the Lifescape project

Review of Biodiversity Metrics

Considering approaches relevant to the United Kingdom, applied to the Natural Capital Laboratory – Birchfield

University of Cumbria

AECOM

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Disclaimer

The selection of biodiversity metrics and indicators presented in this report are provided as examples that are most closely relevant for application to the Natural Capital Laboratory at Birchfield, and is therefore not an exhaustive list. The information presented in the report is meant for informative purposes and should not be interpreted as an endorsement of any individual or organisation, nor as an endorsement of their work. The authors of this report do not assume responsibility for any actions taken based on the information provided.

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Executive Summary

The following review examines biodiversity metrics and monitoring methods, with a particular emphasis on their applicability to rewilding efforts in the UK. The review forms part of the Biodiversity Monitoring workstream for the fourth year of the Natural Capital Laboratory (NCL), a 100-acre rewilding site in the Scottish Highlands that serves as a testing bed for trialling different techniques, technologies, and valuation methods in natural capital accounting and rewilding.

During the first three years of the project, various methods have been employed for gathering data on biodiversity at the NCL including installing camera traps and AudioMoths, taking aquatic eDNA and Air eDNA samples, and conducting targeted baseline field surveys, such as for soils and fungi. There has been one primary challenge, however - synthesising diverse data types into a measure that can be easily compared over time. In light of this, this review seeks to respond to the question of how biodiversity data can be organised and standardised into metrics for tracking biodiversity change. For the purpose of the review, we define a biodiversity metric to be a quantitative measure that tracks changes in the state of biodiversity (that is, relating to species, function, ecosystems, genetics, or a combination of these) or ecological health more broadly, following what we have assessed to be the current global discourse.

This review focuses on addressing the specific metric requirements of the NCL, whilst aiming to offer transferable insights for other rewilding projects. The review is finance-agnostic (i.e. there is not a view to monetise biodiversity uplifts on the NCL site), so where metrics related to finance are reviewed, their ecological relevance to the NCL site is the focus, rather than aspects related to, for example, validation, verification and revenue potential.

The following is a high-level summary of the review and conclusions:

- ***Monitoring Techniques:*** As a pre-condition to considering metrics, we review commonly-employed biodiversity monitoring techniques. Methods included are camera traps, environmental DNA (eDNA), field surveys, citizen science and bioacoustics. These monitoring methods are discussed with regards to the taxa they are most used to detect, some key advantages and limitations, and examples of their use in rewilding projects across the UK.
- ***Methods:*** We combined information obtained through two approaches. The first, through synthesising information from published academic and grey literature. The second, through conducting semi-structured interviews and engaging in iterative discussions with experts and practitioners.
- ***Overarching Theme:*** A prevailing view emerging from thematic analysis regarding both biodiversity monitoring methods and metrics is that there is no one-size-fits-all solution. In this context, participants emphasised the importance of recognising the distinct strengths and weaknesses of various monitoring techniques before adopting and implementing them, and that it was crucial to understand the purpose and conceptual foundations of biodiversity metrics when evaluating, choosing, and implementing them.
- ***Key Themes:*** An overview of the main topics and sentiments that emerged from thematic analysis of interview transcripts and notes from iterative discussions is presented in Figure 1.

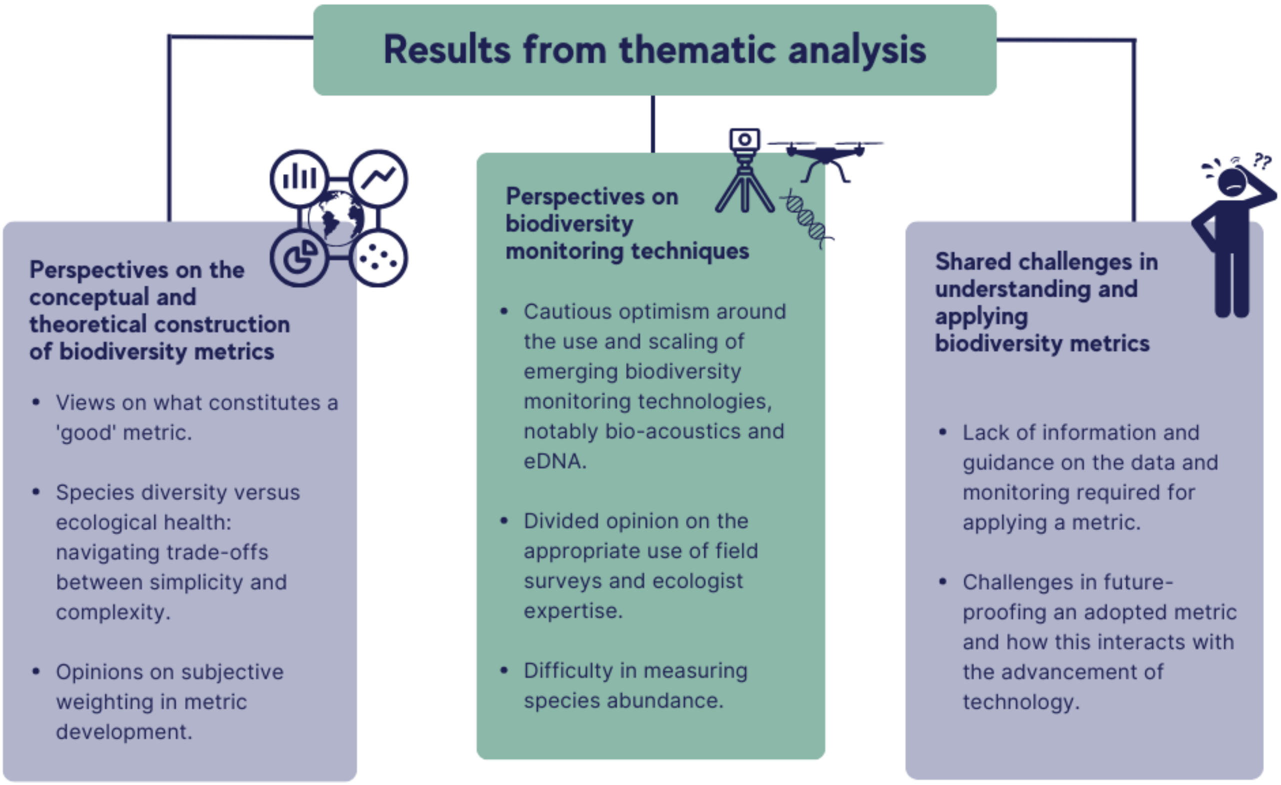

Figure 1. Key topics and sentiments arising from thematic analysis of interviews and discussions.

NCL Criteria: Expert input, especially concerning the conceptual and theoretical aspects of metrics (the left side of Figure 1), contributed to the formulation of principles to guide the metric selection process. In addition, we incorporated context-specific criteria. These principles and criteria are summarised below.

Criteria:

- Flexibility of the approach or metric to suit NCL data collection methods.
- The metric is able to be applied using open-source methodology guidelines and resources.
- Size and habitat appropriate – it needs to be able to show change across a 100-acre site, and be compatible with the rewilding dynamics of the NCL where habitats are being actively converted.
- Aligns with the philosophy of the NCL and the knowledge the project seeks to create, namely:
    - The use of the metric is compatible with a rewilding approach to conservation.
    - The use of the metric facilitates knowledge-sharing and learning and is aligned with innovation and pioneering approaches to natural capital and rewilding.

Principles:

- Ideally, the metric incorporates a measure of structure, composition, and function of the ecosystem.
- Holistic in its capacity to reflect biodiversity in different dimensions – potentially a pluralistic metric.

Metrics Considered: Metrics and their methodologies that were deemed relevant (that is, loosely matching the above criteria) were gathered and grouped into categories, as shown in Table 1.

Table 1. Metrics reviewed in this report, grouped by category.

Metric category	Metric
Foundational species-focused metrics	Shannon's Diversity Index
	Simpson's Diversity Index
	Hill Numbers
Financially-orientated metrics	Operation Wallacea (rePLANET) - Methodology for Awarding Units of Biodiversity Gain
	Credit Nature – Natural Asset Recovery Investment Analytics (NARIA) framework
	Plan Vivo in partnership with Pivotal – PV Nature Methodology
	Verra Biodiversity Standard
Metrics from regulatory bodies and conservation governance	Defra - The Biodiversity Metric for use in Biodiversity Net Gain
	UNEP-WCMC – Biodiversity Intactness Index (BII)
	Joint Nature Conservation Committee (JNCC) - UK Biodiversity Indicators
	IUCN – Species Threat Abatement Risk (STAR) metric
Rewilding focused metrics	Rewilding Europe – Rewilding Score
	Rewilding Britain – Monitoring Framework for Rewilding

Recommendation: Following a shortlisting process, the primary recommendation is for the NCL to adopt the PV Nature methodology, followed in addition by Rewilding Britain's framework for monitoring rewilding.

The PV Nature methodology:

- The methodology is open source and can therefore be applied for organising biodiversity data without participating in the voluntary biodiversity market.
- It is a state-based, direct measure of biodiversity, aligning with existing monitoring methods implemented at the NCL.
- The methodology developers and the NCL team noted the potential for mutual benefit in research and development by applying this metric to existing and future data collection at the site.

Rewilding Britain's monitoring framework:

- The framework aims to help rewilders track progress across a range of social, ecological and economic parameters, which aligns with NCL's capitals accounting approach.
- It will include pressure- and response-type metrics, which are helpful for contextualising progress on state-based metrics and rewilding interventions.
- The feasibility of adopting the framework will be further evaluated in November 2023 when a draft becomes available, and through further discussions with Rewilding Britain.
- The NCL's risk-tolerant and innovative approach presents an opportunity to pioneer the new framework and generate learnings for other rewilders.

1. Introduction

The following report reviews biodiversity metrics and monitoring methods relevant to biodiversity conservation projects, with a specific focus on their applicability to rewilding in the UK.[1] The impetus for this review arose from reflections of the Biodiversity Monitoring workstream of Year 3 of the Natural Capital Laboratory (NCL) at Birchfield. The NCL is a 100-acre rewilding site near Inverness and is operated through a partnership between the Lifescape Project, AECOM, the University of Cumbria and the landowners Emilia and Roger Leese. The NCL provides a risk-tolerant and open space to test different techniques, technologies and valuation methods related to natural capital accounting and rewilding. During the four years of the NCL project to date, we have obtained a wealth of baseline data using a range of methods and technologies (such as camera traps, bio-acoustics, eDNA, and field surveys), but have not yet been able to define an approach for integrating that data into a streamlined metric that can be used to track biodiversity change over time.

Recognising that this challenge was not unique to the NCL and that others were grappling with similar questions, we incorporated a review of biodiversity metrics into the Year 4 biodiversity monitoring workstream. Biodiversity metrics are assuming an increasingly important role in various sectors and policy domains, including natural capital markets, planning and development, conservation and rewilding work, and sustainable agriculture. Moreover, there are untapped opportunities for enhanced collaboration and knowledge exchange between those delivering nature restoration and rewilding projects, the private sector, the third sector, and other stakeholders. Given this context, this review aims to shed light on commonly utilised and emerging biodiversity metrics, as well as the monitoring methods used to collect ecological data. This will inform future work at the NCL regarding biodiversity monitoring and valuation and help to foster exchange of knowledge related to the utilisation and application of biodiversity metrics.

While the review primarily centres on biodiversity metrics and monitoring techniques, it also touches on developments in biodiversity credits and markets, as there are strong interlinkages between the monitoring, measurement, valuation, and trade of biodiversity.

Biodiversity, and indeed markets for ecosystem services more broadly, are rapidly evolving, as are developments around corporate environmental, social and governance (ESG) targets and the Taskforce for Nature-related Financial Disclosures (TNFD). Consequently, some of the most rigorous and innovative thinking around biodiversity metrics has been in response to these corporate- and finance-facing developments and the need for biodiversity and ecological targets to be based on quantified, replicable, verifiable and auditable metrics. While numerous reviews are surfacing that are focused on market trends, financial elements, and credit scheme comparisons[2], we are presenting here a review on biodiversity metrics that is finance-agnostic. That is, exploring the question of how organisations dedicated to restoration or rewilding can practically adopt contemporary research and concepts related to biodiversity metrics, irrespective of their inclination toward securing financial backing for their projects or objectives. The UK remains the main focus, though global metrics are also considered here to the extent that they have been or could be of use in a UK context.

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[1] See section 5.1 for a working definition of biodiversity metric for the purposes of this review.

[2] See for example:

i) Dalberg Advisors. (2022, November). Key design principles in developing biodiversity measurement tools for investors.

ii) Institute of Environment and Development (IIED). (2022, November). Biocredits to finance nature and people: Emerging lessons (Publication No. 21216IIED). IIED Publications Library.

iii) The Biodiversity Consultancy. (n.d.). Exploring design principles for high integrity and scalable voluntary biodiversity.

iv) Gradeckas, S. (2023, August 31). Biodiversity credits vs carbon credits. [Blog post]. Bloom Labs Substack.

As articulated in the Biodiversity Monitoring report for NCL Year 3, this review aims to synthesise research to prepare the NCL to adopt a method to quantify biodiversity change at a site level in a way that is holistic, can be repeated by rewilding practitioners and can pave the way for other restoration projects. Moreover, the Natural Capital Accounting process within the NCL has encountered challenges in quantifying and assigning monetary value to biodiversity, so an ancillary aim of this review is to provide some conceptual groundwork for addressing those challenges.

2. Methodology and structure

The review was constructed by synthesising information gathered through two methods: collating data from published literature and conducting discussions with experts and practitioners engaged in a range of relevant domains, such as in metric development, rewilding, policy-making and academia.

2.1 Literature review

The literature review was based on academic literature, government reports, published guidance from relevant institutions, rewilding projects' annual reports, and selected other pieces of work such as papers recommended by experts during discussions. Summaries were written of each metric, monitoring framework, or indicator, then common themes and points of interest that emerged were included in this review, organised by theme. Each metric was then included in a summary table and assessed according to defined criteria.

2.2 Discussions with experts and practitioners

A combination of semi-structured interviews and informal discussions on the topic of biodiversity metrics were arranged with people working across a number of sectors, in an effort to understand the rapid acceleration of developments in this field. The approach we took to synthesising information from interviews and informal discussions was modelled on grounded theory which is a form of exploratory research[3] that allows for the exploration of patterns, ideas and hypotheses in the data rather than starting with a set of questions reflecting an already determined perspective[4]. There was a cross-sectoral representation of experts and practitioners interviewed offering diverse and nuanced perspectives, including those working within government policy making, the private sector, rewilding entities, environmental NGOs, and academia. Additionally, several people we spoke with were familiar with the NCL in terms of having visited or worked on the project, which was helpful with regards to providing context-specific insights into the metrics we could explore and experiment with going forward.

Collation of knowledge from that diversity of expertise requires iteration and flexibility in the research approach, and bespoke sets of questions appropriate for different types of expertise and experience. Some of the participants preferred to remain anonymous, while others' names and affiliations appear throughout the review in footnotes where an original idea or perspective is included, or project or approach is referenced. We engaged in a permissions process, during which metric summaries were reviewed by their respective developers when applicable, and all quotes were verified by the participants who provided them. A summary of the types of questions asked and a participant list of those interviewed (excluding those who wished to remain anonymous), are provided in the Appendix section A1.

[3] Stebbins, R. (2001). Exploratory research in the social sciences: what is exploration?. Exploratory Research in the Social Sciences. 2-18.
[4] Charmaz, K. (2014). Constructing Grounded Theory. Los Angeles: Sage.

2.3 Review structure

The remainder of the document is subsequently organised into the following sections:

- **Section 3** provides an overview of previous measurement of biodiversity at the NCL, to set the context for the biodiversity monitoring review that follows.
- **Section 4** reviews of some of the most commonly employed monitoring methods and technologies used by rewilders to gather data on species, habitats, interactions and other information on biodiversity.
- **Section 5** discusses the concept of biodiversity metrics, offering clear definitions and outlining some of the common practical uses.
- **Section 6** outlines the overarching criteria guiding the processes of the metric review, in the context of the NCL's aims and physical attributes.
- **Section 7** presents summaries of the metric methodologies, categorised into finance-facing metrics, policy and conservation governance metrics, foundational species-focused metrics, and rewilding-specific frameworks. It also includes a metric comparison table.
- **Section 8** summarises the shortlisted metrics and recommends the adoption of a metric for the NCL, as well as outlining how it can be implemented in practice.

3. Measuring biodiversity at the Natural Capital Laboratory

3.1 Accounting for biodiversity within natural capital

3.1.1 Natural capital concept summary

The term 'natural capital' is a concept that connects economic decision-making with environmental concerns, to emphasise responsible and sustainable use and management of ecosystems. Natural capital assessments typically involve understanding how a specific region or site contributes to underpinning economic activities, creating economic opportunities, and enhancing human wellbeing more generally. The concept of natural capital can be applied for varying purposes — for example, as an overall approach to decision-making, an analytical tool, framework to track restoration benefits, or ESG reporting tool used by a corporation. A natural capital account typically includes an asset register, physical flow accounts and monetary accounts that monetise the ecosystem services and record maintenance costs. Analogous to financial accounting, a balance sheet is used to track and report on changes in natural assets and liabilities. This growing diversity of applications is both exciting for linking projects to investment and finance and, at the same time, can cause confusion for practitioners as they contemplate how to engage with the idea.

3.1.2 Conceptual challenges of incorporating biodiversity into natural capital accounts

As discussed further in section 3.2, biodiversity at the NCL is currently accounted for through the creation of an asset register accounting for the extent and condition of species and habitats, but not yet monetised. Biodiversity metrics are multifaced and differ markedly in their designed purpose and the ecological parameters they measure. Accordingly, environmental economists need to be cognisant of these differences when translating metric outputs into monetised estimations of economic value within natural capital accounting.

In natural capital accounts, biodiversity is typically incorporated conceptually through qualitative comment and narrative, but rarely in quantitative or monetary terms due to methodological obstacles large uncertainties. With the emergence of biodiversity markets however, biodiversity ‘prices’ will be available to be incorporated into natural capital accounts, allowing quantification and monetisation of biodiversity, albeit based on very crude measures. This is important because presently, willingness-to-pay estimates based on hypothetical markets for biodiversity and ecosystem services are often the only estimates available, and these are typically very costly to design and implement (for example, contingent valuation).[5] However, having some concrete prices for biodiversity (such as statutory credit prices set by Defra as part of the Biodiversity Net Gain) may introduce as many new challenges than it solves for those engaged in natural capital accounting. Discussions with experts as part of this review confirmed that biodiversity accounting within natural capital continues to be a conceptual and methodological stumbling block for practitioners. This particular issue will be an explicit focus of the year 5 NCL project workstreams, but scoped out of this current review. Some examples of guidance relating to including biodiversity into natural capital assessments are briefly summarised in the appendix, section A2.

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[5] Organisation for Economic Co-operation and Development. (2013). Contingent valuation method. In OECD Handbook on Measuring the Non-Observed Economy.

