The Agile Initiative at the Oxford Martin School

Sprint 3: Scaling up Nature-based Solutions in the UK

BIODIVERSITY & SOIL HEALTH METRICS TOOL

USER GUIDE

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Overview of the Biodiversity & Soil Health Metrics Tool

Nature-based Solutions (NbS) involve working with nature to tackle societal challenges, with benefits for both people and biodiversity. They cover a wide range of interventions, such as woodland creation to tackle flood and erosion risk, agro-ecological measures such as cover crops and beetle banks for sustainable farming, saltmarsh restoration for coastal protection, or green roofs and urban trees to reduce flooding and cool our cities.

It is important to monitor the outcomes of NbS, for several reasons:

- to build the evidence base on what works and what doesn't work, and demonstrate impacts to funders and stakeholders;
- to allow management to be adapted in response to any future environmental changes that threaten the success of the project;
- to identify and manage any trade-offs that occur between different objectives such as food production, flood protection, recreation, biodiversity and carbon storage.

Various tools and approaches exist for monitoring the different outcomes of NbS, but often monitoring is restricted to just one or two aspects such as carbon sequestration. This guide focuses on the ecological outcomes, both for biodiversity and soil health, which are often neglected. Some approaches for monitoring socio-economic outcomes are listed in the Agile Initiative's Recipe for Engagement.

The Biodiversity & Soil Health Metrics Tool provides practitioners with information to design effective ecological monitoring approaches for Nature-based Solutions (NbS) projects. There are many acknowledged and recognised biodiversity and soil health metrics used in academia, industry, and policy. This tool simplifies the selection process by highlighting the most informative and feasible metrics to provide a wide assessment of both biodiversity and soil health outcomes.

The biodiversity metrics chosen were derived from Noss's biodiversity framework (Noss 1990). This framework characterises the variety and variability of organisms and the processes that are crucial to maintaining them, identifying the major components (composition, structure, function) of biodiversity at multiple scales of organisation (landscape, community, population, genetic) (Figure 1).

Soil health reflects the capacity of soils to perform their optimal functionality and to sustain the delivery of important ecosystem services over the long-term (Faber et al. 2022; Guo 2021; Bonfante et al. 2020; Vogel et al. 2019). The soil health metrics in this framework cover biological, chemical, and physical properties (Figure 2).

