THE BIODIVERSITY CONSULTANCY

Understanding the benefits and limitations of Environmental DNA for monitoring biodiversity

Summary

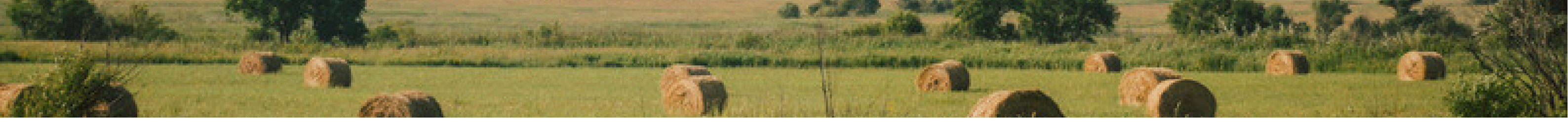
Environmental DNA (eDNA) is an innovative and increasingly used approach for biodiversity monitoring. Often held up as a solution to many biodiversity-related problems, it has a range of impressive capabilities and benefits to business - improving the cost-effectiveness and breadth of possible biodiversity surveys.

It is particularly powerful in the early stages of project planning to understand potential species presence, and when used in combination with other methods to expand, sense-check and triangulate results it can provide an enhanced understanding of biodiversity at project sites.

However, the technology is also complex and has substantial limitations which are important to understand when managing biodiversity risks. Here we outline the benefits and limitations of the technology and recent advances, alongside recommendations and guidance to allow businesses to get the most out of eDNA technologies.

Key highlights from this briefing note:

- What environmental DNA technologies are
- When and how to use eDNA effectively
- Implications for businesses and key recommendations

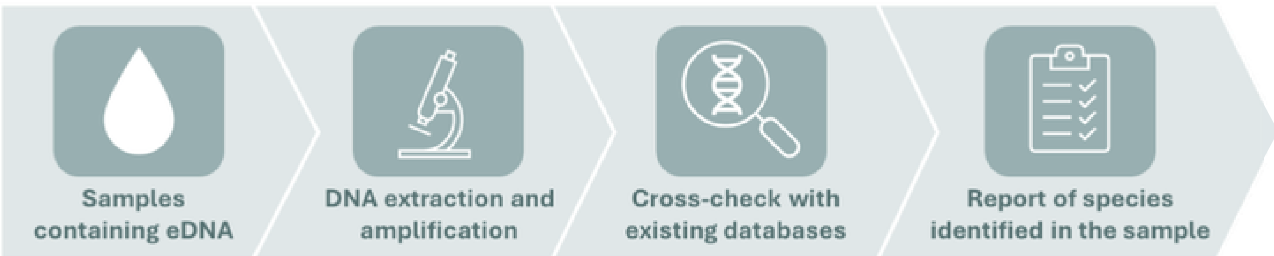


What are Environmental DNA technologies?

Environmental DNA (eDNA) refers to "genetic material originating from the hair, skin, urine, feces, gametes, or carcasses of organisms that is present, in a more or less degraded form, in water, soil, or sediment" (Beng & Corlett, 2020). The term is often used to describe a set of approaches that can detect genetic material in the environment to provide information on species' presence and ecosystem condition.

Interest in eDNA has grown rapidly, due to its ability to expand the breadth, cost-effectiveness and feasibility of surveys for many species. To date, application has focused in freshwater environments (especially for amphibians, fish and mammals), but use is expanding in marine and terrestrial settings (Takahashi et al., 2023).

