Reference site and biodiversity quantification method

This document outlines the methods used to identify suitable data for a database of biodiversity in near natural or previously restored peatland and woodland sites. We also outline a potential approach to modify the Wallacea Trust method for measuring biodiversity change to make the method more appropriate to the context of peatland restoration and woodland creation and restoration in the UK.

1. Reference state

1.1. Use of Reference sites in the Wallacea Trust methodology

The Wallacea Trust methodology recommends measuring biodiversity on both the project site and a reference site (habitat in near-natural condition or previously restored), enabling uplift in biodiversity to be estimated through direct comparison with the references site. The methodology also proposes an alternative calculation where no reference site is available, and uplift is simply calculated against the site's baseline (Wallacea Trust, 2023). The Wallacea Trust documentation states that a reference site must have the following characteristics:

• Allow for the design and implementation of a comparable sampling strategy to the Project site;

• Allow to have a matching sampling effort and field data collected as near contemporaneously as possible to the Project site (to avoid issues such as seasonally variable weather conditions);

• Ideally has started from a similar point to the Project site in terms of habitat structure and has undergone a comparable management system to the one being proposed for the Project site for a comparable period of time to the proposed Project period. In certain situations, it may be impossible to find a perfect match between the Project site and the Reference site in terms of original habitat composition or management system. In these cases, the likely biodiversity improvement at the Project site can be compared with similar habitats in a variety of Reference sites. We have made some additional recommendations to the above, to ensure that the definition of a reference site is suitable for UK peatlands and woodlands.

1.2. Further definition of a reference site

We propose to adopt the Wallacea Trust definition which indicates that a suitable reference site should reflect the likely end point following project completion. This would be a minimum period of 40 years for the Woodland Carbon Code and 30 years for the Peatland Code. Where possible, reference sites should be selected in the local vicinity of the project site and be comparable to the starting point. This may include a similar pre-intervention habitat type, management and condition, topography, altitude, or soil properties. Reference sites should have undergone comparable management interventions to the proposed project and for a comparable timeframe to the intended project duration.

In some instances, it may be tricky to find suitable reference sites locally due to lack of historical records. For example, robust information on the reference sites original habitat type and condition, alongside management interventions implemented. Additionally, it may be difficult to find sites with comparative conditions, or restored sites with a sufficient timeframe. For example, Peatland restoration was not widely undertaken prior to suitable funding vehicles, such as Peatland ACTION in 2012. In such instances, the use of near-natural reference sites of moderate to good quality maybe used instead. Where possible, sites should be chosen in the local vicinity with similar topography, altitude and soil properties to the project site. The reference site should reflect the habitats proposed for the project site, such as lowland mixed deciduous woodland, upland mixed ashwoods, etc. Suitable sites may include ancient or semi-natural woodlands, and raised bogs or blanket bogs in moderate to good condition. Such sites will typically be older than the project site at its end point, and as such the project site is unlikely to reach the same biodiversity status as the reference site. To account for this, it is recommended to apply a correction factor. For example, assuming that the project site will reach 80% of the biodiversity status of the reference site. Any correction factor and justification for this correction factor should be included in the monitoring programme which should be validated by an independent biodiversity expert/ecologist.

Coniferous plantations

In comparison to native woodlands, coniferous plantations are typically thought to be of lower biodiversity value (Bremer and Farley, 2010). However, trends in species richness vary among taxa, and the two habitat types can differ substantially in terms of community composition and structure (Day et al., 1993; Humphrey et al., 2002). Thus, using a mature coniferous plantation as a reference for Woodland Carbon Code native woodland projects is not suitable as the reference site, as this would inflate the biodiversity uplift for coniferous plantations. As such, we suggest that a native woodland of a similar age and type to the project period is a more appropriate comparison. The native woodland used as a reference must be suitable for the location, for example, using native Scots pine for upland plantations in Scotland.

Forest to bog

For peatland restoration projects that convert forest-to-bog we have the option of setting the baseline as either pre-felling or post-felling. However, since post-felled land is in a transitional state, we suggest using pre-felled as a baseline for biodiversity uplift.

Rewilding/ natural regeneration

Naturally regenerating woodlands and peatlands may arrive at different community composition compared to planted woodlands and peatland restoration with heavy human intervention. Reference sites that have been subject to natural regeneration are likely to be most appropriate, however, where these are not available near natural sites can provide a useful benchmark. As the biodiversity value of near natural sites is unlikely to be realised within the project duration, a correction factor should be applied.

