PLAN VIVO

PV Nature

Methodology and Data Protocol

Version 1.1

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Contents

CONTEXT & PURPOSE 4

Glossary of terms 9

PV Nature Methodology for calculating Plan Vivo Biodiversity Certificates 13

Scope 13

1 Section 1 – Metric & Certificate Methodology 14

1.1 Overview 14

1.2 Project eligibility 15

1.3 Sampling 15

1.4 Input data 16

1.5 The pillar metrics 17

1.6 Multimetric 27

1.7 Restoration certificates 28

1.8 Conservation certificates 29

1.9 Change confirmation 31

1.10 Global significance labels 32

2 SECTION 2 – BIODIVERSITY DATA PROTOCOL 35

2.1 Overview 35

2.2 Sampling plan design 37

2.3 General data requirements 41

2.4 Specific requirements for species, habitat and environmental data 42

2.5 All ecosystems 47

2.6 Requirements for particular data types 48

2.7 Requirements for data labelling and quality control 49

2.8 A note on new technologies 50

2.9 Bibliography 51

Appendix 1 – KBA and IPA criteria 55

Appendix 2 – Domesticated Species 57

Annex 1 – Version Control 58

PLAN VIVO

CONTEXT & PURPOSE

In August 2023, Plan Vivo carried out a public consultation on a new Plan Vivo Biodiversity Standard (PV Nature) Methodology developed in partnership with Pivotal. In December 2023, Plan Vivo launched the PV Nature, including the first version of the PV Nature Methodology in partnership with Pivotal, which incorporated updates in response to feedback received through the official PV Nature Public Consultation and the expert review process, both of which were conducted between 14th August and 4th September 2023 on this Methodology. In July 2025, Plan Vivo broadened the implementation of PV Nature to be agnostic for data analytic providers, meaning biodiversity data analysis and certificate calculation may be conducted by any Plan Vivo approved data analytic service provider. Consequently, this has led to an update of this document resulting in the current version of as PV Nature Methodology 1.1. While version 1.0 of the PV Nature Methodology was developed in partnership with Pivotal, any and all changes to version 1.0 (i.e., changes that appear in this version 1.1) of the methodology have been made independently by Plan Vivo.

What are the objectives of this Methodology?

Given the complexity of biodiversity, there is unlikely to ever be one 'silver bullet' unit or method of quantification. There will likely be a number of good approaches, but all of them will entail trade-offs. Selecting a methodology involves understanding those trade-offs and how they affect delivery of a Standard's overall goals. There will be no 'right' methodology in general, but there will be a methodology that is right for a particular Standard.

This Methodology makes a number of design choices that aim to support the following objectives of PV Nature:

1. To set a high standard in the market:
    - Measure outcomes: meaning absolutely no assumptions or predictions about the outcomes an intervention may deliver for nature.
    - Create a strong link between financial incentives and real, evidenced outcomes for people and nature.
    - Pioneer an evidence-driven approach that relies on high integrity, auditable data.
    - Build on the scientific state of the art, by selecting metrics from peer-reviewed research.
    - Minimise 'reductionism' and its inherent risks, by tracking change across a number of aspects and dimensions of biodiversity rather than one or a few aspects (e.g., indicator species); taking a wider measurement scope avoids the risk of creating incentives to improve only a few things while harming or neglecting others.

2. To minimise subjective choices and therefore the potential for gaming:
    - Measure within-system change, rather than use real or theoretical reference sites or 'states'.
    - Enable buyers to feel confident in how Plan Vivo Biodiversity Certificates (PVBCs) are measured and the outcomes that a PVBC represents. The Data Protocol, which forms part of the PV Nature Methodology, plays a key role by minimising between-project variation in the biodiversity outcomes that are evaluated and how they are evidenced.
3. To support global goals (e.g., the Global Biodiversity Framework 2022), by positively incentivising restoration of degraded landscapes and conservation of areas that are important for globally threatened species and ecosystems.
4. To make nature markets as accessible as possible to different people, groups and projects, including Indigenous Peoples and local communities, by:
    a. enabling high-quality monitoring that is affordable and feasible and does not necessarily require access to on-site ecologists.
    b. ensuring that projects can be community-led from the start in terms of the overall project design (see PV Nature requirements) and in agreeing the key metrics selected for the methodology.
    c. maximising participation (especially from marginalised groups, for example youth and women) and therefore long-term engagement, by simplifying data collection, analytics, and auditability, without compromising on quality or integrity and providing training and materials to support wider engagement.
5. To enable different levels of success to be distinguished, by reliably determining not just whether biodiversity has improved, but by how much.
6. To be applicable across a broad range of ecosystem types and geographies.

How does the Methodology fit into the PV Nature Standard?

This Methodology forms one part the Plan Vivo Biodiversity Standard (PV Nature). Projects will be certified via a process that is summarised in Figure 1. The Methodology describes the stages listed in the 'Specific PV Methodology Steps' section.

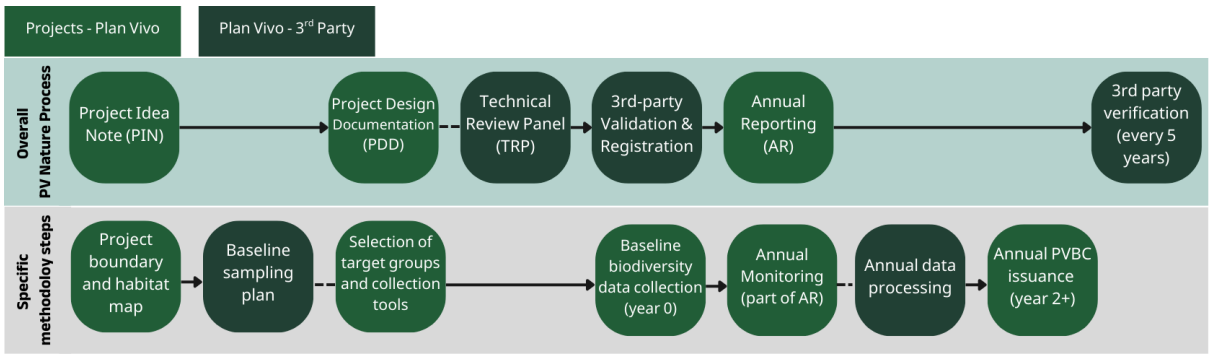

Figure 1. Workflow for PV Nature projects. This document covers the Methodology steps. Boxes in green are led by projects with support from Plan Vivo. Boxes in blue are led by Plan Vivo and third-party organisations.

Why are there no reference sites or counterfactuals?

Most methods for calculating biodiversity credit/certification metrics or units fall into one of three broad categories:

1. Those (like this one) that quantify 'within system change' - meaning they compare a site to itself over time, quantifying the gains or losses in biodiversity against a site's own biodiversity baseline.
2. Those that compare a site against a theoretical 'target state' or 'hypothetical reference' (sometimes called 'comparison with pristine').
3. Those that compare a site against a measured 'reference site', either a fixed reference or a counterfactual scenario.

This Methodology was designed specifically to avoid the use of reference sites, both theoretical and measured, because the use of either involves steps that depend on subjective choices, often based on theoretical assumptions or equivalences rather than data. Additionally, if credit/certification quantification requires comparison to a reference of any kind, then errors in that reference can have considerable impacts on the integrity of the quantification.

Measured reference sites (number (3) above) are often chosen on a project-by-project basis, which can introduce both risk and uncertainty. It is difficult or impossible to independently verify the integrity of the reference site choice, and biodiversity is so locally variable that many projects will have no directly comparable reference available to them, forcing them to compare against an unsuitable reference site.

Theoretical references (number (2) above) can avoid this problem, as they can be imposed by the certifier. But they are still subjective and the huge variability of biodiversity at site level means it is likely that:

(i) A great many theoretical references will be needed, as well as multiple replicate measurements for each reference (so that building the 'library' of theoretical references potentially requires years of work, see e.g., Oliver et al 2022); and

(ii) They are often wrong, particularly because the target state will vary not only by ecosystem and location but also by features like site size (larger areas support more biodiversity, all else being equal) and measurement approach.

Use of theoretical references also risks prioritisation of well-studied ecosystems, where it will be easier to define the target state.

This Methodology avoids the subjective choices that come with using references, whether theoretical or measured. It also seeks to avoid incentivising conservation and restoration in well-studied areas that may be less urgently in need of finance for nature. In doing so, the trade-off is that it lacks a 'definition of complete' for restoration projects. This is a conscious choice made in order to prioritise high integrity, transparency, and confidence in the claims of the PVBCs.

Where does the assessment of threat and additionality fit in?

Requirements to evidence site-level threat to biodiversity sit as a core part of PV Nature. All projects must demonstrate, through a theory of change, how the proposed project interventions aim to address the threat of loss or degradation facing the project area. These aspects of the project design are verified through independent third-party verification. Projects that are unable to demonstrate how their planned interventions will mitigate threats are not eligible under PV Nature.

Global-scale threats to biodiversity (e.g., threat of global extinction) are assessed under this Methodology in two ways. First, to be eligible to issue conservation certificates, projects must demonstrate that they are conserving globally significant biodiversity (see Section 1.2, below, for details). Second, the Methodology includes a set of 'labels' that will be calculated and attached to each project. Most of those labels are related to the degree of threat faced by the biodiversity conserved or restored. For example, this could be the number of species supported by the site that are threatened with global extinction. This is intended to provide a set of features that buyers can use as decision criteria when purchasing PVBCs.

What happens next?

Biodiversity crediting methodologies are very new, and biodiversity is highly complex. All methodologies will need to adapt over time as we learn more about their application and as technological advances increase the availability of high-quality data on additional dimensions of biodiversity. Periodic updates to this Methodology will therefore be issued as more real-world

data and evidence becomes available. Projects will not be penalised for having already started measuring under this version. Updates or changes to the Methodology will always be transparent, evidence-driven, and include methods for backwards compatibility and/or calculation of PVBCs.

This version of the Methodology has been tested on both real and synthetic datasets, and this testing will continue as the Methodology is updated iteratively.

Further, a range of 'modules' will be added over the coming months, to support projects with practical implementation. These will be developed in partnership with projects, incorporating their knowledge and feedback. Modules to be added after launch will include, for example:

1. Data collection 'toolboxes', to provide practical support to projects collecting data on different target groups in a range of ecosystems;
2. A protocol that will guide and standardise use of eDNA., for example as a source of data on the biodiversity of freshwater and soils; this protocol is currently in development with experts in the eDNA field;
3. Evidence-based sampling protocols for sites larger than 10,000 hectares that minimise effort and cost while maintaining scientific rigour; this protocol is currently under development with early project partners.

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Glossary of terms

Definitions used in this document follow the PV Nature Glossary, and the definitions below:

Anurans

Frogs and toads

Biodiversity baseline

The initial survey of biodiversity present on a site, including the pillar metric values. Referred to in this document as 'Year 0'.

Benthic vegetation

The plants and algae on a site that make up the marine, biogenic habitat.

Counterfactual

A comparator to the observed results, that is designed to represent a scenario in which a particular intervention, or set of interventions, had not occurred.

Data collection tool

A checklist and procedures (e.g., device specification, calibration and collection protocol) used to collect any specific type of species, habitat or environmental data applied under the PV Nature Methodology.

Data labelling

The process by which targeted features are identified and tagged in a data file, either by human experts or by algorithms. For example, the labelling of biodiversity data generally involves the identification of species and/or habitats within an audio or image file.

Detection probability

How likely it is that a technique or method correctly detected the presence of a species and correctly classified it. Expressed as probability range from 0 to 1. With 1 meaning all species present were detected and correctly identified and 0.5 meaning half were (etc).

EXIF data

Exchangeable Image File Format – a standard metadata format for imagery and audio data. Generated by digital recording equipment (e.g., a camera) when data is collected.

Global significance labels

A piece of metadata that accompanies a PVBC and signals how a project area's biodiversity contributes towards global biodiversity conservation goals.

Habitat patch

A contiguous area of a single habitat type.

Habitat type

An area characterised primarily by its physical and biotic features (topography, plant or animal composition, soil characteristics, climate, water availability etc.), as defined by established classification schemes. For example: boreal forest, savannah grassland, and so on.

Herpetofauna

Reptiles and amphibians

Land cover class

Land cover is the physical material on the surface of the earth. Examples of land cover classes include water, grassland, deciduous forest, and bare soil. Landcover classes tend to be less detailed than habitat types, but the two sometimes overlap. In most cases, classifying habitat types requires more data than classifying landcover types.