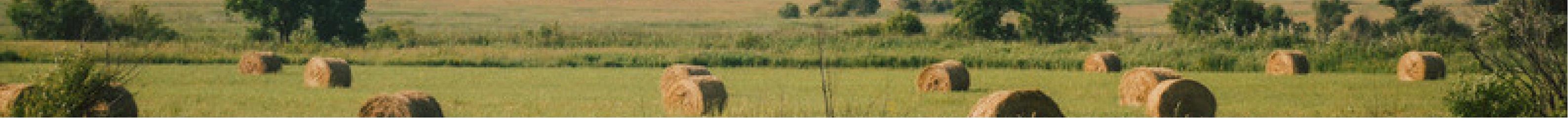
The approach works by taking an environmental sample (usually water or substrate) and filtering it to extract DNA. The sample is then taken to a lab to be amplified where primers are used to bind to the DNA of particular species groups. The amplified DNA is then sequenced and compared to online databases of genetic information to identify the species present in the sample (See figure below modified from NatureMetrics & TBC, 2021).



There are two main approaches to eDNA monitoring (The Biodiversity Consultancy & NatureMetrics, 2021):

1. **Targeted barcoding** – This uses species specific primers to amplify only the DNA of target species in a sample. qPCR is (quantitative polymerase chain reaction) commonly used as a method here. Best approach for answering: 'Is this species present in my sample?'

2. **Metabarcoding** – This uses universal primers to amplify all DNA present in a sample. Best approach for answering: 'What is the full set of species represented in my sample?'



Compared to traditional biodiversity monitoring, eDNA offers several benefits, including cost-effective non-invasive sampling, accessible methods for non-specialists, detection of species or ecosystem interactions that have been challenging to survey, including proxy indicators of ecosystem condition.

Potential uses and benefits of eDNA are summarised below (based upon Beng & Corlett, 2020).

Cost-effectively surveying for species' presence

- eDNA provides a cost-effective way to identify species' DNA in water and soil samples, indicating likely presence in the environment.
- Particularly valuable for cryptic or rare species that are costly to survey using traditional methods.
- Example: Biggs et al. (2015) showed eDNA surveys were highly effective at detecting Great Crested Newts in UK ponds, outperforming traditional techniques and at lower cost.

Gathering insights on species distributions

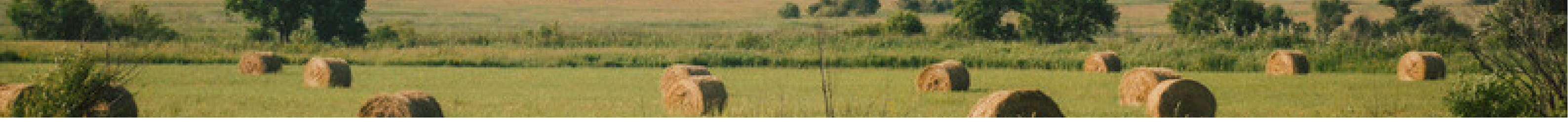
- By efficiently sampling different locations for species' presence, eDNA can help provide information on species distributions.

Detecting species across their life cycle stages

- Some animal life stages are difficult to detect or poorly understood. eDNA can help by detecting organisms across all life stages (e.g., larval stages), filling important ecological knowledge gaps.

Early identification of invasive species outbreaks

- eDNA can detect species even at very low abundances, offering potential for early identification of invasive species or disease outbreaks that may be missed with traditional methods.
- Example: Chucholl et al. (2021) demonstrated the value of eDNA for detecting invasive crayfish in freshwater systems.



Indications of community diversity

- eDNA can also be used, through metabarcoding approaches, to gain insights into community diversity by assessing the presence of different species compared to a reference state. This could include species richness, functional or phylogenetic diversity.

Insights into ecological interactions

- eDNA can reveal species interactions, not just presence. Applications include analysing diet or feces to identify prey species and sampling DNA from plants and pollinators to map interaction networks.

An innovative and exciting technology...

eDNA can therefore be used to gain a more complete understanding of biodiversity baselines and potential impacts at given sites. It is **particularly useful at early project stages** to gather high level information on likely species' presence, which can then be used to guide further survey effort. It can also be used as a technology to monitor the impacts of development or mitigation actions (White et al 2021).

