sensors (five reports): some sensors have limitations and can be buggy. The group was also interested in diverse applications and the sensitivity of acoustic sensors. They mentioned establishing the current state-of-the-art for existing tools and interest in exploring other tools that could be implemented.
- Species hearing (two reports): importance of knowing the species' hearing capacities and evolutionary influences on hearing.
- Experiments with humans and animals (two reports): playback experiments and the need for improvement regarding audio-visual synergy.

Table 2. Classified gaps collected through Focus Group (N = 33) and *Feedback form* (N = 13)

Gaps	Workshop session / Feedback form	Responses
Assessment methods (n = 15)	Biodiversity assessment using acoustic techniques	• "**Optimisation** of **assessment protocols and methodologies**." • "**Comparable**: using different frequency ranges for different species." • "Difficulty of **standardisation of methods**."
	Industrial and consultancy best practices	• "Be **usable, robust and consistent**." • "**Accounting** of anthropogenic noise." • "**Accountability** (clustering – criteria – reliability – guidance for noise predictions – holes in research)." • "Biodiversity Net Gain and its structure **(survey, metrics, design, delivery and discussion**)." • "**Position** of sensors." • "**Repeatability and reproducibility** of research on noise impact assessment in wildlife."
	Feedback form	• "Assessments more **manageable**". • "Some **quantification of uncertainties**" • "What further key considerations are there relevant to **durations, habituations, context, types of noise**, etc." • "Beyond noise (**vibration**)" • "**Reduction of uncertainty**" • **"How best to quantify** the impact of anthropogenic noise on fitness – long-term, short-term, reproduction, population trends, etc."
Classifiers and indicators (n = 9)	Biodiversity assessment using acoustic techniques	• "Lack of acoustic biodiversity **classifiers**." • "Anthropogenic noise is **hard to quantify**." • "The classification of sound quality should be developed **(lack of qualifiers**)."

	Behavioural changes in different systems	• "Difficult to **determine an acoustic niche**." • "Thresholds."
	Industrial and consultancy best practices	• "Audio configuration in **FFT**". • "Approximate **thresholds**."
	Feedback form	• "What sound **metrics**/measurement methods make the most sense for assessing impacts (depending on impacts and organism/group?" • "What **parameters** are important to the wildlife of different species/taxa?"
Applied AI (n = 7)	Biodiversity assessment using acoustic techniques	• "**Scene classification**."
	Behavioural changes in different systems	• "**Possibility of doing computer analysis** regarding **animal behaviour**".
	Industrial and consultancy best practices	• "**Species-based** and regard species at risk." • "**Grouping organisms** and having more information on impacts and behaviour". • "**Grouping species**." • AI applied to "**Types of noise**."
	Feedback form	• "**Group organisms**."
Impacts (n = 6)	Industrial and consultancy best practices	• "Lack of **differentiation between chronic and acute impacts**." • "**Direct and indirect impacts** caused on organisms." • "**Impact effect** (Bad - not bad, etc.)." • "**End-points**, how stressors link to end-points."
	Feedback form	• "What **main impacts** should we be focusing on? Stress? Sleep disturbance? Breeding success? Communication impairment? Is it wrong to focus on these things, and better to be more open to other impacts (i.e., not to humanise)?" • "**What to do about the problem**?"
Equipment and sensors (n = 5)	Biodiversity assessment using acoustic techniques	• "Limitations of the **equipment. Audiomoth** can be buggy."
	Industrial and consultancy best practices	• "Diverse applications of **sensors**". • "Sensitivity of **sensors**". • "**Tools** that can be implemented".
	Feedback form	• "What **tools** are available that help us? What tools do we lack that we could encourage the development of."
Experiment with humans and animals (n = 2)	Biodiversity assessment using acoustic techniques	• "**Playback experiments**".
	Industrial and consultancy best practices	• "**Audio-visual** synergy".
Species hearing (n = 2)	Behavioural changes in different systems	• "**Hearing capacities**."
	Industrial and consultancy best practices	• "**Evolutionary hearing** with palaeontologists to understand differences between species."