Macrophytes

Aquatic plants growing in or near water that are large enough to be seen with the naked eye, excluding algae.

Marine habitats

Habitats that occur in salt water, including oceans and estuarine areas, for example sea grass meadows, kelp forests and coral reefs. Here these are limited to coastal sites, since affordable tools for multi-taxonomic biodiversity data collection in the deep ocean are unlikely to be available in the near term.

Metadata

A set of data that gives you contextual information about data you have collected.

Morphospecies

A taxon differentiated from other taxa based on some aspect of form and structure (i.e., morphology), rather than species identification.

Motile, marine macroinvertebrates

Motile, marine invertebrates that are large enough to be observed with the naked eye (e.g., lobsters, urchins, nudibranchs, etc.)

Multimetric

The function that summarises the five-pillar metrics to produce a single value representing site-level biodiversity change. The multimetric is the cumulative sum of percent change across the pillar metrics.

OTU

An operational taxonomic unit – a set of organisms grouped together based on the similarity of their DNA sequences of a specific taxonomic marker gene.

Pillar metric

A metric that tracks change in one specific aspect of site-level biodiversity. The pillar metrics are aggregated into the multimetric to produce a single value representing site-level biodiversity change.

Project area (or site)

A discrete area (terrestrial or aquatic) within which one or more project intervention(s) is/are applied across the entire area, and across which biodiversity is being quantified. Used interchangeably with 'site' and 'site-level' in this document.

Post-hoc analysis

A statistical analysis carried out after the data has been collected and the primary analyses carried out in order to examine additional patterns in the data.

Sample coverage

A measure of how completely a community has been sampled: the estimated ratio of the observed species weighted by their abundances in a sample to the true species richness (observed plus undetected) in the entire community.

Sampling location

A location at which data is collected within the project area.

Site-level

At the level of the project area that is targeted for project interventions and biodiversity outcome monitoring.

Sessile marine invertebrates

The non-motile, structure forming invertebrates (e.g., corals, sponges, oysters, etc.) on a site that make up the marine, biogenic habitat.

Target group

A broad assemblage of species (for example, 'fish' rather than a specific type of fish) that will be surveyed using the same data collection tool.

Taxonomic classification

The taxonomic grouping of an organism, for example species, genus, family or order.

Tropics

Koppen climate classification Af, Am, or Aw/As

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PV Nature Methodology for calculating Plan Vivo Biodiversity Certificates

Scope

This document describes the Methodology and Data Protocols underpinning the calculation of Plan Vivo Biodiversity Certificates (PVBCs).

Section 1 lays out the Methodology that converts site-level biodiversity data into PVBCs. It describes the:

- Key features of the input data required by the Methodology (later described in more detail in Section 2).
- Underlying biodiversity metrics, and the methods for calculating them.
- Method for converting the metric values into the number of PVBCs.

Section 2 outlines the protocols for collecting biodiversity data for use with the Methodology described in Section 1. It describes the:

- General principles underlying the types of data that can be collected, and how.
- Minimum requirements for the sampling techniques used by projects to collect the biodiversity data.
- Data that must be collected by projects – described for terrestrial, marine, and mixed-habitat ecosystems separately.
- Method for quality controlling data before it is analysed and PVBCs are quantified.

Box 1: Roles and responsibilities

All of the analyses detailed in Section 1 will be carried out on behalf of the projects - i.e., projects do not need to conduct the data analyses, as these are conducted by an approved third-party data analytics provider. Projects will have full visibility of all analyses carried out.

Projects are encouraged to undertake data collection themselves. See Section 2 for further details on data collection roles and responsibilities.

Projects will be provided with a set of supporting guidelines and tools, including a toolbox of data collection techniques, with training materials and guidelines on how to use those techniques to ensure that data requirements for the PV Nature Methodology can be met.

1 Section 1 – Metric & Certificate Methodology

1.1 Overview

Biodiversity is the variety and variability of life on Earth. It is characterised by a complex, interacting, and interdependent system of attributes, all of which are in and of themselves challenging to measure, monitor and evaluate. This complexity is one of the key barriers that prevent us from reliably and consistently assigning 'value' to nature. To incorporate natural capital into our economic system and account for its intrinsic and extrinsic value, we must find a way to cut through the complexity of biodiversity data and measurement.

The PV Nature Methodology tackles this challenge by measuring real, quantified gains in biodiversity, using habitat and species data collected on the ground and analysed using rigorous ecological science and statistics. It outputs simple indices that scale intuitively as biodiversity changes over time and that communicate real, useful information to stakeholders regarding the direction and magnitude of those changes.

This section sets out the PV Nature Methodology that assesses biodiversity changes over time: it uses five peer-reviewed, well-established metrics (hereafter referred to as 'pillar metrics') to track different elements of biodiversity, and then summarises them in a single index called the multimetric. The multimetric is based on percentage change in the pillar metrics: calculated yearly in the case of four of the pillar metrics, and every five years for the fifth pillar metric. Calculation of the fifth pillar metric coincides with five-yearly, on-site, third-party verification. The multimetric can be used to issue PVBCs representing biodiversity outcomes that are real, robust, and verifiable. All pillar metric values and the multimetric are calculated by an approved third-party data analytics provider for projects, using the site-level biodiversity data collected by projects.

There are two types of certificates: 1) **restoration certificates** that represent a percentage uplift in biodiversity, and 2) **conservation certificates** that represent a percentage of biodiversity conserved. Alongside the quantification of biodiversity outcomes, a set of four 'global significance labels' are provided as information to support the purchase of PVBCs. These labels describe different elements of the global significance of the biodiversity supported by a project and in turn the PVBCs it issues (see Section 1.10).

The Methodology is open-source – it is based on existing, published research and open-source packages available in the R statistical computing environment. The quantification of certificates from biodiversity data also incorporates an assessment of confidence and controls for sources of error and uncertainty.

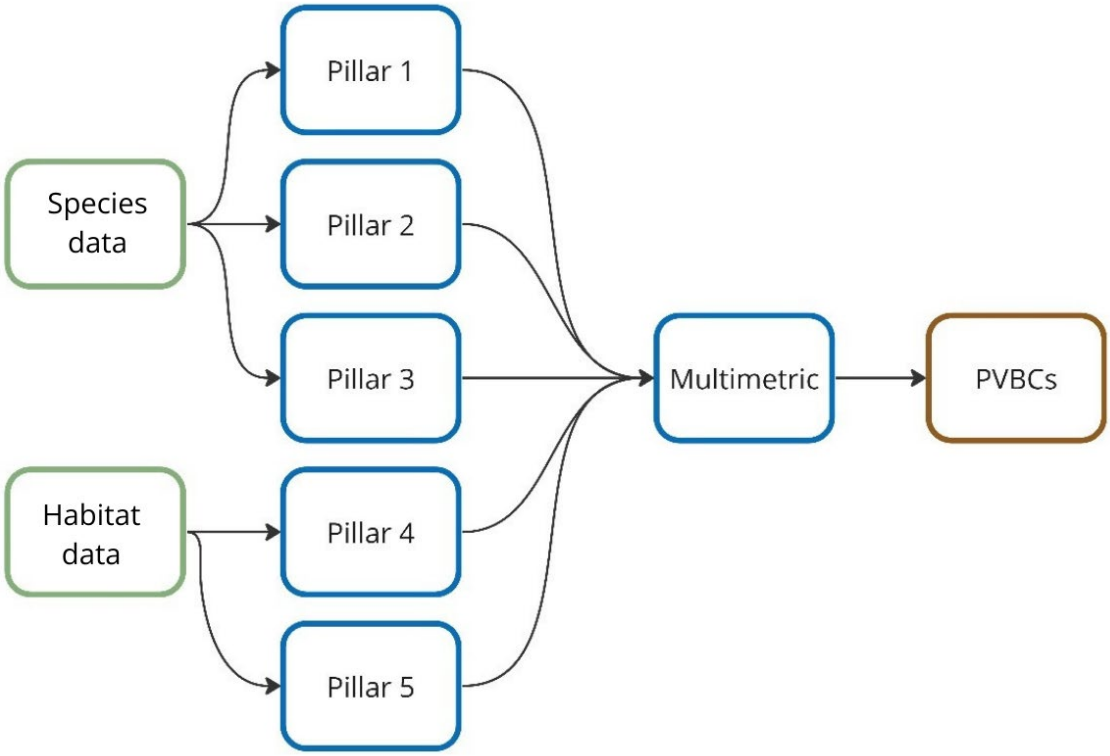

Figure 2. Overview of the analytical steps used to convert biodiversity survey data to Plan Vivo Biodiversity Certificates (PVBCs). From the data collected by projects , five pillar metrics are calculated (see Section 1.5) by an approved third-party data analytics provider (blue boxes), which are then summarised by a multimetric (see Section 1.6), and finally converted to a number of restoration or conservation PVBCs (see Sections 1.7, 1.8 and 1.9).

1.2 Project eligibility

To issue conservation certificates, a project area must meet at least one of the Key Biodiversity Area (KBA) criteria, or two of the Important Plant Area (IPA) criteria (see Appendix 1). Project areas do not need to have already been designated as a KBA or IPA, but do need to be able to show that they meet the criteria.

1.3 Sampling

Based on a project's boundary and habitat map, a sampling plan is generated by an approved third-party data analytics provider for each project. The sampling design is created by an algorithm that constructs a randomised sampling plan stratified by habitat. A new, randomised sampling plan is created for each data collection event (i.e., usually annually), such that the randomly located sampling points are 'shuffled', while still stratified by habitat. The design

ensures sufficient distance between sampling points, and between sampling points and habitat boundaries, to maintain independence and to avoid edge effects. A detailed description of the sampling design algorithm can be found in the Data Protocol in Section 2.2. Consultations and discussions will be held with all projects with regards to their respective sampling plans, to ensure inclusion of local knowledge and the safety and accessibility of the sampling plan.

For conservation projects, any globally threatened species, or other biodiversity attributes, present at the site that would designate the site as a KBA and/or IPA must be included in monitoring activities, i.e., the project must detail activities for monitoring these attributes. If the random stratified sampling plan is unlikely to capture data on these (for example where a species is present within only a very limited area of the site), a set of fixed sampling points can be added to the site-wide set of random sampling points (see Section 2.2 for more details).

1.4 Input data

Box 2: Scope of monitoring

The goal of the Methodology is to ensure that PVBCs represent positive biodiversity outcomes achieved through the restoration or conservation of biodiversity in the project area. The Methodology describes (and prescribes) the minimum monitoring effort required to achieve this goal. It is therefore important to emphasise that the Methodology **is not intended to prescribe the entirety of the monitoring that projects can or should undertake.**

The Methodology requires species community data and habitat data:

- a list of species detected at each of the sampling points within a project area;
- the relative abundances of those species; and
- a geospatial vector file of the project area's habitats (for all sites)

Species identifications and relative abundances are derived by an approved third-party data analytics provider from the digital data collected by the projects.

The species measured during sampling must cover a sufficient range of target groups to capture the important elements of a site's biodiversity. Target groups are broad species assemblages (for example, 'fish' rather than a specific type of fish), meaning there is broad coverage of biodiversity in the data collected.

At least four target groups of species must be monitored for terrestrial projects and at least three target groups must be monitoried for marine projects. The target groups selected by the

project must reflect those that are important for the ecosystem in which the project is located, and those that are likely to be impacted by project activities. Target group selection is reviewed by the PV Nature Technical Review Panel (TRP) (see Figure 1).

All species data must be digitally recorded to allow third-party verification and to ensure integrity in the PVBCs generated. Full details on the required and recommended target groups and the minimum data integrity requirements can be found in the Data Protocol in Section 2.

Invasive species

Invasive species are those that are not native to the location in which they are observed and that cause harm via their ability to spread out of control and outcompete native species. They are one of the major sources of pressure on biodiversity globally (IPBES 2019).

Given their harmful effects on local biodiversity, any species detected within a project area that are known to be invasive to the ecosystem and/or ecoregion in question are discounted during pillar metric calculations. In other words, invasive species do not contribute to the calculations of biodiversity change.

Species omitted from the methodology are those listed as 'invasive' in the Global Register of Introduced and Invasive Species (GRIIS), (Pagad et al 2018). This register is maintained by the IUCN SSC Invasive Species Specialist Group with the goal of addressing Aichi Biodiversity Target 9.