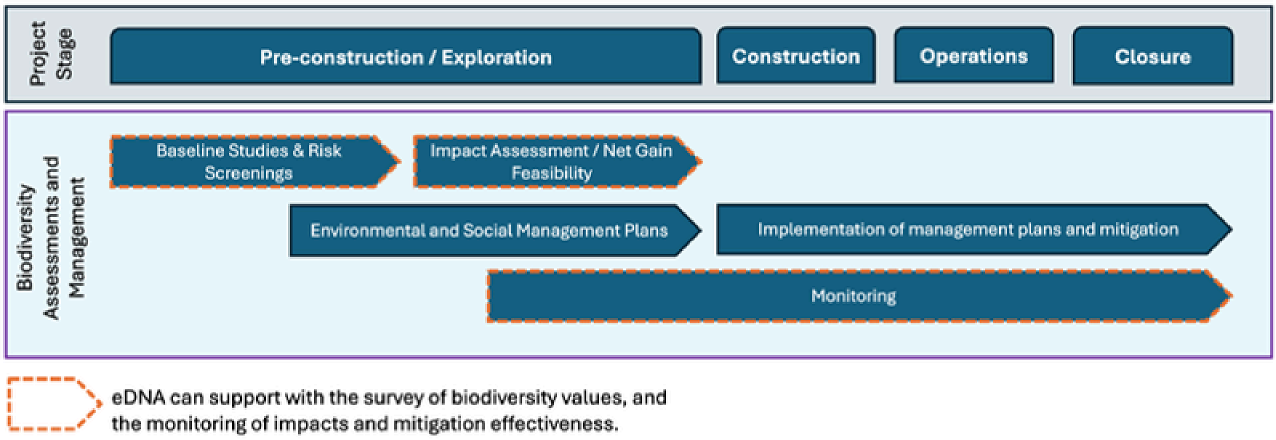
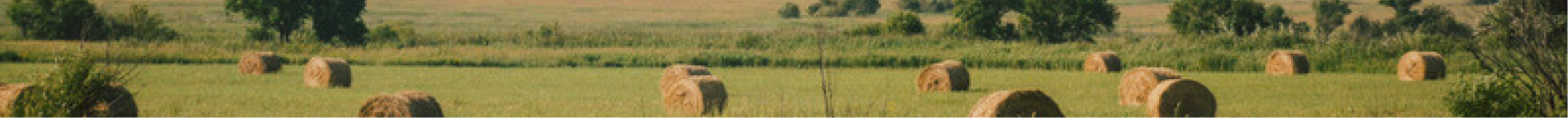


Figure modified from White et al 2021.

It can help assess the presence of species challenging or expensive to survey for using traditional survey techniques (e.g., rare, cryptic species), improve the breadth and cost-effectiveness of some surveys. It is likely **most valuable however as a complement to other survey types** and technologies – allowing us to gain a more complete and nuanced understanding of multiple taxonomic groups and species' presence in ecosystems.



... But beware of its limitations

However, eDNA is not a complete solution to all biodiversity survey challenges. Whilst a useful tool, its effectiveness depends on appropriate use, and several limitations can reduce robustness if overlooked. Key limitations are outlined below, building on Beng & Corlett (2020), to ensure businesses assess when and where the technology can be applied reliably.

Species abundance is challenging to detect

- Understanding business impacts on nature, requires information on both species presence and abundance. While abundance can be determined using eDNA samples, in some cases, unreliable and must be supplemented with other survey types. The amount of eDNA in a sample can be impacted by many factors and not just the abundance of species - including the rate of DNA shedding, rate of DNA degradation, and proximity to the DNA source.

