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Exploring the potential impact of metrology to advance the use of airborne environmental DNA (eDNA) for biodiversity monitoring

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Approved on behalf of NPLML by

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1 Contents

2 Purpose

In this strategic project funded by the Department of Science and Technology (DSIT) under the National Measurement System (NMS), the National Physical Laboratory (NPL) and the National Measurement Laboratory (NML at LGC) explored the measurement challenges and stakeholder needs for the use of airborne environmental DNA (eDNA) for biodiversity monitoring. This was identified through engagement with external stakeholders and a review of policy, industry and research outputs. The aim of this project was to understand where metrology research and measurement science can be focused to address some of the key barriers and measurement challenges to collecting, analysing and utilising airborne eDNA for biodiversity monitoring.

3 Introduction

3.1 Background: eDNA and airborne sampling

Environmental DNA refers to DNA extracted from environmental specimens (including soil, water and air) derived from organisms (including animals, plants, bacteria, fungi and viruses) within the ecosystem(s) of interest. The extracts are examined using sequencing methods to determine which DNA sequences are present within the specimen. The sequences found in the specimen are then compared to references databases of known organism sequences enabling them to be identified within the specimen. Various methods for collecting eDNA are emerging as transformative tools for a range of purposes including for monitoring biodiversity, disease epidemiology, biosurveillance and the effects of pollution.

Airborne eDNA extends the capabilities of eDNA sampling beyond more established methods in aquatic environments and offers new opportunities for biodiversity monitoring by enabling the detection of species from DNA present in the air (The Royal Society, 2025). Airborne eDNA methods provide opportunities to collect DNA from terrestrial and flying species and pathogens from sources not present in aquatic environments. Air quality samplers used to collect particles from the environment, including soot, carbons, dust and pollen can collect fragments of eDNA suspended in the air, either attached to other particles or on their own. NPL operates a number of UK air quality monitoring networks for the UK Government, several of which have been collecting DNA from the environment at the same time (Williams, et al., 2025a; Williams, et al., 2025b). A pilot study was carried out on a selection of archived samples from the UK Heavy Metals Network to understand the efficacy of air quality monitors to collect eDNA (Littlefair et al. 2023). A further study identified 1,100 taxa by extracting, amplifying and sequencing DNA from air filter samples (Tournayre et al., 2025). NML at LGC, the UK's designated institute responsible for underpinning metrology in chemical and bioanalysis, has led numerous international studies focused on improving the accuracy of DNA quantification and sequence identification (O'Sullivan, 2021). Further scientific research is being explored on airborne eDNA sampling and analysis methods to support the collection of eDNA for airborne biodiversity monitoring (e.g. Sullivan et al., 2025).