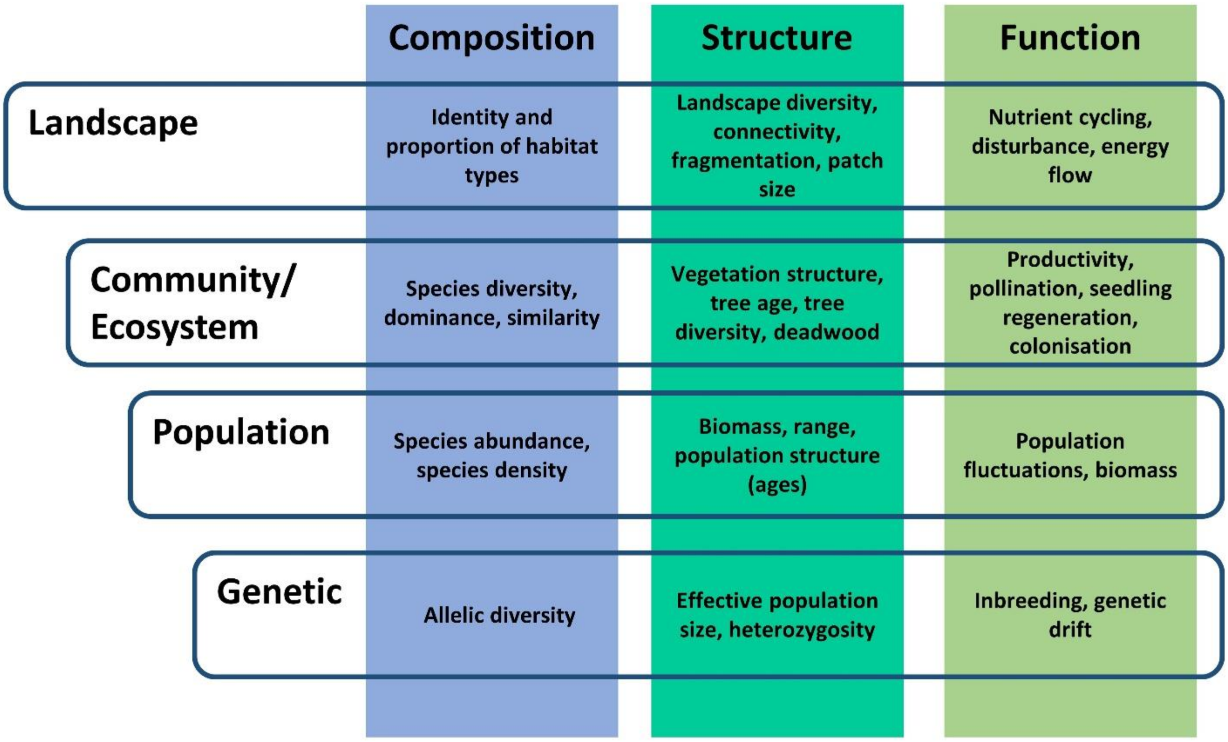

Figure 1. Noss' Hierarchy of Biodiversity (adapted from Noss 1990): three primary attributes of biodiversity at different scales, with examples of metrics (note: some metrics overlap multiple scales or attributes)

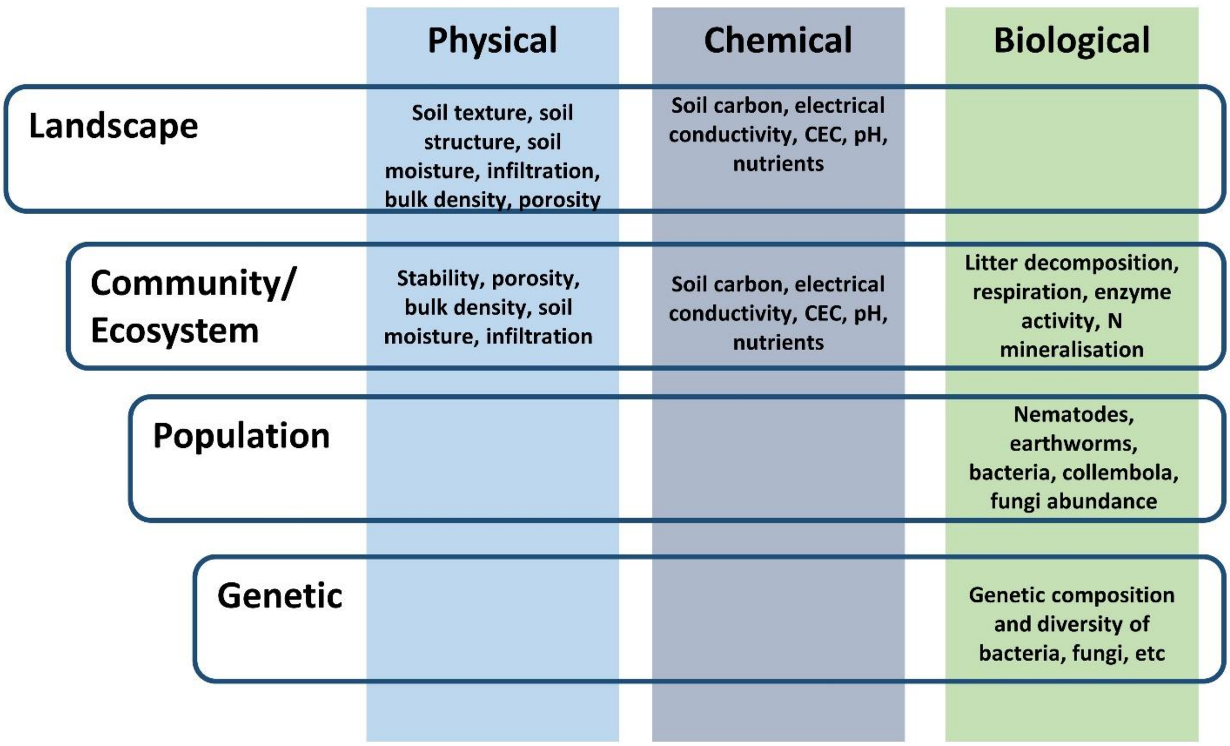

Figure 2. Structure of the soil health metrics, using the same scale categories as the Noss framework but different aspects of soil health (physical, chemical, biological).

