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An Action Plan for making progress with using DNA to monitor terrestrial invertebrates

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Summary

- Terrestrial invertebrate monitoring is a key priority for developing DNA-based methods across several environmental public bodies in the UK. This is because the scale of invertebrate monitoring is substantial and conventional monitoring methods have important limitations – particularly where large numbers of specimens are collected and/or identification is challenging. This project aimed to make progress in moving DNA-based methods for invertebrate monitoring through to operational use by:
    1. Summarising key barriers to using DNA for monitoring invertebrates
    2. Assessing the causes and consequences of these barriers
    3. Producing an Action Plan that identifies key activities for tackling the barriers to using DNA for terrestrial invertebrate monitoring.

- The Action Plan was informed by an initial survey to assess the importance of 11 potential barriers to applying DNA-based monitoring methods
- Survey respondents included several sectors (public bodies, research, NGOs, and commercial) and were largely consistent in viewing most barriers as either important or very important.
- Workshop discussions identified actions for tackling the most important barriers. Discussions focused on:
    1. End user understanding of methods and confidence in results
    2. Lack of funding to produce methods and resources
    3. Using DNA to understand ecosystem functioning and resilience[1]
    4. Gaps and quality of terrestrial invertebrate DNA barcode libraries[2]
    5. Developing protocols and incorporating DNA methods into regulations
    6. Communications and awareness of end user needs

- Similar projects and activities were often suggested for more than one barrier. As such, suggestions were consolidated to give 24 actions, which were grouped under five broad themes: Collaboration; Communication; Funding; Guidance & Training; Methods Development. The suggestions represent the Action Plan (Appendix 2). Additional more general principles not defined by a specific action are also included in Appendix 2 – these should be incorporated into project design and implementation.
- Feasible short-term next steps are suggested as:
    1. Identify potential leads and collaborators for each action and populate the remaining cells in the plan.
    2. Produce a directory with brief information on interests and priorities of anyone involved in using DNA for monitoring terrestrial invertebrates.
    3. Trial a short bulletin-type update circulated to the Terrestrial DNA Technical Group with brief information on, e.g., recently published papers, ongoing projects and opportunities, and any other items of interest.

- Many of the remaining actions require dedicated resources – progress will be difficult without this. However, the agreed importance of these actions should provide a good justification for funding. An initial approach could be for individuals to register interest in particular actions and then jointly discuss the best way to make progress.

[1] Viewed as important by several participants but not a barrier *per se*. Discussion focused on opportunities, challenges and potential projects.
[2] Actions identified in previous work by Macadam *et al*. (2020) and Price *et al*. (2020) and so discussion focused on how to prioritise improving barcode libraries and on identifying potentially useful sample collections.

Contents

1 Introduction

The environmental monitoring carried out by public bodies is constrained by resources, methodological challenges, and the availability of taxonomic expertise. Simultaneously, policy priorities require monitoring that is more comprehensive and provides deeper insights into ecosystem structure and functioning. DNA-based methods for species detection and identification can contribute to these needs, in both routine surveillance and in addressing evidence gaps on the effectiveness of interventions. However, operational use of DNA-based methods in terrestrial systems has been limited and development has tended to involve pilot studies each with a relatively specific focus. These pilot studies are important for understanding feasibility, but do not necessarily tackle the broader-scale challenges that limit applications of DNA-based methods (beyond what is needed for the specific pilot study).

To contribute to addressing more general constraints on applying DNA-based methods in terrestrial systems, a project funded by the Defra DNA Centre of Excellence (CoE) proposed:

(i) gathering details of a range of terrestrial monitoring priorities for environmental public bodies in the UK, to identify where DNA might be most beneficially applied, and

(ii) producing an Action Plan to outline activities and projects needed to move DNA-based methods to operational use in these priority areas.

The first part of this project was carried out in 2019/20 (Woodcock 2020), through discussions with taxon specialists in several environmental public bodies. This identified terrestrial invertebrate monitoring as a key priority for developing DNA-based methods. Particular areas of interest included describing assemblages (e.g., for protected site monitoring and for evaluating the effects of interventions) as well as more targeted surveys for some individual species. The emphasis on invertebrates is because the scale of monitoring is potentially substantial and because there are important constraints on the use of conventional methods for monitoring invertebrates where large numbers of specimens are collected and/or identification is challenging.

To make progress with moving DNA-based methods for terrestrial invertebrate monitoring through to operational use, this phase of the project aimed to:

1) Summarise the key barriers to using DNA for monitoring terrestrial invertebrates
2) Assess the causes and consequences of these barriers
3) Produce an Action Plan that identifies key activities that are needed for tackling the barriers to using DNA for terrestrial invertebrate monitoring.

The Action Plan is intended to allow projects to be carried out in a coherent and co-ordinated way, with progress tracked to minimise duplication. It may also form the basis for collaborative future work between and within sectors.