3.2 Recording biodiversity at the NCL

The approach used to measure biodiversity up to Year 3 of the NCL project involved collating species richness data from the various workstreams into a comprehensive asset register in the form of a spreadsheet. Simple calculations were then applied to approximate the extent and condition of biodiversity, as detailed in section 3.2. Between 2019 and 2022, a range of biodiversity surveys and monitoring techniques were employed to collect data across multiple taxonomic groups. The biodiversity component within the asset register forms one of several environmental data categories included in the natural capital accounts, used to assess changes in assets and flows over time. that are incorporated into the natural capital accounts that are used to measure change in the assets and flows over time.

Years 1 and 2 of data collection included the following:

- Macroinvertebrate survey
- eDNA invertebrate survey
- Diatom survey
- Camera trap image collection
- Bio-Acoustic surveys
- Small mammal survey
- Butterfly drag survey
- Breeding bird survey

Year 3 included:

- Site walkovers
- Baseline fungal survey
- AirDNA survey
- Phase 1 National Vegetation Classification (NVS) survey

In Year 3, further breeding bird and butterfly/dragonfly surveys were undertaken as part of the ecological walkover surveys, however no significant additions were noted to species on site.

3.3 Calculations and outputs

To make calculations around biodiversity, there were components included for species richness (species counts from the NCL) and species rarity (number of those species which are priority species – BAP). Species richness was categorised/conceptualised as species 'extent' and species rarity as 'condition', to align with how habitat is categorised as extent and condition as well. The outputs were categorised by different taxa, including amphibian, bird, invertebrate, mammal, reptile, fish, algae. In Year 3, newly added categories, "plants" and "fungi," were based on additional survey data. Figure 3.1 illustrates what these outputs look like, as presented in the PlanEngage platform for the NCL. [6]

[6] PlanEngage is an interactive online platform developed by AECOM that enhances communication and engagement to improve project outcomes.

Species	Y1 (2019/20)		Y2 (2020/21)		Y3 (2021/22)	
All species records	Total	BAP	Total	BAP	Total	BAP
Amphibian	1	0	3	1	3	1
Bird	31	6	36	6	36	6
Invertebrate	7	0	205	1	209	1
Mammal	6	3	16	5	20	5
Reptile	1	1	1	1	1	1
Fish	n/a	n/a	3	2	3	2
Algae	n/a	n/a	80	0	80	0
Fungi	n/a	n/a	n/a	n/a	192	0
Plant	n/a	n/a	5	0	103	0
TOTAL	**46**	**10**	**349**	**16**	**647**	**16**

Figure 3.1 Total and BAP priority species counts at the NCL.

3.3.1 Assumptions

Several assumptions were made during the reporting process:

1. Information on species was reported as cumulative, assuming that species existing in the previous years were still present, even if unrecorded in the current year. This assumption may not always hold true, as species could have left the site and that could be the reason for not being observed. Reporting individual year counts, as an alternative, could also introduce errors and omissions due to human error or variations in survey effectiveness and efficiency. However, doing so would be very resource-intensive and not always feasible, particularly for relatively small sites like the NCL. Both cumulative and individual counts have their advantages and disadvantages.
2. Species were not separated by habitat type, which could be a valuable classification to include going forward especially as the NCL has a diverse mosaic of habitats in a relatively small area. The focus up to now has been on recording species counts rather than detailed distributional data, limiting insights into the relative richness between each species type.
3. The species count that is recorded in the spreadsheet reflects survey effort - with more surveys resulting in a higher likelihood of discovering additional species. This observation highlights that species richness in the spreadsheet may continue to increase over time with more comprehensive survey efforts.

After adopting a metric to track biodiversity using existing monitoring methods, a subsequent goal for the NCL is to decide on a method to translate biodiversity change into monetary terms for inclusion in the natural capital accounts. This is a conceptually difficult task within the field of natural capital, with no clear consensus on how best to address it. However, the uptake of biodiversity accounting is increasingly a challenge faced by many project developers in the context of growing political and corporate discourse around natural capital. Some reflections on this topic are provided in section 3.3.

4. Review of approaches to biodiversity monitoring

Diverse methods and technologies are available for biodiversity monitoring, each with their own unique advantages and limitations. There is no single solution that universally and objectively provides suitable data for effective biodiversity monitoring. However, certain combinations of approaches can work synergistically to offer a comprehensive assessment of a site's biodiversity and ecological health.

The NCL employs various methodologies for biodiversity monitoring, including camera traps, AudioMoths, eDNA, remote sensing, and field surveys. In this section, an overview is provided of commonly used technologies and methods for biodiversity monitoring, highlighting their respective advantages and limitations. Additionally, examples of their application in other rewilding projects and initiatives are presented.

4.1 Camera Traps

4.1.1 Description of camera traps

Camera traps are specialized cameras strategically positioned within a location to capture images and videos of wildlife as they move through the area. To streamline data gathering, these cameras are typically configured to activate automatically when there is a change in activity, typically triggered by the presence of an animal. Camera traps serve as a valuable tool for biodiversity monitoring, as they record the passage of various animal species. This technology has risen in popularity as a reliable method for wildlife monitoring as affordable and more reliable cameras have become available.[7]

4.1.2 Taxa commonly detected

- Medium to large mammals are commonly the target when setting up camera traps.
- Less commonly, birds and bats can be detected, if the settings of the camera traps are set up to suit their patterns of movement (e.g. high motion trigger sensitivity, video setting, and adjust to higher angle and height).
- Smaller ground-dwelling mammals can also be detected, such as voles, mice and shrews, with appropriately adjusted settings or with supplementary equipment.[8]

4.1.3 Examples of camera trap use in rewilding

- The NCL has 8 camera traps set up across the range of habitats (peatbog, established Sitka forest, regenerating Birch forest, etc). In the 3 years of data collection, species detected include badger, fox, sika deer, fallow deer, red squirrel, pine marten and various bird species.[9]

[7] Wearn, O. R., & Glover-Kapfer, P. (2019). Snap happy: camera traps are an effective sampling tool when compared with alternative methods. *Royal Society Open Science*, 6(3), 181748. doi:10.1098/rsos.181748.
[8] How to make a Littlewood box for small mammal camera-trapping.(2018).
[9] Natural Capital Laboratory Year 3 (2021-2022) End of year Report. Retrieved from <https://lifescapeproject.org/uploads/ncl-yr-3-report-2022.pdf>

- Bunloit Estate utilised camera traps to capture video footage of both large and small non-flying mammals. The traps were set to record 20-second videos triggered by motion and were active for 90 days. The data collected during this period were shared on sika deer (53%) detections, the camera traps also captured bird species and bats, which is unusual for this type of monitoring. Analysts further categorised these species by habitat type to gain valuable insights into their distribution.[10]
- Alladale Estate undertook a three-month camera trapping project in Summer 2021 to put together an inventory of species on the reserve. Mossy Earth processed and analysed the data, from 30 camera traps placed across the main habitats of the site. Cameras were set to record short videos, and 56 species were recorded. Following this initial survey effort, the researchers designed targeted camera trap monitoring plans for pine martens and mountain hare at Alladale, as well as neighbouring Croick and Amat Estates.[11]

Table 4.1 Advantages and limitations of camera traps

Advantages	Limitations
The image meta data (for example the time stamp) and location data (for example habitat type) can be used in combination with the detection data to understand species behaviour better, such as diurnal activity patterns, habitat use etc. Again, given sufficient data, species presence can also be modelled together to understand interactions between species.	There is a considerable amount of work involved between setting up camera traps in a site according to a designed sampling grid, getting the images, sorting through the images to filter out false positives (like pictures taken when grass sways in the wind), and actually analysing the images in a meaningful way.
Very light touch and non-invasive, eliminating potential stress on species.	Limited to animals which are large enough and conspicuous enough to be identified in an image.
With sufficient detection data, species population dynamics can be modelled such as population size change over time.	Medium to large mammals disproportionally trigger images due to their size and movement.
The image output can be used with AI to speed up the identification of species and potentially individuals within a population. A wide range of analyses are becoming available. If individuals can be separately identified including home ranges, movement behaviour, intraspecific interactions etc.	To process the often-large amounts of data, AI tools and statistical modelling are needed. It is likely that whatever AI software is used to filter pictures will need to be manually ground truthed for accuracy. Data analysis packages are not always user friendly and may need expertise in statistical analysis software *R* to analyse the data.
Licences are not needed which makes it accessible for more general use.	
Provides opportunities of story-telling and emotive connection with the public on the benefits of rewilding.	
Can enable 24/7 monitoring and be deployed for long periods, weeks or months at a time.	
Causes minimal disturbance and the lack of human presence allows undisturbed detection and particularly elusive species to be detected.	
Enables previously unknown or rarely evidenced behaviours such as feeding, reproduction, territoriality and social interactions to be captured.	

[10] Highlands Rewilding. (2021). Natural Capital Report - 2021.
[11] https://www.mossy.earth/projects/monitoring-pine-martens-mountain-hares

4.2 Environmental DNA (eDNA)

4.2.1 Description of eDNA

Environmental DNA (eDNA) refers to the genetic material that organisms release into their environment.[12] Using eDNA in biodiversity monitoring involves taking a sample from the environment (from water sources, soil, tree bark, etc), and processing the samples in a lab to extract DNA from the sample, enabling identification of species by comparing the DNA found to that in an existing database. Most often, a metabarcoding approach is taken, where the output is essentially a list of species detected. However, research is developing rapidly to respond to the need for biodiversity information beyond species richness. The potential for measuring additional biodiversity parameters like abundance, behaviour, distribution and trophic interactions is contingent on sampling complexity and design, which depends on available resources, time and expertise.

4.2.2 Taxa commonly detected

- Particularly good for detecting different species of fungi (AirDNA was used to find species at the NCL site).
- Species that produce mucus, slime, or skin secretions are relatively easy to detect such as certain fish and amphibians.
- Generally, eDNA is less effective at detecting mammalian species in terrestrial environments than in semi-aquatic environments.
- For animals with fur, such as Beavers, grooming behaviours release large amounts of DNA and it can be analysed in ways that provide insights on behaviour and social aspects.

4.2.3 Examples of eDNA use in rewilding

Targeted surveys can be designed to detect species of interest. For example, in 2014 Natural England approved the use of eDNA for detecting the presence of Great Crested Newts and other species of interest may be included as the use of eDNA for monitoring increases. Environmental DNA is not yet used as a common or mainstream monitoring technique in rewilding. Some rewilding entities are pioneering the approach though, including the NCL.

- The NCL has conducted eDNA analysis of the site through aquatic samples, which enabled detection of rare and interesting species that might have otherwise been missed. Currently a PhD student[13] is using the NCL as the research context and is testing how different substrates pick up different species and the potential for sampling design to provide useful information on biodiversity, beyond species presence. Additionally, AirDNA tests have been done at the NCL, though it picked up almost exclusively fungi species, suggesting the approach may still be too novel to be particularly reliable for recording species presence across different taxa.
- A novel sampling method for detecting the elusive hazel dormouse was carried out at Knepp rewilding estate, among other locations. Detection of dormouse DNA through this method was found to have 12-fold increase in detection efficiency when compared to other methods. This highlights the potential for bespoke eDNA sampling to assist in detecting priority species for

[12] Ashish Sahu, Neelesh Kumar, Chandra Pal Singh, Mahender Singh. (2023). Environmental DNA (eDNA): Powerful technique for biodiversity conservation, Journal for Nature Conservation, Vol 71.
[13] Clare Cowgill, PhD candidate, University of Hull.

rewilding sites to better understand the rare and elusive species on their site, However, it's important not to underestimate the potential financial and research resource investment potentially required in doing so.

- Highlands Rewilding, while testing datasets that fed into the development of CreditNature 's NARIA framework, undertook an assessment of soil data using eDNA approaches, conducted by NatureMetrics. The analysis of the 40 soil samples taken indicated the presence of 1,168 fungal species and 352 soil fauna species. Interestingly, the data showed that peat bog habitat, often categorised as having low biodiversity value, harboured the most diverse soil fauna community.[14]

Some nascent advancements in the field of eDNA are summarised as the following:

- The development of more efficient and cost-effective techniques for collecting, extracting, and analysing eDNA samples.
- Moving from single-marker analyses of species or communities to meta-genomic surveys of entire ecosystems.
- Environmental RNA may also expand the use of eDNA analysis as a practical biodiversity monitoring tool.[15]
- Developing efficacy of AirDNA[16][17] and advancements in the sophistication of detection of organisms in other substrates such as soil.[18][19]

Table 4.2 Advantages and limitations of eDNA

Advantages	Limitations
Very light touch and non-invasive, eliminating potential stress on species.	Access to the technology for analysis will be relatively cost-prohibitive until nature-finance and the entities able to run analysis are scaled up adequately.
Samples can be collected by anyone, regardless of expertise and do not require a licence to use. This reduces field trip and travel costs of ecological experts, particularly at remote sites.	Results are skewed towards species that shed large amounts of DNA.
Can detect multiple species, across multiple taxa, in a single sample using metabarcoding techniques. Therefore, very good for assessing species richness at large sites.	Less good for assessing species richness at smaller sites, especially when using flowing water as the testing substrate (as the DNA the samples capture may be attributed to sites upstream, and impossible to pinpoint where).
It is particularly good for getting a cross-taxa, comprehensive snapshot of species richness and can pick up traces of species that are extremely rare, and are missed by camera traps and field surveys.	It does not necessarily pick up what might otherwise be fairly conspicuous species - in one study, eDNA was observed to miss key species including fox and badger in a study that compared findings from different methods.[20]

[14] NatureMetrics. (2022, May 24). Soil eDNA data forms part of world-leading research for Highlands Rewilding.
[15] Marshall, N.T., Vanderploeg, H.A. & Chaganti, S.R. Environmental (e)RNA advances the reliability of eDNA by predicting its age. *Sci Rep* **11**, 2769 (2021). https://doi.org/10.1038/s41598-021-82205-4.
[16] Johnson, M. D., Cox, R. D., Grisham, B. A., Lucia, D., & Barnes, M. A. (2021). Airborne eDNA reflects human activity and seasonal changes on a landscape scale. *Frontiers in Environmental Science*, *8*, 563431.
[17] Lynggaard, C., Bertelsen, M. F., Jensen, C. V., Johnson, M. S., Frøslev, T. G., Olsen, M. T., & Bohmann, K. (2022). Airborne environmental DNA for terrestrial vertebrate community monitoring. *Current Biology*, *32*(3), 701-707.
[18] Gellie, N. J., Mills, J. G., Breed, M. F., & Lowe, A. J. (2017). Revegetation rewilds the soil bacterial microbiome of an old field. *Molecular Ecology*, *26*(11), 2895-2904.
[19] Andersen, K., Bird, K. L., Rasmussen, M., Haile, J., Breuning-Madsen, H. E. N. R. I. K., Kjaer, K. H., ... & Willerslev, E. (2012). Meta-barcoding of 'dirt'DNA from soil reflects vertebrate biodiversity. *Molecular Ecology*, *21*(8), 1966-1979.
[20] Harper, L. R., Lawson Handley, L., Carpenter, A. I., Ghazali, M., Di Muri, C., Macgregor, C. J., Logan, T. W., Law, A., Breithaupt, T., Read, D. S., McDevitt, A. D., & Hänfling, B. (2018). Environmental DNA (eDNA) metabarcoding of pond water as a tool to survey conservation and management priority mammals. Biological Conservation, 221, 69-76.

eDNA data can be digitally stored and easily shared with collaborators and the wider scientific community, contributing to data transparency and collaborative research.	There are persistent biases involved in metabarcoding, in that some types of eDNA tend to show up consistently more than others (squirrel fur will shed and spread widely, whereas reptiles scales do not shed as much, therefore spreading less DNA material).[21]
Potential to be very versatile. Samples can be kept frozen in storage, to be analysed retrospectively for a different taxa or target species when funding or opportunities arise.	There are abiotic-related biases related to the breakdown of DNA. The average half-life of eDNA is 2 days, though this varies and can be up to 2 weeks. DNA degrades slowest in cold and dark, less acidic environments, and quickest in warm, wet environments with more organic matter.[22]
	Results, in terms of what is detected, are extremely sensitive to sampling strategy.

4.3 Field surveys

4.3.1. Description of field surveys

Field surveys are very commonly employed for monitoring biodiversity for a site, and can be used to develop species richness lists, abundance and distribution, depending on the survey design and research interests. Field surveys can be adapted and designed for most taxa, and they comprise a collection of tried and trusted methods depending on the species (or taxonomic groups) that are being surveyed.[23]

4.3.2 Taxa commonly detected

- A field survey for insects might involve pitfall trap or pooter sampling, where the specimens can be preserved in alcohol and identified by an entomologist in a lab, or made into a paste which can be analysed using DNA barcoding technologies.[24]
- Plant transect surveys and quadrat counts are commonly used to assess diversity of vegetation.
- The United Kingdom's Breeding Bird Survey (BBS) is one of the most well-known and widely used bird field survey techniques in the UK.[25]
- Reptiles and amphibians are notoriously under-reported due to the difficulties in detecting them[26], but can include pond surveys (which focus on breeding sites) and refuge surveys, which involve placing cover boards or artificial refuges in suitable habitats and periodically checking them to find sheltering reptiles.[27]
- Taxa that are less likely to be reliably detected using field survey methods include micro-organisms, aquatic species, nocturnal species, migratory species, and rare or cryptic species.

[21] Valentini, A., Taberlet, P., Miaud, C., Civade, R., Herder, J., Thomsen, P. F., ... & Dejean, T. (2016). Metabarcoding of environmental DNA samples to explore the effects of landscape and habitat on biodiversity. Molecular ecology, 25(7), 1661-1673.
[22] NatureMetrics. (2021, January 29). FAQs.
[23] The Amphibian d Reptile Conservation Trust provide guidance on best practice for surveying, from simple presence/absence surveys, to calculating population densities. https://www.arc-trust.org/survey-protocols.
[24] Duffus, N., pers. comm., 2023.
[25] https://www.bto.org/our-science/projects/breeding-bird-survey/taking-part/bbs-online
[26] Turner, R.K., Griffiths, R.A., Wilkinson, J.W. *et al.* Diversity, fragmentation, and connectivity across the UK amphibian and reptile data management landscape. *Biodivers Conserv* **32**, 37–64 (2023). https://doi.org/10.1007/s10531-022-02502-w
[27] The Amphibian d Reptile Conservation Trust provide guidance on best practice for surveying, from simple presence/absence surveys, to calculating population densities. https://www.arc-trust.org/survey-protocols.