Metrics are grouped into Tier 1, Tier 2, and Future metrics. Tier 1 covers a core set of metrics that broadly capture biodiversity and soil health responses to NbS interventions. Tier 2 represents metrics that are useful and informative but may be less feasible to monitor or only apply to some ecosystem types. Future metrics are assessed as being highly informative but currently not usually feasible for regular monitoring. Ideally, projects will select metrics that represent all axes of biodiversity (composition, structure, function) and soil health (biological, physical, chemical) at multiple scales (landscape, community, population).

How to use the Tool

The tool is for anyone implementing an NbS project and designing a monitoring protocol that covers biodiversity and soil health.

For each metric, the tool contains the following information:

- *Metric summary:* The relevance of the metric to biodiversity or soil health.
- *Methodology summary:* A summary of the sampling layout and data collection approach to follow, with links to existing standardised methodologies. Approaches for calculating the metrics (e.g. using software packages) are summarised. Where multiple related derived metrics are possible the pros/cons of each are summarised. Connections and linkages between metrics are also highlighted.
- *Metric threshold or direction of change:* Thresholds for the desired level of a metric or a desirable direction of change are given (where available).
- *Technological innovations:* Highlights developing technologies that could improve or simplify future data collection.

The metrics can be filtered using the following criteria (see Glossary for definitions):

- Type of metric (Biodiversity, Soil health)
- Aspect of biodiversity (Composition, Structure, Function)
- Aspect of soil health (Chemical, Physical, Biological)
- Scale (Landscape, Community, Population, Genetic)
- Tier (Tier 1, Tier 2, Future metrics)
- Ecosystem (Forest, Grassland, Peatland, Heathland, Saltmarsh, Wetland, Agricultural, Other)
- Cost (High, Medium, Low)
- Technical expertise (High, Medium, Low)
- Standardised methodology (Yes, No, Partial)

Planning ecological monitoring within a Nature-based Solutions project

Selecting your metrics

TIER

Tier 1 metrics provide the greatest amount of information on biodiversity and soil health while remaining feasible to measure. Where possible, projects should aim to collect data on all Tier 1 metrics.

Collectively, the Tier 1 metrics represent all aspects of biodiversity (Composition, Structure, Function) and soil health (Chemical, Physical, Biological).

Tier 2 metrics are designed to supplement the core data collection, providing opportunities to gain an understanding of additional aspects of biodiversity and soil health that are likely to be relevant in specific projects only.

Future metrics would be highly informative but have prohibitive data collection requirements or lack a standardised methodology, limiting the consistency of data collection across projects. Collection of these metrics may be possible in some projects but will require the development of a bespoke sampling plan and potentially a high level of specialist skills for processing samples and interpreting the derived data.

Sampling regimes should aim to integrate the simultaneous collection of as many of the selected the metrics as possible, to save duplication of effort (see section on Planning your surveys).

SCALE

Metric scale (see Glossary) should be interpreted based on the project context. For instance, landscape-scale metrics, such as landscape diversity, are most likely to be relevant to larger-scale projects with multiple habitats present. For metrics that are collected at the community scale, the optimum sampling intensity may depend on the project area: recommendations on how to scale this are given. Population-scale metrics focus on understanding species-level dynamics and will be particularly relevant to projects that have species-specific objectives. Genetic metrics provide information on underlying genetic diversity, which predicts long-term resilience, adaptive capacity, and vulnerability of a species. These are most relevant in projects targeting conservation of specific species and where the project area covers most of a distinct population of that species, or as part of a larger-scale monitoring effort.

COSTS

An indication of the costs involved in data collection is given. Costs may differ depending on existing expertise and staff already available to collect data. See Glossary for thresholds between different cost classifications.