2 Methods

2.1 Survey

Barriers to using DNA in operational and routine monitoring have been explored in general by the UK DNA Working Group (UK DNAWG – http://www.ukeof.org.uk/our-work/ukdna) and were also discussed to an extent during the first phase of this project in 2019/20 (Woodcock 2020). We used a more targeted survey to build on this and assess the importance of several potential barriers to using DNA specifically in relation to monitoring terrestrial invertebrates. Survey respondents were asked to rate ten barriers from 1 (not important) to 5 (very important) with a free text field for any additional barriers. Further questions provided background information on interests and level of knowledge (see Appendix 1 for full survey form):

1. Name (optional)

2. Organisation (optional)

3. Type of organisation

4. How would you rate your knowledge and experience of DNA-based methods? (1-7: 1=basic understanding, 7=very familiar)

5. What is the focus of the invertebrate monitoring/research you carry out?

6. Are any invertebrate taxa of particular interest to you?

7. Are any terrestrial habitats of particular interest to you?

8. What is the purpose of the monitoring or research that you carry out?

9. How important do you think the following barriers are to the uptake of DNA-based methods for monitoring terrestrial invertebrates (1-5: 1 = not important at all, 5 = very important)

    - Lack of standard protocols and guidance
    - End user[3] understanding of methods or confidence in results
    - Lack of awareness of end user monitoring needs
    - Completeness or quality of reference libraries
    - Data management and sharing
    - Cost savings are not clear
    - Fast pace of technology change
    - Lack of funding to develop methods and resources
    - Regulations are not flexible to include new technologies
    - Inadequate communication between end users and researchers/contractors
    - Difficulty in quantifying abundance

10. Please add any further comments on barriers to using DNA

11. Please add any further comments that you feel are important but aren't fully addressed by the above questions

[3] In the survey, 'end user' refers to public bodies and other organisations potentially using the results from DNA-based methods operationally – e.g., for routine survey/monitoring rather than research.

A link to the questionnaire was circulated to the Terrestrial DNA Technical Group, which is co-ordinated through the UK DNAWG and is open to anyone interested in using DNA for monitoring terrestrial systems. The group includes users of DNA-based methods in the public sector as well the academic, commercial, and NGO sectors. The survey was primarily to determine which barriers to focus the workshop on, but a basic descriptive analysis is provided in the Results.

2.2 Workshop

Two 2.5-hour online workshops were used to discuss the main barriers identified during the survey. Both workshops were attended by academics, public bodies, NGOs and industry (Table 1), with 27 people participating in total. Each workshop included three facilitated discussions in breakout groups of 7-8, in addition to presentations from government agencies, NGOs, and researchers.

Table 1: Workshop Participants (organisation and facilitation by JNCC).

Workshop 1 (22 participants)[1]	**Workshop 2 (20 participants)[1]**
ADAS	Applied Genomics
Applied Genomics	Buglife
ETH Zurich	ETH Zurich
Forest Research	Fera
Forestry England	Forest Research
Natural England	James Hutton Institute
Natural History Museum	Natural England
NatureMetrics	Natural History Museum
NatureScot	NatureMetrics
National Trust	NatureScot
Newcastle University	National Trust
Prismea	Newcastle University
UK CEH	Prismea
University of Derby	Sanger Institute
University of East Anglia	UK CEH
University of Sheffield	University of Derby
	University of East Anglia

[1] Some participants were only able to contribute for a portion of the workshop.

Discussions were generally 20-25 minutes and loosely followed a problem tree analysis approach, by first focusing on understanding the causes of each barrier and then on what actions would help tackle these causes. To reduce duplication, some similar barriers were consolidated into a single discussion topic as described below:

<u>Workshop 1</u>

- *End user understanding of methods and confidence in results*
- *Funding to develop methods and resources*
- *Using DNA with invertebrate monitoring to understand ecosystem functioning**

* This was not considered a barrier *per se* but was included as an area of high interest. The discussion focused on the potential to use DNA to provide greater insights into ecosystem-level properties such as structure, functioning, and resilience, and to identify possible projects in this area.

Workshop 2

- *Gaps and quality of terrestrial invertebrate DNA barcode libraries* **
- *Developing protocols and incorporating DNA methods into regulations*
- *Communication between end users and researchers/contractors, and awareness of end user monitoring needs*

** Previous work funded under the CoE and by Natural England identified actions to make progress with improving barcode libraries, both for invertebrates (Macadam *et al*. 2020) and more generally (Price *et al*. 2020). Rather than duplicate this work, the discussion on reference libraries focused on beginning to tackle some of the actions identified, in particular **(i)** if/how filling barcode gaps should be prioritised and **(ii)** gathering information on existing sample collections.