4 DISCUSSION

4.1 Knowledge gaps in anthropogenic noise impact assessment on wildlife

Based on the results of this study, the identified knowledge gaps in anthropogenic noise impact assessment for wildlife can be summarized as follows:

1. Assessment methods: More robust and reliable assessment methods are needed.
2. Classifiers and indicators: Better classifiers and indicators for acoustic biodiversity and sound quality are needed.
3. Applied AI: AI algorithms need to be developed and applied to improve the classification and grouping of species, organisms, and types of noise.
4. Equipment and sensors: New equipment, sensors, and tools need to be developed that will minimise the need for human presence within investigated habitats.
5. Experiments with animals: More research is needed on the hearing capacities of different species and the differentiation between chronic, acute, direct, and indirect impacts of noise.
6. Species hearing: More research is needed on how species hear across taxa and the noise thresholds for the animals' health and well-being.
7. Impacts: More research is needed to investigate the potential impacts on a wider range of species, their reaction, hearing thresholds, and behaviour, and to verify the effects of long-term exposure.

These gaps highlight the need to develop more robust and reliable assessment methods, as well as better classifiers and indicators for acoustic biodiversity and sound quality. There is also a need to develop and apply AI algorithms to improve the classification and grouping of species, organisms, and types of noise. The first generation of AI classifiers are often based on Google Audioset (Gemmeke et al., 2017), which is itself based on human labelling of YouTube soundtracks. New wildlife audio datasets will be required for better bioacoustics classifiers. The gaps related to classifiers and indicators are also directly related to the topics of species hearing and experiments with animals. More research is needed on how species hear across taxa, the noise thresholds for the animals' health and well-being, the differentiation between chronic, acute, direct, and indirect impacts of noise, and the development of new equipment, sensors, and tools that will minimise the influence of human presence on investigated habitats. This information is essential for quantifying anthropogenic noise and establishing safe levels considering humans *and* wildlife.

The gaps related to impacts need to consider different approaches adopted on impact assessment, such as direct and indirect impact, as well as dose-response, through the definition of acute and chronic noise. Few studies have observed direct, indirect, and chronic impacts of anthropogenic noise on wildlife (Kok et al., 2021, Kok et al. 2023). More research is needed to investigate the potential impacts on a wider range of species, their reaction, hearing thresholds, and behaviour, and to verify the effects of long-term exposure.

4.2 Strategic priorities for research

The identified knowledge gaps in anthropogenic noise impact assessment on wildlife can be used to prioritize research efforts and financial support to improve our understanding of the impacts of noise on biodiversity and develop effective mitigation strategies. To achieve these goals, we recommend that research be prioritized in the following areas: Soundscapes and ecoacoustics, environmental noise, bioacoustics, biophysics, and psychophysics. Impact assessment is also important to develop effective mitigation strategies. By prioritizing research in these areas, we can improve our understanding of the impacts of anthropogenic noise on wildlife and develop more effective mitigation strategies.

4.3 Good practice guideline for long-term ecoacoustic monitoring in the UK

Noise is a stressor impacting on biodiversity and requires collaboration between ecologists and acousticians to develop approaches to predict and assess the potential implications of noise exposures. However, ecologists and acousticians can also utilise ecoacoustic techniques to monitor biodiversity. In 2023, the Acoustics Network of the UK, Manchester Metropolitan University, and Baker Consultants published a "Good practice guideline for long-term ecoacoustic monitoring in the UK". This guideline provides guidance on how to collect and analyse acoustic data for biodiversity monitoring. It covers many important topics, such as hardware selection, study protocol, and data storage. However, based on the results of this study, there are some gaps in the guideline, and these are summarised in Table 3.

Table 3: Gaps in Good practice guideline for long-term ecoacoustic monitoring in the UK

Gap in good practice guideline	**Suggested improvement**
Context	Address the importance of contextual information, such as meteorology, weather, physiological state, hearing conditions, emotional, sensory, and behavioural state, the reason to be in the place, activities, time of the day, and lighting.
Types of noise	Differentiate between the types of noise and their spectral differences.
Metrics	Consider all relevant acoustic, bioacoustic, psychoacoustic, and ecological indicators.
Propagation	Consider other ways of sound propagation besides airborne, such as vibration.
Classifiers and indicators	Cover classifiers and indicators for a wide range of species and organisms.
Applied AI	Cover the development and validation of AI algorithms for classifying a wide range of species and organisms, as well as animal behaviour classification and grouping.