TECHNICAL EXPERTISE

Technical expertise refers to the expertise required throughout the process of data collection, metric calculation, and interpretation. For example, *vegetation biomass* is a low technical expertise metric, simply requiring the diameter at breast height of trees to be measured. Collection of *invertebrate biomass* data requires a medium level of technical expertise: little expertise is required to collect the initial sample, but more specialist knowledge is needed to sort the specimens into high-level taxonomic groups. *Functional trait diversity* is a high expertise metric; expert taxonomic skills are needed to identify species and the process of classifying species by their functional traits and using R to calculate functional trait diversity also requires a high level of expert knowledge.

METHODOLOGY

We have noted where standardised methodologies for data collection are available. In some cases, the methodology will only cover part of the process, e.g. it might cover the sampling regime for species surveys, but not the process of deriving the species diversity metrics from the data collected.

TECHNOLOGICAL INNOVATIONS

For many metrics we note emerging technologies that have the potential to enhance and simplify monitoring in the future. For example:

- For monitoring *vegetation structure*, the use of LiDAR could help to standardise the sampling and metric derivation process, particularly in terms of collecting data across non-forest ecosystems.
- Species-level monitoring using eDNA reduces the need for taxonomic expertise however, it is currently very expensive and does not provide the abundance data needed to assess *species diversity* and *relative abundance*, which we have highlighted as important for understanding the ecological communities within NbS projects.

Planning your surveys – integrating data collection for multiple metrics

Data collection for different metrics should be co-located where possible.

BIODIVERSITY

- *Landscape diversity* requires a full site survey, mapping habitat areas of 400 square metres or more. *Habitat areas* are calculated from this survey. The landscape diversity survey can be used calculate the areas of different habitat types within a project. This can be used to stratify sample plots by habitat type: sample plots are proportionately allocated based on the area of each habitat within the site, with more plots on habitats covering the largest areas. In large sites with distinct habitat types, multiple plots per habitat type will allow metrics at the habitat-level.
- *Species diversity* surveys are collected using either transect-based methods or plot-based methods – surveys should aim for shared plots/transects across taxonomic groups and intersection of plots and transects. Suggestions on minimum numbers of plots per site/habitat type are given in the methodology summary for each metric.

- *Dominance-diversity curves*, *similarity*, and *absolute/relative abundance* are derived from the data collected during species diversity surveys.
- *Functional trait diversity* and *identity* are derived by linking functional trait data to data collected during the *species diversity* surveys.
- *Vegetation structure* data is collected using plots. These should be overlaid with the *species diversity* plots where possible and, in large sites with multiple habitats, stratified by habitat type.
    - For forests a standardised method is available following the National Forestry Inventory methodology.
    - For herbaceous-dominated ecosystems (grassland, peatland, wetland, saltmarsh) and shrub-dominated ecosystems (heathland, scrub) there are no standardised methodologies available in the UK, but modification of a methodology used in the US is suggested.
- *Vegetation biomass* data is collected using plots.
    - For forest ecosystems, metrics are derived from the data collected during *vegetation structure* surveys.
    - For herbaceous-dominated ecosystems (grassland, peatland, wetland, saltmarsh) and shrub-dominated ecosystems (scrub, heathland), destructive sampling is required so sampling should not occur within the *species diversity* or *vegetation structure* plots. Plot placement for *vegetation biomass* should be in areas that are representative of the *species diversity*/*vegetation structure* plots.
- Tree diversity, tree age and seedling regeneration data can be collected during the vegetation structure surveys.
- *Pollination* data is collected using pan traps; these should be aligned with data collection for *species diversity* and stratified by habitat type.
- Deadwood volume is collected in the same plots as vegetation structure, tree diversity, tree age and seedling regeneration data.