3 Results

3.1 Questionnaire Responses

21 responses were received, primarily from government or universities/research organisations, but also including NGOs and the commercial sector (Figure 1a). Note that NGOs are particularly under-represented in the survey because of the composition of the Terrestrial DNA Technical group, and so further consideration of views from invertebrate recording schemes and societies (and potentially also individual recorders) is important. Five respondents were affiliated to more than one sector – where breakdowns of results by sector are given, these responses are included for each relevant sector (e.g., respondents with academic and commercial affiliations are included in both sectors). Knowledge and experience of DNA-based methods varies within public bodies (Figure 1b), although note that the public sector respondents typically have existing interest and involvement in DNA-based methods, so are not representative of environmental public bodies more generally.

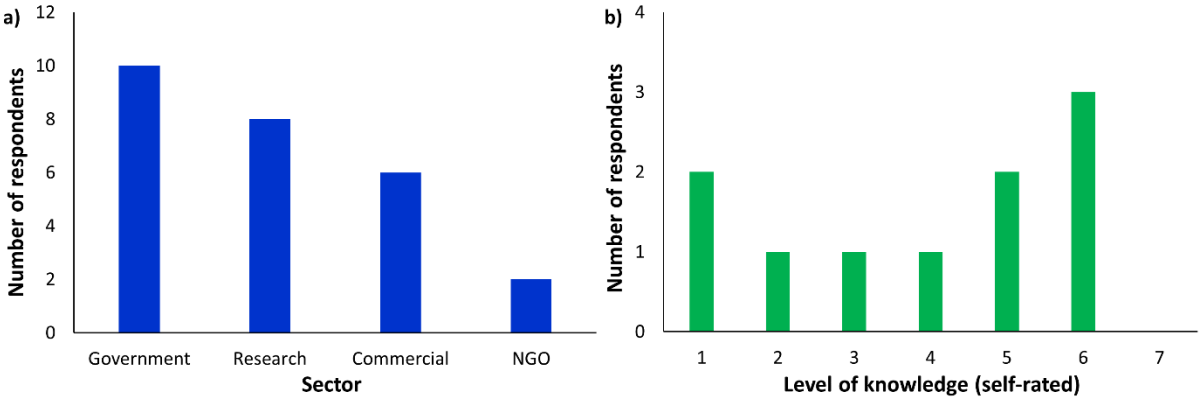

Figure 1: (a) Number of respondents in each sector, and (b) self-rated level of knowledge (on DNA-based monitoring methods) for environmental public bodies. Where respondents belonged to two sectors (e.g., 'government research organisation', 'academic and commercial affiliations') these are counted in both sectors. Level of knowledge is from 1 (Basic Understanding) to 7 (Very Familiar). This survey is not intended to be representative of levels of knowledge within environmental public bodies more generally.

Most of the potential target groups and applications for DNA methods were relevant for the majority of respondents, particularly describing invertebrate assemblages and understanding the effectiveness of interventions (Figure 2). Interests were generally consistent across sectors, although detecting single species of conservation concern was more important for environmental public bodies than for researchers. Additional interests highlighted in free text fields included: monitoring remediation of contaminated sites and understanding impacts of pollution; informing species distribution and red listing; natural capital accounting.