Since GRIIS is an aggregation of national invasive species registries, it may be incomplete in some specific cases (for example, omitting species which are considered invasive at very local scales). However, GRIIS is a registry with consistent eligibility and admission criteria that can be applied worldwide. Work will be conducted on an ongoing basis to fill gaps in invasive species datasets at finer resolutions.

Domesticated species

The most common species of domesticated livestock will be filtered out of the species list after data collection but before calculation of the pillar metrics. The list of domesticated livestock subject to removal from the calculations is provided in Appendix 2.

1.5 The pillar metrics

Certificates are calculated based on a multimetric, which summarises five pillar metrics. Each pillar represents a different, important aspect of biodiversity and captures quantifiable change as overall site-level biodiversity increases or decreases. While the pillars are of course

interdependent, being linked by the data from which they are calculated, none are redundant. Each is sensitive to change in a different aspect of, and provides its own information about, the state of biodiversity, ecological function, and ecosystem health under different scenarios of change. A multimetric based on more than one biodiversity metric is more sensitive to changes in the factors driving biodiversity shifts than a univariate measure, and therefore more informative.

Terrestrial Projects

The first three pillar metrics are based on the species data collected at a site, while the fourth and fifth pillar metrics are calculated from satellite data and habitat data (respectively) for terrestrial projects. The first four pillar metrics are calculated yearly, while the fifth pillar metric is calculated at Year 0 (i.e., the biodiversity baseline) and then every 5-years thereafter, to coincide with independent, third-party verification. Pillar metric values and the multimetric are calculated by an approved third-party data analytics provider for projects using the site-level biodiversity data that the projects collect.

Marine Projects

The pillar metrics for marine projects, will follow the same approach as for terrestrial projects where possible, to allow for continuity between different ecosystem types. As with terrestrial, the first three pillar metrics are based on the species data collected at a site, and the fourth and fifth pillar metrics are based on the health, quality and structure of the habitat. However, as defined in the Methodology for terrestrial habitats, Pillars 4 and 5 will not be appropriate for most marine habitats. Given the variability between different marine habitats, it may be more appropriate to use different metrics for different marine habitat types (e.g., metrics of habitat health or structural complexity that are specific to the changes seen in recovering coral reefs, kelp forests, hard bottom habitats, seagrass beds, etc.). As such, in the marine setting, a suitable Pillar 4 and 5 will most likely need to be ecosystem specific.

Further development is being carried out to identify an appropriate Pillar 4 and 5 for marine habitats and will be available for future projects to apply following a review and pilot phase. An update to the Methodology will then be issued after testing with early marine projects to determine the most suitable habit metrics for a range of marine habitats. This Methodology update will be published before the first projects become eligible to issue certificates (i.e., because no projects can issue certificates until they reach Year 2 (see Figure 1)).

1.5.1 Pillar 1: Species richness

Species richness is the number of unique species detected at a site. Greater species richness enhances ecosystem functionality and resilience (e.g., Oliver et al 2015). As a site recovers from

degradation and more natural habitats and ecological niches are added, species will return to inhabit them. As they do, the number of species detected at the site – the species richness - will increase. If instead a site becomes more degraded over time, then the inverse occurs and species richness will decrease. For conservation, the goal is to maintain or conserve natural habitats and ecological niches, so that species can continue to inhabit them, and the site's total species richness remains stable.

Species richness is calculated for each target group of species individually, and then the richness values for the target groups are summed together (they are initially calculated separately for each target group as differences in data collection methods for the different target groups often requires different methods of richness calculation).

Species richness is equal to the Hill number with parameter $q = 0$ (Hill 1978). This pillar is calculated using the *iNEXT* function from the iNEXT package in R (Hsieh et al 2016).

Pillar 1 is defined by the equation:

$$P_1(t) = \sum_{k=1}^{K} S_{t,k}$$

(Eq. 1)

where $P_1(t)$ is the site-level species richness at time t, and $S_{t,k}$ is the total number of species from target group k detected at the site at time t.

1.5.2 Pillar 2: Species diversity

Species diversity is an ecological concept that accounts for both the number of species, and the distribution of the relative abundances of each species. Diversity metrics therefore respond to biodiversity changes in different ways and over different timescales than richness alone (Dornelas et al 2012). A species diversity metric that accounts for relative abundances of species is important because as a site recovers from degradation, it is usual to see a natural process of change in the distribution of abundances of species. The distribution generally shifts away from a very skewed distribution with a small number of overly dominant species, towards a less skewed distribution where the abundances are spread more evenly between different species, while maintaining a subset of rare species to buffer the community's resilience (Lembrechts et al 2017).

Calculation of this pillar uses the Hill number with $q = 1$ to measure species diversity (Hill 1978). This 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.

Species diversity is calculated using the *iNEXT* function from the iNEXT package in R (Hsieh et al 2016).

The Hill numbers at time t are defined by the equation:

$$P_2(t) = \sum_{i=1}^{S} \left(p_{i,t}^{q}\right)^{\frac{1}{1-q}}$$

(Eq. 2)

where $P_2(t)$ is species diversity at time t, S is the number of species, $p_{i,t}$ is the proportion of individuals belonging to species i at time t, and q is a parameter that determines the relative weighting of common and rare species. We use $q = 1$, to provide equal weighting across common and rare species. Note that while the equation for the Hill numbers is not defined for $q = 1$, the limit of the function exists at this point (and is equal to the exponential of the Shannon index).

The Hill numbers range from zero without an upper bound and increase as biodiversity increases. There is no theoretical maximum value but in practice the maximum will be set by the natural maximum level of biodiversity that a site can support.

The abundances of different target groups can be measured or estimated in different ways, for example, the number of individuals of an animal species vs percent cover of different plant species. Directly combining these different abundance units could create misleading results. Instead, Pillar 2 is first calculated for each target group separately, so that relative abundance is always calculated using the same abundance unit. These per-target-group diversity values are then summed to obtain the site-level estimate of species diversity (Pillar 2). The validity of this step is one of the advantages of using Hill numbers (compared to some other diversity indices such as the Shannon index): Hill numbers have a common unit and can therefore be summed in this way (Hill 1978).

1.5.3 Pillar 3: Taxonomic dissimilarity

Taxonomic dissimilarity measures the distance in the taxonomic tree between the different species detected, and therefore how similar or dissimilar, in terms of their taxonomic groups, those species are. Healthy ecosystems, with varied habitat types and structures and many different ecological niches, will tend to support a wider range of species 'types' (or taxonomic groups) that perform a wider range of functions that support ecosystem health, functionality and productivity, in comparison to less healthy, more homogenous ecosystems (Moreno et al 2009).

There are two components to site-level taxonomic dissimilarity: the dissimilarity within each target group, and the dissimilarity *between* target groups. Pillar 3 measures both components and aggregates them into a single value that summarises site-level taxonomic dissimilarity.

Change in within-group taxonomic dissimilarity tracks the addition (or loss) of species within a single target group. Between-group taxonomic dissimilarity is also included in Pillar 3 to track the effects of species being added or lost *across* target groups, suggestive of a broader ecological recovery than one linked to the addition of species within a single target group. Because *relative change* in Pillar 3 determines quantification, not its absolute number, the selection of which target groups to monitor (i.e., how similar they are) is much less important than their scope for change over time in response to project actions. Selecting target groups that are relevant to the project's ecological and conservation context makes it more likely that survey results will track the desired outcomes of the project.

To measure within-group dissimilarity, we calculate separately for each target group the estimated Δ^* metric first described by Clarke & Warwick (1998, 2001). This metric considers both the distances between species and their relative abundances. It can be interpreted as the average taxonomic distance between two randomly selected individuals in the target group. These group-level measures are then aggregated up to site level, by weighting each value by the proportion of species within that group relative to the site's total species richness and summing the results. This provides a single value that summarises within-group dissimilarity across the site.

To measure between-group dissimilarity, while accounting for different scales of relative abundance (e.g., between plants and birds), we use the estimated Δ^+ metric, which considers only presence/absence of species. It can be interpreted as the average taxonomic distance between two randomly selected individuals from the site. This provides a single value that summarises between-group dissimilarity across the site.

To obtain an overall measure of site-level dissimilarity as the third pillar metric, the within-group dissimilarity value (i.e., the weighted sum of the Δ^* values) and the between-group dissimilarity value (i.e., the Δ^+ value) are summed.

Taxonomic distance is calculated using the *taxa2dist* function and the final metric with the *taxondive* function, both from the vegan package in R (Oksanen et al 2022). The GBIF backbone taxonomy (GBIF Secretariat 2022) is used for classifying species.

Δ* at time t is defined by the equation:

$$\Delta_t^* = \frac{\sum\sum_{i<j} \omega_{ij} p_{i,t} p_{j,t}}{\sum\sum_{i<j} p_{i,t} p_{j,t}}$$

(Eq. 3)

where $\Delta^*(t)$ is the within-group taxonomic dissimilarity at time t, the summation runs over species i and j (i.e., is calculated for every pair of species in the target group), w_{ij} is the taxonomic distance between species i and j, and p_i and p_j are the relative species abundances.

Δ+ at time t is defined by the same equation as Δ*, but where presence/absence data is input instead of relative abundances. Then, for example, p_i equals 1 if the species was detected at the site and equals zero if the species was not detected at the site.

Pillar 3 aggregates Δ* and Δ+, and is defined by the equation:

$$P_3(t) = \Delta_t^+ + \sum_{k=1}^{K} \frac{S_{t,k}}{S_t} \Delta_{t,k}^*$$

(Eq. 4)

where $P_3(t)$ is the site-level taxonomic dissimilarity at time t, Δ^+ is the between-group taxonomic dissimilarity, S_t is the total number of species detected at the site, $S_{t,k}$ is the total number of species from target group k detected at the site, and $\Delta^*_{t,k}$ is the within-group taxonomic dissimilarity for target group k.

Ideally, a functional diversity metric could be used in place of taxonomic dissimilarity. However, a robust and scalable metric of functional diversity requires sufficiently complete and standardised trait databases, with broad coverage of target groups and ecosystem types. Currently, these databases are either incomplete in terms of their species and geographical coverage, and/or contain traits that are not easily linked to changes in ecosystem health or productivity. This precludes the use of such a metric in this version of the PV Nature Methodology, but it is likely that the coverage of these databases will improve rapidly, and that it will be possible to include a functional diversity metric in a future update.

1.5.4 Pillar 4: Habitat health

Habitat health strongly affects both the structure and dynamics of ecosystems and the species communities they support. Increased habitat quality is linked to greater biodiversity via several

mechanisms, for example: increasing the number of ecological niches (e.g., micro-habitats) so that the ecosystem can sustain a wider variety of species; increasing the stability and productivity of food webs; or offering more protection from either physical or biological disturbances (Velasco-Charpentier et al. 2021).

Habitat health can be measured in many different ways, given that the concept has no consensus definition. In addition, different structural features are important in different habitat types. Here, we track change in vegetation health and density for terrestrial habitats.

For marine habitats, an equivalent approach will be developed and added as a future update to the Methodology (see 'Marine habitats' section below).

Terrestrial habitats – vegetation health and density

The amount and distribution of vegetation in terrestrial ecosystems strongly influences the distributions and dynamics of other species inhabiting those ecosystems (Pettorelli et al 2005). Changes in vegetation health, extent, and density are therefore linked to direct and indirect changes in the wider biodiversity of the ecosystem. To make the link to site-wide changes in ecosystem functioning, it is important to measure habitat health across the entire site rather than at discrete sample points, which in most cases is only feasible to achieve with remotely sensed data from technology such as drones or satellites. The NDVI (normalized difference vegetation index) is one example of easily available, remotely sensed information that can be extracted and analysed at sufficient scale to track site-wide habitat health.

NDVI tracks the 'greenness' of vegetation by measuring the ratio of reflectance in the red spectra to the near-infrared spectra (Pettorelli et al 2005). It therefore correlates well with (for example) levels of primary productivity and vegetation density (Pettorelli et al 2005). NDVI values range from -1 to +1. Negative values indicate an absence of vegetation (e.g., water or bare ground), while larger positive values indicate 'greener' vegetation. NDVI is well established as a metric of vegetation productivity and health (Roerink et al 2003), although the positive correlation does not hold in every ecosystem type (see end of this section).