1.3. Sampling effort

As sampling effort increases, the number of new species encountered also tends to increase. This is known as the Species Accumulation Curve. Thus, if metrics based on species richness are used to quantify uplift, sampling effort should be kept consistent between the project site and the reference site. The Wallacea Trust methodology suggests randomly dropping samples to ensure consistent sampling effort between the project and reference site. An alternative would be to use species rarefaction curves to control for differences in sampling effort. However, as some metrics require species identification, to obtain a measure of conservation value or similarity, this would not be appropriate.

1.4. Sampling methods

Following the Wallacea Trust methodology, sampling method should be kept the same between the reference site and the project site. Ideally, this should be kept the same throughout the duration of the project, as different methods can yield different results (Doxon et al., 2011; Rochefort et al., 2013). However, we acknowledge that as sampling methods become more automated in future, for example using AI or metabarcoding, there may a desire to update methods part way through the project. This would only be acceptable if the project can demonstrate similar results between the original method and the new method. They could do this by running the two methods alongside each other for a trial period, or through peer-reviewed literature. Any changes to the method would need to be signed off by the validation and verification bodies. The sampling methods used should be appropriate for the species or taxonomic group of interest, using standardised methods. For example, following CIEEM's Good Practice Guidance for Habitats and Species or other reputable standards.

1.5. Reference site database

Conducting biodiversity surveys on both the project site and a reference is likely to be prohibitively costly. A main outcome of this project was to aggregate available biodiversity data for peatlands and woodlands in the UK that are in relatively intact condition. This database could then be used to identify appropriate reference data for projects. This removes the need to pay for a reference site to be surveyed, especially where comparable reference sites are not available in vicinity of the project site.

1.5.1. Overview of method for selecting data

A comprehensive search of the published literature was carried out using the search terms included in Appendix A, as well as a comprehensive search for publicly available databases (including searching the NBN Atlas for full datasets). In a previous phase of the project, suitable taxonomic groups for measuring peatland restoration and woodland creation success were identified through expert opinion. Thus, we limited our search to the target taxa of vegetation, arthropods, birds, as well as bats for woodland. Any articles where data collection did not occur in the UK were removed. We did not include data from meta-analyses to avoid duplication. For datasets to be included as suitable, there needed to be a reproducible sampling protocol, using methods that are widely used for the taxonomic group of interest (eg. quadrat surveys for vegetation, pitfall traps for beetles etc.). Data where no location was given were excluded, although we kept data where information on approximate location was provided. We included both abundance and occurrence (i.e. presence/absence) datasets.

We then filtered the data to reference sites that were in good condition. Because of the lack of UK-wide information on peatland and woodland condition, we used a variety of approaches to filter reference sites. Woodland sites in Scotland were filtered to good condition using the Native Woodland Survey condition score of 3 and above (Forestry Commission, n.d.). For sites in England and Wales, no information on woodland condition was available in publicly available datasets or GIS layers (we ruled out the use of SSSI status since assessments are rarely up-to-date). Studies have found that woodland structural diversity, as measured by the standard deviation of tree diameter at breast height (DBH), is closely linked to successful establishments of woodland plants (Waddel et al, 2024) and the diversity of other species groups (Wagenaar et al., 2025). Thus, for datasets where tree DBH was measured alongside biodiversity data, we calculated standard deviation of DBH and used this to filter out sites with low structural diversity, including only sites within the top quartile of structural diversity. For peatlands, there are no reliable datasets showing peatland condition across the UK. Thus, we gathered expert opinion on the condition of peatlands within our dataset, and removed anything that was deemed by the expert to be in poor condition. Figure 1 shows the final dataset for woodlands (a.) and peatlands (b.). These datasets are proposed to be dynamic with additional data added as it becomes available.