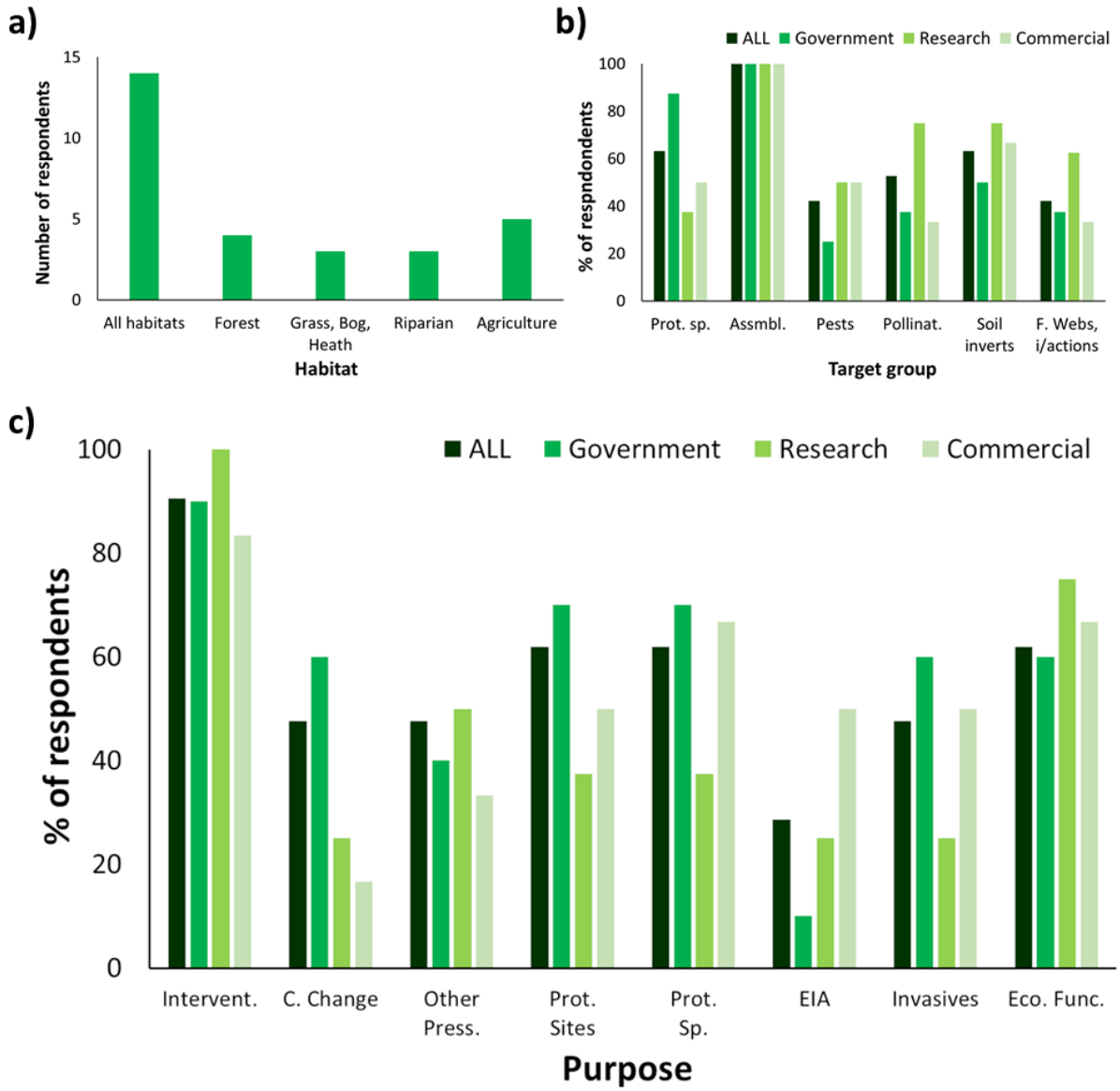

Figure 2: Interests of respondents in relation to (a) particular habitats, (b) the target of monitoring, and (c) and the purpose of monitoring. Figure (b) and (c) show the percentage of All respondents with each interest and the percentage of respondents from different sectors with each interest. The two responses from NGOs are included within the 'All' category but are not shown separately. Note that survey responses are not sufficiently comprehensive to assess the overall level of interest in each priority. Abbreviations: Prot. Sp. (protected species); Assmbl. (assemblages); Pollinat. (pollinators); F. Webs, i/actions (food webs and interactions); Intervent. (interventions); C. Change (climate change); Other press. (other pressures); EIA (Environmental Impact Assessments); Eco. Func. (ecosystem functioning).

Overall, most barriers were viewed as important, with median responses either 3 or 4 (on a scale of 1-5: 1='Not important at all' and 5='Very important'; Table 2). Perceptions of barriers were generally consistent across different groups of respondents, although there were some exceptions. For example, *'Regulations not flexible to include new technology*' was viewed as a particularly important barrier by the academic and commercial sectors, whereas public bodies felt that the availability of standard protocols was a bigger problem. This discrepancy might arise if end users view the regulations as sufficiently flexible *provided* there are agreed protocols to ensure that DNA-based methods are carried out appropriately.

Table 2: Views on importance of barriers to implementing DNA-based monitoring methods, from 1 (not important at all) to 5 (very important). Medians are given for All respondents and for different sectors. Note that respondents affiliated with two sectors are represented in each relevant column.

Barrier	All	Government	Research	Commercial	NGO
End user understanding	4	4	5	5	2.5
Lack of funding	4	4	4	4.5	4.5
Awareness of end user needs	4	3	4	4	2.5
Reference libraries	4	3.5	3	4	5
Lack of standard protocols and guidance	4	4	3	3.5	4
Rapid technology change	4	3.5	4	2.5	3
Data management	3	3	3	3	3.5
Unclear cost benefits	3	3	3	3	2.5
Regulations inflexible	3	3	4	4.5	2.5
Inadequate communication	3	3	3.5	4	4
Difficulty quantifying abundance	3	3	3.5	3	4

Although there was some consensus on the relative importance of each barrier, this masked variation in individual responses. As shown in Figure 3, every barrier had a range of responses, including some rating it is important or very important and some rating it as low importance. This was not a consequence of some respondents assessing all barriers in the same way (e.g., by scoring every barrier as unimportant).