Pillar 4 is based on the distribution of NDVI values across a site. Freely available Sentinel-2 Level-2A Multispectural instrument data is used to estimate the NDVI values across the project area. To mask out pixels with a high probability of cloud cover, the Sentinel-2: Cloud Probability dataset is used. A mosaic is constructed using the median NDVI value for each pixel (corresponding to 100m^2) of the site, where the median is calculated over a three-month period.

The exact parameters (e.g., the cloud probability threshold) used in the cloud mask, and which three-month period is used to calculate Pillar 4, will depend on the characteristics of the project and will be chosen to reflect the peak of vegetation cover while reducing the probability of cloud cover. This will be included in the sampling plan for each project, to be verified by the PV Nature TRP.

Once the site's NDVI raster has been compiled from the Sentinel database, the site's spatial distribution of NDVI values needs to be condensed into a single summary value. This must be calculated in a way that reflects changes in vegetation extent, density, and health. Since NDVI is a continuously-valued index (i.e. it has values between -1 and +1 rather than categorical labels, e.g. related to land use), a continuous surface metric should be used to summarise the NDVI raster (Smith et al. 2021). This reflects the underlying distribution of NDVI values across the landscape, rather than lumping them together in sometimes arbitrary patches.

Continuous surface metrics reflect the smooth nature of landscapes, by summarising the underlying data layer (e.g., an NDVI raster) as continuous values rather than discrete patches of categorical values (Smith et al. 2021). One example is the surface bearing index (SBI), initially developed to model the roughness of machine surfaces.

The SBI is the ratio of the height from the maximum to the 95 percentile of the bearing area curve, to the root mean square roughness (the standard deviation of surface values). In other words, it is a measure of how extreme the landscape's top 5% of NDVI values are when compared to the overall distribution and density of NDVI values across the landscape, i.e., how skewed the distribution is (Kedron et al. 2018). The reciprocal of SBI will therefore increase as vegetation health improves.

In sum: Pillar 4 is an SBI used to summarise the site's NDVI raster, calculated annually, using freely available Sentinel satellite imagery. The SBI is then calculated using the *geodiv* package in R (Smith et al 2021). All calculations are performed on behalf of projects and are reviewed by the TRP.

Pillar 4 is defined for terrestrial habitats by the equation:

$$P_4(t) = \frac{z_5(t)}{\sigma_{\mathrm{NDVI}}(t)} \qquad \text{(Eq. 6)}$$

where $P_4(t)$ is the habitat health metric at time t, z_5 is the 5th-percentile of the cumulative distribution of the NDVI values across the site, and σ_{NDVI} is the standard deviation of surface

heights from the mean surface height (note that 'height' refers to the value of the NDVI raster, not the physical vegetation height).

This pillar metric has been tested on both real world and synthetic data. Testing demonstrated that it responds appropriately to both loss and degradation of vegetation, as well as to gains in vegetation health and density as ecosystems recover.

More specifically, Pillar 4 increases as the 'height' of extreme NDVI values decreases – which occurs as healthy vegetation replaces areas of no or degraded vegetation and a 'smoother' landscape (in terms of NDVI values) emerges. Hence an increase in Pillar 4 occurs when the distribution of vegetation quality, extent, and density increases across the site, such as when secondary forest recovers to primary forest, grassland recovers from overgrazing, agricultural land is restored to woodland, and so on.

On the other hand, Pillar 4 decreases when vegetation is cleared or degraded, since this widens the range of NDVI values at the site – the cleared or degraded areas now have lower NDVI values, while healthier areas of the site still have high NDVI values, and so the landscape is 'rougher' in terms of NDVI values.

There are certain project contexts that require further testing – i.e., specific types of sites where positive restoration outcomes may not correspond to increases in NDVI or Pillar 4. For example, projects that aim to increase the extent of standing water (e.g., rewetting projects), or projects where the restoration goal involves replacing greener vegetation with less green vegetation. In these particular ecosystems, a different index of habitat health may be more appropriate than an SBI that summarises the site's NDVI distribution. Testing and refinement of Pillar 4 calculation for these types of cases is underway and will continue in collaboration with projects as more evidence of real-world habitat changes becomes available for different scenarios and ecosystem types. An update to the Methodology will be published based on the results of this testing. Until this update is issued, the Plan Vivo TRP will review the appropriateness of Pillar 4 on a project-by-project basis and may recommend substituting a different, equivalent, ecosystem-specific index in the calculation of Pillar 4.

1.5.5 Pillar 5: Habitat spatial structure

The level of biodiversity that a section of habitat can support is a direct function of its spatial structure, namely its extent and structural complexity. For terrestrial habitats, habitat connectivity is therefore an important indicator of ecosystem health (Fischer and Lindenmayer 2007). A terrestrial site's capacity to support biodiversity will increase when the patches of natural habitat contained within the site are larger and more connected.

Terrestrial habitats – habitat connectivity

Pillar 4 (see Section 1.5.4) tracks changes in the distribution of vegetation health and density but does not track changes in the spatial distribution of habitat types – i.e., it does not track habitat connectivity, which is a different, important, structural aspect of ecosystem condition.

Pillar 5, for terrestrial habitats, tracks habitat connectivity. The CPLAND index (Hesselbarth et al 2019) is used to measure the degree to which different patches of habitat at a site are connected to each other. The focus is on habitat types that are important for supporting a wide range of biodiversity conservation or recovery, rather than for particular species; habitats are therefore broadly classified into 'intensive human use' and 'low intensity human use'. This classification does not require information about specific species' habitat preferences and/or dispersal distances, which would not be feasible to calculate for all species in all target groups.

In this binary classification, arable crops or plantation forestry would, for example, be classed as 'intensive human use'; semi-natural forests, low-use agroforestry systems and primary forests would be classed as 'low intensity human use'. This categorisation will depend on the habitat classification system[1] and local context relevant to each project; it will be determined at biodiversity baseline, in consultation with projects, and ground-truthed with on-site project visits (i.e., third-party validation).

The CPLAND index measures how well-connected the patches of 'low intensity human use' habitat are to each other. It is a percentage and therefore ranges in value from zero to 100. It responds to both the extent and spatial arrangement of the habitat patches (i.e., how well connected they are) present at a site (Wang et al 2014). This is in contrast to habitat indices that isolate the effect of spatial aggregation separately from habitat extent, which can lead to counterintuitive results, for example increasing in value when large areas of natural habitat are removed, as the connectivity improves for the small patches remaining. The CPLAND index avoids this behaviour by varying with both extent and connectivity.

[1] Habitat classification uses the most high-definition, locally relevant classification system available for the site in question, whether national, regional, or global. Some of these systems are based on landcover classes rather than habitat types (See Glossary and Section 2.5.1).

Pillar 5 is defined for **terrestrial habitats** by the equation:

$$P_5(t) = 100 * \frac{1}{A_t} * \sum_{j=1}^{n} a_{ijt}^{\text{core}}$$

(Eq. 7)

where $P_5(t)$ is the habitat connectivity (in percent) at time t, A is the total area of the site, and a_{ij} is the core area of the j-th patch of type i. Core area is defined as the area of a patch that is not an edge, which is set as the outer 10m of a patch. In other words, the core is the part of patch j of type i that is not touching a habitat patch of the other type, with a buffer of 10m.

To calculate the metric, freely available satellite imagery from Sentinel-2 is used to construct a polygon habitat map, classified by high or low intensity human use. Next, the polygon habitat map is converted to a raster at resolution of 10m. Then, the CPLAND index is calculated using the *lsm_c_cpland* function from the *landscapemetrics* package in R (Hesselbarth et al 2019).

Pillar 5 is calculated at biodiversity baseline and every 5 years thereafter, unlike the other four pillars that are calculated yearly. Each calculation of Pillar 5 (after biodiversity baseline) coincides with independent, third-party, on-site verification, as part of the PV Nature Validation and Verification process.

In all cases, the habitat classification for CPLAND calculation will also be reviewed by the PV Nature TRP. The calculation of this index is therefore always linked to on-site ground truthing and does not rely entirely on satellite imagery.

1.6 Multimetric

The multimetric is the cumulative sum of the year-on-year percentage changes in the pillar metrics. The multimetric value at time T, where T is not a verification event, is therefore the cumulative sum of changes since the biodiversity baseline for Pillars 1-4, and is defined by the equation:

$$M(T) = \sum_{t=1}^{T} (P_1(t) + P_2(t) + P_3(t) + P_4(t))$$

(Eq. 9)

where $P_i(t)$ is the percentage change in pillar metric i between year t and year $t-1$:

$$P_i(t) = 100 * \frac{P_i(t) - P_i(t-1)}{P_i(t-1)}$$

(Eq. 10)

Only changes in the pillars which are confirmed in a post hoc analysis (Section 1.9) are included in the calculation of the multimetric value.

In years where additional verification measurements are taken (e.g., at biodiversity baseline, and every 5 years after), Pillar 5 is calculated in addition to Pillars 1-4, and included in the multimetric:

$$M(T) = \sum_{t=1}^{T} (P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t))$$

(Eq. 11)

where the percentage changes $P_i(t)$ in the pillar metrics are again calculated as in Equation 10. Note that the percentage change in Pillar 5 is calculated between the two most recent measurements, e.g., in Year 5 the percentage change from biodiversity baseline (Year 0) is calculated, in Year 10 the percentage change from Year 5 is calculated, and so on.

Figure 3. An example of how the multimetric summarises the pillar metrics, for A) restoration, and B) conservation cases – note the different scales on the vertical axes. Biodiversity change over time is represented as a stacked bar chart: each bar represents one year, and each 'stack' within a bar represents a pillar metric (colours indicated in the legend). By plotting the cumulative sum of the percentage change in the pillars over time, the multimetric (black line) tracks the overall trend in biodiversity.

1.7 Restoration certificates

Plan Vivo Biodiversity Restoration Certificates ($PVBC_{RESTORE}$) represent increases in biodiversity at a site, as measured by the multimetric. A single restoration certificate is equal to a 1% increase in the multimetric in one year in one hectare of a site.

In year *t*, the number of restoration certificates $C_R(t)$ is calculated as the difference in multimetric value from the most recent certificate issuance (to remove double counting due to the cumulative function), multiplied by the size of the site in hectares:

$$C_R(t) = (M(t) - M(t-1)) * H$$

(Eq. 12)

where *M(t)* is the multimetric in year *t* and *H* is the size of the site in hectares.

After the third measurement (i.e., baselining and two subsequent sampling events), projects can choose to begin issuing certificates. As the multimetric is cumulative and comparison is made to the most recent certificate issuance, this means that gains can be 'saved up' for a larger issuance in a later year. This may be of interest to projects where sites are expected to accumulate gains more slowly. Projects must meet all other requirements of PV Nature before issuance of certificates.

Biodiversity fluctuates naturally over time. Only changes (either positive or negative) that are confirmed in a post hoc analysis will be included in the multimetric value and therefore count towards certificate issuance (see Section 1.9).

Projects proposing to restore areas that would be starting from exceptionally low or zero biodiversity (e.g., bare or heavily contaminated land) are ineligible for PV Nature. In addition, sites that have been intentionally degraded or cleared of the native ecosystem within the last 10-years will not be eligible (see PV Nature eligibility criteria).

1.8 Conservation certificates

To be eligible to issue Plan Vivo Biodiversity Conservation Certificates ($PVBC_{CONSERVE}$), a project area must meet at least one of the Key Biodiversity Area (KBA) criteria, or two of the Important Plant Area (IPA) criteria (see Section 1.2), i.e., conservation certificates can only be issued by projects that are conserving important and threatened biodiversity.

Conservation certificates are issued when the Year 0 (biodiversity baseline) values of the pillar metrics are maintained over time, as measured by the multimetric. A multimetric value of zero for a given year means that 100% of the biodiversity baseline has been conserved. If 100% of the biodiversity baseline is conserved, a project can issue 20 conservation certificates per hectare per year. Issuing 20 certificates per hectare in instances where 100% of the baseline biodiversity is conserved is intended to avoid differences of orders of magnitude between the numbers of certificates created by restoration and conservation projects when they are successful. This assessment is based on testing with currently available data and takes into account that the magnitude of restoration 'success' will vary with ecological context.