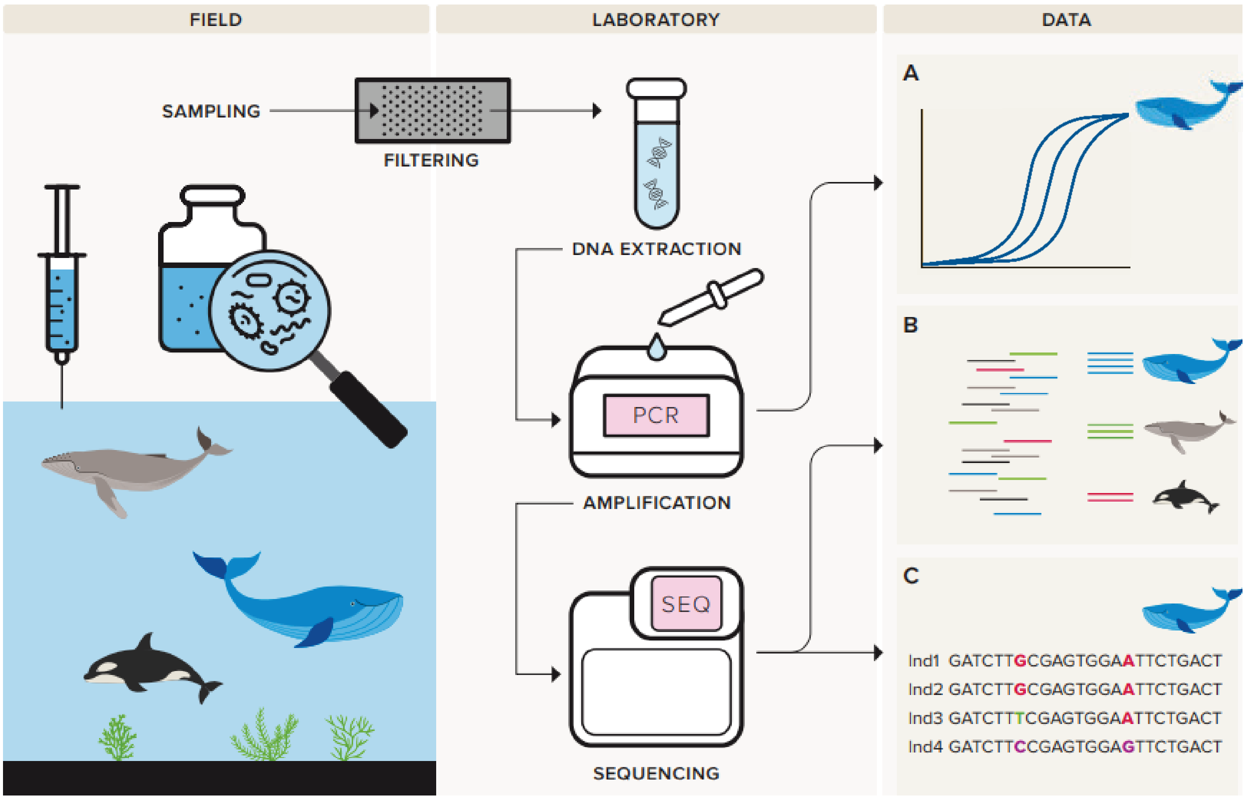

Figure 1: Illustration of eDNA sample collection, extraction and analysis (adapted from Royal Society, 2025)

3.2 Benefits of eDNA methods for biodiversity monitoring

Several eDNA methods are emerging due to their range of applications and advantages compared to traditional environmental sampling methods, outlined in table 1. Despite the many benefits of eDNA methods, there are also several limitations and barriers which are important to acknowledge and, where possible, address to use eDNA data. These barriers are one of the key purposes of this research and are explored in this report.

Non-invasive	Samples can be taken directly from the environment, with minimal disturbance to the species or habitat.
Scalable	Instead of sampling one small area to identify one species, samplers can be placed in various locations to monitor the presence of multiple species across a range of temporal and spatial scales.
Efficient	eDNA monitoring uses samplers which can be left unattended to collect eDNA over time which can collect a large amount of data. This reduces the need for field monitoring and personnel. Automated systems provide the option for samples to be taken continuously and consecutively.
Can detect rare and wide range of species	eDNA monitoring, with robust reference databases, has the potential to provide more specific information than visual identification, particularly for similar looking species. eDNA methods can also be used to detect rare and elusive species, including invasive species without having to hear or see them.

Table 1: Benefits of eDNA methods for biodiversity monitoring

4 Policy context

4.1 Importance: biodiversity monitoring

Biodiversity is a key indicator of habitat health and can be used as a proxy for climate change (DEFRA, 2025a). Many governments are striving to meet international and national targets to halt and decline biodiversity loss, including the UK's legally binding targets under the Environment Act 2021, which require halting the decline in species abundance by 2030 and reversing it by 2042 (UK Government, 2021). This is becoming increasingly important as biodiversity is declining at alarming rates (State of Nature, 2023). Monitoring biodiversity helps understand the presence, abundance, movement and health of species and communities over time and allows governments to define targeting policy interventions.