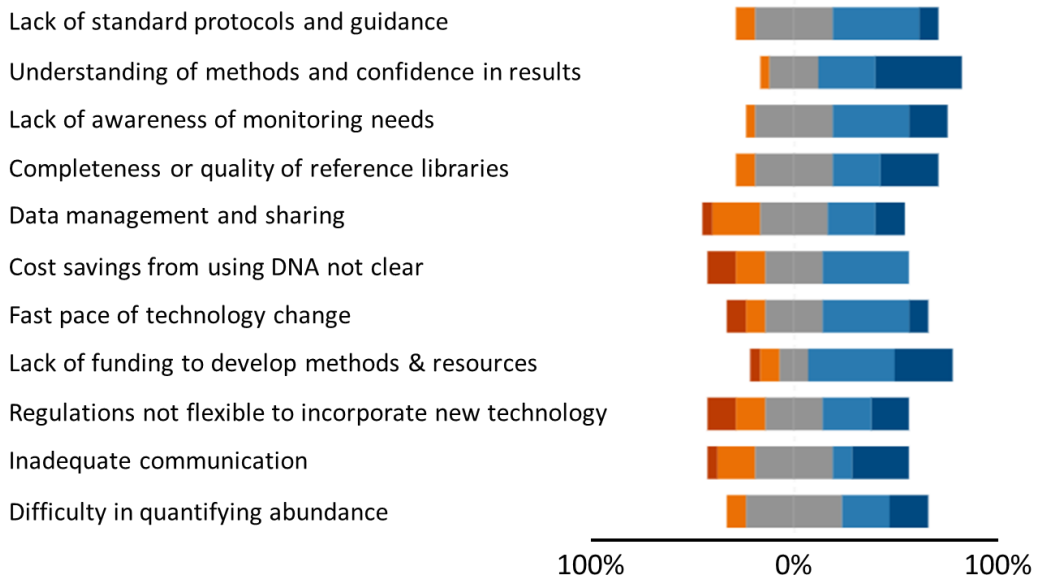

Figure 3: Views on importance of barriers to implementing DNA-based monitoring methods, from 1 ('Not important at all') to 5 ('Very important'). % of respondents for each level of importance are shown from dark orange (not important) through to dark blue (very important).

Several free text responses were also provided. Some of these are partially related to the barriers listed in the survey and others may be useful research topics:

- The importance of expert identification to confirm specimens for barcode libraries, and the associated need to recognise and communicate effectively with taxonomic experts.

- The mismatch between what is required by regulations and the information provided by insect metabarcoding (contrasted with e.g., links between eDNA results and requirements for Water Framework Directive reporting).
- End user requirement for consistency between molecular data and conventional methods, and the need to balance this against the potential for increased taxonomic breadth and cost and time savings from DNA-based approaches.
- Instances where DNA-based methods provide an opportunity to carry out monitoring that was not previously possible. Whilst this is potentially valuable in providing new information, it also requires additional funding.
- Understanding the effectiveness of DNA-based methods at detecting change over time.
- Understanding the number of technical replicates needed for reliably assessing landscape-scale biodiversity.
- Specific challenges associated with developing and validating metabarcoding methods (compared with single-species monitoring).

3.2 Workshop and Action Plan

Although each of the six discussions focused on a specific barrier, similar projects and activities were sometimes suggested as actions in several separate discussions. To prevent duplication, similar actions were therefore combined and grouped under broad themes. This resulted in 23 actions in the final plan spread across five themes. There is also a more general initial action to identify leads and collaborators for each action, populate remaining cells in the plan, and keep this updated.

The themes are briefly described below, along with examples of some of the main actions proposed. Appendix 2 gives the full list of actions, and also highlights actions that are interdependent and potentially contribute to more than one theme.

3.2.1 Collaboration

This theme aims to improve links and make more efficient use of samples, data etc. across sectors. It contains actions suggested particularly during sessions on Funding and on Improving Communication. DNA specialists are sometimes not aware of relevant contacts in government agencies and vice versa, making collaborations more difficult to initiate and limiting opportunities to pool resources or share samples. As such, **a directory of potential collaborators interested in using DNA methods for monitoring terrestrial invertebrates** was proposed several times. This document could cover public bodies, researchers, NGOs, and the commercial sector and include brief information on expertise and interests. If there is demand, it might also provide a way to highlight existing/planned sample collections available for re-use.

3.2.2 Communication

The Communication theme is similar to Collaboration but focuses more on raising awareness of relevant resources (amongst non-specialists), and of monitoring priorities. Improved communication can reduce the risk of duplicating effort, help build knowledge amongst non-specialists, and help the academic and commercial sectors incorporate key monitoring gaps and priorities into project design. Actions in the Communication theme were suggested in almost all of the barrier discussions, with some proposed several times. A **list of key invertebrate monitoring applications for which improved methods are needed** (e.g., ‘top ten questions or problems’) was mentioned frequently. It is important that this explains the problem, the rationale, and the requirements – such information will help the

academic/commercial sector to assess if and how DNA can provide solutions (potentially in combination with other techniques) and can also help target and justify funding proposals.

From the perspective of non-specialists working for public bodies and other organisations, a key challenge is keeping up to date with relevant literature. As such, resources that make this more easily available would be particularly valuable. Several actions were suggested in this respect – e.g., **maintaining a searchable resource of relevant articles and ongoing projects**, **producing briefing notes to summarise relevant papers** (or synthesise several papers), and **circulating periodic updates including recently published articles and other resources**. These may overlap to a degree, and so additional discussion could determine which to prioritise – particularly if there are no dedicated resources to support the activities.