eDNA persistence over space and time varies

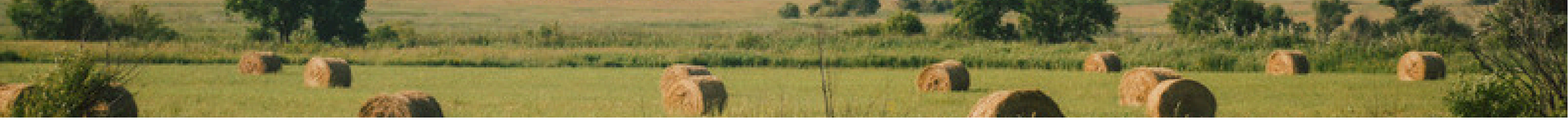
- Detecting eDNA in a sample does not necessarily mean that species is present in the location. It depends on how DNA moves in the environment, and how long it persists. Whilst we have this understanding for some species and geographies, it is lacking in many cases - adding uncertainty into the results of eDNA analyses.

eDNA reference databases are incomplete

- There is increasing effort to build reference databases, but this is still a limitation for many taxa and geographies. Without this information, it is impossible to detect some species in samples.

The source of eDNA is not always clear

- There are often problems of contamination during the sampling process and analysis. Specialist labs and sampling procedures are available to reduce these risks, but contamination can still occur (e.g., meat consumption in an area may introduce eDNA from species not living in the landscape.
- eDNA can also come from dead individuals or passing species that are not regularly found in the site. In results, it can be difficult to distinguish contamination and therefore assess how the presence of eDNA related to biodiversity on the ground.



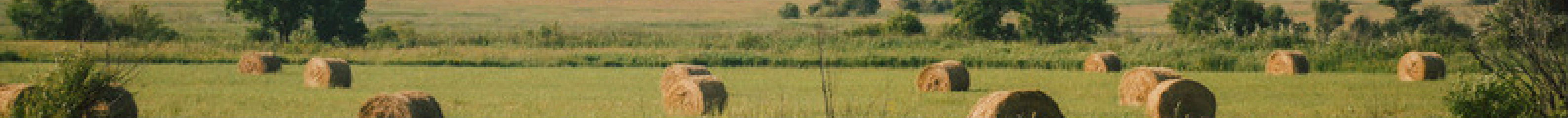
Sampling and analysis techniques can influence results

- The results of eDNA surveys can depend highly on how the environment was sampled, and the analytical techniques used. This includes sampling design, replications, primers used, and minimum sequence thresholds. Without standardised procedures results can be variable and challenging to compare.

These limitations mean that if you do detect DNA from different species in your sample, there is a lot of uncertainty as to what that represents in terms of actual biodiversity in the landscape. For example:

A species is at the site, but eDNA doesn't detect it!	A team of conservation biologists is searching for a rare species of salamander in a remote wetland using eDNA sampling. The salamander is mostly underground in burrows and only enters the water for brief periods. Since it rarely sheds DNA into the water, the sample doesn't contain enough genetic material for detection. Despite historical records of the species in the area, their eDNA tests come back negative.
A species is not at the site, but eDNA surveys says it is!	Officials testing a lake for invasive Asian carp get a positive eDNA result, triggering alarms about an invasion. However, no physical evidence of carp is found in follow-up surveys. The DNA likely came from carp scales or mucus on a boat that had travelled from an infested river upstream. The DNA was introduced into the lake via water runoff or a contaminated bilge pump.
eDNA surveys detects a species, but what does that mean?	Preliminary eDNA surveys in a river basin, from three samples, detect a large amount of DNA of a rare freshwater marine mammal species. This confirmed the presence of the species in the basin. However whilst this high amount of eDNA could also be inferred to be representative of a high abundance of the species, the small sample size means that the sample was skewed by sampling in an area only recently used by the marine mammal. Thus the company would have detected larger amounts of eDNA than would normally occur.

These uncertainties in the results of eDNA surveys highlight that guidance and robust design is needed to collect the data appropriately, interpret its meaning, and embed it within wider approaches for biodiversity monitoring.