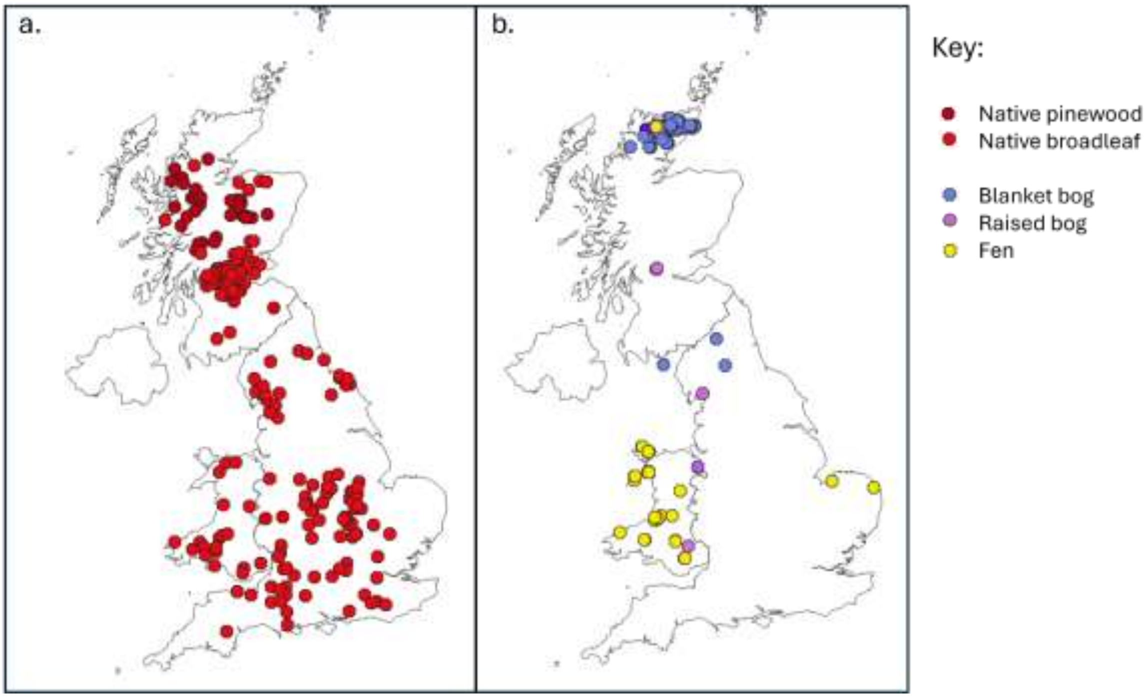

Fig. 1. Overview of aggregated dataset for a. woodlands and b. peatlands. Circles show location of biodiversity data within the dataset. For simplicity we show broad habitat types. However, within the dataset these are further divided into more specific habitat type groups.

1.5.2. Considerations and limitations of the database:

The Wallacea Trust methodology recommends that surveys carried out on reference sites should be as temporally close as possible to those carried out at the project baseline. This means that the validity of the reference database will vary depending on the initial time of sampling, with older projects being less suitable. We identified clear gaps in the data available which means we cannot provide comprehensive coverage of the whole of the UK for all possible taxonomic groups. Data for peatland habitats and bird and invertebrate data in particular were lacking. Consequently, some projects will likely need to cover the cost of surveying a reference site. However, as more reference sites are surveyed, coverage of the database will increase, particularly if projects are incentivised to submit reference site data they have collected to the database. Finally, due to natural variation in time and space, setting a realistic reference state would require comparison to a suite of references sites (Oliver et al., 2023). However, this could be difficult to obtain in the UK where there is a lack of habitats in good condition.

2. Similarity index methodology

2.1. Background:

The Wallacea Trust methodology to quantifying biodiversity uplift relies on weighting species by their conservation value. For example, using the International Union for Conservation of Nature (IUCN) threat categories to classify species based on their extinction risk. For example, Least Concern would have a value of 1, Near threatened a value of 2, Vulnerable a value of 3, etc (Figure 2: IUCN 2012).