4.3.3 Examples of field survey use in rewilding

- Often, field surveys will be focused on a particular species or taxonomic group. For example, alongside other ecological surveys, the NCL biodiversity workstream in year 3 involved an extensive fungal survey, where species identified were listed, and aspects such as proportion of fungi species per functional type (e.g. parasitic, symbiotic, saprotroph).
- At Knepp Estate rewilding project, certain surveys are carried out periodically (bird survey, butterfly survey, and annual herd inspection) and other, more species- or process-specific surveys and studies are conducted, such as wood debris analysis, ragwort surveys, turtle doves, and plant-pollinator relationships.
- Bunloit's Natural Capital report states that most of their data collection to date has been through in-field surveys. This includes mammal transects, targeted refugia-based surveys for amphibians and reptiles, pollinator surveys, and transect surveys for butterflies and moths.[28]
- At rewilding project Wild Ken Hill, a particularly comprehensive vegetation field survey was conducted, looking at structure and composition of vegetation. It was notable due to it being a standardised and repeated survey conducted over a large area – it demonstrated an average doubling of plant species richness over three years.[29]

Table 4.3 Advantages and limitations of field surveys

Advantages	Limitations
Easy to incorporate and apply contextual and local knowledge, as data collection is carried out by experienced ecologists.	Observer bias is a frequent issue – it is inevitable that different experts conducting the surveys will have different experiences, training and even priorities when it comes to field surveys.
Related to the above, this provides opportunity for nuanced, contextualised data and analysis which can be more cost effective to do for small sites like the NCL.	Field surveys are often limited by one habitat or group of taxa – it is uncommon that a wide range of ecological data can be collected in the same field survey.
One of the only biodiversity monitoring techniques unanimously trusted to provide data on abundance.	Survey costs vary significantly, and can be high[30], particularly or very remote or large sites. Additionally, increasing demand for ecological expertise is expected with the introduction of BNG policy and TNFD-related reporting requirements.
Useful for ground truthing results from other monitoring techniques and technologies. For example, comparing data from AirDNA that picks up fungal spores particularly with mycological field survey data.	Increasing costs are likely to limit the scope and frequency of surveys, and therefore affect the quality of data collected through these methods.
Well trusted methodologies that have been developed over decades.	Specific sampling designs, particularly for rare species, may not be cost-effective for wider biodiversity monitoring.

4.4 Citizen science

[28] Highlands Rewilding (2021). Natural Capital Report 2021 - Bunloit Rewilding.
[29] Wild Ken Hill. (2023, February 22). Rewilding boosts plant diversity.
[30] Lõhmus, A., Lõhmus, P., & Runnel, K. (2018). A simple survey protocol for assessing terrestrial biodiversity in a broad range of ecosystems. PLoS One, 13(12), e0208535. https://doi.org/10.1371/journal.pone.0208535

4.4.1 Description of citizen science

Citizen Science is scientific work, for example collecting information, that is done by the general public, in order to support the work of scientists.[31] Within the rewilding or biodiversity restoration field the involvement of the public is often in species detection. Species detection and reporting might be through ad hoc visual sightings (such as project splatter for road kill), purposeful actions to detect species such as installing camera traps (such as mammalweb) or participating in surveys (such as the Big Garden Birdwatch). The recent increase in public involvement in species detection is in part due to the rapid development of technology-based resources to help with species identification (apps such as iNaturalist), data collection (such as camera traps), data collation (such as iRecord) and the subsequent dissemination of results.

The technologies developed for citizen science are increasingly being utilised by conservation projects and organizations with limited resources. These technologies not only facilitate biodiversity monitoring but also engage communities. With the help of a mobile app, anyone interested in participating can take a photo, add the date, time, and location, and use recognition technology to suggest possible species identifications. A collaborative element is often integrated where experts and enthusiasts are involved to review photos and provide identification suggestions. This not only enhances knowledge sharing, as each observation is added to the overarching databases but also fosters a sense of shared environmental values. Participants have the option to join specific projects or create their own based on themes, locations, or species of interest. Platforms used in the UK include:

- iNaturalist: Allows users to upload photos and observations across a wide range of taxa (fungi, plants, insects, mammals, fish, etc) which are then identified by the community of users and used to create data for science and conservation. Users can also, join projects, peruse observations in other projects, and participate in challenges.
- iRecord[32]: Similar use and scope to iNaturalist.
- National Biodiversity Network (NBN): Its function is more focused on providing a central hub to connect information, participants and organisations in this space of citizen science. It doesn't have a specific recording platform itself.
- Open Air Laboratories (OPAL): Offers various projects and surveys related to biodiversity, including surveys on insects, trees, soil, and water quality.
- Nature's Calendar: Managed by Woodland Trust. Focused on recording seasonal changes in the UK, so mainly facilitating public involvement in identifying changes in flowering, leafing, migration and using these to help researchers understand the impact of climate change on species in the UK.

4.4.2 Taxa commonly detected

- Useful across a wide range of taxa – dependent on the interest of the public and niche wildlife groups.
- Birdwatching is a popular citizen science activity, focusing on visual and aural bird observations.
- Mammals like red squirrels, otters, and beavers are recorded, especially for behaviour observations.
- Plant species, flowering times, and habitats are frequently documented in citizen science.

[31] Cambridge Dictionary. (n.d.). Citizen Science. Retrieved September 20, 2023. from <https://dictionary.cambridge.org/dictionary/english/citizen-science>
[32] https://www.brc.ac.uk/irecord/

- Insects, including butterflies, bees, and dragonflies, are commonly observed and recorded.

4.4.3 Examples of citizen science use in rewilding

- The NCL has an account on iNaturalist, which is an online platform for recording species observed. The landowners are particularly active in using this, and volunteers and students have also participated during their visits by recording the species. The continued integration of iNaturalist into the biodiversity monitoring data will further enrich the insights on species richness and even abundance on the site over time.
- Organisations often offer specific training to take part in surveys for particular species, such as the Peoples Trust for Endangered Species offering training for surveying for water voles, and Nature Scot creating a user-friendly Scottish adder questionnaire for farmers and other landowners to be involved in contributing knowledge about their presence.[33]

Table 4.4 Advantages and limitations of citizen science

Advantages	Limitations
Public engagement, advocacy and creation of social value.	Ensuring data quality, consistency and accuracy can be a challenge.
Educational value creation.	Uneven sampling effort is common across a site – bias toward areas that are easily accessible or are particularly aesthetic.
Very cost effective, many of the platforms are free to use.	Can be challenges in terms of sorting, using and analysing the data.
Potentially high scale and coverage.	Biases in data collection leading to skewed representations of biodiversity, due to higher interest in finding charismatic species.
Can cover a large range of taxa, and large amount of data types, for example provide information on their distribution, abundance, behaviour etc.	Data might involve IP complexities related to data ownership, intellectual property rights, and data sharing agreements.
A range of types of platforms exist that can serve a range of different needs – from very broad to specialised.	Accurate species identification requires taxonomic expertise, and participants might not always be experts.
Can use both sound and visual inputs to identify species.	

4.5 Bio-acoustic monitoring

4.5.1 Description of bioacoustics

Bioacoustics is the study of environmental sound and can be used to identify individual species. This data can be used to gain a better understanding of many different aspects of wildlife populations such as distribution, physiological state and behaviour, as well as provide a more precise picture of their acoustic environment.[34] A biodiverse and healthy ecosystem will typically have a very saturated and complex soundscape, and assessing and quantifying these soundscapes is the objective of using bio-acoustic

[33] NatureScot, Amphibian & Reptile Conservation Trust (ARC), & Amphibian & Reptile Groups of the UK (ARGUK). (n.d.). Scottish Adder Survey.

[34] Ecosulis webinar. (July 12 2023). Ecology Technology: The Latest Tech for Surveys, Monitoring & Land Management

monitoring. An AudioMoth is a small, low-energy acoustic detector, that can be used for monitoring biodiversity and the environment. They can be programmed to monitor wildlife populations by recording the calls of specific target species and can handle both audible and ultrasonic sounds (therefore useful for monitoring bats and other hard-to-detect species).

4.5.2 Taxa commonly detected

- Very commonly used to identify birds and bats.
- Less commonly used, but effective for monitoring frog and toad species.
- There are already some examples of insect-specific bio-acoustic devices becoming available[35], and likely will develop further as the demand for biodiversity monitoring in agricultural environments increases.
- Soil bio-acoustics is a new and developing field as well, and but yet to be utilised in restoration substantially.[36]

4.5.3 Use of bioacoustics in rewilding

- The British Trust for Ornithology (BTO) Acoustic Pipeline is an open source, desktop program that provides a space to upload audio recordings, and a website where you can review and analyse recordings. It uses algorithms to automatically identify species within the recordings, mining the data for information on species distribution and abundance. It is particularly useful for assisting with large scale bat call sound analysis.
- Carbon Rewild is a company that specialises in bioacoustic monitoring. They provide bat surveys and bird surveys, and specialise in monitoring following species introductions, and rewilding activities in general.

Table 4.5 Advantages and limitations of Bioacoustics

Advantages	Limitations
Very light touch and non-invasive, eliminating potential stress on species.	Limited to detecting species that generate sound.
Can enable 24/7 monitoring and be deployed for long periods, weeks or months at a time.	If monitoring target species, very noisy environments can mask the sounds that need to be captured.
Data can be stored and analysed retrospectively for different taxa (depending on programmed settings of the device).	To process the often-large amounts of data, ai tools and statistical modelling are needed.
Can be programmed to specifically pick up certain frequencies (e.g. echolocations by bats) or broader soundscapes.	When using AI and identification algorithms, data must be tested and ground-truthed using more traditional methods.
Especially helpful in detecting species that are difficult to observe visually.	Accuracy of detection is affected by the volume of the noise, and the distance between recording device and species.
Is scalable and repeatable.	Specialised expertise is required to analyse the data.

[35] Polly, by AgriSound is a model of acoustic recording device designed to attract and record pollinators specifically
[36] Robinson, J. M., Breed, M. F., & Abrahams, C. (2023). The sound of restored soil: Using eco-acoustics to measure soil biodiversity in a temperate forest restoration context. Restoration Ecology

Data can be used to compile species presence lists for species richness.	Less effective at providing data on distribution and abundance of populations. (Though possible if sample grid and analysis is planned from the outset).
	Costs of passive acoustic monitoring can be immense and include buying equipment, deploying and retrieving recorders, and downloading, storing and analysing data.[37]

4.6 Light Detection and Ranging (LiDAR)

LiDAR is a technology that uses lasers to measure distances, creating detailed 3D images of vegetation and landscapes. Currently, LiDAR and other drone-collected remote sensing data are primarily used for carbon quantification. In particular circumstances and taxonomic groups, LiDAR measures can be used as proxies for biodiversity.[38] Its primary application in biodiversity lies in providing valuable information about vegetation and habitat structure, rather than directly measuring species.[38] Due to a current difficulty in identifying plant species or age classes, any habitat estimates are limited to broad categories. However, there are ongoing developments in hyperspectral sensors that aim to address these challenges, including developing capacities in the observation of species, age classes and vegetation health.[39] For instance, Pixxel, a space data company, plans to launch a satellite constellation offering 10-meter resolution (with future plans for 5-meter resolution), which could greatly enhance habitat structure mapping capabilities such as identifying microhabitats which are critical for many species.[40]

[37] Sugai, L. S. M., Desjonquères, C., Silva, T. S. F., & Llusia, D. (2019). A roadmap for survey designs in terrestrial acoustic monitoring. Remote Sensing in Ecology and Conservation, 5(4), 323-337.
[38] Moeslund, J. E., Zlinszky, A., Ejrnæs, R., Brunbjerg, A. K., Bøcher, P. K., Svenning, J. C., & Normand, S. (2019). Light detection and ranging explains diversity of plants, fungi, lichens, and bryophytes across multiple habitats and large geographic extent. Ecological Applications, 29(3).
[39] Downey, I., pers comm., (Aug, 2023).
[40] Pixxel. (2021, August 4). Pixxel to launch 5 satellites in 2022, aims to democratize access to space-based data.

5. Biodiversity metrics

This section delves into the intricacies of the biodiversity metric concept, examining its diverse interpretations and applications across various sectors and users. A working definition of a biodiversity metric is elaborated, as well as a delineation of the ways in which conservation and rewilding initiatives use and approach biodiversity metrics and how this differs from - and is linked to - metrics being developed for the use in emerging nature markets and the private sector.

5.1 Defining a biodiversity metric

Biodiversity metrics are designed to provide more objective and standardised ways of evaluating ecological change in relation to species, their composition and abundance, their natural habitats and the processes that take place within ecosystems. They will play an increasingly important role in ecological research, conservation efforts, and environmental management, providing valuable information for decision-making and policy development aimed at preserving and enhancing biodiversity. Despite the growing interest in the topic, there is a current lack of a widely accepted and standardised definition of what a biodiversity metric is – both in terms of what biodiversity is meant to represent, and the operational meaning of a metric.

5.1.1 Defining biodiversity

The relationship between ecological integrity and biodiversity is complex, and this lies at the heart of the issues surrounding biodiversity metrics. The lack of a universally agreed definition of biodiversity provides metric developers with various options of how to define it. We take a broad definition of biodiversity based on the IUCN's definition that refers to the condition of ecosystems including species, diversity, processes and function, ecosystem diversity and genetic variability[41]. Therefore, for this review, we define a biodiversity metric to be a quantitative measure that tracks changes in the state of biodiversity (that is, relating to species, function, ecosystem, genetic, or a combination of these) or ecological health more broadly. This approach aligns with the prevailing global discourse, where terms like biodiversity uplift, nature recovery, ecological restoration and other related terms are often used interchangeably.

5.1.2 Comparing metrics and indicators

Within literature and particularly in the policy sphere, the terms biodiversity indicator and biodiversity metric are frequently used interchangeably. There is a subtle distinction however that will help to contextualise the findings of this review. Biodiversity indicators, as the name suggests, are measurable characteristics or parameters of one aspect of biodiversity, that are used to indicate or reflect something about the broader ecological system. In short, they are smaller aspects or parameters that provide insight into the larger picture. For example, the number of breeding birds present on a conservation site is commonly deemed to be a good indication of an ecosystem's health and diversity, and therefore breeding bird surveys may be conducted to track progress in conservation and rewilding based on this one indicator.

Metrics are generally more comprehensive – they aim to represent the overall state of biodiversity and ecological health, rather than indicate changes in isolated variables that imply biodiversity condition. Metrics are often – though not always – multi-dimensional, aiming to incorporate a range of indicators or aspects of biodiversity and bundling them into formulae to generate quantitative outputs. They can also be data-intense modelled metric approaches and even pluralistic measures, where the components included are

[41] IUCN. (2001). IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

not integrated but considered together in parallel. Metrics may also be relatively straightforward and unidimensional (the Simpson's index, for example, see section 7 for more information), which can result in the confusion with indicators.

5.2 Uses and purposes of biodiversity metrics

It is important for anyone adopting a biodiversity metric to fully understand the main purposes and uses they can be put to, as well as the ways in which it may be appropriate to apply them in different contexts.

Numerous biodiversity metrics are evolving in parallel with - and as a response to – advancements within nature-related finance, including impact investing, ESG reporting, and the TNFD. However, aside from these private-sector facing objectives, rewilding and conservation projects also use, develop and apply different indicators and metrics for tracking progress.

Therefore, two categories are outlined below, and further illustrated in Figure 5.1.

1. **Metrics used to track biodiversity uplift for the purpose of guiding management decisions,** planning of rewilding and conservation activities (such as the priorities and timing around species reintroductions) and stakeholder engagement.
2. **Metrics used to facilitate financial and policy objectives** around nature recovery, including ESG, impact investing, Biodiversity Net Gain policy and emerging markets for biodiversity and other ecosystem services.

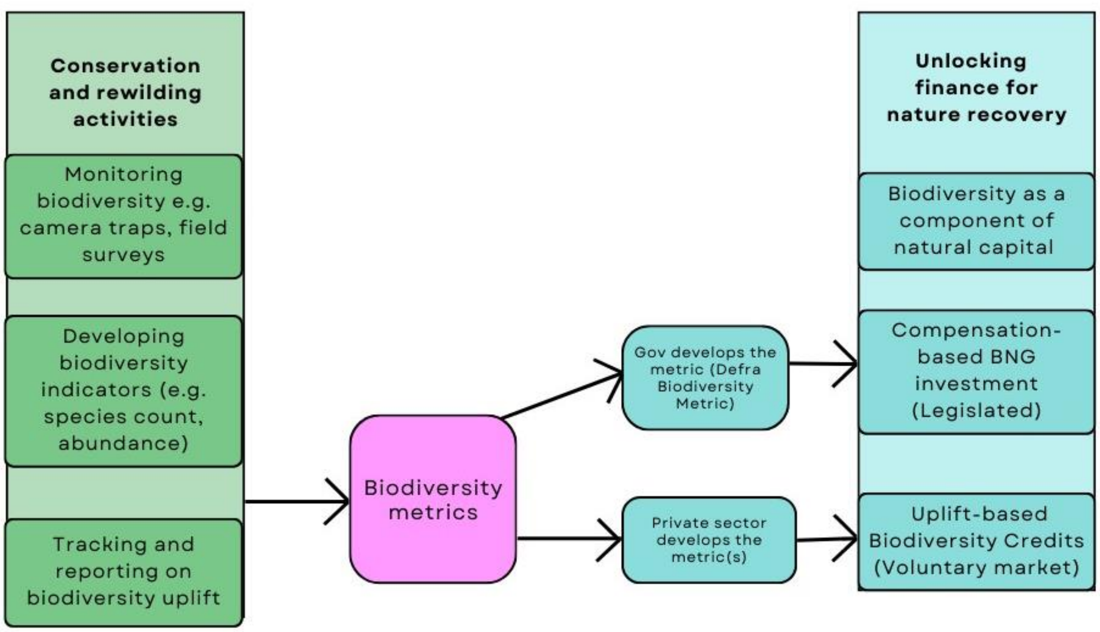

Figure 5.1 A conceptual map showing some of the connections between rewilding and conservation, biodiversity metrics and mechanisms for unlocking of finance for nature recovery in the UK.

The green column on the left outlines activities undertaken by rewilding/conservation projects or landowners to monitor environmental changes over time. Rewilding groups choose monitoring methods based on expertise, resources, and ecological goals. They select indicators to track progress, sometimes packaging data to suit communication needs. Reporting biodiversity may involve using collected quantitative or qualitative information, such as that reported by previous NCL biodiversity monitoring reports. The blue column outlines how biodiversity metrics facilitate the streamlining and scaling of financial mechanisms to support nature recovery.

If the metric is linked to potential finance, there are more risks associated with 'gaming' the situation (i.e. manipulating the metric to cut costs and efforts needed create the uplift and financial returns). This means that metrics developed with this purpose will not only be looking at how best to represent biodiversity and ecological health from a scientific point of view, but also be thinking about how to ensure there are no loopholes and easy ways for a project developer to manipulate the metric and data to maximise financial outcomes. This in turn impacts decisions around monitoring and data collection. On the other hand, when a rewilding or conservation project is looking to adopt or create a metric for the purpose of tracking progress and guiding restoration decisions, there is more flexibility to choose indicators and monitoring methods, as there are no competing interests with regards to the use of the metric (i.e. no tensions between maximising financial return versus maximising biodiversity outcomes).

6. Criteria for adopting a biodiversity metric for the NCL

For the NCL, our aim is to find a biodiversity metric that can effectively demonstrate changes in biodiversity on-site over time and ideally, the learnings from applying this metric can be utilised by other rewilding projects. Ideally, such a metric could also assist us with finding ways to quantitatively report on and ascribe value to biodiversity changes over time as part of our natural capital accounting. We are approaching this question from the position of being agnostic to the financial opportunities, and instead exploring metrics from the viewpoint of understanding:

- What would be suitable for a rewilding site?
- What is compatible with the currently implemented monitoring systems and resources? And;
- What can effectively track progress towards a diverse and intact ecosystem?