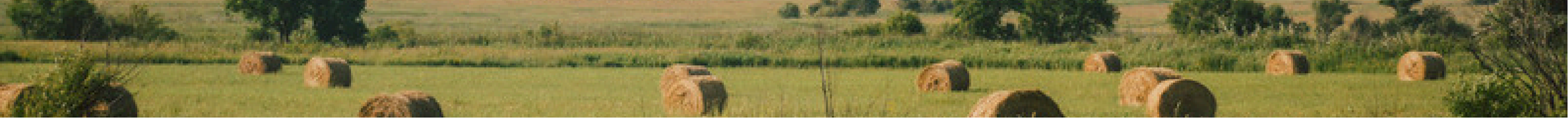


Implications for businesses – Recommendations

eDNA's exciting and powerful business applications can span several stages of project development, as illustrated in Figure 1. It is particularly useful at early project stages which require a baseline on the presence of species on-site and data on general ecosystem condition. However, despite its clear benefits, eDNA cannot completely replace other survey methods. Its limitations mean it must be complemented by traditional approaches and other technologies to ensure scientific rigour.

DO:

- Use eDNA to detect the presence of target species, which are challenging or costly to survey using traditional survey approaches, and for which there is a known primer. This is particularly for rare, challenging to access and cryptic species, as well as invasives.
- Deploy eDNA metabarcoding approaches in combination with traditional survey approaches and other technologies (e.g., bioacoustics) to expand the scope and breadth of survey coverage. This can provide an early indication of species' presence and community composition across a range of taxa.
- Carefully interpret the results of analyses, cross-checking with other surveys to assess the likelihood of false positives, false negatives and incorrect interpretation.
- Engage specialists to evaluate eDNA results and assess the need to additional surveys, and the necessary additional evidence needed.
- Use eDNA to help monitor the success / outcomes of mitigation and restoration efforts in changing species' presence and community composition.
- Engage specialists to design appropriate sampling strategies and analytical procedures to minimize the limitations of the technology.
- Be clear and open about methods used, and limitations/uncertainties in the datasets when reporting results.
- Invest in emerging uses of the technology, to drive innovation, address current limitations, and continue to develop this exciting and powerful survey technology.



DON'TS:

- Solely rely on eDNA for detailed impact assessment datasets or baselines – particularly for species of high biodiversity significance.
- Blindly use eDNA surveys to help assess the abundance of different taxa. This should only be done in limited situations where a clear evidence-base has been developed for the species.
- Use eDNA to try to detect specific species where there are closely related species difficult to separate with current primers.
- Use eDNA uncritically for species where there are not proven approaches and techniques. This should only be done with critical appraisal and expert input.

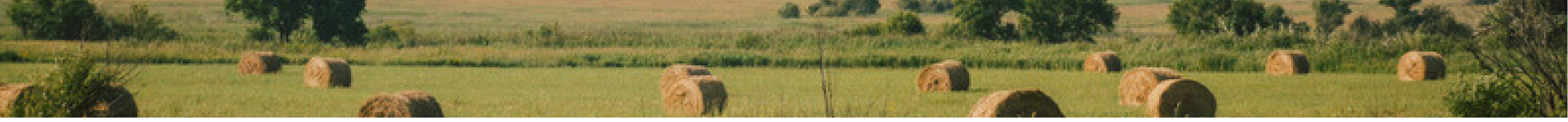
Future directions and opportunities for innovation

eDNA sampling and analysis is a fast-advancing scientific field, which is evidenced by the growing number of academic research and piloting in the field (Takahashi et al., 2023). Many of these developments focus on overcoming current limitations with the technology, including techniques for inferring abundance of species (Yates et al., 2025).

Additionally, alternatives to eDNA sampling, as well as the techniques for analysis, are emerging and although not yet widely available off-the-shelf, these represent an innovative and potentially transformative direction of travel. Businesses can work with consultancies and academics to identify needs and co-develop new solutions for biodiversity monitoring and impact mitigation. Some of these innovations include:

- **Airborne eDNA:** Through the collection and sequencing of bioaerosols and airborne particles, new advances have shown possible to detect species from their genetic remnants in the air. For example, a recent study used the UK's air quality monitoring network to provide a broad overview of species' presence and assess the potential of the technology (Tournayre et al., 2025).