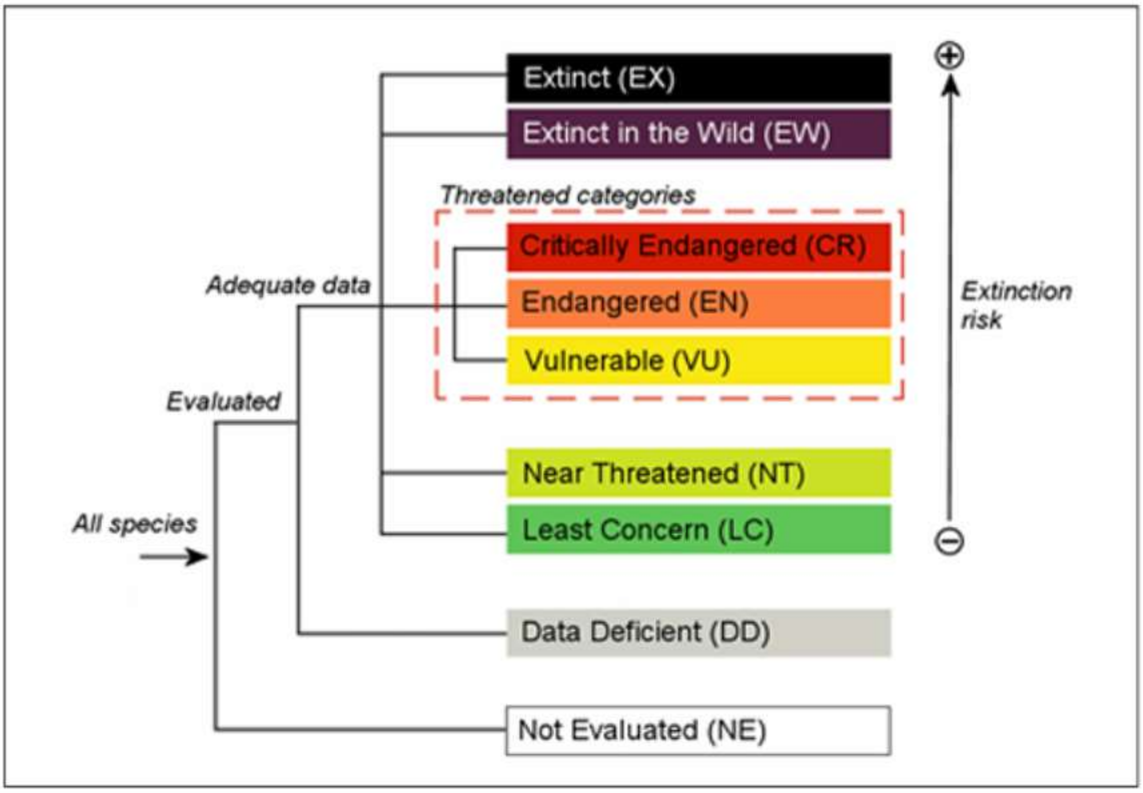

Figure 2: Structure of IUCN threat categories (IUCN 2012)

Adopting this framework would be difficult for many insect groups in the UK that have not been assessed for their conservation status. In addition, where conservation status is available, data exploration using our aggregated dataset has highlighted that the vast majority of species found in reference sites are classified as 'Least Concern'. As such, giving more weight to species of higher conservation value is unlikely to make a difference to the biodiversity score in comparison to applying no weighting at all. A whole-community approach, where change in the community between the baseline and the reference site is measured, may better reflect peatland or woodland-specific biodiversity in uplift calculations.

2.2. Similarity index method

We have been exploring different methods of measuring biodiversity uplift using a similarity metric. Similarity indexes that measure the similarity or 'overlap' between two communities are often used to understand shifts in communities in response to an environmental change including habitat change. Thus, we can expect that following restoration, the community structure of specific taxa will become increasingly similar to the reference site. Being based on community structure, such indices are less impacted by the presence of indicator species, or species of high conservation value. The sensitivity of these different similarity indices to sample size or sampling method is well documented which can help identify the most appropriate index to use in any given scenario. Below are outlined three common approaches to measuring how similar or dissimilar two communities are:

Sorenson and Jaccard index: Communities are given a score between 0 and 1, with '0' meaning that communities are completely different sharing no species in common and a value of 1 indicating that they are identical. Thus, a value of 0.5 would mean that the project and reference site were 50% similar, and as the project site matures, we would expect these indices to move towards a value of 1. Only presence of species is needed for this index (e.g. species lists) as it does not consider the abundance of each species. The Wallacea Trust methodology allows for species lists to be used where collection of species abundance data isn't possible. However, Chao et al. (2006) highlight that when sampling effort is small, these incidence based metrics can suffer from bias, even if sample size between the two sites is the same. This is particularly problematic when one site has many rare species, which we might expect in a good-condition peatland or woodland, and the other has very few rare species. As such, we recommend against using incidence-based metrics unless absolutely necessary. For example, where only species occurrence data is available for existing reference sites and generating data for a new reference site is financially unviable. If presence-only data is the only option, survey effort will need to be adequate to reduce the risk of bias, and this will need to be verified.