There is an emerging trend of eDNA methods being gradually recognised as valuable tools for biodiversity monitoring and conservation policy. Its integration into regulatory frameworks is being explored both in the UK and internationally, driven by the need for robust, scalable methods to assess species presence and habitat health. UK policy frameworks provide a landscape for the more widespread use of eDNA for assessment of biodiversity (e.g. DEFRA, 2018; UK Government, 2021; JNCC, 2024; Green Finance Institute, 2024; TNFD, 2025). The Environment Act explicitly allows for biodiversity reports to include quantitative data, creating opportunities for eDNA to provide high-quality metrics (UK Government, 2021).

Internationally, the Kunming-Montreal Global Biodiversity Framework and UN Sustainable Development Goal 15 influence UK policy directions, reinforcing a need for harmonised approaches to measure and monitor biodiversity (CBD, 2022; United Nations, 2025).

Relevant UK stakeholders are illustrated in figure 2, highlighting the range of government, non-government, private, academia and research institutions involved in eDNA monitoring and therefore collaboration required for effective uptake of eDNA.

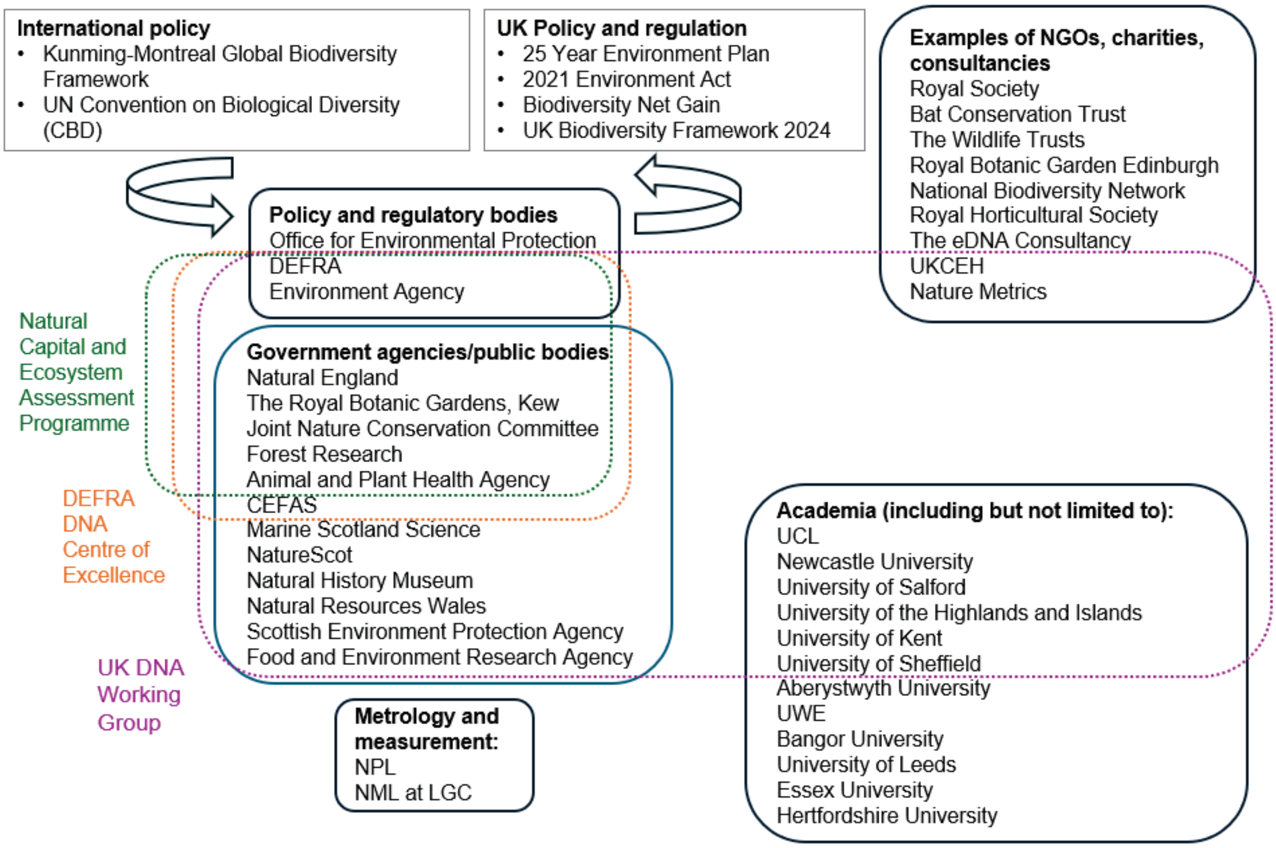

Figure 2: UK stakeholders and policy relevant to eDNA.