Biodiversity is naturally variable, and some downward fluctuation will happen naturally, even in effective conservation scenarios. A realistic 'floor' to these fluctuations is required, to ensure allowances are made for natural processes while still guarding against genuinely poor outcomes. Therefore, to allow for natural, interannual biological fluctuations in biodiversity at site level, certificates can be issued if >90% of the Year 0 multimetric value is conserved. If the multimetric

value drops below 90% of the Year 0 value, no certificates can be issued. The number of certificates that can be issued (per hectare per year) decreases from 20 to 18 as the multimetric value drops from 100% to 90% (see Figure 5)[2]. Note that the threshold of 90% represents a conservative approach and may be updated in future as more real-world data and evidence become available.

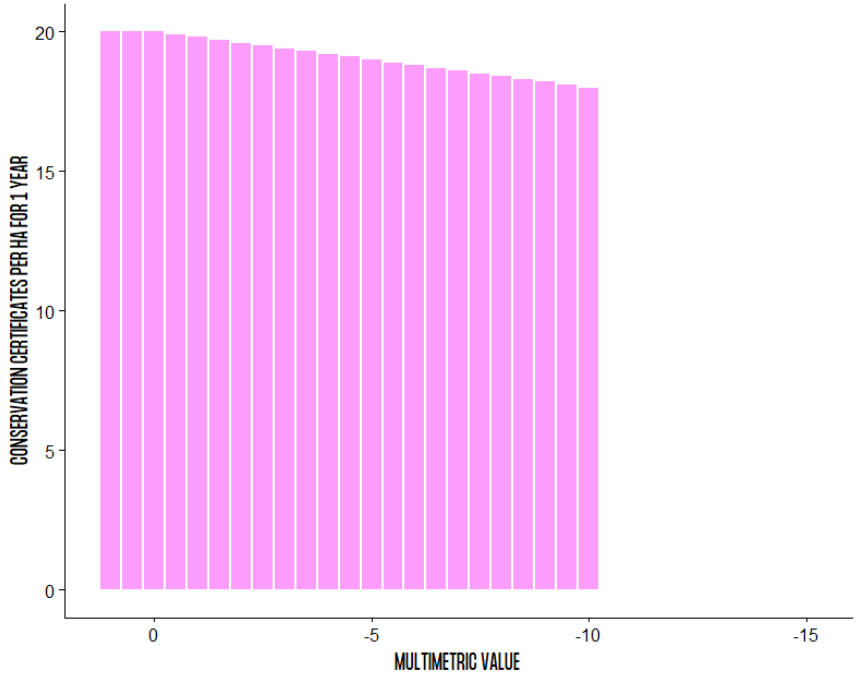

Figure 4. Changes in the number of conservation certificates as the multimetric value decreases in a given year. For values equal to or greater than zero, 20 certificates per hectare of the site can be issued per year. For values below -10, no certificates are issued.

In other words, a single conservation certificate is equal to 5% of the biodiversity baseline conserved per hectare per year (100% divided by 20, 90% divided by 18, etc), but a minimum of 90% of the biodiversity baseline must be conserved to permit any certificate issuance.

Biodiversity fluctuates naturally over time, up and down. Only changes (either positive or negative) that are confirmed in a post hoc analysis will be included in the multimetric value and therefore count towards certificate issuance (see Section 1.9).

Conservation sites can also issue restoration certificates (see Section 1.7), if they achieve evidenced gains above the biodiversity baseline which are confirmed in the change confirmation process (Section 1.9).

Conservation certificates are calculated, for biodiversity baseline conservation between 90% and 100% (i.e., for a multimetric value $M(t)$ between zero and -10), as:

[2] The extent to which biodiversity fluctuates naturally will vary with ecological context. The 'floor' of -10 multimetric units will be kept under review as more data becomes available, and different values for different ecosystem types may be established in the future.

$$C_C(t) = \frac{M(t) + 100}{5} * H \quad \text{(Eq. 13)}$$

where $C_C(t)$ is the number of conservation credits, $M(t)$ is the multimetric in year t and H is the size of the site in hectares. Values are rounded to the nearest whole certificate. The rescaling factor of 5 is included to specify that a multimetric value of 0 (100% of the biodiversity baseline conserved) is equivalent to 20 conservation certificates per ha per year.

After the third measurement (i.e., baselining and two subsequent sampling events), if metric values are confirmed as per Section 1.9, then projects can choose to begin issuing certificates. At the point of issuance, the proportions of baseline biodiversity conserved over the certificate issuance period are summed. Any fall, or gain, in the pillar values must be confirmed in the change confirmation process (Section 1.9) before it can be included in the multimetric value.

1.9 Change confirmation

Biodiversity is complex and naturally variable in both time and space. Measurement of biodiversity values is almost always associated with uncertainty, which can originate from a number of sources, including:

- Measurement uncertainty: for example, the precision and accuracy of the measurement of species and their relative abundances. This can come from both the physical measurements and data processing.
- Environmental variables: for example, the effect of variation in short-term environmental conditions (such as temperature, wind speed, rainfall, etc) and preceding environmental events (such as fire or flooding) on biological activity and detection probability.
- Biological fluctuations: changes in biodiversity are almost never linear and will naturally fluctuate between years, for example, decreasing in an individual year even if the overall trend is upwards.

1.9.1 Years 2-5

In Years 2-5, only changes **outside** the 95% confidence intervals for each target group's pillar value are included in the multimetric value. Confidence intervals are calculated each year using the within-survey variance for the target group pillar values. This is a conservative and precautionary approach to ensure confidence in any values that count towards certificate issuance.

Measurement accuracy will be continuously tested and assessed, and a correction factor applied if there is a statistically significant change in the early years.

Environmental conditions are recorded alongside species level data (see Section 2.1.4) and a consistent seasonal sampling window is required (see Section 2.2.2), to minimise the effect of environmental variation. Data quality checks will also be performed to ensure that conditions were suitable for data collection, for example wind speed was within the range that does not interfere with audio recordings.

The effect of varying environmental conditions and preceding environmental events[3] on pillar values will be continuously assessed during these early years and correction factors applied where necessary. If a wide range of environmental conditions are recorded between data collection events during this early period, it is assumed that yearly comparisons cannot be rigorously made, and certificates therefore cannot be issued. In this scenario, projects must wait until Year 5 to issue conservation or restoration certificates.

By Year 5, a much richer dataset will be available from which to assess trends and distinguish real change from background variation.

1.9.2 Year 5 onwards

From Year 5 onwards, a trend confirmation analysis is used. This is a linear hierarchical model run for each target group's pillar metric values. Input values are those from each sample point, with each point's habitat type used as a random effect, and the key environmental variables and measurement detection probabilities as fixed effects. Note that the key environmental variables included will depend on the specific target group (see Section 2.4).

If the slope of the trend line estimated by the model is statistically significant, meaning it is different from the null model of no change, then the yearly change in the pillar value is included in the multimetric value. This means that the change must exceed the yearly fluctuations. The same process applies for both positive and negative changes. The model is run each year on the previous five years of data.

1.10 Global significance labels

Biodiversity is not evenly distributed around the world and different components of biodiversity face different levels of global threat. For example, some regions of the world support vastly more

[3] Examples of datasets from which data on preceding environmental events (such as floods, fires, etc) will be extracted include the Global Satellite Mapping of Precipitation, and Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies dataset.

species than others; some support species that are found nowhere else on Earth; and some support species or ecosystems that face imminent threat of global extinction.

While it is important to reflect this variation in 'significance', it is extremely difficult to quantify it objectively. Therefore, this Methodology does not attempt to incorporate global significance into the calculation of certificate numbers. Instead, the significance of a site to global biodiversity conservation is included as a 'global significance label', i.e., a piece of metadata that accompanies the restoration or conservation project and signals how a project's biodiversity contributes towards global biodiversity conservation goals.

The site-level significance labels are:

1. **The global threat status of the ecosystem(s) where the site is located,** as listed on the IUCN Red List of Ecosystems. The IUCN Red List of Ecosystems assesses threat based on the global ecosystem distribution (how much there is in the world), the rate of loss, and changes in ecosystem processes. Assessments have not yet been completed for every ecosystem in the world, but the IUCN has a target to assess all ecosystems by 2025. If more than one type of ecosystem is contained within a site (e.g., the site is located along a transition zone), then the label uses the higher threat status, but only if that ecosystem accounts for at least 25% of the total project area.

2. **The number of species present at the site that are threatened with global extinction**, defined as Near Threatened, Vulnerable, Endangered or Critically Endangered on the IUCN Red List of Species[4].

3. **The proportion (%) of the ecoregion's land or sea area that is currently under strict biodiversity protection**, defined as IUCN protected area categories 1-4[5].

4. **For terrestrial sites only, the rarity-weighted richness value for threatened birds and mammals**, as the percentile position within the global distribution. Rarity-weighted richness is recognised as an important indicator of the significance of an area to global conservation efforts (Guerin et al. 2015; Astudillo-Scalia & Albuquerque 2019). It considers both the number of species present and how restricted their ranges are (i.e., how much of the global distribution of a species' habitat is contained within the site in question). The rarity-weighted richness value is calculated based on the threatened species found at the site. The label is reported as a position in the global distribution of rarity-weighted richness values, e.g., the 90th percentile or the 54th percentile. This label is calculated only for birds and mammals,

[4] Target 4 of the Global Biodiversity Framework (GBF) sets a global target to halt human induced extinction of known threatened species.

[5] Target 3 of the GBF sets a target of effective conservation of at least 30% of terrestrial and marine areas.

because it requires high-quality, open-source maps of the Area of Habitat (AOH) of each species, which are currently not available for other groups. However, construction of AOH maps is ongoing work and more taxonomic groups will likely be added in future.

These labels will not be ranked, either within or between label types, e.g., label 2 will present the number of threatened species rather than a ranking on a scale from 1-5, high to low, etc. This is to avoid reducing the information provided by the label, and obscuring differences between sites. It also avoids the risk of over-skewing demand towards specific project types with high-ranking labels, which may not reflect the full spectrum of the global need for nature financing.

Further labels may be added in future, for example, a label equivalent to (4) that is relevant to marine projects.

2 SECTION 2 – BIODIVERSITY DATA PROTOCOL

2.1 Overview

2.1.1 General principles

The PV Nature Methodology aims to assess change over time in a subset of site-level biodiversity that represents the overall trend in the health of the ecosystem. The purpose is to obtain a robust measure of change in biodiversity over time, rather than (for example) to take a complete census of every living thing on a site, or to categorically prove the presence or absence of a particular species or group. Biodiversity trends give us an indication of the health of ecosystems within a site: as biodiversity improves, so do the functionality, productivity, and overall health of the ecosystem (Tilman et al 2014).

This Methodology for assessing and tracking change in biodiversity can be broken down into five stages:

1. Sampling design
2. Data collection
3. Species identification by machine learning and/or human experts
4. Quality control by human experts
5. Calculation of pillar metric values, multimetric and PVBCs

In this Data Protocol, the requirements and minimum standards for stages 1 – 4 are detailed. These stages cover the design and execution of on-the-ground sampling at project areas, as well as the labelling (i.e., species identification) and quality control of the data that is gathered during sampling. The metrics and certificate calculations used in the final stage are detailed in Section 1 of this document.

This Data Protocol aims to standardise, as far as possible and practicable, what data is collected by projects, and how that data is collected and analysed. In doing so, it aims to minimise subjectivity and maximise rigour, while also ensuring PV Nature is accessible to as many potential projects as possible.

In summary, the Methodology requires data on 1) the presence of species, 2) their relative abundances, 3) the type and extent of the different habitats present at a site, and 4) environmental conditions (weather etc.) during species data collection periods.

This data must:

a) **Cover sufficient taxonomic breadth**, or groups of species, to accurately reflect the general trend of biodiversity at a site. This is because different groups will respond over different time scales to land use changes or other restoration or conservation interventions (Jones et al 2018). Surveying multiple groups is therefore crucial to ensuring a robust measurement of biodiversity trends, and to enabling an assessment of trends in ecosystem health. Data must be collected on a minimum of four broad target species groups for terrestrial projects and a minimum of three target groups for marine projects (more detail provided below). See Section 2.1.2 for an overview and Section 2.4 for details per project type.

b) **Be collected using methods that allow the calculation of species detection probability and classification error,** to minimise the risk that changes in detection are mistaken for changes in biodiversity. See Section 2.2.

c) **Be collected with sufficient spatial and temporal sampling density to enable statistically robust conclusions to be drawn** (i.e., to enable trends to be distinguished from stochastic variation). See Section 2.2.

d) **Be robust to error from observer bias and be fully repeatable.** This ensures comparisons can be made between years and trends in biodiversity isolated from other sources of variation or 'noise'. See Section 2.3.

e) **Be fully auditable and of high integrity**. To achieve this, data is required to be digitally recorded, independently quality controlled, and to contain spatiotemporal metadata. This is critical to allowing verification of data integrity and auditing of results by third parties. See Section 2.6.