In order to choose a metric or metrics to trial at the NCL, we identified key criteria that metrics could be compared against. These criteria were classified into both practical NCL-related considerations and more conceptual and scientific considerations (provided through discussions with experts and practitioners), outlined below.

NCL - specific considerations

The following criteria were identified as essential for guiding the choice of a metric which will suit the characteristics of the NCL site, the philosophy and objectives that the NCL is designed around, and the practical implications of adopting a metric to track progress. These are summarised as:

- Flexibility of the approach or metric to suit our data collection methods.
- Size and habitat appropriate – it needs to be able to show change across a 100-acre site, and be compatible with the rewilding dynamics of the NCL where habitats are being actively converted.
- Metric is able to be applied using open-source methodology guidelines and resources.
- Aligns with the philosophy of the NCL and the knowledge the project seeks to create, categorised as:
    - The use of the metric is compatible with a rewilding approach to conservation.
    - The use of the metric facilitates knowledge-sharing and learning and is aligned with innovation and pioneering approaches to natural capital and rewilding.

Conceptual considerations

As mentioned previously, the NCL is a risk-tolerant space to pioneer new ideas, approaches, technologies and ideas regarding rewilding and measuring value. Therefore, it made sense to consider the gaps and concerns around biodiversity metrics that arose from thematic analysis of discussions with practitioners and experts, to see if we could contribute to learnings in this area.

Three central themes arose regarding aspects of biodiversity and ecological health that are critical, but sometimes overlooked when aiming to measure holistic progress. These were structure (usually some measure of habitat), composition (usually pertaining to species and their relative abundances) and function (focused on processes and complexity within an ecosystem). Nuanced perspectives and further elaborations on these themes are provided in section 8, but they are summarised here in the form of guiding principles for choosing a metric for the NCL (point *i*).

As the NCL is not imminently looking at participating in the biodiversity credits market, there is the opportunity to consider adopting a pluralistic metric – meaning a way of measuring biodiversity that includes multiple, conceptually incommensurable attributes of biodiversity and ecological health that may be considered alongside each other, rather than 'collapsed' into a single number or index (point *ii*).

Principles:

i. Ideally, the metric incorporates a measure of structure, composition, and function of the ecosystem.
ii. Holistic in its capacity to reflect biodiversity in different dimensions – potentially a pluralistic metric.

7. Review of metrics

After conducting an initial broad assessment of metrics relevant to the UK, including those already established or nearing final development, a subset of metrics was selected for review. This section provides a summary of these chosen metrics. A thematic approach was taken here in an attempt to categorise metrics by focus and/or purpose. Therefore, the section begins with species-focused metrics, followed by rewilding-focused, then finance-focused, and policy-focused.

7.1 Foundational species-focused metrics

There are a multitude of biodiversity metrics that calculate, in different ways, biodiversity using information about the species that are present at a site.[42] These differ in complexity and what they focus on – some measure the number of species as well as abundances, others focus on community composition. The following aims to be a representative sample of such metrics, including those commonly referenced within academia and known to be included as part of larger multi-metrics described later.

7.1.1 Simpson's Diversity Index

The Simpson's Diversity Index and Shannon's Diversity index (below) are similar in that they provide information about the structure of an ecological community with regards to species composition. The Simpson index gives more weight to common or dominant species, due to the way the formula is structured:

$$D = 1 - \sum (pi)^2$$

Where *D* represents the Simpson Diversity Index, and p_i represents the proportion (or relative abundance) of each species in the community. The formula gives more weight to the proportions of dominant species, essentially reflecting their influence. Consequently, rare species with only a few individuals exert minimal impact on the diversity index. The concept of dominance carries different ecological implications depending on the context. In some ecosystems, dominant species play crucial roles in maintaining stability, while in others, dominance by invasive or non-native species can negatively affect biodiversity.

7.1.2 Shannon's Diversity Index

The Shannon's Diversity Index is a mathematical measure of species diversity in a given community, and is the most commonly used diversity index in ecological science.[43][44] The index is calculated using a formula that accounts for species richness and how similar species' abundances are in an environment (evenness).[45] Higher values indicate higher diversity, because they reflect both the presence of a greater number of species and a more even distribution of individuals among those species. The value of H (the Shannon Diversity Index) ranges from 0 to 1. Data required to calculate the index include the list of species, and abundance data. Shannon's Index involves the use of natural logarithms (ln), adding a mathematical complexity that is absent in Simpson's Index. The 'ln' transformation allows the index to capture the nuances of evenness and rarity more effectively.

[42] Balmforth, Z., pers. comm., (July, 2023).
[43] Thukral, A. K., & Bhardwaj, M. (2019). New indices regarding the dominance and diversity of communities, derived from sample variance and standard deviation. Journal of Environmental Biology, 40(5), 1015-1020.
[44] Roswell, M. (2021). A conceptual guide to measuring species diversity. Oikos, 130(10), 1609-1623.
[45] Biology LibreTexts. (2023). Diversity Indices.

Simpson's index and the Shannon's index require data on the number of individuals of each species present in the community. Some have argued that the Shannon and Simpson indices might not be useful for large-scale monitoring of diversity intactness, due to conservation and rewilding efforts often interested in rare and endangered species and these indices not being very sensitive to changes in the abundances of rare species.[46] This is because rare species, by definition, have low abundances, and their contributions to these indices are relatively small. As a result, changes in the abundances of rare species may not strongly influence the overall diversity score calculated using these indices.

7.1.3 Hill Numbers

Hill numbers are a type of biodiversity metrics that provide their own measures of diversity as well as be used to unify and refine other biodiversity metrics, including species richness, Shannon's diversity index, and the Simpson's index. The versatility is achieved by adjusting a parameter, q. When q is set to 0, it emphasises species richness, resembling a measure closer to Simpson's index, and as q approaches 1, the emphasis shifts toward the evenness of species abundances, akin to Shannon's index. As q increases beyond 1, it places greater importance on the most abundant species, effectively giving more weight to the dominant members of the community. The q parameter within Hill numbers' construction allows researchers to fine-tune the aspect of diversity they want to emphasise, providing flexibility in exploring different facets of ecological diversity, according to specific questions or priorities.

7.1.4 Use in the field

These indices are not commonly utilised in monitoring plans of rewilding and ecosystem restoration projects. In discussions with experts in these fields, the terms are familiar to some but tend to be viewed as more in the realm of academic ecology. There are some barriers to their usefulness which contribute to the lack of practical use for on-site management and monitoring. For example, the indices require a sufficient number of individuals or species to be able to provide a meaningful overview of biodiversity, so the sample size needs to be large enough to allow for this volume of data to be incorporated. The indices are also very sensitive to differences in sampling effort - areas with higher sampling efforts will dominate the results, leading to biased estimates. Shannon's index is also sensitive to rare species, in that where there are very few individuals of certain species, they can disproportionately influence the index, potentially leading to misleading results. It is typically applied to specific taxonomic groups only, like 'plants,' 'butterflies,' or 'freshwater invertebrates,' rather than encompassing all aspects of diversity. Other indicators would need to be considered that reflect genetic, functional, and habitat diversity, which can be essential in specific ecological contexts.

However, several nationwide biodiversity initiatives involving the monitoring of biodiversity have incorporated the use of these indices, including: the UK National Ecosystem Assessment (NEA) used the Shannon index and Simpson's index to assess changes in biodiversity across different ecosystems in the UK; the UK Butterfly Monitoring Scheme (UKBMS); UK Bat Monitoring Programme (BMP); and the UK Breeding Bird Survey. UNEP-WCMC also developed the Biodiversity Intactness Index, based on Shannon's Index.[47]

To make the application of the Shannon's and Simpson's indices more user-friendly, some people have developed useful 'packages' for use in data analysis software such as *R,* for example 'the *vegan* package' and 'the *BiodiversityR* package'. For projects looking to test the index in their context and monitor its change over time, there are very easy to use online calculators that a user can input simple abundance data (for

[46] Lamb, E. G., Bayne, E., Holloway, G., Schieck, J., Boutin, S., Herbers, J., & Darimont, C. T. (2009). Indices for monitoring biodiversity change: Are some more effective than others? Environmental Monitoring and Assessment, 176(1-4), 37-45.
[47] UNEP-WCMC. (n.d.). World Database on Protected Areas Access. UNEP-WCMC.

up to 40 species)[48][49]. PV-Nature Methodology incorporates the Hill number into their overall multi-metric comprising 4 metrics, and this is elaborated further in section 7.2.3.

7.2 Financially-orientated biodiversity metrics

Without robust and standardised metrics, biodiversity markets and credits will lack credibility, which has led to a huge amount of investment and research in this area from the private sector and organisations positioning themselves as intermediaries between available finance streams and reputable projects/initiatives restoring ecosystems. Several UK-relevant developers of biodiversity metrics aiming to facilitate voluntary biodiversity credit markets were identified throughout the process of the review, and these are summarised in this section. The Defra biodiversity metric 4.0 is also included in this section as it is related to finance though through a legislated rather than voluntary market for biodiversity. The biodiversity market in England is driven by the government's Biodiversity Net Gain (BNG) strategy and is enforced through the 2021 Environment Act as the first scheme to establish a biodiversity marketplace at the national level. BNG is designed to ensure property developers' projects deliver at least a 10% gain in biodiversity, following a mitigation hierarchy.[50] Additionally, new schemes are being announced at an accelerating pace which differ significantly in terms of what they offer and their theoretical underpinnings.[51]

7.2.1 Operation Wallacea (rePLANET) - Methodology for Awarding Units of Biodiversity Gain

The Wallacea Trust has developed a methodology for measuring change in biodiversity that is based on the logic underpinning the Consumer Price Index (CPI)[52] (one of the main measures countries use to monitor changes in price inflation). The purpose of the metric is to enable measurement of biodiversity changes on project sites and translate those (positive) changes into awardable biodiversity credits. The CPI identifies baskets of goods and services that represent typical spending in that country, and measures changes in prices of that basket of goods to determine inflation rates. Although the baskets of goods that are typical and are used for each country are not directly comparable, the resulting inflation figures can still be compared to get a picture of economic performance across countries. The biodiversity equivalent of this logic, as posited by Wallacea Trust, is that by identifying a representative 'basket of taxa' for project sites, quantitative comparisons of biodiversity 'inflation' between sites are possible. This ability to compare biodiversity uplift using this inflation model makes biodiversity credits comparable across contexts; applicable for any ecosystem and country worldwide. Each taxa metric should incorporate some measure of species richness, species importance (i.e. conservation status) and relative abundance or biomass (depending on what's most appropriate for that species).

Biodiversity credits are awarded per 1% of uplift (or avoided loss) in biodiversity per hectare. This is represented by the median value across all 5 taxa for which change in per cent terms is calculated. To illustrate with an example, if the 5 taxa chosen to represent a project area or site of interest were amphibians, reptiles, birds, mammals and invertebrates, and these had experienced a 5%, -3%, 5.5%, 10% and 1% uplift per ha in these metrics respectively, the biodiversity units of gain awarded to the project would be 5 per ha. The pricing of these would be largely contingent upon project operation costs, to ensure additionality.

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[48] For example, https://www.omnicalculator.com/ecology/shannon-index
[49] For example, https://www.statology.org/shannon-diversity-index-calculator/
[50] The mitigation hierarchy is a tool used in environmental best-practice in development projects whereby avoiding and minimising any negative impacts is prioritised, followed by restoring sites no longer used by a project, before finally considering offsetting residual impacts.
[51] Gradeckas, S., (2023), Deep Dive: Biodiversity Credit Schemes | Part 1. Bloom Labs.
[52] Consumer Price Index is one of the main measures countries use to monitor changes in price inflation

For selling biodiversity units of gain, a reference site is needed – one that represents the upper limit of the abundance and species richness values potential for the site in question, and ideally as close as possible to the habitat structure and composition as the study site. This is only a requirement if selling credits, however, as it helps with forecasting finance potential and setting long term objectives of the site. If not selling credits, as in the case for the NCL, the taxa metrics and abundance levels can be measured from the baseline, taking the log of the abundance counts.

Wallacea Trust's methodological guidelines are openly accessible, allowing rewilders and restorationists to adopt the metric logic to help them track change on their site. Furthermore, the use of the median to represent overall biodiversity uplift is optional outside of the financial realm, so it could be applied to a site looking for a holistic and pluralistic approach to measuring biodiversity. The methodology is flexible - it allows the user to apply any metrics, measuring any taxa that they deem appropriate, as long as there is justification given. This is reviewed by the Biodiversity Futures Initiative – an international group of academics able to provide independent reviews of biodiversity credit claims.

In discussion with the developer of the metric, an example basket of metrics for the NCL was loosely devised to demonstrate how the metric scaffolding may work in practice for our context[53] (table 7.1).

Table 7.1 Example basket of metrics for the NCL using Wallacea Trust methodology.

Taxa and metric	Data collection/measurement
Natural England biodiversity metric 4.0	Measure uplift in habitat area and condition
Species richness and biomass of arthropods (excluding butterflies), to measure changes in food availability for insectivorous birds	Field surveys – e.g. Fixed time active searches with sweep nets and pooters weep netting, pitfall traps
Butterflies and moth species richness and abundance	Field surveys – e.g. Pollard counts
Changes in breeding birds on site	BTO Breeding Bird Survey
Species richness and abundance of Higher Plants	Field surveys – 0.5m quadrats x 15 per hectare, stratified across habitats
Herpetofauna species richness and abundance	Cover boards and timed active searches

7.2.2 CreditNature - Natural Asset Recovery Investment Analytics (NARIA) framework

CreditNature's Natural Asset Recovery Investment Analytics (NARIA) framework was developed as a response to the need for robust representations of ecological change and uplift, with a strong bend toward fintech (financial technology) and alignment with both landholder and investor preferences and requirements. CreditNature Ltd is a spin-off company, born out of Ecosulis Ltd innovation team. Rewilding science and principles are strongly represented in the set of metrics and overall model that they have designed. The concepts utilised in building the framework draw on advances in long-term and functional

[53] Coles, T., pers. comm., (July 2023) rePLANET

ecology, earth-system science, and complexity theory, which is aligned with literature on rewilding as an approach to ecosystem recovery that focuses on restoring ecosystem integrity and resilience.[54] [55]

From the data fed in, the NARIA framework conceptualises land as an asset that is 'engineered' by human land management practice which impacts ecosystem integrity, and which can give rise to increases in biodiversity and ecosystem services. The framework currently includes an ecosystem integrity index and ecological land management rating. The Ecological Integrity Index (EII) adopts the architecture of the Human Development Index and measures four dimensions of ecosystem integrity. Three of these are taken from Perino et al[56] and CreditNature has added a fourth – niche turnover, which contributes to the recovery of biotic structures and processes.

The metrics included in the NARIA framework are normalised to a figure of 1-100 and combined to produce the EII. The EII scores are reported with a confidence rating based on a rating given to input data quality. Percentage point uplifts per hectare in the index evidence Nature Impact Units (an ecosystem recovery credit), which are linked to ownership of a Nature Impact Token. These tokens facilitate direct investment in land assets on which commitments are made to adopt ecological land management that is nature-positive, guided by rewilding principles, rather than biodiversity per se.

CreditNature has submitted its EII for independent scientific accreditation and a Biodiversity Index is under-development to extend the NARIA framework. Table 7.1 outlines the dimensions of ecological integrity that underpin the logic behind the NARIA framework, as well as some information around the metrics that represent these dimensions.

[54] Fernández, N., Navarro, L. M., & Pereira, H. M. (2017). Rewilding: A call for boosting ecological complexity in conservation. *Conservation Letters*, *10*(3), 276-277.
[55] Pedersen, P. B. M., Ejrnæs, R., Sandel, B., & Svenning, J. C. (2020). Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAAIL): A framework to link conventional conservation management and rewilding. *Ambio*, 49(1), 231–244.
[56] Perino, Andrea & Pereira, Henrique & Navarro, Laetitia & Fernández, Néstor & Bullock, James & Ceausu, Silvia & Cortés-Avizanda, Ainara & van Klink, Roel & Kuemmerle, Tobias & Lomba, Ângela & Pe'er, Guy & Plieninger, Tobias & Benayas, José & Sandom, Christopher & Svenning, Jens-Christian & Wheeler, Helen. (2019). Rewilding complex ecosystems. Science. 364.

Table 7.2 Overview of metrics included in the NARIA framework

Dimension	Description	Rationale for inclusion	Metric used to measure dimension	Data requirements
Dispersal	The movement of organisms across landscapes, which facilitates movement of seeds and nutrients, creates natural disturbance and enables new populations of species to be established.	Dispersal is essential for ensuring genetic diversity across species and is essential for increasing bio-abundance. Connected landscapes means better dispersal.	**CreditNature Landscape Connectivity Metric** – CreditNature have adapted an established connectivity metric to measure the ability of focal species (dispersal agents) to move within a defined area. Combines data layers on linear barriers (roads, fences), and land uses (farms, urban areas) that impact connectivity. Includes measuring permeability of barriers for focal species.	Map of barrier types, derived from e.g. open-street map and iterative mapping interviews.
Natural Disturbance	The creation of microhabitats through random disturbance - abiotic or biotic - in a landscape. Initially, manifests as complexity in vegetation distribution, driving other types of diversity.	Enhances ecological integrity through nutrient cycling and succession, microhabitat diversity, and driving adaptation and evolution of species.	**Vegetation Spatial Diversity Metric -** CreditNature have adapted an establish metric used in landscape ecology to measure disturbance effects. Uses spatial classifications and applies these to habitat layers to quantify distribution of different vegetation types across the landscape. Based on landscape ecology.	Vegetation maps derived from standard habitat maps, satellite imagery or drone-mounted photogrammetry.
Food web complexity (Trophic cascades)	Complexity in food webs is reflected in the presence of multiple trophic levels, and with many different organisms occupying the levels of producers, consumers, and decomposers.	CreditNature's focus for this aspect is on restoring guilds of free ranging large-bodied animals, due to human activities particularly influencing this trophic	**Trophic Function Metric -** CreditNature have re-developed and extended a trophic function metric, using a trophic function index developed by iDiv (German Centre for Integrative	Mega-herbivore presence/absence, abundance and distribution data, derived from direct counts, wildlife/camera trap surveys, ranger interviews etc.

		level. They have based this on trophic rewilding research from Svenning et al 2022.	Biodiversity Research) as the basis.	
Niche Occupation	Describes the process of niches becoming occupied and reoccupied by local species pools. A species pool represents the entire set of species that could potentially inhabit or colonise a particular ecosystem or habitat. It is an emergent property of an ecosystem.	Included to reflect the complex interactions that occur between organisms and their environment, and is therefore indicative, indirectly, of functional diversity.	**Bird Trait Diversity metric** - this measures changes in diversity of morphological and behavioural traits of birds present at the site. It is calculated from data on bird species presence and absence, and linked to species functional traits.	Bird presence and absence data, sourced from online repository, survey reports, field surveys.