4.2 Examples of current use of eDNA in policy

eDNA methods are already being applied to identify species of interest to inform ecosystem assessments, invasive species monitoring and site management. Some examples include:

- Great crested newt monitoring for habitat protection
  - eDNA quantitative real time PCR (qPCR) and metabarcoding is used by Natural England within District Level Licensing to evidence presence of Great crested newts and inform mitigation and habitat protection, with their presence providing an indicator of water ecosystem health (Natural England, 2025; Wildlife Trusts, 2017)
- Crayfish surveys for invasive species monitoring
  - The Environment Agency has validated an eDNA method to detect native white-clawed crayfish, invasive signal crayfish and crayfish plague, enabling year-round surveillance to support invasive species control and management (Environment Agency, 2024)

- Compliance with the Water Framework Directive (WFD)
  - UK regulators have developed an eDNA based lake fish classification tool for WFD assessments, building on Environment Agency research that demonstrated eDNA metabarcoding outperforms gill netting for species detection, which supports status assessment (Environment Agency, 2016).
- Designation of Sites of Special Scientific Interest (SSSIs)
  - eDNA is used across taxa and habitats to inform species and assemblage data that can support site evaluations and management to protect important ecosystems (e.g. Aberystwyth University, 2019).

4.3 Regulatory needs and opportunities for airborne eDNA

However, airborne eDNA methods are currently not used in contributing to policy despite agreed potential. Realisation of this would require efforts towards improved standardisation of airborne eDNA methods and analysis. Emerging taskforces are focused on method harmonisation and standardisation, which will be critical for broader policy adoption. DEFRA's DNA Centre of Excellence is leading workstreams on standardisation and harmonisation to ensure consistency in eDNA applications (DEFRA, 2025b).

Regulatory uptake of airborne eDNA methods to contribute to evidence for policy is hindered by several challenges. These include:

- Issues around consent, privacy, and data ownership.
- No regulatory-approved airborne eDNA tests: Current regulations only cover aquatic eDNA (e.g., great crested newts).
- Policy lag: No national or international standards yet; ISO & CEN standardisation work is ongoing (through the International eDNA Standardisation Taskforce) but only currently focused on aquatic methods.
- Lack of reference materials and methods to support accuracy of eDNA methods
- End user doubt and reluctance: Scepticism across government and industry of eDNA methods due to lack of validation and comparability.

To fully integrate airborne eDNA into policy, eDNA must be able to deliver high-quality, reproducible data to influence policy effectively. To achieve this, several needs must be addressed:

- Development of clear regulatory frameworks for eDNA use
- Creation of efficient, scalable tools that support community-level and citizen science applications
- Development of standard protocols and reference materials for airborne eDNA sampling to underpin traceability (with a specific focus on sampling, preexamination and examination procedures)
- International and national collaboration to ensure consistency of measurement through international standardisation bodies and the international metrology community
- Laboratory performance testing and laboratory accreditation to benchmark methods and individual laboratory performance

The potential for airborne eDNA to provide data to meet regulation and guide policy for biodiversity is significant, with opportunities including:

- Inclusion in statutory biodiversity metrics and planning permissions.
- Supporting compliance biodiversity targets and habitat assessments.
- Enhanced monitoring of endangered and invasive species.