Morisita – Horn: Measures community similarity on a 0 to 1 scale, with 1 indicating two communities that are entirely similar. This method is more conservative as it tends to underestimate similarity. It is heavily influenced by highly abundant species, with rarer species having little impact. This makes it relatively resistant to under sampling. However, being heavily weighted to the most abundant species could be problematic in measuring change towards a near-natural state, as peatlands and woodlands in good condition are likely to support higher numbers of rare species (Everson et al., 2026; Waddell et al., 2024).

Bray – Curtis: A dissimilarity index that takes into account the species present in both samples and the number of individuals of each species. The scoring is on a scale of 0 to 1 however, the scale is the inverse of the previous similarity indices, with a value of 0 indicating that sites are identical (high similarity) and a value of 1 indicating that sites are highly dissimilar (low similarity). Thus, to standardise across these indices we need to use the complement of Bray-Curtis by subtracting the index value from 1. Bray-Curtis relies on equal sampling effort, as small differences in sampling effort can have an important effect on the index. This makes Bray-Curtis most suitable for projects where the project site and reference site are being sampled at the same time and with the same sampling effort. However, Bray-Curtis could be problematic when comparing a project site and a reference site that have been sampled in different years, such as using the Peatland Code/Woodland Carbon Code database.

The most appropriate similarity index to use will depend on a range of factors including data availability, sampling intensity and methodology. In situations where only presence-absence data is available the Jaccard or Soresen indices will be most applicable. For example, when survey methodologies don't accurately provide data on species abundance, such as eDNA data (Brandão-Dias et al., 2026), or when only species occurrence data is present in the Peatland Code/Woodland Carbon Code reference site database. Where possible we recommend that data on species abundance is collected and used to generate similarity index values. In such instances, we recommend that the Morisita-Horn index is used when data on the reference site is obtained from the Peatland Code/Woodland Carbon Code reference site database, or where sampling effort is low. The Bray-Curtis index should be used where there is sufficient resources to baseline a suitable reference site alongside the project site. Since these similarity indexes are on a scale of 0 – 1 this can easily be converted into a percentage similarity, which would give each project an associated percentage of biodiversity uplift. Thus, projects would be able to achieve a maximum of 100% similarity.

2.3. Limitations of the similarity index

Similarity indices that are less susceptible to differences in sampling effort naturally put more emphasis on very abundant species. However, in woodland creation and peatland restoration, initial colonisers are likely to be very abundant generalist species, followed much later by specialists (Waddell et al. 2024). Thus, using a similarity index that is heavily influenced by abundant generalist species will result in a high number of biodiversity credits being generated in the first stages of a project, yielding very little reward for longer term projects. It is also important to note that using a similarity index will inherently constrain biodiversity uplift to 100%, since two communities cannot be more than 100% similar. However, given the fact that many habitats are degraded in the UK, it is possible that a project, if managed well, could exceed the condition of the reference site. Therefore, it may not be desirable to limit projects in this way. In addition, this 0 – 100% scale contrasts with the original Wallacea Trust methodology where biodiversity uplift can exceed 100%. This would mean that biodiversity credits generated from percentage uplift from sites using the similarity index would not be directly comparable to those generated via the original Wallacea Trust methodology.

Finally, the similarity index relies on a reference site which may not always be available, due to limited intact peatland in the UK for example. An alternative method is explored in section 3 that does not necessarily require the use of a reference site.

2.4. Indicator species approach

Whilst a similarity index could provide a good way of measuring change in communities towards a reference state, it relies on having a reference site. This may not always be possible either due to prohibitive costs of surveying a reference site, or due to the lack of a suitable nearby reference site in reasonable condition. The Wallacea Trust methodology proposes an alternative method for quantifying biodiversity uplift for projects with no reference site. In these instances, biodiversity uplift is simply recorded within the project site over time. This methodology requires species to be weighted by conservation status, which is problematic as highlighted in section 1.1. An alternative to weighting species by conservation value is to weight by specialism, giving more weight to species that are peatland or woodland specialists. In the UK, a great deal of work has been done on creating functional and ecological traits databases for a variety of taxonomic groups including moths (Cook et al., 2022), birds (French and Picozzi, 2002), ground beetles (Rogerson et al., 2025), and plants (Hill et al, 2004). If using weighting by species specialism, we propose that woodland and peatland specific species (those that are only found in woodlands or bog/fen) be given a weighting of 5, woodland or bog generalists (those that are found in woodlands/peatlands but also in other habitat types) would be given a weighting of 3, and non-woodland or non-peatland species would be given a weighting of 1. This would give each species a score on a 1 to 5 scale, and would align with the Wallacea Trust's approach to weighting by conservation status. Projects can then follow the Wallacea Trust methodology for calculating uplift where no reference site exists (see section 5.5 of the Wallacea Trust methodology). This method would reward higher presence and abundance of specialist species that are known to be greater in intact woodlands and peatlands.