7.2.3 Plan Vivo (PV) Nature Methodology

The Plan Vivo Foundation, in partnership with Pivotal, have developed the PV Nature Methodology, which underpins Plan Vivo's Biodiversity Standard, PV Nature. The methodology aims to be statistically meaningful at scale, underpinned by Pivotal's contribution as a biodiversity data analytics company that uses an innovative 'Measurement, Reporting and Verification' (MRV) stack including various types of imagery, bioacoustic sensors and machine learning algorithms to collect and analyse biodiversity data. In this way, Pivotal's role is primarily to provide ways to streamline the collection, aggregation and analysis of big data, rather than focusing solely on developing an all-purpose metric. This data pipeline makes detailed third-party auditing possible, enabling verification of high integrity biodiversity outcomes. Plan Vivo is an internationally-recognised Scottish charity that facilitates the creation of high integrity carbon (and now biodiversity) certificates. They are particularly established in the Global South but are exploring options globally, including potentially the UK.

The co-developed methodology will underpin the creation of Plan Vivo Biodiversity Certificates which will operate as an incentivisation mechanism to make biodiversity conservation and restoration financially viable for communities and landowners. This is distinct from the voluntary carbon market – which typically is an offset-based approach that provides a mechanism to compensate for damages (measured in CO_2 emissions).

The methodology comprises four pillars:

i) Pillar 1: Species Richness

ii) Pillar 2: Species Diversity

iii) Pillar 3: Taxonomic Dissimilarity

iv) Pillar 4: Habitat connectivity or rugosity

The specifics regarding what these aim to measure, and the methods for doing so, are elaborated in Table 7.2.

Table 7.3 Overview of metrics included in the PV-Nature Methodology

Pillar	Description	Rationale for including	Measurement description
Species Richness	The number of unique species at a site.	Generally, a positive relationship exists in ecosystems where greater species richness enhances ecosystem functionality and resilience.	Species richness is calculated for each of several specified target groups (groupings of taxa) individually, and then the richness values for the target groups are summed together.
Species Diversity	An ecological concept that accounts for both the number of species, and the distribution of the relative abundances of each species.	Factoring in species' relative abundances is vital, as site recovery often entails natural shifts in species distribution.	The metric scales intuitively and has common units of 'effective species', which means it can be calculated for each target group and then the results summed to obtain a site-level metric.
Taxonomic Dissimilarity	Taxonomic dissimilarity measures how 'far apart' species are in the taxonomic tree. The metric considers both the distances between species and their relative abundances.	Healthy ecosystems, with diverse habitats and roles, typically support a wider range of species and functions than less healthy, more uniform ecosystems.	The average taxonomic distance is calculated for every pair combination of species in each target group (i.e. group of species type or taxa). This is based on Clarke & Warwick's (1998, 2001) metric Δ^*. These target group calculations are then aggregated to the site level, involving some weighting according to relative species richness.
Habitat Connectivity (terrestrial sites) or Rugosity (marine sites)	Rugosity refers to the level of variation, complexity, or unevenness in the physical structure of an ecosystem's surface. Connectivity refers to the area and connectedness of patches of natural and low-human-use habitats across a site.	When natural habitat patches within a site are larger and well-connected, the site's ability to support biodiversity improves. Increases in habitat structural complexity improve the area available for species to inhabit.	The CPLAND index (for terrestrial habitats) is used to measure degree of connectivity between habitat patches on a site. It is measured in percentage, and responds to spatial arrangement of habitat patches, and total area of low-intensity-use habitats. Rugosity (for marine habitats) is used to measure three-dimensional habitat structural complexity, and is equal to the ratio of the habitat's surface area to its projected planar area.
Multimetric	The multimetric is based on the yearly percentage change in the four pillar metrics.	Using multiple biodiversity metrics in a multimetric approach helps to better track and understand changes in biodiversity factors, compared to using a univariate measure.	The multimetric is the cumulative sum of the year-on-year percentage changes in the four pillar metrics.

7.2.4. Verra Biodiversity Standard

Verra is currently in the process of creating a biodiversity methodology within its Sustainable Development Verified Impact Standard (SD VISta) Program. This forthcoming methodology aims to facilitate an impartial evaluation and verification of tangible biodiversity benefits, certifying nature-positive investments accordingly.

Verra is considering the possibility of stratifying ecosystems based on their significance (in a similar way to the Defra metric incorporating a score based on distinctiveness) although more information about this will be available later in 2023. Moreover, they are exploring ways to integrate threat baselining, risk, and threat reduction into their metrics, acknowledging the real changes happening in biodiversity and the challenges posed by climate change and wildfires. As for the biodiversity standard, it may not be solely global but could also be tailored to specific ecoregions or ecosystems to enhance comparability across different contexts. As of August 2023, Verra are compiling a pipeline of pilot projects to test and refine their framework.

7.3 Metrics from regulatory bodies and conservation governance

The post-2020 Global Biodiversity Framework was developed under the Convention on Biological Diversity, hosted by the United Nations Environment Programme. It aims to establish new goals and targets for addressing biodiversity loss beyond 2020, focusing on halting biodiversity loss, restoring ecosystems, and integrating biodiversity with sustainable development. Its emphasis on biodiversity-related reporting, accountability, and global cooperation makes it one of the important frameworks in the policy space, and is what parties to the CBD will need to report against. The post-2020 Global Biodiversity Framework does not prescribe specific indicators or metrics but encourages countries and stakeholders to develop their own indicators and metrics that align with the framework's goals and reflect their unique circumstances and priorities. Within this context, national and international indices and metrics have been developed, some of which are outlined below and which differ in their applicability to site level progress tracking on biodiversity.

7.3.1. The Biodiversity Metric for use in Biodiversity Net Gain – Defra, Natural England

Perhaps attracting the most attention within the discourse of biodiversity metrics within the UK is Defra's Biodiversity Metric 4.0, developed in accordance with the Environment Act introducing a biodiversity net gain condition for planning permissions in England. To meet this net biodiversity gain requirement, developers will need to measure biodiversity losses and gains as part of the planning approval process and will be required to use the Defra metric which involves a Microsoft Excel-based tool and accompanying user guide published by Natural England.[57] This habitat-based metric is designed to be simple to use and allows developers to assess their proposed development's impact on habitats and plan for on-site biodiversity improvements to achieve a 'net-positive' outcome. Apps such as *coreo* are often adopted by users to make the process more streamlined and user friendly.[58] Biodiversity Net Gain pertains solely to England, though Scotland is in the process[59] of assessing the risks and opportunities afforded by implementing similar legislation.[60]

The Biodiversity Metric does not explicitly measure species – the tool is based on assessing an area of land, and classifying its habitat type, condition, and distinctiveness to get a score. It incorporates a range of data sources but employs UKHab survey methodology as the basis of its scoring, estimating biodiversity uplift from habitat data by assigning biodiversity units per hectare to different habitat types. Several multipliers are then applied to the base score depending on the type of habitat, accounting for its condition and the fact that habitat creation is a process that takes time and involves certain risks that can impact the probability of the newly created habitat being established and maintained in the long run.[61]

One of the reasons for the adoption of a habitat-based approach in the Defra metric, as opposed to a metric which focuses on composition (like species richness or species diversity), is to address concerns around developers being rewarded for claimed biodiversity uplift based solely on species observations on their land, even if the actions taken on that land were unrelated or even detrimental to nature recovery overall.

[57] Natural England. (2023). The Biodiversity Metric 4.0 .

[58] Coreo is a UKHab and BNG survey app for ecologists, automating habitat feature area and linear feature length calculations for use with the Metric 3.1 Calculator Tool and applying updated scoring rules from Defra's Biodiversity Metric version 3.1.

[59] As of Sept 5, 2023

[60] It is anticipated that the published report outlining the options and learnings will be available mid-September 2023.

[61] The Green Book discount rate is applied to all assessments, and is currently set at 3.5% in the UK, is used to discount future costs and benefits to present values for cost-benefit analysis in public policy and investment decisions. It allows policymakers and investors to compare different projects over time, considering the time value of money and uncertainties in the future.

7.3.2 UNEP-WCMC - Biodiversity Intactness Index

The UNEP-WCMC, based in Cambridge, UK, developed a model-based index called the Biodiversity Intactness Index (BII) as a measure of the overall state of biodiversity in a given terrestrial area. The index combines data on land use, ecosystem extent, species richness, and changes in species abundance, using Shannon's index as the basis. Calculating the BII requires extensive biodiversity data and the appropriate expertise to apply the model-based approach effectively. The BII is most often applied across large areas, such as regions, countries, and continents, where UNEP-WCMC conducts projects. However, as monitoring methods and technologies become more advanced, it is likely that smaller-scale projects will be able to employ the BII to evaluate biodiversity in their areas – particularly with the continued development of the Local Biodiversity Intactness Index (LBII). It provides a holistic measure of biodiversity and explicitly includes quantified abundance measures, focusing on changes in species abundance rather than species richness. This index therefore addresses a commonly cited concern that came up in discussions with experts regarding the observation that most metrics were only able to represent species richness rather than diversity.

7.3.3 Joint Nature Conservation Committee (JNCC) Indicators

These indicators serve as a set of tools to guide the process of monitoring and assessing changes in biodiversity over time, with the specific aim of informing decision-making and tracking conservation progress, particularly for international reporting. The indicators are primarily intended for use by government agencies, but are also noted to be useful for environmental NGOs and researchers. The JNCC biodiversity indicators are not a single metric, but a collection of indicators that fall under three categories: state, pressure, and response indicators:

- State indicators measure the current status and condition of biodiversity components.
- Pressure indicators track human activities and drivers impacting biodiversity.
- Response indicators assess the efficacy of ecological management actions taken to conserve biodiversity.

These were assessed in relation to the potential use of frameworks for monitoring biodiversity impacts associated with the UK Governments' International Climate Finance Investments, in an informative review.

This categorisation is similar to the approach Torres[62] adopted in determining key parameters for tracking rewilding success (discussed in a later section), suggesting that the JNCC indicators could form a useful base from which to create a holistic biodiversity metric in line with rewilding principles. While they provide valuable information, they are not a comprehensive metric on their own, although they do offer a standardised framework for addressing the complexities involved in the streamlined monitoring of biodiversity.

7.3.4 IUCN – Species Threat Abatement and Restoration (STAR) metric

The STAR metric utilises data from the IUCN Red List of Threatened Species to estimate the potential decrease in species extinction risk that can be attained at a site, across a corporate footprint, or within a country. It does this across a global 5 x 5 km² grid, and checks each grid pixel to see how much the threats affecting species there contribute to the overall value. The values of those pixels are aggregated, to assess areas like corporate footprints, administrative zones, protected areas, etc. The STAR value of a pixel is calculated based on how many threatened species are in that pixel, how much danger they're in (from 100

[62] Torres, A., Fernández, N., zu Ermgassen, S., Helmer, W., Revilla, E., Saavedra, D., ... Pereira, H. M. (2018). Measuring rewilding progress. Philosophical Transactions of the Royal Society B: Biological Sciences, 373(1761), 20170433. https://doi.org/10.1098/rstb.2017.0433

for species that are Near Threatened up to 400 for the super-endangered ones), and how much the pixel's area of habitat represents the habitat of all threatened species.[63]

With regards to conservation and rewilding activities, the STAR metric can also assess the potential species extinction risk reduction through restoring habitat where threatened species once lived. A discount rate is applied to the abatement value, to reflect the longer timelines of restoration impact. Then, led by this metric, land managers, company executives, or conservation project implementers can identify actions that mitigate extinction risk in their areas of intervention. Lowering the threat level corresponds to delivering a certain number of STAR units, which can serve as a target, be compared with values from other sites, or be combined with values from other sites to demonstrate the potential impact of a portfolio of conservation areas.

It is important to highlight here that the STAR metric is primarily designed for assessing *significance* and *risk* rather than *impact*. In other words, it serves as a tool for identifying areas of priority within global conservation efforts. The metric STAR is not intended for tracking changes in biodiversity or quantifying gains or losses. Its purpose lies in screening different areas to identify potential threats to vital biodiversity.

[63] Mair, L., Bennun, L.A., Brooks, T.M. *et al.* A metric for spatially explicit contributions to science-based species targets. *Nat Ecol Evol* **5**, 836–844 (2021).

7.4 Rewilding-focused metrics and frameworks

7.4.1 Rewilding Europe's Rewilding Score

Developed by Rewilding Europe and partners, the Rewilding Score is a way of evaluating rewilding progress from an ecological perspective. The score has been applied across seven rewilding projects across Rewilding Europe's operational areas. In 2020, a three-axis framework was used as the basis for evaluating rewilding impact across seven of Rewilding Europe's operational areas, based on a seminal paper of Perino et al 2019. This framework categorised progress by the following 3 dimensions, aiming to encompass ecological processes that are essential for self-organising and complex systems.

1. Trophic complexity: Complexity of relationships within the food webs of an ecosystem, including the relative biomass of the different trophic levels, and position of species within a food chain.
2. Random natural disturbance: Caused by natural events such as wildfire or flooding. These disturbances can have environmental consequences that may affect which species thrive in an environment.
3. Dispersal: How easy is it for species to spread out across landscapes. Dispersal assists species to persist when their environment changes, to spread and adapt to new ranges.

From there, the authors expanded these components into a total of 19 indicators that quantify the amount of human forcing (i.e. the impact of human activities on natural processes and ecosystem dynamics) and the state of ecological integrity over time.[64] The table outlining these 19 indicators and how a project might be scored on them is provided in the associated academic paper by Torres et al (2018). All indicators are scored between 0 and 1, and are based on subjective assessments of answers to the 'questions' that the indicator seeks to answer. For example, *to what extent is the ecosystem affected by hunting?*

The rewilding score is calculated as the geometric mean across the 19 indicator scores from Torres et al. (2018). Changes in scores over time are calculated by using the relative percentage difference between baseline and current scores. This rewilding score is based primarily on pressure and response types of indicators, rather than attempting to measure biodiversity, or indeed any type of output or outcome, directly. This is again indicative of rewilding philosophy being based around systems dynamics and the aim of creating a self-regulating, self-optimising ecosystem rather than focused on outcomes per se.

7.4.2 Rewilding Britain's monitoring framework for rewilding

Rewilding Britain is developing its own Monitoring Framework which incorporates aspects of ecological, social and economic change related to rewilding. The framework was developed with the aim to contribute to the strong evidence base for rewilding, and the role it plays in addressing the climate and biodiversity crises. The key themes of the Monitoring Framework will primarily be based on the outcomes from a workshop held in May 2023 which brought together 36 participants with diverse professional backgrounds to discuss metrics they considered to be most critical to measuring rewilding progress.

To suit the needs of different types and scales of rewilding projects, the framework will include a base level monitoring guide that is user-friendly, accessible and feasible to adopt. Additionally, the framework includes a more detailed monitoring tier as an option that may suit very large projects and those with ambitions to attract finance at scale. To maximise the potential impact of these frameworks, Rewilding Britain are developing a shared platform for projects to store their data, facilitating knowledge sharing and accelerating the uptake of the framework by as many rewilding projects as possible across the UK.

[64] Torres, A., Fernández, N., zu Ermgassen, S., Helmer, W., Revilla, E., Saavedra, D., ... Pereira, H. M. (2018). Measuring rewilding progress. Philosophical Transactions of the Royal Society B: Biological Sciences, 373(1761), 20170433. https://doi.org/10.1098/rstb.2017.0433

The monitoring framework is currently being developed[65], with a first draft anticipated to be available November 2023. Following this, a piloting phase would be carried out with rewilding projects, which will help to test the conceptual scaffolding, feasibility of collecting the data across the metric goals, as well as to check alignment with metrics and monitoring standards associated with emerging ecosystem service markets.

[65] As of 15 Sept 2023

8. Experts' and practitioners' reflections

8.1 Overview of themes

Considering the dynamic and evolving nature of biodiversity metrics as a topic, discussions with individuals actively working in this space can provide nuanced insights that extend beyond the information contained in published materials. Through a comprehensive thematic analysis of transcripts and notes taken from discussions with practitioners, this section synthesises some of the different perspectives and opinions of experts working in this area, as well as challenges they face when navigating the topic. A list of participants is provided in the appendix, section A1.2.[66]

The thematic findings are summarised here in 3 overarching themes and then elaborated on in turn.

1. **Perspectives on the conceptual and theoretical construction of biodiversity metrics**
   1. Views on what constitutes a 'good' metric.
   2. Species diversity versus ecological health: navigating trade-offs between simplicity and complexity.
   3. Opinions on subjective weighting in metric development.
2. **Perspectives on biodiversity monitoring techniques**
   1. Cautious optimism around the use and scaling of emerging biodiversity monitoring technologies, notably bio-acoustics and eDNA.
   2. Divided opinion on the appropriate use of field surveys and ecologist expertise.
   3. Difficulty in measuring species abundance.
3. **Shared challenges in understanding and applying biodiversity metrics**
   1. Lack of information and guidance on the data and monitoring required for applying a metric.
   2. Challenges in future-proofing an adopted metric and how this interacts with the advancement of technology.

[66] Excluding those who wished to remain anonymous.

8.2 Conceptual construction of biodiversity metrics

Views on what constitutes a 'good' metric.

Many participants emphasised that designing effective metrics requires a clear and explicit articulation of their intended purpose[67]. For example, a biodiversity metric that is to be used by a housing development firm in the spirit of compliance is going to be designed differently from one used by a rewilding entity to measure ecological progress, as the purpose differs markedly. A 'good' biodiversity metric for use in the private sector and biodiversity markets will be one that effectively safeguards against gaming and data manipulation to maximise credit generation. Achieving this requires a meticulous examination and closure of potential methodological loopholes – which may involve excluding complex ecological parameters that are susceptible to manipulation. Participants emphasised that understanding this was important in allowing us to see that no one metric is going to perfectly suit all applications. Metrics will necessarily have disadvantages and a metric that is good for one purpose is likely to be poorly suited for another. This points to the necessity for a theory of change of a given metric to be made clear and transparent, to help users understand the cause-and-effect relationships between the purpose of a metric, the methodology used to collect data, and the expected changes or outcomes in biodiversity that will result. Participants had varying levels of familiarity with the NCL and its objectives and for those with little familiarity we provided context before asking them to suggest what a suitable metric for the site and similar contexts might be. There was general convergence on the idea that a good metric for the NCL would be able to measure different facets of the ecological system, broadly categorised by:

- Composition (particularly with regards to species), for example,
  - What organisms live at the site?
  - What is the abundance and/or biomass of these species?
  - How are the communities comprised, over different habitats?
- Structure (particularly in relation to habitat), for example,
  - What habitats exist and how are they connected?
  - What level of complexity exists within the habitat structure?
  - How are species facilitated/constrained in their mobility across the site and different habitats?
- Function, for example,
  - What trophic levels are represented in the ecosystem?
  - How are species interconnected with each other and their environments?
  - What is the state of the soil microbiome and mycological diversity?