5 Use cases of airborne eDNA

5.1 Current applications

While aquatic eDNA methods are well understood and used in policy contexts to monitor invasive species, ecosystem health and site assessments, airborne eDNA remains at an earlier stage of adoption. Nonetheless, airborne eDNA is already being integrated into biodiversity monitoring programmes, complementing established freshwater and marine eDNA methods. Current applications include:

- Habitat change monitoring and assessments, supporting conservation planning (e.g. NHM, 2024).
- Agri-food system analysis, where airborne eDNA can help track crop-associated species and pests (e.g. Giolai et al., 2024).
- Bat monitoring, providing insights into species presence without direct observation (e.g. Garrett et al., 2023)
- Detection of rare fungi, which are often difficult to survey using conventional methods (e.g. Tournayre et al., 2025)
- Monitoring and tracking biodiversity trends over time using archived filters (e.g. Sullivan et al., 2025)

Interest is growing in integrating airborne eDNA data into national and global biodiversity databases, such as the National Biodiversity Network to enhance data accessibility and inform decision-making (NBN Trust, 2025).

5.2 Potential use cases

The potential uses of airborne eDNA are extensive. Biodiversity use cases include:

- Distribution and abundance assessments: Airborne eDNA can provide measures of relative abundance and spatial-temporal variation of entire communities, complementing traditional survey methods for biodiversity
- Large scale sampling of species: Public engagement and citizen science initiatives could involve communities, improving coverage for species poorly recorded in conventional biodiversity monitoring methods.

- Species-specific applications: For example, dormouse presence/absence data could accelerate mitigation planning, while reptile monitoring could yield population-level insights.
- Nature finance and biodiversity credits: Providing evidence of species composition, habitat condition, and disturbance for compliance with frameworks like TNFD.

While focusing on airborne eDNA for biodiversity monitoring, several of the findings in this report are applicable to other fields where airborne eDNA might be used. Examples of other, more targeted use cases and further potential applications include:

- Climate-driven species movements: Tracking shifts in species distributions under changing environmental conditions.
- Invasive species detection: Early identification of non-native species to prevent ecological disruption.
- Agriculture and rewilding: Monitoring crop health, pest species, and restoration projects success.
- Disease and pathogen monitoring: Offering early warning systems for wildlife and plant health, disease detection.
- Biosecurity: Monitoring and surveillance of bioaerosols including malicious bio-attacks.
- Forensic evidence: Providing data for crime detection and illegal goods movements.
- Pollution and pollen detection: Monitoring microbial communities and allergens for assessing pollution and pollen levels.

Airborne eDNA enables multi-tool monitoring, combining molecular data with traditional methods to deliver richer, more comprehensive insights into ecosystem health and a range of potential use cases if supported by validated, trusted and comparable methodologies.

6 Measurement challenges and metrology needs

6.1. Stakeholder challenges and needs

Stakeholder engagement across government agencies, research institutions, NGOs, and industry was undertaken between July and September 2025 to identify the measurement challenges hindering the uptake, confidence and use of airborne eDNA for monitoring, regulatory or policy purposes. Through engagement with external stakeholders and a review of policy, industry and research outputs, the following measurement and metrology challenges and needs were identified:

Challenges: Sampling methodology, analysis and infrastructure

- **Incomplete reference databases and bioinformatics variability**: Many taxa are underrepresented in databases; no standard assays for multi-species detection; assay choice can bias results. Incomplete reference libraries and metadata standards limit taxonomic resolution, species identification and confidence in results.
- **Lack of harmonised sampling methods and standardised protocols**: Lack of understanding of how to best take samples, the most suitable sampling periods, the potential inherent error and a lack of controls to validate data, likely to lead to inconsistent results and metrics hindering comparability.
- **Low eDNA concentration**: Air samples often contain very little eDNA, making detection difficult. Contamination throughout the process is also an issue.
- **Detection challenges**: Mostly presence/absence data, which can be challenging at low concentrations; abundance estimation is at best relative and can be unreliable.
- **Environmental factors** affecting temporal and spatial resolution: Airborne eDNA signals are difficult to interpret due to unknowns around their persistence, transport, and effects of UV exposure, rain and humidity. Degradation rates are poorly understood.

Challenges continued

- **Measurement uncertainty and reporting**: Lack of understanding of measurement uncertainty and uncertainty is often not considered for eDNA results.
- **Limited validated equipment**: Few commercial airborne eDNA samplers; most are bespoke or experimental or designed for air quality or general bioaerosol applications.
- **Lack of reference materials**: No standard reference materials for airborne eDNA.
- **Interlaboratory variability**: Different suppliers and laboratories use varied methods. No proficiency schemes for airborne eDNA. No standardised methods for the reporting of data.