3.2.3 Funding

Funding was retained as a theme because some actions are very clearly more linked to funding than to the other themes. For example, **identifying small to medium-sized project ideas that could be carried out at relatively short notice** can help to secure funding that becomes available. There was also strong interest in the potential of Ph.D. studentships to help contribute to methods development as well as build up skills and links that will be important in future. **Collaborative studentship ideas** could be discussed as appropriate (which would be facilitated if a directory of interests was made available encompassing public bodies, NGOs, academics, and the commercial sector), or perhaps through **proposing a Centre for Doctoral Training (CDT) programme to NERC or BBSRC**. It will also be important to identify funding sources to support some of the other actions in the plan.

3.2.4 Guidance and Training

Guidance & Training contributes primarily to the barrier on improving understanding. One important action proposed in this respect is **producing a guide (or 'cookbook') that non-specialists can use as reference** to understand how to apply DNA-based methods for a range of different terrestrial invertebrate monitoring applications.

The approach to training depends on the level of expertise required, and there was some debate over what is needed and realistic given time constraints and the fast pace of methodological change in the field. As such, one option is to **design introductory, intermediate, and more advanced training packages** – this would allow a basic understanding across public bodies and other organisations, as well as expertise in a smaller number of people then able to provide advice within the organisation. The need for such training probably also exists for other taxa and systems where DNA-based monitoring methods could be applied (e.g., mammals, soils, freshwater, marine) and so it would be more efficient to develop wider packages rather than being very specific to terrestrial invertebrates.

3.2.5 Methods Development

Seven actions were grouped within this theme, arising from discussions on a range of different barriers – again some actions were proposed in several discussions. **Producing and communicating pilot studies** (to test potential) **and validation studies** (to compare with conventional methods) were suggested as important methods development actions that can help improve understanding and confidence in results as well as demonstrate the value of DNA-based methods to potential funders.

Although the lack of standardised methods is an important barrier for government agencies in particular, it is potentially challenging to tackle because of the diversity of methods and the risk that standardisation restricts the flexibility to innovate. However, actions to standardise methods in some areas were suggested as realistic and useful – in particular **producing Standard Operating Procedures for collecting and storing terrestrial invertebrate samples for DNA analysis** using a range of trapping methods. **Agreeing standard information to report with results** to help non-specialists better understand confidence in findings is also important, and would need to be developed more generally (i.e. not specific to invertebrates).

Other aspects of DNA methods focused more on ring testing or proficiency testing than specifying methods (e.g. Vasselon *et al*. 2021). In this approach, the method is flexible providing the correct answer is returned. In practice, proficiency testing might involve e.g. producing a standard set of invertebrate samples, with laboratories required to correctly identify the samples and no restriction on the method used. **Designing a method for carrying out proficiency testing for important invertebrate monitoring applications would therefore be valuable.** Although the set of samples would necessarily be confidential, the design of these proficiency tests should be collectively agreed between users of the results (e.g. government agencies) and the academic and commercial sectors. One overall model might involve standardising sampling methods but allowing multiple approaches in some other stages of the process, as long as these give the same effective answer – e.g. they have the same practical implications for conservation and management.

3.2.6 General Principles

In addition to the specific actions proposed, several more general principles were suggested. These often related to multiple barriers and so were grouped into four broad themes, covering 11 principles in total (Appendix 2):

- **Communication and collaboration** (e.g. engage with and support taxonomists, build communication strategy into projects from the start)
- **Co-ordination and efficiency** (e.g. try to build more routine outputs such as standardised protocols into novel projects)
- **Embedding DNA-based methods** (e.g. work to ensure DNA-based methods are a recognised approach for monitoring progress on environmental policy objectives)
- **Project design** (e.g. specify and support stakeholder engagement, look to ensure open access to methods, samples, results, etc.)

Embedding these principles into project planning and implementation wherever possible could make an important contribution to tackling many of the barriers.

3.2.7 Completeness or Quality of Reference Libraries

The reports produced by Macadam *et al*. (2020) and Price *et al*. (2020) have already identified actions for tackling barriers associated with gaps in invertebrate barcode libraries. As such, the Action Plan (Appendix 2) refers to these reports, and the discussions during the workshop instead focused on gathering initial information on priorities and on samples that could contribute to barcode libraries. More general comments also highlighted the importance of involving and recognising taxonomists.

Priorities
Reaching consensus will inevitably be difficult because everyone has different priorities. However, two broad (and potentially complementary) approaches to prioritisation were proposed:

1) Prioritise by feasibility, e.g., focus first on species that have:
   a. Specimens already available or easy to obtain
   b. Good existing expertise

2) Prioritise by relevance, e.g., focus first on species with:
   a. A regulatory need for DNA-based monitoring methods
   b. An important impact on ecosystem services that are policy priorities. Examples highlighted were pollinators, soil organisms, and parasitoids

Current priorities for barcoding based on Price *et al*. (2020) are at https://tinyurl.com/PrioritySpecies, and a short form to add species to this list of priorities is at https://tinyurl.com/SuggestSpecies.