These three conceptual considerations were added to the criteria for metric choice for the NCL, as represented in tables 9.1 and 9.2.

Trade-offs between representing ecological complexity and pragmatic simplicity.

When developing a metric, there are often trade-offs that are required between a) taking a complex systems approach which recognises context-specific dynamics, drivers and processes of an ecosystem in its entirety, and b) prioritising conceptual simplicity for easier replicability and useability, for example, focusing primarily on priority species or habitat. The NARIA framework (section 7.2.2) may be considered an

[67] For a discussion of common purposes of biodiversity metrics, please refer to section 5.2.

example of the former, and the Defra metric (section 7.3.4), or IUCN's STAR metric (section 7.3.3), an example of the latter.

Several participants noted that ecological integrity should be considered the primary guiding principle for metric development and expressed concerns about the risks associated with using overly simplified metrics, as they could lead to perverse outcomes. One participant explicitly expressed that they foresee a future where biodiversity measurement and monitoring converge towards measuring broad ecological health parameters rather than biodiversity per se, assessing concepts such as composition, structure and function, whether directly, by proxy, or through modelling.[68]

Elaborating on point 3 in the preceding section, a topic frequently raised in discussion was the importance of functional diversity in understanding biodiversity, and the difficulty of measuring it directly. Within ecology, functional diversity refers to the variety and range of ecological functions or processes that occur within the relationships between species and their environment as well as between organisms. A higher level of functional diversity indicates that the ecosystem can carry out a wider array of important functions, such as nutrient cycling, pollination, and decomposition, which contributes to its resilience and ability to respond to environmental changes. One participant explained functional diversity with the analogy of considering all the 'jobs' carried out by organisms in an ecosystem, and thinking about how those jobs are being filled. For example, ecosystems that only have honeybees available to carry out the job of pollination are going to be weaker to a disease outbreak of tracheal mites (which mainly affect honeybees), than an ecosystem being pollinated by 100 species of wild bee. In the latter case, one could say that the pollinator 'job' is being filled by a range of workers, therefore representing high functional diversity.[69] Translating the concept of functional diversity into a measurable ecological parameter is challenging, however, and established methods or approaches for systematically incorporating it into metrics have not yet been developed.

In discussions with participants, functional diversity was frequently and explicitly linked to the concept of ecological health and resilience. For example, an ecologist from a rewilding group emphasised that focusing on ecological function and health rather than species alone is preferable in metrics and expressed that while higher biodiversity is often associated with healthier ecosystems, it's not always the case. In their words:

> *... Rewilding in my view is much more about ecosystem function and natural resilience...if you reduced progress to be 'more species equals better', we'd be heading down the wrong path.*[70]

This is also reflected in CreditNature's NARIA framework, based on rewilding principles, which, instead of focusing on biodiversity, focuses on the maintenance and restoration of ecosystem integrity by measuring key dimensions of complex, resilient ecosystems. A focus on ecological integrity helps to address a key concern when measuring biodiversity – how to account for the natural ebbs and flows of species populations that are inherent to healthy ecosystems.

Subjective weighting in biodiversity metrics.

In the context of a biodiversity metric, "weighting" refers to assigning different levels of importance or significance to various components, species, or factors within the metric calculation. Currently, the NCL natural capital accounting process involves weighting species in the biodiversity account using UK BAP and IUCN Red Lists. It is relatively common in biodiversity metrics to include some kind of weighting to species or ecosystems as a way to try and reflect relatively importance or rarity. For example, the Wallacea trust's method involves assigning each species included a value from 1 to 5 according to conservation value, as defined through, for example, the IUCN Red List of Threatened Species. The Defra metric

[68] Welch, A., pers. comm., (June, 2023).
[69] Duffus, N., pers. comm., (June 2023).
[70] McDonnell, A., pers. comm., (June, 2023).

includes a distinctiveness score for particularly distinct or rare ecosystems to incentivise the creation of and protection of these high-priority habitats.

When talking with practitioners, there were differing opinions on whether it is appropriate to weigh different components according to subjective importance within a metric. One participant noted that weighting species in calculations can be good in that it detracts from generalists; for example, by rewarding a species composition outcome that has less magpies and crows, and more turtledoves and warblers. However, including this type of qualifier – particularly when linked to financial incentives – might lead to potentially perverse management outcomes (i.e. planting vegetation that favour turtledoves but not overall species richness or ecological integrity).

Another person proposed an alternative approach to assigning weights to species that minimises human subjectivity around charismatic species, by instead weighting species that can be ecologically justified as serving a key role in overall ecological health and function.[71] By attaching a coefficient to these elements within a given metric formula, their contribution to the ecosystem function can be at least approximately represented. Examples could include mycorrhizal fungi and pollinator species.

[71] Lipscombe, S., pers. comm., (June, 2023).

8.3 Perspectives on biodiversity monitoring techniques

Cautious optimism about the use of technology for scaled biodiversity monitoring (eDNA and bioacoustics).

Throughout discussions, the use of eDNA emerged as a subject of particular interest and debate, with the technology generally being regarded as a promising technology with good scaling potential. However, there was also a sense of caution regarding whether it will be able to provide the depth of data required for underpinning robust biodiversity metrics. Commonly mentioned advantages of using eDNA included its scalability potential, the capacity to circumvent human subjectivity, the convenience of one sample providing information across taxa, samples being storable for later re-analysis, and the ability to detect rare and elusive species.

On the other hand, factors that raised concerns included (currently) relatively high costs, particularly for small sites. Additionally, there was a challenge in easily obtaining information on species abundance (which will be discussed further in the next section), and the uncertainty regarding the origin of DNA which makes it challenging to establish causal links between species presence and management interventions.

As mentioned above, a common appeal of using eDNA is its (perceived) ability to overcome human subjectivity and inconsistency that is inherent in traditional human-conducted ecological surveys. This aspect was particularly highlighted in the context of scaled-up monitoring efforts; for underpinning a global biodiversity market, for example. A participant noted that at least hypothetically, relying on eDNA analysis could mean that reporting to investors becomes straightforward and transparent, reducing the need for lengthy methodological justifications. Relatedly, while it was acknowledged that eDNA analysis entails a sometimes high degree of stochasticity, some participants noted that this random variability in the data was more tolerable than the potential biases in the data resulting from human opinions, such as political or aesthetic preferences, to which traditional survey methods are more susceptible.[72] Another benefit of using eDNA for those familiar with the technology was its ability to detect rare species. As one participant notes:

> *"You could be looking for a rare fish species in a river that it may take up to three years to find with electrofishing methods, but would be picked up within a couple of samples with eDNA."*[73]

The problem of contamination was a significant concern raised regarding eDNA, especially when taking samples from fast flowing rivers, where there is a high chance that DNA originates upstream and outside of the target site. Birds, too, will disperse DNA material widely, leading to potentially ambiguous links between rewilding efforts, their outcomes, and, ultimately, the status and enhancement of biodiversity if eDNA technologies are relied on too heavily.

So, considering this, and although the conceptual appeal of eDNA was widely noted among participants, there was a prevailing concern around whether the output is worth the investment. This was particularly relevant for smaller-scale rewilding projects where the eDNA results may not truly reflect the on-site biodiversity, and where species richness isn't considered the main parameter of importance.

[72] Lipscombe, S., pers. comm., (June 2023).
[73] Coles, T., pers. comm., (July, 2023).

Participants had similar worries regarding bioacoustics, expressing that machine learning and AI were not yet dependable enough to reliably classify and analyse the large amounts of data this technique generates.

Edge effects (the boundary or transition area between two different environments),[74] pose another obstacle to acquiring robust bioacoustics data, and these are more pronounced in areas with numerous small habitats (often the case in rewilding projects). One participant recounted a case where data collected from AudioMoths and analysed using detection software was so inaccurate that rather than requiring ground truthing of a sub-set of data, the project instead had to conduct a complete resurvey through a more hands-on and traditional field approach. This, in turn, carries substantial cost implications.

Difficulties in measuring species abundance.

Some individuals pointed out that discussions regarding biodiversity have been evolving, with a shift in focus from primarily emphasising species richness (i.e. number of species) to recognising the importance of bio-abundance (i.e. species populations) in ecological assessments. That is, we need to not only know what species are present but also understand their populations and distribution across the landscape. This shift has become particularly evident over the last five years, especially in the context of developing quantitative indicators and how these might incorporate information on abundance.

As previously mentioned, these considerations come to the fore particularly when deciding which monitoring techniques to employ and whether advancements in technology are able to provide the crucial data. Some individuals explicitly expressed scepticism around the capacity for eDNA to provide useful data on abundance. One participant suggests that getting a temporal and/or spatial measure of abundance could be hypothetically possible – though likely financially prohibitive – if, for example, 100 samples (for a 50 ha site) and were analysed, and the ratios of samples that successfully identified specific species of interest were calculated, and this exact process was repeat for a defined time period.[75] Usefully, research akin to this approach is being currently conducted at the NCL as part of a PhD project hosted by the University of Hull.[76]

Regarding bioacoustics and Audiomoths, some individuals highlighted the possibility of proxying relative abundance over time through monitoring changes in number of detections. However, deriving measures of absolute abundance using bioacoustics poses significant challenges (though it may be possible using carefully designed sampling grids and high-powered analysis models).

This is a particularly important point for the NCL to consider regarding the choice of a metric. In terms of our approach to biodiversity monitoring, generally it is emerging and cutting-edge technologies which have precedence over traditional field methods. Many people have noted that currently, established field methods (transect surveys, etc) are the only reliable way to get abundance estimates for species. This may be a trade-off we will need to consider at the NCL – and indeed one other rewilding and conservation sites are struggling with when trying to embrace new technology and approaches.

One participant noted:

> *…I think collectively, in the biodiversity credit and metric world, that the critical thing is abundance... the relationship between (species) abundance and richness is critically important and people are trying to crack it but it's proving very difficult.*[77]

In discussion with practitioners, some mentioned that contracting varying ecologists to conduct surveys can mean that it is hard to maintain consistency in data. Even where methodologies are comparable on paper, each ecologist will have their own prior knowledge of the site, particular expertise, and ways of conducting field surveys. This was mentioned as a challenge in creating robust, consistent monitoring data on

[74] Fonseca, M. S. (2008). Edge Effect. In S. E. Jørgensen & B. D. Fath (Eds.), Encyclopedia of Ecology (pp. 1207-1211). Academic Press.
[75] Coles, T. pers. comm., (July, 2023).
[76] See the NCL Biodiversity Monitoring Year 4 report: Primary Data report.
[77] Ivan De Klee, pers. comm., (July 2023).

biodiversity over time (when compared to scalable, technological solutions). However, there are some particular taxa for which detection and abundance is difficult to do without field surveys. In one participants' own words:

> *"Surveying butterflies and moths is quite interesting because there's no technological way of doing it – but that's where citizen science is particularly helpful."*[78]

Interestingly though, a common distinction in opinions was observed between those working in the investment, BNG, and global biodiversity credits space, and those looking to optimise ecological monitoring for a site outside of those financial mechanisms. For example, the inherent subjectivity that exists between human ecologists surveying a site was much more of a concern for those looking for ways to compare sites in terms of financial credits and compensation, compared to a lot of members of the rewilding community putting more emphasis on local, place-based ecological knowledge by experts.

[78] Coles, T., pers. comm. (June, 2023).

8.3 Shared challenges in understanding and applying biodiversity metrics

Challenge in deciphering 'what data for what metric'.

Interestingly, most of the metric methodologies reviewed in this report are non-prescriptive with regards to how data is collected for input into a metric calculation. This grants flexibility for projects to tailor data collection to their resource constraints, ecological interests, and priorities. However, it can also result in confusion for projects as they grapple with the lack of information regarding what the metrics calculations are and what type of data is needed - and therefore what sampling methods are appropriate.

This has implications for rewilding and conservation entities by impacting their capacity to make informed decisions regarding long-term strategic planning, as well as data collection infrastructure and management. Several participants looking to imminently apply a metric for their collected data expressed that this information is especially difficult to find, along with difficulties in finding clear distinctions between different conceptual and analytical steps in applying a metric. This was expressed by one participant:

> *"Even finding and gaining clarity on the distinctions between methodology, metric and credit...should be easy to find but is actually incredibly difficult*."[79]

This has further implications when considering participation in emerging markets for biodiversity credits and other ecosystem services. Another challenge lies in the heterogeneity of these voluntary markets, where each market employs its own distinct methodology and valuation system. For example, much like different national currencies such as the Australian dollar, US dollar, and Canadian dollar are named similarly but valued differently, Plan Vivo 'nature certificates', Wallacea Trust 'units of biodiversity uplift', and CreditNature's 'Uplift Tokens' function as distinct currencies within these markets, each underpinned by its unique methodology and supply/demand dynamics.

Future Proofing.

Concerns about a metric being "future-proofed" arose in discussions, with some participants fearing that committing to a certain metric will mean they are locked into certain data collection regimes in perpetuity, in order to collect consistent time-series biodiversity data. The concern is that to collect data over time that is directly comparable to the original baseline may imply that no changes can be made to the data collection process, including the sampling grid, data collection and sorting methods, and analysis techniques. It was generally observed that if strict consistency in data collection and monitoring practices was required from a project, that this may be incompatible with flexibility needed to keep pace with advancements in remote sensing and other biodiversity monitoring technologies, including the integration of artificial intelligence and machine learning.

Participants also wondered if new taxa and species could be integrated into their chosen metric and how this might impact the results, although some metrics developers have conveyed that there are ways to incorporate new species and data collection improvements over time.[80]

[79] Atkinson, C., pers. comm., (Aug, 2023).
[80] For example, developers of PV-Nature in partnership with Pivotal methodology, and Wallacea Trust methodology. Balmforth, Z., pers. comm., (July 2023). Coles, T., pers. comm., (July, 2023).

9. Metrics Assessment

Table 9.1 presents the metrics discussed in section 7, categorised and compared according to the criteria discussed in section 6. Table 9.2 is a continuation of Table 9.1 in that it follows the same structure but focuses on the criteria related to the conceptual construction of the metric and what ecological attributes it represents. From this, a selection of metrics has been identified for inclusion in the shortlisted metrics table (Table 9.3).

Table 9.1 Review of all metrics against defined criteria

	Biodiversity metric	Primary Purpose	Stage of development and whether open source	Rewilding focus	Metric type (State, Pressure or Response)	Linkages with other metrics
Voluntary Biodiversity Markets	Wallacea Trust Methodology (Developed by Operation Wallacea)	Used to quantify expected biodiversity benefits for projects aiming to increase or maintain biodiversity via restoration and/or protection interventions that have positive impacts on local livelihoods and ecosystems.	Published, open source methodology.	No	State	Relative abundance features strongly, specifically assessed using the quintile method.
	NARIA Framework (Developed by CreditNature)	Designed to support the growth of new nature-related financial instruments, such as biodiversity credits and bonds, by providing high-integrity KPIs that can be reported against nature-positive and ESG commitments.	Whitepaper upon request, detailing the logic behind the NARIA framework and the metrics developed. Not yet an open source methodology. Currently undergoing accreditation with Accounting for Nature.	Yes	Pressure and Response	Not directly, but there is crossover in that the NARIA framework and Rewilding Europe's Rewilding score (developed by Torres et al) are both based on three core principles critical for self-sustaining ecosystems (Perino et all).
	PV-Nature methodology (Plan Vivo in partnership with Pivotal)	Facilitate flow of biodiversity finance through sale of high-integrity, community-led projects for protecting and restoring biodiversity.	Published PV-Nature methodology 2.0 for public consultation as of Aug 2023. Final version will be open source.	No	State	The four pillars in the methodology are all based on peer-reviewed existing metrics including species richness and species diversity (calculated using Hill numbers), and established taxonomic dissimilarity and connectivity metrics.

Table 9.1 Review of all metrics against defined criteria

	Biodiversity metric	Primary Purpose	Stage of development and whether open source	Rewilding focus	Metric type (State, Pressure or Response)	Linkages with other metrics
	Verra Biodiversity Methodology (Developed by Verra)	Aimed to provide a robust framework for assessing and validating biodiversity uplift, in a way akin to the voluntary carbon market.	No methodology published yet, but currently implementing pilots (Aug 2023). Likely similar to carbon accreditation (several approved methodologies, others can be approved).	No	TBC, likely state.	TBC
Regulatory Bodies and Conservation Governance	Defra Metric 4.0 (Developed by DEFRA, UK Gov)	For use in the Biodiversity Net Gain policy, for developers to use and guide their development plans to ensure a net gain of 10% in biodiversity following the mitigation hierarchy.	Defra Biodiversity Metric 4.0 is the latest version, last updated in March 2023. Is an open source, excel-based assessment tool.	No	State	Defra metric can be used where a habitat metric is to be included in a multi-dimensional metric, for e.g. Wallacea Trust methodology.
	JNCC Indicators (Developed by the Joint Nature Conservation Committee)	The UK indicators have a specific purpose for international reporting, particularly designed to align with the post-2020 Kunming-Montreal Global Biodiversity Framework.	N/A (set of indicators rather than a methodology for calculating a metric).	No	State and response	N/A
	Biodiversity Intactness Index (BII) (Developed by UNEP-WCMC with partners)	A model-based indicator most often applied across large areas, such as regions, countries, and continents, where UNEP-WCMC conducts projects. Comprises two-models: one of total abundance, and one of compositional similarity.	Difficult to locate, but there are tutorials available of how to use the PREDICTS (partners in development) database to apply the BII to the region of interest.	No	State and response	Strong focus on abundance metrics; estimates how the average abundance of the native terrestrial species in a region compares with their abundances in the absence of pronounced human impacts.

Table 9.1 Review of all metrics against defined criteria

	Biodiversity metric	Primary Purpose	Stage of development and whether open source	Rewilding focus	Metric type (State, Pressure or Response)	Linkages with other metrics
	Species Threat Abatement and Restoration (STAR) metric (developed by IUCN).	Measures how much reducing threats and restoring habitats may lower the risk of species extinction. Mostly used to help corporations understand biodiversity risk across large regions.	It is open source and there are user guides available.	No	Pressure	Sometimes the STAR metric is included as a component in multi-dimensional metrics. E.g. It provides a 'weighting' for the conservation value of the sites assessed under the Value Nature Biocredits methodology.
Rewilding Focused	Rewilding Score (Developed by Torres et al with Rewilding Europe)	A way of evaluating rewilding progress of rewilding sites, particularly large scale projects.	The 19 indicators that comprise the score are all pressure and response-based, and are found in the supplementary table.	Yes	Various, but mainly response	As mentioned above - not directly, but there is crossover in that the NARIA framework and Rewilding Europe's Rewilding score (developed by Torres et al) are both based on Perino et al's three core principles critical for self-sustaining ecosystems.
Rewilding Focused	Rewilding Monitoring Framework (currently in development by Rewilding Britain)	Not a metric per se. Designed to enhance the robust body of evidence supporting rewilding efforts and to consolidate and standardise monitoring and measurement efforts of rewilders across the UK.	Forthcoming - anticipated first draft for consultation in Nov 2023. Planned to be collaborative and an open, shared platform for rewilders to contribute to and learn from.	Yes	TBC. Likely a combination - though it is a monitoring framework rather than a metric per se.	TBC when the framework becomes available.
Species-focused	Shannon-Wiener (Shannon's) Index (Academic)	Emphasizes overall diversity and evenness of species.	Published academic methodology established in ecological science.	No	State	Often used as an element of multi-dimensional metrics, or as the basis of newly developed metrics.
Species-focused	Simpson's index (Academic)	Focuses on dominance and the likelihood of selecting individuals from the same species.	Published academic methodology established in ecological science.	No	State	Often used as an element of multi-dimensional metrics, or as the basis of newly developed metrics.