Needs: Standardisation, measurement assurance and comparability

- Development of standard and harmonised methods for sampling and analysis
- Improved understanding of measurement uncertainty, efficiency, data reliability and comparability.
- Support understanding of eDNA stability, transport and degradation rates.
- Reference measurement procedures and reference materials to validate sampling and analysis protocols
- Robust calibration frameworks for eDNA measurement
- Standard development through e.g. ISO, CEN, to ensure reliability, comparability and consistency of methods and uncertainty quantification
- Benchmarking schemes: Interlaboratory comparisons and proficiency testing to increase the confidence in eDNA data for laboratories and decision makers.
- Need for centralised data hubs and FAIR data principles when storing, using and sharing data.

6.2. Current NPL and NML at LGC metrology and research

Airborne eDNA holds significant potential for enhancing biodiversity monitoring and informing policy, however the uptake of airborne eDNA and usability for policy and regulation is constrained by measurement challenges. Work at NPL and NML at LGC is underway to develop a metrological infrastructure for eDNA, as part of a project in the DSIT funded NMS programme, shown in figure 3. This research includes the development of robust reference measurement procedures and candidate reference materials, adapting dispersion models to simulate airborne eDNA behaviour transport and comparing and evaluating air quality samplers for their effectiveness as airborne eDNA samplers.

Further scientific research is underway by NPL and NML at LGC to understand the size fraction and form of airborne eDNA and evaluating the stability of eDNA sampled onto filters.