SOIL HEALTH

- Texture, soil moisture, cation exchange capacity, soil organic carbon, pH, nutrient analysis (P,K,N), electrical conductivity, N-mineralisation and soil respiration can all be sampled using the same sampling pattern and samples could be taken at the same time, ready for laboratory analysis. Each sample location should be recorded with GPS, to ensure that subsequent sampling is taken from the same place. Fields up to 10 hectares can be sampled as one unit, providing each field is uniform (same soil type and management), by sending a composite sample to the laboratory. Each composite sample will be composed of a minimum of 20 samples collected following the recommendations in the metric methodology, and mixed thoroughly together before sending to the laboratory. This composite sample will give an average of the whole field. Larger fields and fields that are not uniform should be subdivided and each part sampled separately.

- When digging a soil pit for visually assessing *soil structure,* it is possible to integrate the visual assessment of *porosity*, surveying *earthworms*, and assessing *aggregate stability*.
- *Litter decomposition* bags can be placed in specific areas within the grid cells where visual assessments of soil structure are taking place, as well as measurements of *infiltration rates*.
- *Nematodes* are usually unevenly distributed and sampling procedure needs to be more thorough. At least 50 cores must be taken evenly from an area of no more than 4 hectares.

How the metrics were chosen and assessed

Literature review

As a starting point for selecting biodiversity metrics we used Noss' Biodiversity Hierarchy (Noss 1990). Noss' Hierarchy organises biodiversity into three sub-categories: composition, structure, and function, aiming to capture the breadth and complexity of biodiversity (Figure 1). These metrics apply at different scales (landscape, community, population, genetic). For each category of biodiversity at each scale, Noss defines metrics or groups of metrics. These were supplemented by literature searches on biodiversity monitoring, biodiversity metrics, ecological indicators, ecological integrity, and ecological health, and assessment of the grey literature, to provide the maximum set of metrics. The literature reviewed is listed in the Bibliography.

Soil health can be classified using a combination of physical, chemical, and biological indicators (Jian et al. 2020). Potential metrics of soil health were identified through literature searches of academic and grey literature on soil health monitoring, soil health indicators, soil quality, soil ecosystem services, soil biological indicators, soil biodiversity, soil physical indicators, soil chemical indicators and soil health assessment. A total of 118 indicators were obtained from the literature, these were then ranked by frequency and the percentage of papers and monitoring frameworks that considered each metric in their assessments was calculated. The indicators that were mentioned in at least 20 % of the literature were shortlisted. Indicators that were considered as part of the minimum set of indicators required for a monitoring framework in grey literature, even if not mentioned in at least 20 % of the academic literature, were also considered and combined with the shortlist. This yielded a total of 39 indicators, which were further evaluated to select the minimum set of metrics as described in the section on Scoring the metrics.

Methodologies for data collection for both soil and biodiversity indicators were identified during the literature, grey literature, and web searches. We prioritised identification of existing standardised methodologies and monitoring schemes. This will allow integration with existing datasets, comparison between sites, and comparison to UK-wide trends. The UK National Biodiversity Network database of Wildlife Survey and Recording Schemes (https://nbn.org.uk/tools-and-resources/useful-websites/database-of-wildlife-surveys-and-recording-schemes/) and UK Environmental Change

Network (https://ecn.ac.uk/measurements) were used to identify standardised methodologies for taxonomic monitoring – mostly focussed on surveying specific taxonomic groups. Habitat-focussed survey schemes e.g. the UK Habitat Classification, UK Countryside Survey and the National Forest Inventory were also assessed. Soil health focused survey schemes that included standardised methodologies were identified, e.g. the UK Countryside Survey, AHDB soil health score card, FAO Soil Doctor Programme and Farm Carbon Toolkit.

The most relevant and useful metrics were identified by reviewing literature to assess evidence on the relationship between each metric and biodiversity or soil health. Information on pros, cons, and feasibility was also evaluated during the literature review process. We collated information on technological innovations that could simplify or accelerate the data collection process in the future.

Scoring the metrics

As discussed above, Tier 1 indicators cover a core set of metrics that broadly capture the response of biodiversity and soil health to NbS interventions. Tier 2 metrics build on the Tier 1 metrics and in some cases are applicable to some ecosystem types only. Future metrics are indicators that are highly informative but generally not yet feasible to collect, and/or require further testing and development.