Box 3: A note on terminology.
In this document the words 'must', 'need(s) to' and 'required' indicate that something is mandatory. The word 'should' indicates a recommendation.

2.1.2 Species data – target groups

Data is required on species presence and relative abundances for a minimum number of target groups. Target groups are categories of species. Although some groups overlap with taxonomic classifications, they are not strictly limited to, nor necessarily entire, taxonomic groups. Examples of possible target groups include (but are not limited to): birds, bats, herbaceous and woody plants under 2m in height, flying insects, or medium and large mammals.

More important than the number of target groups measured is that they cover a range of taxonomic groups, trophic levels, and ecological niches. The subset of groups targeted for survey will vary depending on the ecosystem. The more groups that are sampled, the more likely it is that trends will be distinguishable in the overall data and the richer the 'story' a site can tell.

A recent habitat map is required for each project area. This habitat map is critical to ensuring robust sampling methods and coverage.

2.1.3 Habitat data

A recent habitat map is required for each project area. This habitat map is critical to ensuring robust sampling methods and coverage.

2.2 Sampling plan design

It is almost always impossible, for cost and complexity reasons, to exhaustively census a site across all taxonomic groups and measure its biodiversity precisely. Instead, sampling methods are used: measurements are taken at a random sample of locations, and then an estimate of the overall biodiversity is obtained from a robust statistical analysis of the collected data. These are standard, well-established methods in biodiversity monitoring (see e.g., Magurran 2003), and at their heart lies the design of the sampling plan.

The sampling plan for a project area is constructed by randomly choosing sampling locations (i.e., the locations at which target groups will be assessed) within the project area, stratified by habitat. In other words, a site-specific random stratified sampling plan is prepared for each project. This ensures consistent sampling coverage across habitat types and across the total extent of the site. Sampling plans are discussed with projects to ensure inclusion of local knowledge and the safety and accessibility of the sample points.

A new, randomised sampling plan is created for each data collection event (i.e., usually annually), such that the randomly located sampling points are 'shuffled', while remaining stratified by habitat.

For marine projects, the site area will first be zoned to exclude areas unsafe or inaccessible for data collection, e.g., shipping lanes. This zoning will be done in consultation with the project, who are familiar with the area. The sampling plan will then be constructed using a random set of sampling locations, stratified by habitat, within the safe zones. On a project basis, a combination of both random and fixed sampling will be considered and reviewed by the TRP.

Random sampling is essential to track changes across the entire site. However, an *additional* set of fixed sampling points may be necessary to ensure monitoring of irreplaceable elements of a site's biodiversity, e.g., small populations of threatened species known to inhabit specific, restricted areas. In these cases, subject to approval by the PV Nature TRP, the sampling plan will include the required random sampling points that vary from year to year, plus an additional, smaller set of fixed sampling points specifically designed to capture data on threatened species.

2.2.1 Spatial requirements

Construction of a sampling plan requires:

1) a boundary polygon of the project area and;
2) a habitat map.

Both need to be provided in standard geospatial vector file formats (e.g., a shapefile, KMZ/KML, etc.). The boundary polygon must be submitted by the project. The habitat map can be provided by the project, or one can be created for them[6] (see Section 2.5).

To create the sampling plan, a randomising algorithm is used to select sampling locations. It treats contiguous areas of a site as distinct 'patches', given the biological importance of connected or contiguous areas. This ensures that different site configurations (e.g., one contiguous plot or many separate smaller plots) can be included in the algorithm. The algorithm balances a number of requirements:

- Proportional representation of habitat (or landcover) types (by area). This includes important transition areas between habitats, to ensure these are surveyed while avoiding edge effects.
- Independence of sampling locations (i.e., maintaining a minimum separation distance).
- Avoidance of edge effects (i.e., maintaining a minimum distance from the edge of a habitat patch).
- Sufficient replication within a habitat type; any patches too small to allow minimum replication are excluded from sampling.
- Sufficient sampling coverage, starting at approximately 1 sampling location per 10 ha for contiguous habitat patches of up to 100 hectares, and then scaling non-linearly as habitat patches increase in size (i.e., large, contiguous habitat patches require fewer sampling location per hectare than small patches)[7]. This scaling is built into the sampling plan design to account for the natural spatial scaling in biodiversity trends.

[6] Where possible, projects will submit their own habitat map. Projects without this capacity can opt to request support.

[7] Above 10,000ha it becomes possible to apply other scaling methods; these are currently in development.

A tolerance of 100m in the placement of a sampling location is permitted to allow surveyors on the ground to avoid obstacles. In consultation with each project, if a certain sampling location is inaccessible due to (for example) difficult terrain or geography, then the sampling plan will be updated if appropriate.

Finalised sampling plans will be sent to projects as either a list of point locations (lat/long), a geospatial vector file (e.g., a shapefile), or within a navigable map.

It is important to note that sampling plan designs are constantly improving. The automated sampling design aims to maximise sample coverage and as more data becomes available over time, the design algorithm will be continuously reviewed to ensure this goal is achieved while minimising data collection effort.

2.2.2 Temporal requirements

Monitoring of target groups must occur at least once per year and must be timed to minimise measurement variation due to seasonal changes in biology or ecology (e.g., plants flowering in spring). In some project areas, this consistency in seasonal timing will be achieved by ensuring data collection occurs at roughly the same time each year. In other project areas, sampling time and consistency may be defined more suitably by season rather than by calendar date, for example, within two weeks of the start of the rainy season rather than within the first two weeks of March. The appropriateness of the data collection timing planned by the project will be assessed by the PV Nature TRP.

Projects can, if they wish, split data collection so that specific target groups are monitored at different times of year – for example, recording data on birds and amphibians in spring, trees in summer, and so on. However, if this option is selected, then each individual target group must be monitored in the same season in each subsequent year. For example, if birds are monitored in spring, they must always be monitored in spring. Splitting data collection in this way is likely to involve higher costs for projects but may be beneficial in some specific cases in terms of the probability of capturing ecological changes in the data.

Target groups must be assessed once per year as a minimum. However, more frequent sampling is allowed (for example, to enable assessment of seasonal patterns at the site) and, if conducted, can be used to help to guide the timing of sampling in following years.

2.2.3 Species accumulation curves

Species accumulation curves are a well-established method to check the adequacy of sampling (e.g. Roswell et al 2020). They track the number of species detected at a site (or transformations

of that quantity, such as species diversity) as a function of sampling effort – typically the number of sampling units. It is important that the species accumulation curve should at least begin to plateau (mathematically: the slope of the curve achieves its maximum value and then begins to converge to a much lower value), and ideally travel some distance along the plateau, to provide a realistic estimate of species richness and/or diversity. This indicates that additional sampling effort would not lead to significant additional species detections, and therefore that the sampling effort was adequate.

Species accumulation curves will be generated for projects (one curve for each target group that was surveyed), as a data sufficiency check for all target groups that are included in calculation of biodiversity metrics. Minimum sampling requirements for individual data collection tools (see Sections 2.6) have been deliberately set high initially (i.e., a precautionary approach is applied to sampling density) and will be reviewed as more data on limits of sampling adequacy becomes available.

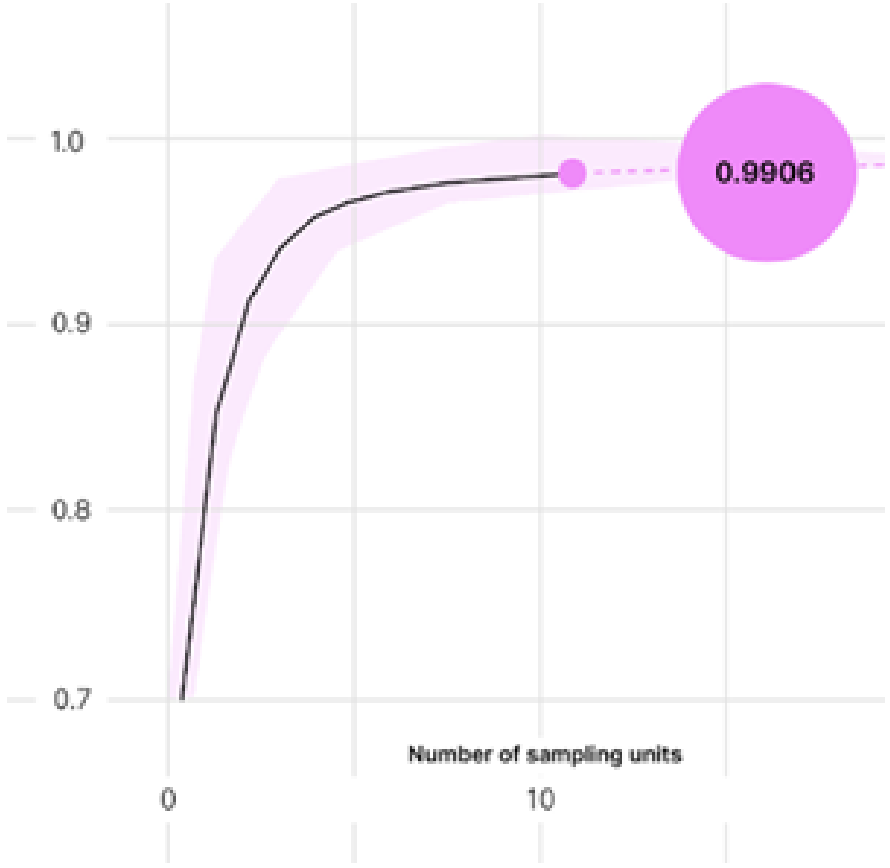

Figure 5. An example of a species accumulation curve. The x-axis shows the number of sampling units (e.g. number of recording devices or photographed quadrats), and the y-axis tracks the detection of new species. The curve increases very quickly at first, as many species are discovered, and slows down once the common species have all been detected, and only rare species remain to be detected with relatively more sampling effort.

2.3 General data requirements

The Methodology sets a number of data requirements. The aim is to ensure rigour and consistency in the data that is used as evidence of biodiversity outcomes, and to minimise the number of subjective choices made by projects. At the same time, an important goal is to retain the flexibility required for the Methodology to be applicable across a range of ecological and social contexts.

This section outlines the general specifications that apply to all data types used to evidence biodiversity outcomes within a project area.
Once data has been collected, its integrity is assessed against these minimum data requirements, taking into account the different data types that have been collected (see Section 2.4), before it is labelled (for example, with species identifications) (see Section 2.7.1). A quality control process is applied to the results of data labelling (see Section 2.7.2). Results are then analysed and PVBCs calculated (see Section 1). Database access is available for third-party verification of the entire data pipeline.

In order to verify the biodiversity outcomes achieved by individual projects, an auditable data trail is required. That is, records of species and their (relative) abundances, habitat assessments, and environmental data collected by/for a given project must be traceable back to where and when the data points were recorded, who and/or what created a specific record and/or label (e.g., a machine learning algorithm or a human expert), and how the data were quality controlled (e.g., machine-generated species identifications were checked by a domain expert, or human expert-generated identifications were checked by a second, independent expert). This ensures that a third-party auditor can trace back through the data and independently verify not only the calculation of change on the ground, but also the data that underpins that calculation.

All data must therefore meet the following specifications:

1. All data must be digitally recorded.
2. Each digital data point must be associated with digital metadata (e.g., EXIF metadata) that, as a minimum, captures the location (lat/long), date and time at which the record was collected.
3. The digital metadata associated with each data point must also capture a unique ID (e.g., serial number) that relates to the sensor, hardware or piece of equipment that made the record.

Metadata will be used to run checks on the data, for example determining that records were captured at the pre-defined sampling locations during the correct time period(s).

2.4 Specific requirements for species, habitat and environmental data

2.4.1 Overview

The Methodology calculates a set of metrics that track some of the most important components of biodiversity (see Section 1). The data requirements for this are: 1) the presence of species; 2) their relative abundances, and 3) a map of the different habitats present at the site.

These data, which feed directly into the calculations of change in site-level biodiversity, require:

a) Identifying the species (from each target group) that are present at each sampling point;
b) Determining the relative abundances of those species; and
c) Segmenting and labelling the site's habitat map.

Species identifications and relative abundances are derived by an approved third-party data analytics provider from the digital data collected by the projects.