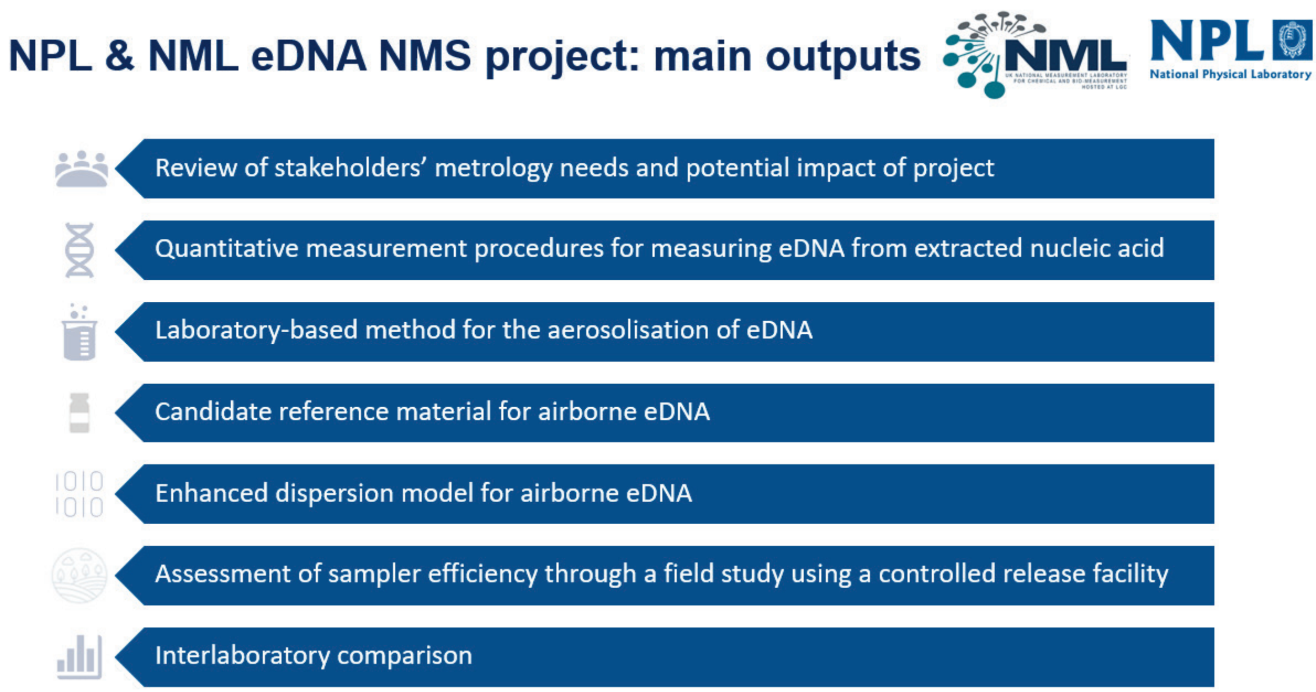

Figure 3: Outputs of the NMS project to improve metrology for airborne eDNA

6.3. Impact of developing a robust metrological framework for airborne eDNA

Robust metrology has the potential to:

- Provide routes to define and compare the performance of eDNA studies
- Improved confidence in eDNA data for:
    - Decision-makers: Standardisation would make airborne eDNA credible for policy and industry.
    - Biodiversity monitoring: Enables confidence in data from landscape-level assessments and long-term biodiversity reporting, with defined measurement uncertainties.
    - Climate adaptation strategies: Metrology provides confidence in data for detecting species movement and ecosystem health trends.
- Facilitates regulatory integration and compliance: Validated airborne eDNA methods for regulatory use in providing robust evidence for planning and conservation decisions, with legal defensibility.
- Supporting quality assurance of eDNA tests

7 Conclusion and next steps

7.1 Conclusion

Airborne eDNA holds significant potential for enhancing biodiversity monitoring and informing policy. Realising this potential requires robust metrology and reliable measurement and analysis of eDNA to provide accurate and trusted data. This strategic research has identified a critical and timely opportunity for metrology to support the positioning of the UK as a global leader in airborne eDNA and its application to environmental policy and biodiversity conservation.

Opportunities for airborne eDNA supported by robust metrology include:

- Data harmonisation: Feeding eDNA observations into national and global biodiversity databases

- Early detection of invasive species and pathogens: Airborne eDNA could enable rapid detection and response
- Integration with existing networks: Use and expansion of air quality monitoring infrastructure for eDNA sampling and developing a new eDNA-specific network
- Automation and remote sensing: Potential for self-powered, distributed sensor networks

Measurement challenges of airborne eDNA methods identified in this research include sampling uncertainty, issues dealing with air as a substrate and associated environmental factors such as wind speed and direction, lack of standardisation, incomplete reference databases and variation in sampling, extraction and analysis methodologies. Stakeholders identified several needs for metrology to provide a better understanding of accuracy, range, efficiency, reliability and comparability of eDNA methods and monitoring, and thus regulatory uptake.

7.2 Recommendations

To support the establishment of airborne eDNA as a reliable method for biodiversity monitoring, this research recommends addressing the gaps identified. This includes method harmonisation and eventual standardisation to enable comparability and validity of methods, improved reference databases to support species identification and metrology to factor in air movement and eDNA degradation. Continued NMS funded scientific research at NPL and NML at LGC will focus on addressing these challenges and support the development and reliability of airborne eDNA as a tool to monitor biodiversity.

Understanding the metrology needs through stakeholder input will serve to ensure more trusted, comparable eDNA data which could be used for a range of applications and provide a vast comprehensive dataset for use by the UK research community. A future opportunity which could support the realisation of use cases for airborne eDNA is the development of a UK-wide airborne eDNA monitoring network underpinned by robust metrology. This research recommends continued stakeholder collaboration, bringing together multiple stakeholders from across disciplines and research areas to ensure a synergistic approach to improving methods and the development of a coordinated roadmap to guide the standardisation and regulatory acceptance of airborne eDNA methods as evidence for regulation and policy.

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Bat Conservation Trust

Department for Environment, Food and Rural Affairs (DEFRA)

Joint Nature Conservation Committee (JNCC)

Natural England

Nature Metrics

Royal Botanic Garden Edinburgh

The eDNA Consultancy

UK Centre for Ecology & Hydrology (UKCEH)

University College London

University of Leeds

The Wildlife Trusts

WSP

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