The guideline focuses on passive acoustic hardware, such as Autonomous Recording Units (ARUs), but some gaps regarding equipment and sensors were Identified, including the appropriateness of the ARUs for measuring different spectral characteristics. The good practice guideline partially covers applied AI. It mentions some Deep Learning algorithms that are available for building classification models. For general use and to build classification models OpenSoundscape (Rhinehart et al. 2022) can be applied. BirdNET (Kahl et al., 2021) from the Cornell Ornithology Lab is ideal for the recognition of birds, and BTO Acoustic Pipeline facilitates bats recognition (BTO). However, more research is needed to develop and validate AI algorithms for classifying a wider range of species and organisms, as well as animal behaviour classification and grouping. Advancing the development and implementation of ecoacoustic methods will provide valuable tools that ecologists can draw on to support field studies requiring quantification of the response of biodiversity to anthropogenic noise.

4.4 Recommendations for future research

The identified knowledge gaps in anthropogenic noise impact assessment on wildlife highlight the need for further research in this area. By addressing these gaps, we can improve our understanding of the impacts of noise on biodiversity and develop effective mitigation strategies. Based on the results of this study, recommendations for future research on managing the impacts of anthropogenic noise on wildlife are summarised in Table 4.

Table 4: Recommendations for future research

Research gap	Research suggestions
Assessment methods	Develop and validate more robust and reliable assessment methods.
Classifiers and indicators	Develop and validate better classifiers and indicators for acoustic biodiversity, sound quality, and a wide range of species and organisms.
Applied AI	Develop and apply AI algorithms to improve the classification and grouping of species, organisms, and types of noise.
Equipment and sensors	Develop new equipment, sensors, and tools that will not influence the investigated habitat with human presence.
Experiments with animals	Conduct more experiments with animals to investigate their hearing capacities and the differentiation between chronic, acute, direct, and indirect impacts of noise.
Species hearing	Conduct more research on how species hearing varies across taxa and what the appropriate noise thresholds would be from the perspective of the animals' health and well-being.
Impacts	Conduct more research to investigate the potential impacts on a wider range of species, their reaction, hearing thresholds, and behaviour, and to verify the effects of long-term exposure.
Impact assessment	Investigate different approaches adopted on impact assessment, such as direct and indirect impact, as well as dose-response in the context of both acute and chronic noise exposures.

The identified knowledge gaps in the development of anthropogenic noise impact assessment for wildlife highlight the need for further research in this area. By addressing these gaps, we can improve our understanding of the impacts of noise on biodiversity and develop effective mitigation strategies.

5 CONCLUSIONS

The Habitats workshop on "noise impact assessment for wildlife" provided a valuable opportunity to learn from experts and identify gaps in our knowledge. The main gaps identified were in the areas of assessment methods, classifiers and indicators, applied AI, equipment and sensors, experiments with humans and animals, species hearing, and impacts.

Anthropogenic noise impacts on wildlife are a complex issue that involves a wide range of disciplines, including soundscape, ecoacoustics, environmental noise, bioacoustics, biophysics, psychophysics, and impact assessment. To effectively assess these impacts, we need to develop a comprehensive understanding of the entire noise pathway, from emission to transmission to reception.

One of the key challenges is the development of robust and reliable assessment methods. This includes the development of classifiers and indicators for acoustic biodiversity and sound quality, as well as the application of AI algorithms to improve the classification and grouping of species, organisms, and types of noise.

Another challenge is the development of new equipment and sensors that are sensitive enough to detect and measure low-level noise, without influencing the investigated habitat. Additionally, we need to better understand the hearing capacities of different species and how they react to anthropogenic noise.

Finally, we need to develop a better understanding of the impacts of anthropogenic noise on wildlife, both in the short-term and long-term. This includes differentiating between chronic, acute, direct, and indirect impacts. The findings of this workshop will help to inform future research and policy on the assessment and mitigation of the ecological impacts of anthropogenic noise.

6 ACKNOWLEDGEMENTS

The authors thank the Habitats Project from the University of Salford for the financial support of this work. We also thank the presenters of the Habitats workshop Helen Whitehead, Christoph Meyer, Jenna Lawson, Amy Leedale, Robert Young, Jon Tofts, Adam Scott and Andre Farinha, for their contributions to focused presentations. We are indebted to all the hybrid workshop participants, for their significant contributions to discussion and freely sharing their opinions about anthropogenic noise impacts on wildlife. This helped extract knowledge gaps and research questions on this work.

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