This section outlines the broad data types that must or should be collected, including:

- Required target groups;
- Required environmental data; and
- Required habitat data.

The aim is to standardise data collection as far as possible, while at the same time maintaining the flexibility required for applicability across a range of ecological contexts.

Terrestrial, marine, and mixed-habitat ecosystems are covered separately. In all cases, projects can either collect data themselves or request support for data collection. A 'toolbox' of recommended, easy-to-use data collection techniques, and guidelines for their implementation, will be available to support projects and maximise accessibility.

Box 4: The importance of replicability

To enable changes in biodiversity to be detected, data collection techniques must be reliably replicable with a low probability of variation due to observer bias. For example, the technique of 'active searching' would not be suitable because variation between observers makes it almost impossible to replicate reliably (e.g., some observers will find more frogs, insects, etc., because they are better at searching rather than because more are present).

2.4.2 Terrestrial projects

2.4.2.1 Target species groups

At a minimum, terrestrial projects are required to collect data to the lowest possible taxonomic classification (preferably species level) from at least four target groups (see below).

For terrestrial projects, these four target groups must include:

1. Herbaceous and woody plants <2m in height
2. Birds

Terrestrial projects must also include at least two other target groups selected from the following list. Target groups selected from this list should be relevant to both the ecosystem type and the intended biodiversity outcomes of the project:

3. Medium and large mammals8
4. Bats
5. One broad group of invertebrates (e.g., flying insects, ground-dwelling arthropods, etc.)
6. Amphibians
7. Other herpetofauna9
8. Woody plants (e.g., trees), palms and bamboo >2m in height
9. Lichens and mosses
10. Soil microbes10

Selecting target groups that are relevant to the project's ecological and conservation context makes it more likely that survey results will track the desired outcomes of the project. The target groups selected will be reviewed by the PV Nature TRP (see Figure 1).

In addition, any species or other biodiversity attributes that would trigger a site to be eligible as a conservation project through one KBA criterion or two IPA criteria must also be monitored (note that the site does not need to have been designated as a KBA or IPA). If these species cannot be monitored using the random stratified sampling plan (e.g., there is a small population in a specific, restricted area of the site), then additional, fixed sampling points should be used (see Section 2.2). If obtained using fixed sampling points, species data will not be included in the calculation of the

[8] Defined here as mammals with body size >500g, excluding bats

[9] Recommended data collection tools for reptiles are still in development; any tools deployed must generate consistent results that can be compared across years with statistical validity and must meet the minimum requirements outlined in this Methodology & Data Protocol.

[10] Data collection requires eDNA; a protocol for the use of eDNA as a data collection tool under PV Nature is under development and will be added as a forthcoming update. In the meantime, projects wishing to use eDNA should contact Plan Vivo for guidance.

multimetric (since it estimates site-level biodiversity changes, requiring random sampling). This data will, however, be reviewed by the PV Nature TRP to ensure there are no unintended outcomes occurring with respect to potentially irreplaceable biodiversity (see PV Nature Project Requirements Section 4.7).

2.4.2.2 Environmental data

Environmental conditions are an important potential source of variation in some biodiversity datasets.

Wherever possible, environmental data will be extracted from publicly available weather datasets (i.e., projects will usually not be required to collect or submit environmental data themselves).

Where suitable public datasets are not available, projects may be required to record environmental data directly, on site, using a single, digital 'weather station'[11] or other methods suitable for the project area. This need only be deployed at one location within the project area[12], but its location and positioning should be consistent between years.

2.4.3 Marine projects

Data collection techniques are available for shallow-water marine ecosystems that are digital, repeatable, minimise observer bias and enable third-party verification of the results. However, most of these techniques are less well tested than their terrestrial equivalents, and more work is needed to test the cost and feasibility of their deployment by projects. Collaborative testing of data collection techniques will therefore be conducted with early projects, to ensure marine projects have access to a range of techniques that provide data meeting the Methodology's requirements.

The Methodology will be updated after launch with more specific data requirements for marine ecosystems, including more details of available data collection tools and how to use them. During the first phase after launch, early projects will work to the following protocol and will not be penalised for any future changes made to it.

It is assumed that marine projects will be limited to nearshore sites, since affordable tools for multi-taxonomic biodiversity data collection in the deep ocean are unlikely to be available in the near term.

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[11] Suitable digital weather stations are available for <$200; they must be deployed only for the period during which biodiversity data collection takes place (i.e., it is not a requirement to collect environmental data throughout the year), but it is recommended to collect data for as much of the year as possible because long-term environmental data can provide projects with useful contextual information.

[12] Very large sites > 50,000ha may need to deploy multiple sensors depending on their sampling plan to ensure the environmental data collected is at sufficient resolution.

2.4.4 Target species groups

At a minimum, marine projects are required to collect data to the lowest possible taxonomic level (preferably species level) from at least three target groups. Target groups should be chosen based on a site's general location and ecosystem.

Marine projects must include at least three of the following:

1. Benthic vegetation
2. Sessile invertebrates, as appriate to the ecosystem (see Glossary for definition)
3. Fish
4. Motile macro-invertebrates (see Glossary for definition) (e.g., molluscs, crustaceans, etc.)
5. Sea birds (only if relevant to the ecosystem and project context)

In addition, any species or other biodiversity attributes that would trigger a site to be eligible as a conservation project through one KBA criterion or two IPA criteria must also be monitored (note that the site does not need to have been designated as a KBA). If these species cannot be monitored using the random stratified sampling plan (e.g., there is a small population in a specific, restricted area of the site), then additional, fixed sampling points should be used (see Section 2.2). If obtained using fixed sampling points, species data will not be included in the calculation of the multimetric (since it estimates site-level biodiversity changes, requiring random sampling). This data will, however, be reviewed by the PV Nature TRP to ensure there are no unintended outcomes occurring with respect to potentially irreplaceable biodiversity (see PV Nature Project Requirements Section 4.7).

2.4.5 Mixed-habitat projects

2.4.5.1 Target species groups

Projects located in areas of mixed habitats (e.g., covering both terrestrial and marine) are required to collect data to the minimum possible taxonomic level (preferably species level) from at least four target groups, except mixed terrestrial and freshwater projects which are described separately (see Section 2.4.4.2). Target groups should be chosen based on a site's general location and biome, while reflecting the approximate proportions of project area located in different habitat zones. The list of target groups provided by the project will be reviewed by the PV Nature TRP on a project and ecosystem basis.

2.4.6 Mixed terrestrial and freshwater projects

Terrestrial projects that contain areas of significant freshwater habitat[13] are required to collect data to the lowest possible taxonomic level (preferably species level) from at least four target groups, one or two of which must be freshwater target group(s) from the following list:

1. Fish
2. One broad group of freshwater invertebrates
3. Amphibians
4. Freshwater microbes[14]
5. Macrophytes (see Glossary for definition; excludes algae)

Target group selection must be appropriate to the ecological context and project interventions, and will be reviewed by the PV Nature TRP.

When selecting the other target groups, Section 2.4.2.1 applies.
In addition, any species or other biodiversity attributes that would trigger a site to be eligible as a conservation project through one KBA criterion or two IPA criteria must also be monitored (note that the site does not need to have been designated as a KBA or IPA). If these species cannot be monitored using the random stratified sampling plan (e.g., there is a small population in a specific, restricted area of the site), then additional, fixed sampling points should be used (see Section 2.2). If obtained using fixed sampling points, species data will not be included in the calculation of the multimetric (since it estimates site-level biodiversity changes, requiring random sampling). This data will, however, be reviewed by the PV Nature TRP to ensure there are no unintended outcomes occurring with respect to potentially irreplaceable biodiversity (see PV Nature Project Requirements Section 4.7).

2.4.7 Freshwater Projects

Specifications for projects that are exclusively in the freshwater realm are under review and will be added in a future version of the Methodology.

[13] 'Significant freshwater habitat' is defined by either the proportion of the project area that is freshwater habitat and/or the global significance of the freshwater habitat present within the project area. Projects must make clear whether or not they fall into this category.

[14] Data collection requires eDNA; a protocol for the use of eDNA as a data collection tool under PV Nature is under development and will be added as a forthcoming update. In the meantime, projects wishing to use eDNA should contact Plan Vivo for guidance.

2.5 All ecosystems

2.5.1 Habitat / landcover data

A map of the habitats (or in some cases landcover types, see e.g., Lumbierres et al 2021)[15] present across the project area is required for all projects at biodiversity baseline and every 5 years thereafter, based on either recent drone mapping or recent high-resolution (50cm or finer) satellite imagery[16]. Imagery must have been taken no more than 6 months prior to the period of biodiversity data collection. Imagery can either be provided by the project or sourced/collected for the project[17].

Based on this imagery, a habitat map can then either be provided by the project or created for the project.

The map must be:

- of sufficiently high resolution (0.5m/pixel or finer)[18];
- segmented into habitat classes; and
- labelled with habitat classes.

Segmentation requires delineation of the patches of different habitat types. This is typically done in a GIS (e.g., ArcGIS, DIVA-GIS, or QGIS) by delineating habitat patches within aerial or satellite imagery. DIVA-GIS, QGIS and Google Earth Pro are three examples of free, open-source GIS tools that would be suitable for this task.

Labelling requires the use of an official, national, regional, or global habitat classification system to assign a habitat type to each segmented patch. For a given project, the most detailed, localised classification system available for the area must be used (i.e., national systems must be used for projects within a country that has an established national system, regional systems must be used

[15] Landcover classes tend to be less detailed than habitat types. Although habitat is a complex multidimensional concept that is difficult to simplify into landcover classes, the two sometimes overlap, especially if land use is considered alongside landcover (Lumbierres et al 2021). Wherever feasible, classification in this Methodology is based on habitats; landcover classes are used only where this is not possible.

[16] Note that this may not be possible for some marine sites where there is significant turbidity over long periods and overhead imagery cannot determine habitat types. Projects to which this applies should contact Plan Vivo for guidance.

[17] The strong preference is that projects will source or collect overhead image data themselves and use this to create their own habitat map. Projects without this capacity can opt to request support.

[18] Projects with contiguous areas larger than 10,000 hectares will be mapped and sampled according to a specific protocol that is in development with projects. These large sites will require high resolution satellite data for sub-sections (samples) of the project area only, rather than its entirety. A future update to the Methodology will provide further details, once sufficient testing has been completed with projects and real-world data. Until this update is issued, potential projects with a contiguous area >10,000 hectares should contact Plan Vivo regarding sampling requirements.

for projects within a country that lacks a national system but falls within a regional system, and a recognised global classification system must be used for projects that fall outside of national and regional systems). If a project wishes to use a specific classification system to create their own map, the classification system must be submitted for pre-approval.

For marine projects, the approach for generating a habitat map as describe above may not be appropriate due to, for example, the limitations of obtaining suitable marine habitat data from satellite imagery or drones. Habitat maps can be created or obtained following best practice protocol for each ecosystem or habitat type and will be assessed on a case by case basis.

2.6 Requirements for particular data types

This section covers the detailed requirements for different data types. Projects will also have access to a 'toolbox' of suggested data collection methods that, if correctly deployed, will produce data that meets the Methodology's requirements. No list of data collection approaches can ever be exhaustive, particularly given the rapid development of technology and tools. Other technologies or approaches can be considered if they meet the minimum data quality requirements outlined in this Methodology and Data Protocol.

Some requirements (e.g., those related to resolution, total recording time, etc) are specific to the group targeted for data collection. For example, bats require different audio frequency specifications to birds; minimum resolution of images captured by underwater video systems is different to the minimum resolution required from imagery used to identify plants, and so on. Projects will be provided with detailed requirements that are specific to their chosen target groups and data collection tools, and all data will be checked for integrity and sampling adequacy.

Some data requirements also differ between sites located in the tropics or not, given the much higher biodiversity present in those areas of the world and therefore the increased sampling effort needed to evaluate their biodiversity. Again, projects will be provided with clearly defined minimum sampling requirements that are specific to their location and chosen data collection techniques.

Data type: imagery (e.g., from digital cameras, camera traps, underwater video, drones, etc)	
Specifications	Images must be sufficiently high resolution to allow species identification. Metadata must meet requirements in Section 2.3 and must include information required for estimation of the area covered within each image. Sufficient sampling density to enable statistically meaningful analysis

	(depending on the target species group, this can be spatial or temporal sampling density, or both).