Table 9.1 Review of all metrics against defined criteria

	Biodiversity metric	Primary Purpose	Stage of development and whether open source	Rewilding focus	Metric type (State, Pressure or Response)	Linkages with other metrics
	Hill Number (Academic)	Hill Numbers represent biodiversity from various angles. Lower orders focus on species count, while higher orders consider both species richness and abundance evenness.	Published academic methodology established in ecological science.	No	State	Often used as an element of multi-dimensional metrics, or as the basis of newly developed metrics.

Table 9.2 Metric composition and ecological attributes. Note that this table is to be read as a continuation of table 9.1, focusing on the conceptual components of the metric and its composition.

	Biodiversity metrics	Comprised of individual metrics?	Ecological Attributes		
			Structure	**Composition**	**Function**
Voluntary Biodiversity Markets	Wallacea Trust Methodology (Developed by Operation Wallacea)	Yes - five taxa are chosen as representative of the site, and context-appropriate metrics are chosen for them and validated by a quasi-independent body.	Yes, one of the metrics must be habitat based, e.g. UKHab.	Yes, strongly represented, as 4 of the 5 metrics would be stratified by types of taxa.	Yes, indirectly, as the basket of metrics should include taxa strongly linked to ecological function (e.g. soil invertebrates).
	NARIA Framework (Developed by CreditNature)	Yes, there are 4 dimensions, measured by 4 metrics.	Yes	Yes	Yes
		CreditNature Landscape Connectivity metric (to represent dispersal).	Yes, as connectivity is an aspect of habitat structure.		
		Vegetation Spatial Diversity metric (to represent natural disturbance).	Yes, as natural disturbance creates microhabitat and complex structure.	Yes, indirectly as it doesn't survey species directly but uses spatial data.	
		CreditNature Trophic Function metric (to represent food web complexity).		Yes, but focus on large bodied animals.	Yes, as it based on functional trait dissimilarity of large-bodied animals.
		CreditNature Bird Trait Diversity metric (to represent niche occupancy).		Yes somewhat, but only for specific taxa (birds).	Yes, as bird trait diversity indicates the biodiversity-ecosystem function relationship.
	PV-Nature methodology (Plan Vivo in partnership with Pivotal)	Yes, there are 4 pillars that comprise a multimetric:	Yes	Yes	Yes

	Biodiversity metrics	Comprised of individual metrics?	Ecological Attributes		
			Structure	Composition	Function
		Species Richness		Yes, as it is a species focused metric.	
		Species Diversity		Yes, as it is a species focused metric.	
		Taxonomic Dissimilarity			Yes potentially indirectly, as taxonomic diversity can indicate functional diversity to some extent. Higher taxonomic diversity often implies a broader range of traits and functions within a community.
		Habitat connectivity	Yes, as connectivity is an aspect of habitat structure.		
	Verra Biodiversity Methodology (Developed by Verra)	Components of the methodology TBC.	TBC	TBC	TBC
Regulatory Bodies and Conservation Governance	Defra Metric 4.0 (Developed by Defra, UK Gov)	No, but has several components and multipliers. A habitat-based metric that is a proxy for biodiversity potential.	Yes directly, habitat is the crux of the metric.	No, but BAP or IUCN species importance can be added.	No
	JNCC Indicators (Developed by the Joint Nature Conservation Committee)	N/A as it is more a compilation of indicators, grouped by theme and purpose at the national scale, rather than a metric or set of metrics.	Yes, through the habitat-focused indicators.	Yes, many of the indicators are species-focused.	

	Biodiversity metrics	Comprised of individual metrics?	Ecological Attributes		
			Structure	Composition	Function
	Biodiversity Intactness Index (BII) (Developed by UNEP-WCMC with partners)	Comprised of two models - one based on compositional similarity, and the other for total organismal abundance. Both are compared to a 'without human impacts' type of reference state.	No – although Biodiversity Habitat Index appears to be a companion index so can likely be used in conjunction.	Yes strongly, as the two models are based on abundance and species composition.	No
	Species Threat Abatement and Restoration (STAR) metric (developed by IUCN).	Has two components: the STAR threat-abatement score (STARt) and the STAR restoration score (STARr).	No	Strongly species-focused.	No
Rewilding Focused	Rewilding Score (Developed by Torres et al with Rewilding Europe)	Comprised of 19 indicators, classified into Direct Human Inputs and Outputs and Ecological Integrity Indicators. All scored between 0 and 1, and calculated into a single score.	Yes, indirectly.	Yes, indirectly.	Yes, includes trophic complexity score.
Rewilding Focused	Rewilding Monitoring Framework (currently in development by Rewilding Britain)	TBC	TBC	TBC	TBC
Species-focused	Shannon-Wiener (Shannon's) Index (Academic)	No	No	Yes	No
Species-focused	Simpson's index (Academic)	No	No	Yes	No
Species-focused	Hill Number (Academic)	No	No	Yes	No

9.3 Shortlisted metrics

In addition to the comprehensive table summarizing various parameters, we identified a selection of biodiversity metrics which we considered to be more suitable for the NCL and provided explanations regarding their potential usefulness or limitations. These are discussed in Table 9.3.

Table 9.3 Shortlisted metrics and comment on feasibility of applying them at the NCL

Metric	Potential for implementation at NCL
Wallacea Trust Basket of Metrics Methodology for measuring biodiversity units of gain (developed by the Wallacea Trust)	The Wallacea Trust methodology satisfies the essential criteria of the NCL. Five or more metrics are chosen by the project or biodiversity providers and externally validated. The metrics are categorised by taxa, so calculations are made on a group of species that represent that particular taxon type for the site - with the requirement that one of metrics is a habitat/structure metric. With rigorous thinking around the basket of metrics used, it is possible to represent structure, function and composition of the ecosystem within the metric – the desired overarching conceptual criteria outlined in section 6. For translating into biodiversity units of gain, the median is taken as the overall biodiversity uplift. However, for our purposes at the NCL, where the objective is to assess improvements in species richness and other ecological indicators rather than reporting to a central body for validation of biodiversity uplift units, all five measurements could be considered in parallel, making it a potentially pluralistic metric. There is an open-source methodology, and it is site-based and compatible with the data we are collecting. The requirement of habitat-specific reference sites (to measure progress against) may be a limitation, particularly if we were looking to sell credits, but is probably also necessary for abundance calculations. The habitats at the NCL are compatible with the methodology.
NARIA Framework (developed by CreditNature)	The theory and philosophy underpinning the metrics in the Ecological Integrity Index (part of the NARIA framework) are based on the key tenets of rewilding, including a focus on ecological function and process. The methodology is not open source yet, and it is currently going through the process of being verified by Accounting for Nature. CreditNature have developed a sophisticated blockchain technology that enables the trade of uplift tokens. Their methodology is intended for the purpose of linking rewilders to vetted, high integrity finance streams, and as such it is not as suitable for projects not wishing to participate in these endeavours. However, the NARIA framework has key learnings for the NCL and other rewilders, particularly in providing a proof of concept that it is possible to represent ecological dynamics and complexity (such as the ebbs and flows of species and their abundance) with metrics.
Rewilding Europe's Rewilding Score (developed by Torres et al for Rewilding Europe to measure impact)	Very aligned with our overall objectives for the site, though doesn't include guidance for state-type metrics into which primary data can be inputted. The score is a metric in the sense that many different indicators are brought together, measured on a 0-1 scale and integrated into a final score between 0-1. However, it doesn't include any direct measures of biodiversity, so would need to be paired with an outcome-measured approach if we were to apply it to the site. The suite of indicators are much better suited to rewilding projects that have mixed-used and varied amounts of human activities and impacts on landscapes across large scales. There are some broadly applicable themes, such as the state of ecological succession and impact of invasive species. However, most are more applicable for large sites - for example, including information on fire regimes, and amount of area under grassland pasture, commercial forestry and mining.

Defra Biodiversity Metric 4.0 (Developed by Natural England and Defra)	For our purposes, the Defra metric can be (and to date has been) used at the NCL to help track changes in the site. An advantage of the Defra metric is that it is a habitat-based metric that is straight-forward to use. However, it is essentially a habitat metric and does not measure biodiversity directly, it can only indicate what the potential biodiversity of a site may be, estimated by habitat type and condition. While helpful as one of a set of measures, it cannot track progress on species directly, or provide a way to use camera trap and AudioMoth data.
PV-Nature Methodology (Developed by the **Plan Vivo** Foundation **in partnership with Pivotal)**	The PV-Nature methodology is very suitable for use at the NCL. Four pillars that represent different aspects of biodiversity (and are indicative of ecological health) are calculated separately before being integrated through a separate formula to obtain to an overall figure of biodiversity, titled the multi-metric. The four pillars are species richness, species diversity, taxonomic dissimilarity, and connectivity. In small sites where connectivity is less relevant, it may be possible to use a measure of habitat structure instead. The overall approach meets the conceptual criteria outlined, by representing some aspect of structure, composition, and function within the metric. Data requirements for pillars 1-3 can be likely be met through the current monitoring system infrastructure set up at the NCL. This consists of ongoing data collection by camera traps and AudioMoths set up following a random grid approach that is representative of the diverse habitats across the site. Details of this can be found in the Natural Capital Laboratory Year 4 Biodiversity Monitoring: Primary Data Report. There is an open-source methodology, and it is site-based and compatible with the data we are currently collecting, and the methodology does not require projects to find a reference site. The habitats at the NCL are mostly compatible with the current iteration of the methodology, with the caveat that it does not work as well for restored areas of peat bog, which comprises around an eighth of the site. This may not be a problem in our context (where we are not selling credits) however.

The following metrics were scoped out at the shortlist phase of the metric review.

- **IUCN STAR Metric:** Primarily suited for regional and large-scale applications, especially valuable for corporations assessing risk of harm to biodiversity (measured by extinction risk), for example of their global supply chains. It is not useful for tracking overall ecological/restoration progress at specific sites and focuses on priority (endangered) species.
- **Verra Biodiversity Standard:** Designed for potentially extensive biodiversity uplift projects in the voluntary carbon market, with a likely emphasis on Global-South regions. There is not yet an available open-source methodology and due to the emphasis on large scalable projects, is probably not suitable for use for small sites like the NCL.
- **JNCC Indicators**: Valuable indicators, particularly at the regional and national levels, though these are indicators rather than metrics, and more useful for regional or at least landscape scale conservation activities.
- **Biodiversity Intactness Index:** This index has a notable focus on species abundance. It is commonly used for regional and national assessments, aiming to understand the relationship between human pressures and species abundance across different regions. This approach guides and prioritises actions, particularly concerning threatened species. However, considering there is negligible direct human impact in the NCL, these layers of analysis are not relevant, and it does not offer a way to organise and analyse bespoke primary data rather than projected data layers.
- **Foundational species-focused metrics:** Relevant and incorporated into other multi-dimensional metrics which have additional value associated with their application.

10. Recommendations and adoption of a metric

10.1 Rationale regarding metric choice

After reviewing the evidence, the information collected through the production of this report, and the synthesis of this in Tables 9.1 and 9.2, we have determined that the PV-Nature methodology aligns best with our conceptual and practical criteria for the NCL, as well as our existing monitoring framework and technology capabilities. An additional recommendation is to incorporate Rewilding Britain's monitoring framework for rewilding, to ensure we are also understanding changes in pressure and response variables influencing rewilding progress at the NCL.

Both the Wallacea Trust methodology and the PV Nature methodology were suitable metric choices, compatible with the monitoring systems set up at the NCL and the objectives of the project. Applying the PV Nature methodology is the primary recommendation for two main reasons. The first, is that it may be better conceptually aligned with natural capital accounting of biodiversity which will be further developed in year 5 of the NCL project. This is because the PV Nature multimetric will be representative across all taxa measured (as the pillars are calculated and integrated), whereas the Wallacea Trust methodology takes a median value across taxa, so will only be representing one type of taxa. If the metric is to be taken as the only or at least main input into the accounting process, then a metric which integrates all information gathered is the preferred approach. Secondly, we identify a potential anticipated challenge in that implementing the Wallacea method outside of its intended use in biodiversity markets is a conceptual necessity for reference sites, even when using for internal (i.e non-financial) purposes. This is due to a step in the calculations of abundance scaling, which relies on having abundance data collected for the species of interest at reference sites. This is a significant challenge because, without participation in biodiversity markets, we may lack the necessary resources to locate and validate suitable reference sites for the NCL, thereby affecting the feasibility of its application.

10.2 Adopting Rewilding Britain's monitoring framework for rewilding

Although not officially yet drafted, discussions with Rewilding Britain have indicated that the NCL could pilot their Rewilding Monitoring Framework. It is expected that doing so would be mutually beneficial, generating valuable insights into monitoring progress for small rewilding projects within a risk-tolerant environment. The monitoring framework aims to track progress across a broad range ecological, societal and economic dimensions. This integration with socio-economic dynamics would synergise conceptually well with other NCL workstreams which also look across dimensions at social capital and natural capital accounting. However, the feasibility of properly adopting this framework in a meaningful way (in a way that influences how data is sampled, collected, analysed and shared) will need to be assessed in November when the draft is available, and in further discussions with Rewilding Britain.

10.3 Adopting the PV Nature Methodology

During discussions with the developers of the PV Nature methodology, we explored potential applications of the current methodology to the NCL.[81] The pillars comprising the multi-metric of the PV Nature methodology are depicted in Figure 10.2.

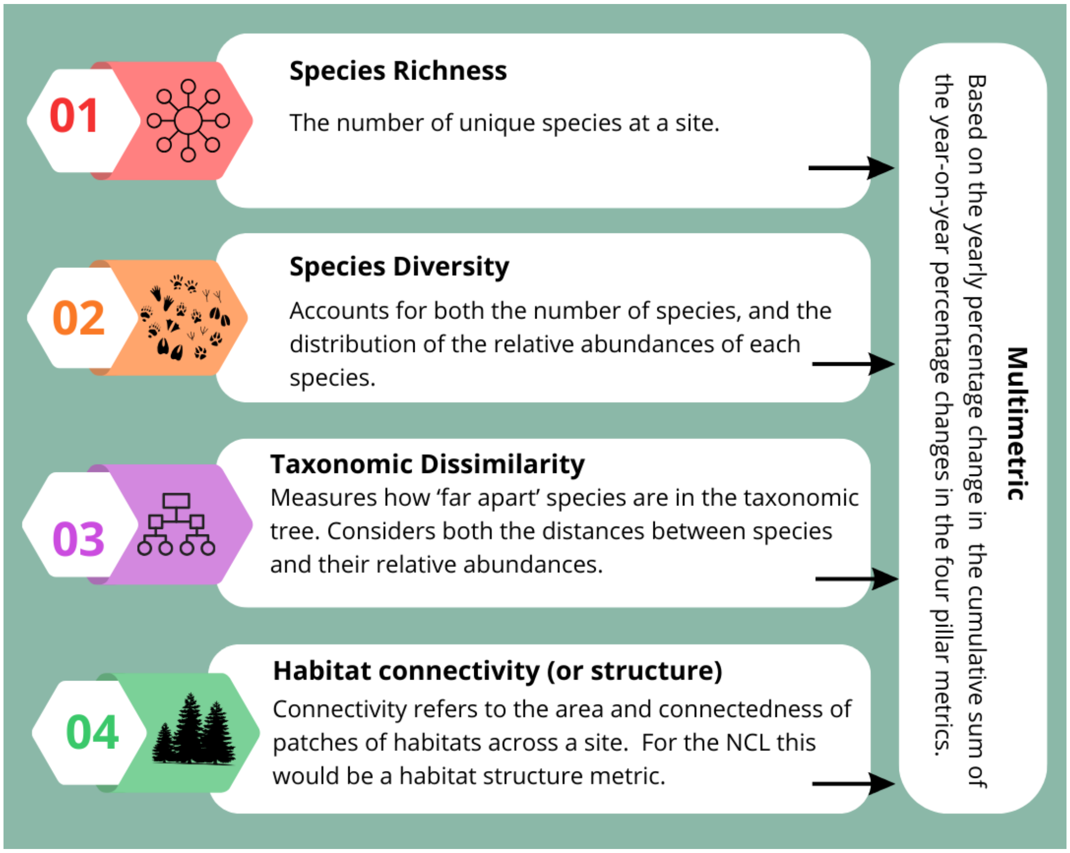

Figure 10.2 Illustration of the pillars comprising PV-Nature methodology, ultimately calculated as the multimetric

As outlined in table 9.3, data requirements for calculating a PV-Nature metric baseline can be met through our current data collection methods. In addition to ongoing data collection using remote technologies, several baseline field surveys and eDNA collected and analysed over the four years of the project to date (initial surveys of invertebrates and vertebrates, and a trial of AirDNA) can be used to contextualise and add richness to the data included in the metric calculations. In the future, it is very possible that eDNA data may be incorporated into calculations, contingent on the eDNA sector specifying minimum sampling designs (to enable comparability between data sets), and if these are followed according to best practice.

As discussed further in the Natural Capital Laboratory Year 4 Biodiversity Monitoring: Primary Data Report, some resources will need to be channelled into scaling up the data processing for both camera trap and bioacoustics data. Section 5 of the aforementioned report discusses some next steps for refining artificial intelligence tools for filtering and processing data.

[81] Balmforth, Z., pers. comm., (July, 2023).

A PhD candidate[82], is using the NCL as a site to test different substrates and DNA collection, and in doing so has implemented a relatively intense sampling regime across the site, of around 120 samples stratified by habitat. Once analysed, these samples may be able to contribute to some spatial analysis of relative abundance of some species.[83] However, although this research will contribute valuable knowledge to the field and for the NCL, an established DNA-based method for reliably measuring abundance, over time and different habitats, is not yet available and therefore cannot feed in directly to abundance-dependant calculations.

One caveat to this conclusion is that the methodology may not effectively apply to peatland habitats. Genuine improvements in biodiversity on peat bogs may not necessarily correspond to changes in the quantitative measure. This is especially the case if established woodland exists on an area identified for eventual conversion back to peat bog, as the woodland is likely to have higher species diversity than the bog it replaced. However, this limitation is less critical for the NCL's purposes because the area designated as degraded peat bog contains primarily young saplings rather than fully established woodland. Additionally, the primary purpose of the methodology is to facilitate data organisation rather than for the purpose of credit sales. With sufficient data, it will be possible to identify if and to what extent the biodiversity in peat bog habitat is increasing or decreasing, and attribute these to changes in each pillar. Doing so will also provide information on the biodiversity alongside the physical restoration of the habitat, which commenced in September 2023.