There was some disagreement/uncertainty on the extent to which barcodes from specimens collected outside the UK can be used versus the need to collect UK specimens – this may be species-specific to an extent (e.g., depending on whether the species is highly mobile/migratory or more sedentary). There was also discussion on the trade-off between obtaining multiple barcodes for fewer species vs. single barcodes for more species.

Existing and Planned Collections
Understanding the potential of existing and planned sample collection is important for ensuring that resources are used efficiently, and that collection and identification is not unnecessarily duplicated. Fully collating this information is a fairly substantial exercise beyond the scope of this project. However, the short discussion provided an introduction to some potentially important sources of material. Filling barcode library gaps is an ongoing and increasing area of work (partly supported by another CoE project being led by the Natural History Museum) and key future actions will include communicating with organisations involved in collecting and identifying samples that could contribute.

Table 3: Initial examples of existing and planned surveys that may contribute samples to UK barcode libraries (in addition to museum specimens). Not intended to be exhaustive

Organisation	Potentially relevant surveys	Comments
Fera	Sampling and collection of invertebrates for plant health monitoring	Invertebrate collections owned by Defra
Forest Research	Woodland Restoration Network (WReN) project has/is sampling at 133 woodland sites across the UK	Potentially other relevant surveys
Industry	Potentially wide range of samples as contracted	When setting up contracts, need to establish collection protocols and agree requirement to share samples
Public bodies (NE, NatureScot, etc.)	Several, e.g., protected site assessment, agri-environment monitoring, etc.	Need to better understand how to ensure samples can be re-used
Rothamsted, SASA	Rothamsted Insect Survey	
Sanger Institute	BIOSCAN project	
UK CEH	Several, e.g., Pollinator Monitoring Scheme, ERAMMP, Environmental Change Network	Potentially other relevant surveys

3.2.8 Using DNA with invertebrate monitoring to understand ecosystem functioning and resilience

This is not a barrier *per se* but is relevant to the majority of workshop participants. The discussion focused on key policy needs, challenges, and potential project topics. Note that this aimed specifically to consider the use of DNA for providing ecosystem-level information and so the needs and suggestions below do not include other important applications (e.g., use for monitoring specific non-native or rare species).

Policy needs and opportunities in relation to ecosystem-level information:

- Metrics for 25 Year Environment Plan reporting. Similar drivers in Scotland (e.g. CBD targets, understanding ecosystem health) and Wales (e.g. SoNaRR, Area Statements, emphasis on resilience through Wellbeing of Future Generations Act)
- Providing data to **support payments by results** made under the Environmental Land Management Scheme, or similar evidence requirements, e.g.:
    - Strategic needs that are priorities for particular organisations, e.g., **natural capital accounting**
    - Metrics to give better insights on **site quality and condition** and inform protected side designation and monitoring
    - Providing more taxonomically comprehensive information to contribute to proposed **biodiversity offsets**
- **DNA-based metrics that help inform and evaluate restoration** and other conservation management
- **Being able to attribute change to an intervention**
- **Understanding resilience** using time series data, which DNA has strong advantages for
- **Combining DNA with other data** (e.g., physical and chemical data) and techniques (e.g., EO, ecological networks, diet analysis) can provide new insights in a number of ways, e.g.:
    - Helping understand *why* biodiversity is changing
    - Supporting creation of biotic and abiotic indices that provide a richer description of ecosystems

Challenges

- **We need to define terms more clearly**: what ecosystem functions are interesting, what is meant by terms such as ecosystem health etc.
- **Functional approaches (probably?) need abundance data**
- Ensuring there is **appropriate metadata** with samples
- Ensuring suitable pre-intervention **baseline data**
- **Substantial developmental work** is needed to get approaches that combine metabarcoding and network ecology into standard monitoring
- International obligations require certain types of monitoring, and there is a **lack of legislative drivers to push towards new approaches**
- Academia may not be well-placed to be involved with long-term monitoring

Project ideas and ongoing work in relation to providing ecosystem-level information:

- **Better understanding soils by** combining data from different taxonomic groups (e.g., fungi, mesofauna) with environmental information (e.g., nitrates)

- **Informing nature-based solutions to pest control (e.g., habitat creation?) or understanding resilience to pests** by using DNA to monitor the abundance/effectiveness of natural predators
- **Developing metrics using data from the Pollinator Monitoring Scheme (PoMS)**, which includes conventional sampling and the potential for DNA analysis
- **Understand the causes of biodiversity change across systems** by combining DNA with Earth Observation and physical and chemical data (ongoing project in Switzerland)
- **Create tools/evidence that can help predict consequences if an organism/habitat is altered, removed or added**
- **Online directory to make information sharing and finding contacts easier**
- Potential opportunities through DTPs with academia, industry and end users working together.