Data type: audio	
Specifications	Frequency range that captures all species within the group(s) targeted. Sufficient total recording time to enable statistically meaningful analysis. Sufficient recording intensity (duty cycle) to enable statistically meaningful analysis and to ensure data are captured across each 24-hour period.

Data type: eDNA and metabarcoding	
Specifications	Details for use of eDNA and metabarcoding are under separate consultation with experts in the field. This includes defining minimum sampling densities, accepted bioinformatics protocols and evidence of sampling integrity.

2.7 Requirements for data labelling and quality control

Data labelling is the process by which targeted features are identified and tagged in a data file, either by human experts or by algorithms. For example, the labelling of digital biodiversity data generally involves the identification of species and/or habitats within an audio or image file. An annotator/labeller adds tags to a file, each of which represents an object class, for example a species name or taxonomic unit. Data labelling requires quality control (QC), i.e., a process by which those labels or tags are checked for accuracy. This is not the same as third-party auditing – it is an earlier step that quality assures the accuracy of (for example) species identifications, which can be difficult and error prone, especially when analysing data from ecosystems that are complex or poorly-studied. It helps to identify errors and less precise annotations, and to identify and reconcile disagreements between experts.

QC takes place on every dataset, before PVBCs are calculated. Details of the labelling and QC processes applied to each dataset will be retained and made available for third-party verification.

2.7.1 Data labelling

Data labelling can be performed either by machine-learning models or by human experts with knowledge of the species present in the project area/ecosystem. For each data collection

technique (e.g. imagery, audio), associated minimum requirements for labelling coverage will be provided, including a protocol for specimens that cannot be identified to species level (and should instead be labelled to, for example, morphospecies or OTU (operational taxonomic unit) level).

Projects are encouraged to put forward local taxonomic experts to perform species identifications. Experts can be sourced on behalf of any projects without the capacity to do so.

In cases of changes to source databases used for labelling (e.g., species reclassification), a backwards comparison will be used to ensure at least one year of overlap in labelling consistency. This ensures that any certificates generated after a source database change can be directly compared to any certificates generated before the change. For example, if a source database is updated in Year X, then in the calculation of change between Year X and Year X-1 will use the database version from Year X-1. In Year X+1, the calculation of change between Year X+1 and Year X will use the updated source database.

2.7.2 Quality control

QC must always be performed by human experts. If labelling was performed by a human expert, QC must be performed by at least one different, independent expert. For each data collection technique, the minimum requirements for QC coverage will be provided.

Only species that are confirmed by QC are included in biodiversity pillar metric calculations.

Experts used for QC purposes must be independent of the project and are required to declare any conflicts of interest.

2.8 A note on new technologies

The PV Nature Methodology is designed to be as modular as possible, allowing the incorporation of new technologies as they are developed (e.g., high-resolution thermal imagery, hyperspectral imaging, etc.). If a method or technology can meet the general principles of the PV Nature Methodology (see Section 2.1), and the associated data requirements under the Data Protocol, then it can most likely be incorporated into a project's sampling plan after submission to Plan Vivo for review and approval.

It should be noted that whenever a novel piece of technology is incorporated into the sampling design, at least one year of monitoring with both technologies is required. This is so that any certificates generated after the inclusion of the technology can be directly compared to any certificates generated before its inclusion.

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Appendix 1 – KBA and IPA criteria

The KBA (Key Biodiversity Area) and IPA (Important Plant Area) criteria are well-established and globally standardised criteria used to designate areas of international importance in terms of biodiversity conservation. The Methodology refers to the KBA and IPA criteria when determining eligibility for conservation projects (see Section 1.2).

KBA criteria:

A. Threatened biodiversity		
A1 Threatened species		Assessment parameters
A1a	≥0.5% of global population size and ≥5 reproductive units (RU) of a CR/EN species	(i) no. of mature individuals (ii) area of occupancy (iii) extent of suitable habitat (iv) range (v) no. of localities (vi) distinct genetic diversity
A1b	≥1.0% of global population size and ≥10 RU of a VU species	
A1c	≥0.1% of global population size and ≥5 RU of a species listed as CR/EN due only to past/current decline [= Red List A1, A2, A4 only]	
A1d	≥0.2% of global population size and ≥10 RU of a species listed as VU due only to past/current decline [= Red List A1, A2, A4 only]	
A1e	Effectively the entire population size of a CR/EN species	
A2 Threatened ecosystem types		
A2a	≥5% of global extent of a CR or EN ecosystem type	
A2b	≥10% of global extent of a VU ecosystem type	
B. Geographically restricted biodiversity		
B1. Individual geographically restricted species	≥10% of global population size and ≥10 RU of any species	(i) no. of mature individuals (ii) area of occupancy (iii) extent of suitable habitat (iv) range (v) no. of localities (vi) distinct genetic diversity
B2. Co-occurring geographically restricted species	≥1% of global population size of each of a number of restricted range species in a taxonomic group: ≥2 species or 0.02% of the total number of species in the taxonomic group, whichever is larger	
B3. Geographically restricted assemblages		
B3a	≥0.5% of global population size of each of a number of ecoregion-restricted species in a taxonomic group: ≥5 species or 10% of the species restricted to ecoregion, whichever is larger	(i) no. of mature individuals (ii) area of occupancy (iii) extent of suitable habitat (iv) range (v) no. of localities
B3b	≥5 RU of ≥5 bioregion-restricted species or ≥5 RU of 30% of the bioregion-restricted species known from the country, whichever is larger	
B3c	Site is part of the globally most important 5% of occupied habitat for ≥5 species in the taxonomic group	(i) relative density of mature individuals (ii) relative abundance of mature individuals
B4. Geographically restricted ecosystem types		
	≥20% of the global extent of an ecosystem type	
C. Ecological integrity		
	Site is one of ≤2 per ecoregion with wholly intact ecological communities	composition and abundance of species and interactions
D. Biological processes		
D1. Demographic aggregations		
D1a	≥1% of global population size of a species, over a season, and during ≥1 key stage in life cycle	no. of mature individuals
D1b	Site is among largest 10 aggregations of the species	no. of mature individuals
D2. Ecological refugia	≥10% of global population during periods of environmental stress	no. of mature individuals
D3. Recruitment sources	Produces propagules, larvae or juveniles maintaining ≥10% of global population size	no. of mature individuals
E. Irreplaceability through quantitative analysis		

Source: https://www.keybiodiversityareas.org/working-with-kbas/proposing-updating/criteria

IPA criteria:

Sub-criterion	Threshold
(A) Threatened species	
A(i) Site contains one or more **globally threatened** species	Site known, thought or inferred to contain ≥**1%** of the global population AND/OR ≥**5%** of the national population OR the **5 "best sites"** for that species nationally, whichever is most appropriate
A(ii) Site contains one or more **regionally threatened** species	Site known, thought or inferred to contain ≥**5%** of the national population, OR the **5 "best sites"** for that species nationally, whichever is most appropriate
A(iii) Site contains one or more **highly restricted endemic** species that are potentially threatened	Site known, thought or inferred to contain ≥**1%** of the global population AND/OR ≥**5%** of the national population, OR the **5 "best sites"** for that species nationally, whichever is most appropriate
A(iv) Site contains one or more **range restricted endemic** species that are potentially threatened	Site known, thought or inferred to contain ≥**1%** of the global population AND/OR ≥**5%** of the national population, OR the **5 "best sites"** for that species nationally, whichever is most appropriate
(B) Botanical richness	
B(i) Site contains a **high number of species** within **defined habitat or vegetation types**	For each habitat or vegetation type: up to 10% of the national resource can be selected within the whole national IPA network OR the **5 "best sites"** nationally, whichever is the most appropriate
B(ii) Site contains an **exceptional number of species of high conservation importance**	Site known to contain ≥**3%** of the selected national list of species of conservation importance OR the **15 richest sites** nationally, whichever is most appropriate
B(iii) Site contains an **exceptional number of socially, economically or culturally valuable species**	Site known to contain ≥**3%** of the selected national list of socially, economically or culturally valuable species OR the **15 richest sites** nationally, whichever is most appropriate
(C) Threatened habitat	
C(i) Site contains **globally threatened or restricted** habitat/vegetation type	Site known, thought or inferred to contain ≥**5%** of the national resource (area) of the threatened habitat type OR site is among the best quality examples required to collectively prioritise **20–60%** of the national resource OR the **5 "best sites"** for that habitat nationally, whichever is the most appropriate
C(ii) Site contains **regionally threatened or restricted** habitat/vegetation type	Site known, thought or inferred to contain ≥**5%** of the national resource (area) of the threatened habitat type OR site is among the best quality examples required to collectively prioritise **20–60%** of the national resource OR the **5 "best sites"** for that habitat nationally, whichever is the most appropriate
C(iii) Site contains **nationally threatened or restricted** habitat/vegetation type, AND/OR habitats that have **severely declined in extent** nationally	Site known, thought or inferred to contain ≥**10%** of the national resource (area) of the threatened habitat type OR site is among the best quality examples required to collectively prioritise up to **20%** of the national resource OR the **5 "best sites"** for that habitat nationally, whichever is most appropriate

Source: https://www.plantlife.org.uk/protecting-plants-fungi/important-plant-areas/

Appendix 2 – Domesticated Species

The most common species of domesticated livestock are filtered out of the species list after data collection but before calculation of the pillar metrics. The list of domesticated livestock subject to removal from the calculations is:

- **Pig** – *Sus domesticus*
- **Cattle** – *Bos taurus, Bos indicus* and *Bubalus bubalis*
- **Horse** – *Equus caballus*
- **Sheep** – *Ovus aries*
- **Chicken** – *Gallus gallus domesticus*
- **Duck** - *Anas platyrhynchos domesticus*
- **Cat** – *Felis catus*
- **Dog** – *Canis familiaris*
- **Turkey** – *Meleagris gallopavo domesticus*
- **Goose** – *Anser anser domesticus* or *Anser cygnoides domesticus*
- **Goat** – *Capra hircus*
- **Llama** – *Lama glama*
- **Alpaca** – *Vicugna pacos*
- **Rabbit** – *Oryctolagus cuniculus domesticus*
- **Donkey** – *Equus asinus*

PLAN VIVO

Annex 1 – Version Control

Version 1.0 (December 2023)

Version 1.0 of the Methodology includes several modifications with respect to the draft version released in the PV Nature Methodology public consultation (held 14th August - 4th September 2023), including:

- Addition of a new pillar metric (Pillar 4).
- Pillar 4 (version released for the PV Nature Methodology public consultation) now renamed as Pillar 5 in this version, and to be calculated every 5 years to coincide with independent, third-party verification.
- Projects are required to collect data on any biodiversity attributes that would trigger KBA and/or IPA designation.
- Reduction in the tolerance around the maximum biodiversity loss that is permitted before no conservation certificates can be issued.
- Addition of 'mixed habitats' as a habitat type (subsuming intertidal habitats).
- Some changes to requirements and recommendations for marine projects.

Version 1.0 of the Methodology was developed in partnership with Pivotal.

Version 1.1 (July 2025)

Version 1.1 of the Methodology includes several modifications to allow the PV Nature Methodology to be data analytic provider agnostic. These include:

- Update of the mention of Pivotal to Data Analytics Provider throughout.
- Removal of required environmental data for projects as this will be dealt with on a project-by-project basis.
- Section 1.5 Pillar Metrics has been updated to differentiate between terrestrial and marine projects.
- Section 1.5.4 Pillar 4: Habitat Health – Section on marine habitats has been removed based on ongoing developments for the habitat pillar metrics and will be included in the future versions of the PV Nature Methodology.
- Section 1.5.5 Pillar 5: Habitat Spatial Structure - Removal of Digital Surface Models (DSMs) for marine projects based on marine pilot project learnings, this is unaffordable and often inappropriate for marine ecosystems. Plan Vivo is working with marine pilot projects to refine the PV Nature Methodology for marine projects.

- Section 1.5.5 Pillar 5: Habitat Spatial Structure - Removal – Section on marine habitats has been removed based on ongoing developments for the habitat pillar metrics and will be included in the future versions of the PV Nature Methodology.
- Change of required target groups for marine projects to three target groups (previously four).
- Pillar 5 will be calculated using freely available satellite imagery.
- Section 2.5 – An additional note on habitat data and generation of habitat maps for marine ecosystems is now included.

All changes made to Version 1.0 (i.e. changes that appear in this version 1.1) of the Methodology have been made by Plan Vivo independently.