To calculate pillars 1 to 3 for the NCL, the main analytic steps we currently envisage taking (subject to further engagement both outside of and within the NCL team) would include:

- Grouping data by taxonomic categories such as birds, bats, frogs, and mammals.
- Additionally, categorising data according to monitoring technique it was collected by, to account for differences between the ways in which camera traps, AudioMoths, etc. detect species.
- Using the PV Nature methodology conceptual and calculation guidance provided here, apply mathematical analysis using an R package to calculate the metrics.
- Develop, with feedback from the Pivotal team, an ongoing monitoring regime that is aligned with the resources and time required to demonstrate change in the particular habitats comprising the NCL.

Pillar 4 concerns connectivity of the habitat in the context of terrestrial ecosystems (for marine ecosystems, it concerns rugosity instead). In the context of the NCL, connectivity may not be particularly relevant to track over time. However, structure of habitat is closely related to structural connectivity, which is arguably more relevant than internal connectivity for a small (100 acre) site. Understanding habitat structure and how it is changing helps with further understanding vegetation complexity and the population trajectories that other species may follow. The NCL is particularly well-placed to implicitly (and potentially explicitly) explore these relationships as there are areas of the site which are currently undergoing and will continue to undergo significant habitat restructuring, transforming the landscape and ecological communities that reside there. For example, the gradual felling of non-native sitka forest, to be replaced with other types of forest. It also has wider implications for contributing to knowledge of the relationship between biodiversity and habitat structure, as this relationship varies widely by ecosystem and context. Monitoring species distribution during these dynamic shifts is crucial for both site management and knowledge sharing.

Previously, LiDAR was indirectly used at the NCL to derive the National Tree Map (NTM), which served as a testing dataset for the carbon model.[84] The NTM contains data on tree height and canopy extent, albeit with some data gaps in the case of Scotland. Remote sensing activities at the NCL are closely linked to the creation of a Digital Twin, designed as a virtual site representation. Therefore, to generate structural

[82] Clare Cowgill, the University of Hull
[83] See the NCL Biodiversity Monitoring Year 4: Primary Analysis
[84] See previous NCL annual reports and the PlanEngage NCL site for details on the carbon model.

information at the NCL for supporting pillar 4, close collaboration work will be essential in year 5 of the NCL between the teams responsible for the digital twin and remote sensing efforts, and those working on the application of the PV Nature methodology.

Key mutualistic research outcomes have been identified through the NCL's distinctive partnership and its capacity to offer research opportunities for students, in conjunction with the developers and users of the PV Nature methodology. An overarching research question that describes this mutualistic relationship is:

> *Given the set of metrics comprising the PV Nature methodology, which are published, peer-reviewed, and grounded in ecological science - how do they perform in a rewilding context in the UK, and what insights can be gained?*

To effectively implement the PV Nature methodology metric, the NCL in the next year of work would need to progress the following:

- Transition toward more automated AudioMoth analysis, as recommended in the Biodiversity Monitoring Year 4 Preliminary Analysis report. This could involve utilising external services like the bioacoustic services offered by Carbon Rewild or Wilder Sensing. However, quality control of machine learning-based detections will still be required, which may open up opportunities for further academic collaborations, including inviting master's or PhD students to explore related questions using the AudioMoth data.
- Similarly, expanding the use of Conservation AI, including refining the online filtering application developed by AECOM, which aims to enhance the accuracy and efficiency of camera trap data classification.
- Continue to collaborate with researchers to identify emerging synergies related to eDNA sampling strategies and data collection, particularly with relation to the PhD research being currently conducted by Clare Cowgill.

  Develop concept notes for dissemination to NCL partners University of Cumbria, and other academic institutions on research questions around biodiversity monitoring at the NCL. Particularly, though not exclusively, more refined research on the use of automated techniques and machine learning for data processing and crucially, data analysis using these technologies. For example, occupancy modelling approaches and similar models will need to be developed to create insights into abundance of species – crucial for input into any biodiversity metric, even the relatively simple ones like the Shannon's Diversity Index.

The practical implementation of this methodology will be determined through collaboration with PV Nature methodology developers, in conjunction with our NCL partners such as the University of Cumbria, landowners, and other stakeholders actively engaged in utilising the site as a living laboratory.

11. References

Sahu, A., Kumar, N., Singh, C. P., & Singh, M. (2023). Environmental DNA (eDNA): Powerful technique for biodiversity conservation. Journal for Nature Conservation, 71, 126325

Andersen, K., Bird, K. L., Rasmussen, M., Haile, J., Breuning-Madsen, H. E. N. R. I. K., Kjaer, K. H., ... & Willerslev, E. (2012). Meta-barcoding of 'dirt'DNA from soil reflects vertebrate biodiversity. Molecular Ecology, 21(8), 1966-1979.

Cambridge Dictionary. (n.d.). Citizen Science. Retrieved September 20, 2023. from https://dictionary.cambridge.org/dictionary/english/citizen-science

Charmaz, K. (2014). Constructing Grounded Theory. Los Angeles: Sage.

Dalberg Advisors. (2022, November). Key design principles in developing biodiversity measurement tools for investors.

Fernández, N., Navarro, L. M., & Pereira, H. M. (2017). Rewilding: A call for boosting ecological complexity in conservation. Conservation Letters, 10(3), 276-277.

Fonseca, M. S. (2008). Edge Effect. In S. E. Jørgensen & B. D. Fath (Eds.), Encyclopedia of Ecology (pp. 1207-1211). Academic Press.

Gellie, N. J., Mills, J. G., Breed, M. F., & Lowe, A. J. (2017). Revegetation rewilds the soil bacterial microbiome of an old field. Molecular Ecology, 26(11), 2895-2904.

Gradeckas, S. (2023, August 31). Biodiversity credits vs carbon credits. [Blog post]. Bloom Labs Substack.

Harper, L. R., Lawson Handley, L., Carpenter, A. I., Ghazali, M., Di Muri, C., Macgregor, C. J., Logan, T. W., Law, A., Breithaupt, T., Read, D. S., McDevitt, A. D., & Hänfling, B. (2018). Environmental DNA (eDNA) metabarcoding of pond water as a tool to survey conservation and management priority mammals. Biological Conservation, 221, 69-76.

Highlands Rewilding (2021). Natural Capital Report 2021 - Bunloit Rewilding.

MammalWeb (2018). How to make a Littlewood box for small mammal camera-trapping. https://www.mammalweb.org/images/pdfs/HowToMakeALittlewoodBoxForSmallMammalCameraTrapping.pdf

Institute of Environment and Development (IIED). (2022, November). Biocredits to finance nature and people: Emerging lessons (Publication No. 21216IIED). IIED Publications Library.

IUCN. (2001). IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

Johnson, M. D., Cox, R. D., Grisham, B. A., Lucia, D., & Barnes, M. A. (2021). Airborne eDNA reflects human activity and seasonal changes on a landscape scale. Frontiers in Environmental Science, 8, 563431.

Lamb, E. G., Bayne, E., Holloway, G., Schieck, J., Boutin, S., Herbers, J., & Darimont, C. T. (2009). Indices for monitoring biodiversity change: Are some more effective than others? Environmental Monitoring and Assessment, 176(1-4), 37-45.

Lõhmus, A., Lõhmus, P., & Runnel, K. (2018). A simple survey protocol for assessing terrestrial biodiversity in a broad range of ecosystems. PLoS One, 13(12), e0208535. https://doi.org/10.1371/journal.pone.0208535

Lynggaard, C., Bertelsen, M. F., Jensen, C. V., Johnson, M. S., Frøslev, T. G., Olsen, M. T., & Bohmann, K. (2022). Airborne environmental DNA for terrestrial vertebrate community monitoring. Current Biology, 32(3), 701-707.

Marshall, N.T., Vanderploeg, H.A. & Chaganti, S.R. Environmental (e)RNA advances the reliability of eDNA by predicting its age. Sci Rep 11, 2769 (2021). https://doi.org/10.1038/s41598-021-82205-4.

Mair, L., Bennun, L.A., Brooks, T.M. et al. A metric for spatially explicit contributions to science-based species targets. Nat Ecol Evol 5, 836–844 (2021).

Moeslund, J. E., Zlinszky, A., Ejrnæs, R., Brunbjerg, A. K., Bøcher, P. K., Svenning, J. C., & Normand, S. (2019). Light detection and ranging explains diversity of plants, fungi, lichens, and bryophytes across multiple habitats and large geographic extent. Ecological Applications, 29(3).

NatureMetrics. (2021, January 29). FAQs.

NatureMetrics. (2022, May 24). Soil eDNA data forms part of world-leading research for Highlands Rewilding.

NatureScot, Amphibian & Reptile Conservation Trust (ARC), & Amphibian & Reptile Groups of the UK (ARGUK). (n.d.). Scottish Adder Survey.

Natural Capital Laboratory Year 3 (2021-2022) End of year Report. Retrieved from https://lifescapeproject.org/uploads/ncl-yr-3-report-2022.pdf

Natural England. (2023). The Biodiversity Metric 4.0.

Pedersen, P. B. M., Ejrnæs, R., Sandel, B., & Svenning, J. C. (2020). Trophic Rewilding Advancement in Anthropogenically Impacted Landscapes (TRAAIL): A framework to link conventional conservation management and rewilding. Ambio, 49(1), 231–244.

Perino, Andrea & Pereira, Henrique & Navarro, Laetitia & Fernández, Néstor & Bullock, James & Ceausu, Silvia & Cortés-Avizanda, Ainara & van Klink, Roel & Kuemmerle, Tobias & Lomba, Ângela & Pe'er, Guy & Plieninger, Tobias & Benayas, José & Sandom, Christopher & Svenning, Jens-Christian & Wheeler, Helen. (2019). Rewilding complex ecosystems. Science. 364.

Pixxel. (2021, August 4). Pixxel to launch 5 satellites in 2022, aims to democratize access to space-based data.

PlanEngage is an interactive online platform developed by AECOM that enhances communication and engagement to improve project outcomes.

Polly, by AgriSound is a model of acoustic recording device designed to attract and record pollinators specifically.

Robinson, J. M., Breed, M. F., & Abrahams, C. (2023). The sound of restored soil: Using eco-acoustics to measure soil biodiversity in a temperate forest restoration context. Restoration Ecology.

Roswell, M. (2021). A conceptual guide to measuring species diversity. Oikos, 130(10), 1609-1623.

Stebbins, R. (2001). Exploratory research in the social sciences: what is exploration?. Exploratory Research in the Social Sciences. 2-18.

Sugai, L. S. M., Desjonquères, C., Silva, T. S. F., & Llusia, D. (2019). A roadmap for survey designs in terrestrial acoustic monitoring. Remote Sensing in Ecology and Conservation, 5(4), 323-337.

Thukral, A. K., & Bhardwaj, M. (2019). New indices regarding the dominance and diversity of communities, derived from sample variance and standard deviation. Journal of Environmental Biology, 40(5), 1015-1020.

Torres, A., Fernández, N., zu Ermgassen, S., Helmer, W., Revilla, E., Saavedra, D., ... Pereira, H. M. (2018). Measuring rewilding progress. Philosophical Transactions of the Royal Society B: Biological Sciences, 373(1761), 20170433. https://doi.org/10.1098/rstb.2017.0433

Turner, R.K., Griffiths, R.A., Wilkinson, J.W. et al. Diversity, fragmentation, and connectivity across the UK amphibian and reptile data management landscape. Biodivers Conserv 32, 37–64 (2023). https://doi.org/10.1007/s10531-022-02502-w

UNEP-WCMC. (n.d.). World Database on Protected Areas Access. UNEP-WCMC.

Valentini, A., Taberlet, P., Miaud, C., Civade, R., Herder, J., Thomsen, P. F., ... & Dejean, T. (2016). Metabarcoding of environmental DNA samples to explore the effects of landscape and habitat on biodiversity. Molecular ecology, 25(7), 1661-1673.

Wearn, O. R., & Glover-Kapfer, P. (2019). Snap happy: camera traps are an effective sampling tool when compared with alternative methods. Royal Society Open Science, 6(3), 181748. doi:10.1098/rsos.181748.

12. Glossary

Biodiversity Net Gain (BNG): an approach to development, land and marine management that leaves biodiversity in a measurably better state than before the development took place and is additional to existing habitat and species protections. Intended to reinforce the mitigation hierarchy, BNG aims to create new habitat as well as enhance existing habitats, ensuring the ecological connectivity they provide for wildlife is retained and improved. From late 2023, most developments in England will need to achieve a minimum 10% net gain in order for their development to receive planning permission. They will use Natural England's Biodiversity Metric to calculate how many biodiversity units they need, in order to achieve this. When they cannot fully deliver BNG on site, they can deliver gains off site.

Biodiversity Indicator: A parameter of an ecological system that is used to indicate something about the health of that system. For example, the existence of a sustained population of an apex predator may be used as an indicator of the overall biodiversity of that ecosystem.

Biodiversity Metric: A formula or calculation into which ecological data from various aspects of biodiversity can be inputted, and the output is in quantitative terms. The purpose of metrics is to track changes in biodiversity in quantitative terms and can be used and developed to create financial mechanisms to support conservation, but may be used simply by projects to inform management strategies and communicate progress.

Ecological Equivalence: The concept of replacing or offsetting ecological losses caused by human activities, with ecological gains elsewhere. The idea is to achieve a net-neutral or balanced impact on the environment. Often used in the context of highlighting the difficulty of achieving true re-creation of the same habitat with similar levels of functionality and value.

Pluralistic (metric): A pluralistic metric refers to an approach or system that uses multiple indicators or measures to assess a particular concept or phenomenon. Instead of relying on a single metric, a pluralistic approach takes into account various factors and perspectives to provide a more comprehensive and nuanced understanding of the subject being measured.

Ecosystem Health/Ecological Integrity: Ecological health and ecological integrity are often used interchangeably. It refers to the overall condition of an ecosystem in terms of its structure, composition, and functioning. An ecologically healthy ecosystem can be understood as one that exhibits robust biodiversity, functioning nutrient and energy cycles, and the ability to adapt to changing conditions.

Species Richness: Species richness refers to the total number of different species present in a specific area, ecosystem, or sample. It is a straightforward measure of biodiversity that focuses on counting the variety of distinct species within a given habitat. A higher species richness indicates a greater diversity of species in the area.

Species Diversity: Considers species richness but considers also the distribution of individuals among different species, revealing the balanced or uneven composition of a community. Species diversity generally offers a more complete insight into an ecosystem's complexity (when compared to using species richness alone).

Species Abundance: Also referred to as bio-abundance. A measure of the number of individuals of a particular species within a specific area or ecosystem. Can be simply a direct count of individuals or estimation of population numbers using sampling, or where the species numbers are substantial, measured in biomass (as with invertebrates).

Appendix

A1. Interviews and discussions with practitioners and experts working within biodiversity metrics.

A1.1 Example questions used in discussions

For those involved in the development of metrics from the perspective of facilitating private finance for conservation, restoration and rewilding, question included:

- Deep-dive technical questions into the mechanisms of their, or others' metrics (for example, what components are included in formulas and how are they mathematically related, modelling approaches)
- What principles, and priorities led to the development of that approach (for example, is representing complexity important, or replicability) and how that relates to the intended purpose of the metric)
- What monitoring methods complement a given metric, and opinions on the advancements in monitoring technology
- How do you approach inclusion of biodiversity in a natural capital account and what metrics might be suitable for this purpose?

Questions with rewilding estates and project developers included:

- What do you think is important to measure, for your project and objectives and why?
- What metrics have you seen or do you use that seem to incorporate these aspects?
- What would your ideal biodiversity metric look like – in terms of what would types of things it would represent given no practical constraints?
- What monitoring methods and technologies are you currently using or plan to adopt?

A1.2 List of individuals participating in the qualitative interview phase of the review*

Name	Organisation
Ash Welch	AECOM
Steven Lipscombe	Northumberland National Park - Hadrian's Wall: Recovering Nature Project
Natalie Duffus	University of Oxford
Alistair McVittie	Scotland's Rural College (SRUC)
Zoe Balmforth	Pivotal
Harry Tittensor	Plan Vivo Foundation
Tim Coles	RePLANET (Wallacea Trust)
Alan McDonnell	Trees for Life
Ben Hart	Nattergal
Ivan de Klee	Nattergal
Cathy Atkinson	Highlands Rewilding
Sara King	Rewilding Britain

*Excluding those who wished to remain anonymous

A2. Summary of approaches used to value biodiversity in a Natural Capital framework

Enabling a Natural Capital Approach (ENCA) - Defra 2021. Services handbook and Assets handbook

The ENCA services databook is a comprehensive Excel workbook that offers evidence and sources for valuing natural capital and ecosystem services. Each tab focuses on a specific natural capital asset or ecosystem service and includes descriptions of its relevance and potential benefits, factors influencing its benefits, suggested physical and monetary metrics, sources for biophysical and monetary evidence, limitations, and guidance for appraisal, accounting, and value projection to avoid double counting.

There is a dedicated tab providing guidance on biodiversity valuation, offering various valuation sources and data for biophysical evidence. This falls under the 'bundled ecosystem function' category, alongside Amenity, Biodiversity, Soil Quality, Water Quality, Landscape, and Non-use benefits. This category is distinct from provisioning, regulating, cultural, and abiotic flows[85] It may encompass services with intricate interdependencies and ecosystem dynamics, making them challenging to categorize. Nevertheless, the workbook lists sources with primary valuation data of biodiversity for different habitats, facilitating the use of a benefit transfer method to create monetary values in natural capital accounts for biodiversity at specific sites, typically based on habitat types. However, it's worth noting that most values originate from papers published between 2003 and 2011.

The text highlights that biodiversity is closely linked to many other ecosystem services, which presents methodological challenges. To address this, the guidance suggests valuing biodiversity only in cases where it directly impacts human wellbeing and offers additional benefits beyond other ecosystem services.

The Economics of Ecosystems and Biodiversity (TEEB)

- TEEB does not provide a specific biodiversity metric, but it offers some guidance on integrating biodiversity into natural capital accounts. It includes market-based and stated preference methods, enabling the assignment of economic values to biodiversity, highlighting its contributions to human wellbeing, and facilitating better decision-making. The methods are divided into:
- Revealed preference, which observes actual monetary transactions associated with biodiversity-related goods like national park ticket prices.
- Stated preference, which involves direct surveys asking individuals about their preferences and trade-offs. Commonly used methods include Choice Experiments (CE) and Contingent Valuation (CV).

Other natural capital guidance on biodiversity

Several guidance tools have been developed to assist corporations in valuing biodiversity from the perspective of its impact. Notably, the Biodiversity Integrated Reporting for Impact and Sustainability (IRIS) framework, and the Natural Capital Coalition's Biodiversity Guidance. While these tools, frameworks, and guidelines are beneficial for incorporating natural capital dependencies and impact into corporate reporting systems, they may not provide significant tangible value in terms of measuring biodiversity uplift for a rewilding or other type of conservation project or site.

[85] Abiotic flows are not commonly included category of ecosystem services, but in workbooks include renewable energy as an example.