2.5. Limitations of the indicator approach

The indicator approach can be used with or without a reference site. However, the approach proposed by the Wallacea Trust methodology for calculating uplift in circumstances where no reference site is available is more conservative than if using a reference site. As such, using this indicator species method, projects with no reference site would not be able to obtain the same uplift as sites where a reference is used (see Wallacea Trust method section 5.5). Classification of species into 'generalists' and 'specialists' can also sometimes be ambiguous and relies on the accuracy of available databases and classifications.

2.6. Integration with the Peatland Code and Woodland Carbon Code

Both the Wallacea Trust methodology and BSI Flex 702 recommend that biodiversity is surveyed every five years. However, the Codes are currently verified year five, then every ten years after that. Surveying for biodiversity every ten years puts the Codes at risk of not complying to BSI Flex standards. Furthermore, one survey every ten years poses a risk to projects, since biodiversity can be highly variable depending on weather conditions. A project may see a sudden drop in biodiversity if the 10-year survey period falls on a bad weather year. Finally, surveying every ten years is unlikely to enable projects to detect adverse, or unexpected impacts on biodiversity before it is too late to intervene. This would reduce the potential for management interventions to be put in place to address any issues. We would advise that sites carry out interim surveys, which could be a less in-depth version of surveys carried out for validation. This would enable sites to identify declines in biodiversity and intervene much sooner than if only 10-yearly monitoring is carried out. In addition, if weather conditions during the verification year are unfavourable (which will likely cause a drop in abundances and presence of certain species), projects could potentially use these interim surveys to evidence their continued biodiversity uplift.

Conclusions

The three approaches outlined above (i.e. the Wallacea Trust approach, similarity index approach and the indicator species approach) all have strengths and weaknesses which will vary depending on project context. The Wallacea Trust methodology offers a robust and accepted way to quantify biodiversity uplift. This approach is highly flexible enabling it to be adapted to different projects, ecosystems and locations. A suite of project specific metrics (typically five) are selected, which increases survey time and costs. In contrast, Peatland Code and Woodland Carbon Code projects are more constrained with respect to habitats, restoration techniques, target species and location. Thus, a more targeted selection of metrics may be sufficient to capture biodiversity change, which would reduce monitoring costs.

The use of a similarity index avoids the need for data on conservation status which is lacking for some key taxa, such as beetles. Furthermore, where a suitable reference site exists, similarity indices offer an ecologically explicit measure of change. However, with voluntary nature markets in their infancy and buyer demand uncertain, there is a need to ensure we balance robust, high-integrity monitoring with costs. Utilising existing data sources for reference sites would thus increase the economic viability of projects. However, where existing reference site data is not available, additional costs would be incurred to survey a suitable reference site for use of the similarity index. Furthermore, in some instances suitable reference sites may not be available at all, and monitoring uplift within the project site would be the most viable option.

The indicator species approach provides a viable alternative, suitable for use both with and without a reference site. Across the UK there is a wealth of knowledge on the species associated with particular habitats (i.e. woodland or peatland specialists). This approach would more closely align with the Wallacea Trust methodology and would reduce costs associated with identifying and surveying reference sites. However, this approach relies on the ability to robustly categories the degree of specialism of the selected taxa. Additionally, while indicator species can signal ecological change, they do not provide a direct measure of overall community similarity or progress towards a target condition.

We propose that either approach (based on similarity indices or weighting by indicator species) are more suitable than the Wallacea Trust methodology based on conservation status. These two approaches clearly demonstrate the trade-off between ecological resolution, costs and applicability. While the similarity index approach using a reference site is likely to be most accurate in providing a measure of biodiversity uplift, it is constrained by cost and data availability. The indicator species approach is more cost-effective, but lacks a benchmark of expected project outcomes. We also highlight that biodiversity uplift value is not comparable between these two approaches as they are on different scales. The decision regarding which approach will be adopted by the Codes will likely be based on feedback from pilot studies, and input from the executive and advisory boards.

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