- **Terrestrial eDNA:** Advances have occurred in surveying for terrestrial species relying on the collection of eDNA deposited on fruits, vegetation, tree barks and similar surfaces, and swabs of the water droplets on leaves or leaf surface (Macher et al., 2023).



- **eRNA:** RNA is another type of genetic material found in cells. Differently from eDNA, it does not last as long in the environment, it is expressed differently in different tissues and provides more information on profiles of species, so research has been exploring if eRNA surveys could acquire more information on individuals' health, phenotypes and sexes (Cristescu, 2019). For example, it can look at where juvenile stages of species' are found, or potentially assess levels of stress in species populations by looking at the expression of specific proteins (Glover et al., 2025).

Case Studies

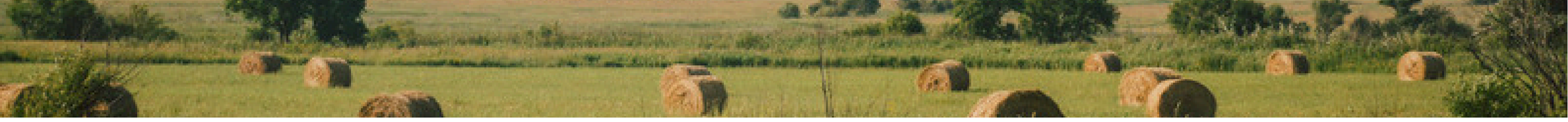
- **Case Study 1:** Detecting freshwater species for infrastructure project in Serbia – As part of a biodiversity impact assessment for a motorway infrastructure project in Serbia, TBC utilised eDNA technologies to provide an additional lens to refine natural and critical habitat mapping as part of a critical habitat assessment in 2021. The eDNA analysis was used to identify the presence of the Striped Nerita (Theodoxus transversalis) to assess whether critical habitat was present. Whilst suitable habitat was thought to exist in the area, both field-based habitat suitability studies and eDNA analysis did not provide evidence of the species being present in the area. Other priority species were identified as present through the eDNA surveys.

- **Case Study 2:** Detection of rare groundwater fauna: Some species are notoriously difficult to survey for, and eDNA surveys can open up new avenues to explore their distribution and ecology. For example Boyd et al (2020) used eDNA surveys to assess the presence of the Sweet Home Alabama Cave Crayfish (Cambarus speleocoopi), a species that resides in subterranean habitats and of high conservation concern due to its limited distribution. The eDNA techniques developed can rapidly help understand the distribution and ecology of the imperilled species.

Get in touch

TBC can help you understand the potential for eDNA for monitoring biodiversity across the project cycle. This can help make sure it is used appropriately to deliver cost-effective solutions alongside other tools and approaches needed to provide a robust understanding of biodiversity impacts, risks and opportunities.

We've worked for a range of sectors to design robust biodiversity surveys, using eDNA to assess biodiversity as part of a complement of survey techniques. We also have leading expertise in the use of new and emerging technologies for biodiversity management, leading syntheses of emerging technologies for biodiversity impact mitigation and monitoring (White et al., 2021), and recently reviewing the existing and emerging uses for eDNA across the project cycle for a leading mining client.



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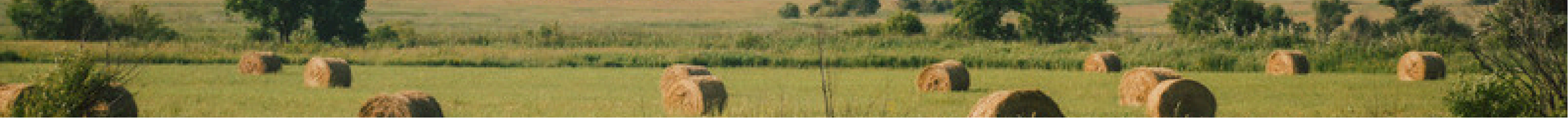

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