To help to group the metrics into Tier 1, Tier 2 and Future, we developed a scoring system assessing informativeness and feasibility of data collection for each metric (Table 1). The derived scores served as a guide for metric selection, and assessment of the suitability of each metric was also based on the literature review described above. Each metric was assigned 1, 2, or 3 points for each criterion; more points indicate better metric performance for that criterion. For example, 3 points for Relevance means there is strong evidence that the metric is relevant to biodiversity or 3 points for Cost means the metric is less expensive to monitor. The maximum possible score is 36 points.

For the biodiversity metrics, Tier 1 required an informativeness score ≥15, a feasibility score ≥12, and met the additional criteria of being applicable across all ecosystem types. Tier 2 metrics had an informativeness score 12-14 and a feasibility score ≥12; some Tier 2 metrics are applicable in some ecosystem types only. Future metrics scored <12 for feasibility and were split into Future Tier 1 if informativeness scored ≥15 and Future Tier 2 if informativeness scored 12-14.

For soil health, Tier 1 metrics scored ≥30, Tier 2 metrics scored 25-30 and Future metrics scored 23-25. All indicators scoring <30 points underwent additional scrutiny if they demonstrated a high degree of informativeness and relevance. In-depth analysis was conducted, including a comprehensive literature review, to assess their potential suitability as either Tier 2 or prospective metrics for future consideration. Metrics that scored 25 were further analysed and if their lower score was due to lower feasibility, they were not included in Tier 2 and were categorised as Future metrics despite being informative.

Table 1. Criteria used to score biodiversity and soil health metrics.

Informativeness	Feasibility
Relevance: How strong is the evidence that the metric is directly or indirectly relevant to biodiversity/soil health?	**Sample collection:** How straightforward is sample collection & analysis?
Information rich: How many metrics can be calculated from one data collection method? Can the metric be used as a surrogate for other metrics?	**Cost:** How expensive is data collection and analysis?
Sensitivity: How sensitive is the metric to management changes?	**Technical:** How much technical expertise or equipment is needed?
Functions/services: Are there clear links between the metric and ecosystem functions and derived services?	**Methodology:** Is there an existing standardised methodology available?
Applicability: Can the metric be applied across habitat types?	**Compatibility:** Is the methodology robust and repeatable?
Literature: How widely is the metric considered in the academic literature?	**Interpretation:** How easy are results to interpret?

The biodiversity metrics *functional trait diversity* and *identity* were elevated from Future Metrics to Tier 1, despite a feasibility score of 11, to represent the Function aspect of biodiversity within Tier 1. These two metrics lack a clearly defined framework for classifying species by functional traits, however we offer guidance for applying functional traits in different contexts, which can be tailored to meet project needs. *Vegetation structure* is also an informative biodiversity metric but currently lacks a standardised and straightforward data collection approach in some ecosystem types. However, we encourage practitioners to work with guidance provided to collect data on vegetation structure in their projects and have therefore included it in Tier 1.

Glossary of Terms

METRIC TYPE

Biodiversity: Metrics representing the diversity of living organisms within a Nature-based Solutions (NbS) project. Biodiversity supports the functioning of ecosystems and their capacity to deliver ecosystem services. It is captured at multiple scales, from genetic to landscape scale.

Soil health: The current capacity of a soil to function within natural or managed ecosystem and land-use boundaries. The healthier a soil is, the better it is at providing important ecosystem services and helping to sustain plant, human and animal productivity and health.

ASPECT OF BIODIVERSITY

Composition: The identity and variety of elements that comprise biodiversity. Composition indicators describe the species present and the communities that they form. Example indicators: habitat types, species diversity, allelic diversity (diversity of alleles within population).

Structure: The physical organisation within a system. Structural indicators describe the physical patterns that support species. Example indicators: habitat diversity, vegetation structure, genetic heterozygosity (presence of two different alleles at a locus within an individual).

Function: The ecological and evolutionary processes and dynamics that underpin functioning within a system. Function indicators describe the processes that result from interactions between species, species interactions with the physical environment, and genetic processes within species. Example indicators: natural disturbances, nutrient cycling, gene flow.