4 Conclusions

4.1 Survey interests and links to Action Plan

The survey was primarily intended to understand potential interest in workshops and inform what to prioritise during workshop discussions. However, some insights are possible on areas of shared interest and concern. Most notably, there was a very consistent interest across sectors in using DNA to understand the effectiveness of interventions. This covers a wide range of activities (e.g., agri-environment interventions, forest management, habitat restoration, etc.) that are ecologically interesting and conservation-relevant. Consistent **sample collection and storage guidelines** are important in this respect, because if samples are all collected in the same way re-analysis can take place using different methods in future. The **case studies** proposed in the Action Plan could also include collaboration to test and demonstrate the use of DNA for assessing the effectiveness of interventions. To facilitate this, the **list of end user priority questions and needs** in the Action Plan should include key interventions for which evidence is required.

Because the survey was not intended to be comprehensive or representative, results should not be over-interpreted as reflecting the views of all stakeholders with an interest in monitoring terrestrial invertebrates. For example, the Terrestrial DNA Technical Group that formed the core of the survey responses has relatively few participants involved in using DNA for detecting plant insect pests, but this is an important monitoring priority for other areas of government. It would also have been beneficial to try to obtain more survey responses from NGOs with an interest in terrestrial invertebrates (e.g., recording schemes and societies, and potentially also individual recorders). Lastly, whilst the group does contain varying levels of expertise, those involved typically have at least some familiarity with DNA-based methods and (in the case of environmental public bodies) are probably not representative of the wider organisations in this respect.

4.2 Barriers and Actions

The workshop discussions highlighted interdependencies between barriers. For example, lack of funding can restrict the potential for demonstration case studies, which in turn reduces opportunities for non-specialists to improve understanding of DNA-based methods. A lack of awareness within government agencies and other organisations can then affect the emphasis on developing DNA methods. Similarly, if operational monitoring needs are not effectively communicated to the academic/commercial sector it is more difficult to design funding proposals with applied relevance. An important point in this respect is for public bodies to focus on articulating the *monitoring need or problem* (rather than e.g., asking more

specific questions about DNA), because this makes it easier for experts to assess if and how DNA can contribute to the need – potentially in combination with other techniques.

Given the interdependency between barriers, co-ordination can help to maximise the benefits from specific actions. Case studies to raise understanding and develop methods require a good knowledge of potential collaborators and interests and need suitable communication channels. However, interdependencies between actions should not restrict projects from being implemented on a case-by-case basis if opportunities arise. If regularly updated, the Action Plan provides a means to track progress and identify areas where more concerted effort is needed. Lastly, it is important to stress that many actions are not specific to terrestrial invertebrates.

4.3 Next Steps, Suggested Actions and Wider Relevance

Ideally, the Action Plan should be updated with ongoing and recently completed work periodically through requests for information. This can help facilitate collaboration and pooling resources and can reduce the risk of duplicating effort. One of the main constraints on carrying out the actions is the need for dedicated resources – ***without this, it will be difficult to make substantial progress in most cases***. However, the plan represents a consensus across sectors, and so would hopefully provide a strong justification for funding proposals targeting particular actions. In addition, there are some actions that are feasible in the short-term to maintain momentum:

1. Identify potential leads and collaborators for each action, and populate the remaining cells in the plan
2. Produce a directory with brief information on anyone interested in collaborating on work using DNA for monitoring terrestrial invertebrates
3. Trial a short bulletin-type update to be circulated periodically to the Terrestrial DNA Technical Group with brief information on e.g., recently published papers, ongoing projects and opportunities, and any other items of interest.

Actions 2 and 3 largely depend on information submitted by the community and so should be possible to co-ordinate ***if*** there is continued engagement from a reasonable number of people. The first step for the remaining actions is to identify potential leads and collaborators. As most actions will require funding, this is initially just to register interest and could be followed up by a joint discussion on the best way to make progress – e.g., potentially by considering funding options

More generally, the workshop approach was beneficial in facilitating discussions between sectors. Holding the workshops online had limitations (e.g., the problem tree approach of linking the causes of barriers to specific actions probably would have been more effective if built up visually through in-person discussions; no real opportunity for informal discussions between participants). However, these were outweighed by the greater accessibility, which meant that a wider range of people were able to attend and consequently that discussions were more productive and representative. Lastly, despite the interest in terrestrial invertebrates amongst all participants, the discussions were often more general. Many of the actions could therefore be extended to other terrestrial applications and perhaps more broadly.

5 Appendices

The following are provided on the report entry as additional information:

Appendix 1 - Terrestrial invertebrate interests and barriers – survey questionnaire (.pdf)

Appendix 2 - Action Plan for making progress with using DNA to monitor terrestrial invertebrates (.xlsx)

6 References

Macadam, C., Robins, J. & Thomson, T. (2020) 2020 gap analysis of the BOLD database for key English invertebrates. *Natural England Commissioned Report Number 324*

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