ASPECT OF SOIL HEALTH

Biological: Indicators connecting to living organisms within or connected to soil. Biological indicators are more dynamic in nature than chemical and physical indicators, and therefore will change more over time and with management. Example indicators: earthworms, nematodes, bacteria, soil respiration, microbial activity.

Chemical: Indicators connecting to substances of which matter is composed. Chemical indicators relate to soil properties and how they react/change over time. Example indicators: pH, Cation Exchange Capacity (CEC), Soil Organic Carbon (SOC), salinity, heavy metals.

Physical: Indicators connected to the structure of a soil, particularly in connection to solid particles and pores. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile. Example indicators: bulk density, porosity, texture, compaction, aggregate stability.

SCALE

Landscape: Metrics that apply at landscape scales, encompassing a mosaic of habitat types, landforms, and land uses. (Measurement scale: 100m – km)

Community: Metrics that apply at the ecosystem scale, focussing on a group of interdependent plants and animals usually within a relatively homogeneous area of habitat. (Measurement scale: cm – 100m)

Population: Metrics that apply at the species level, assessing population trends. (Measurement scale: mm – m)

Genetic: Metrics that assess genetic variation and processes within species. (Measurement scale: nm – mm)

TIER

Tier 1: Metrics that are highly informative, have standardised methodologies available, are highly feasible to monitor and apply across all ecosystem types.

Tier 2: Metrics that are informative, but methods for data collection may only be partially available or metrics are less feasible to monitor.

Future metrics: Highly informative metrics but methodology not standardised and generally unfeasible to monitor (i.e., requires high level of expertise or costs too high).

ECOSYSTEM

Agriculture: Areas characterised by production of crops and raising livestock. This can include cropland, pasture, and agroforestry.

Forest: Areas with >25% tree cover (that are more than 5m in height).

Grassland: Vegetated areas (not on waterlogged soils) characterised by herbaceous vegetation (>75% grasses, sedges, rushes, ferns & forbs) rather than woody vegetation.

Heathland: Vegetated areas with >25% cover of plants from the heath family, dwarf gorse, or western gorse.

Peatland: Rain-fed inundated or waterlogged habitats where peat has formed.

Saltmarsh: The upper, vegetated portions of intertidal mudflats.

Wetland (non-peat): Vegetated areas that are waterlogged or inundated, but with greater variation in the water table (compared to peatlands) which prevents peat formation.

COST

The exact expenses can differ considerably depending on the location, and are influenced by factors such as the availability of laboratories or specialized field equipment. There are many soil testing facilities in the UK and pricing information is frequently obtainable only through direct inquiries. The exact expenses will also be influenced by the uniformity of the area to be sampled. As for uniform plots it is possible to send composite samples to the laboratory, in which case you still sample 20 different spots but mix them properly and send off only 1 sample to the laboratory (max for 10 Ha of uniform fields/plots) incurring in lower laboratory costs than described below.

Low: Limited funds required for fieldwork activities. Cost of sampling a 10-ha field <£600 for soil health and <£2000 for biodiversity.

Medium: Requires some funding for fieldwork activities. Cost of sampling a 10-ha field £600-£1200 for soil health and £2000-5000 for biodiversity.

High: Requires high funding for fieldwork activities. Cost of sampling a 10-ha field >£1200 for soil health and >£5000 for biodiversity.

TECHNICAL EXPERTISE

Low: Requires limited knowledge and understanding to collect data and/or does not require a high level of technology or machinery and/or does not require technical expertise to analyse/interpret results.

Medium: Requires moderate knowledge and understanding to collect data and/or requires moderate understanding of appropriate technology or machinery and/or requires moderate technical expertise to analyse/interpret results.

High: Requires expert knowledge and understanding to collect data and/or requires a high level of technology or machinery and/or requires technical expertise to analyse/interpret results.

STANDARDISED METHODOLOGY

Yes: International/nationally recognised methodology (including sampling regime, sampling method and metric calculation).

No: No international/nationally recognised methodology (including sampling regime, sampling method and metric calculation).

Partial: International/nationally recognised methodology (including sampling regime, sampling method & metric calculation) partly established or only covers part of the process of metric calculation.

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https://www.agile-initiative.ox.ac.uk/

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