JNCC Report 780

Setting biodiversity monitoring objectives

(Guidance Report)

Solène Marion, Nicola du Plessis, Caroline Coogan, Emma Wright and Maddie Harris

December 2024

ISSN 0963 8091

JNCC's report series serves as a record of the work undertaken or commissioned by JNCC. The series also helps us to share, and promote the use of, our work and to develop future collaborations.

For further information please contact:
JNCC, Quay House, 2 East Station Road, Fletton Quays, Peterborough PE2 8YY.

https://jncc.gov.uk/

Communications@jncc.gov.uk

This report was produced by JNCC for Defra through the Natural Capital and Ecosystems Assessment (NCEA) programme.

NCEA Natural Capital and Ecosystem Assessment

This document should be cited as:
Marion, S.[1], du Plessis, N.[1], Coogan, C.[1], Wright, E.[1] & Harris, M.[1]. 2024. Setting biodiversity monitoring objectives (Guidance report). *JNCC Report 780*. JNCC, Peterborough, ISSN 0963-8091.
https://hub.jncc.gov.uk/assets/f592f2bc-ab02-4acd-a615-90d5fe9c9069

Author affiliation:
[1] JNCC, Quay House, Peterborough

Acknowledgments:
This project was funded by the Department for Environment, Food and Rural Affairs (Defra) as part of the Natural Capital and Ecosystem Assessment (NCEA) programme. The NCEA programme is leading the way in supporting Government ambition to integrate natural capital approaches into decision making. Find out more at https://www.gov.uk/government/publications/natural-capital-and-ecosystem-assessment-programme

JNCC EQA Statement:
This document is compliant with JNCC's Evidence Quality Assurance Policy https://jncc.gov.uk/about-jncc/corporate-information/evidence-quality-assurance/

Summary

Clear monitoring objectives are essential to ensure the effectiveness of any biodiversity monitoring process. Clear objectives ensure the collection of relevant data, resource allocation, and successful evaluation of conservation efforts. Despite their importance, many monitoring programmes lack explicit statements of their goals. This work aims to explain what well-defined monitoring objectives are, outline steps to articulate them and identify potential barriers. Well-defined monitoring objectives are concise and unambiguous, articulating the specific goals and desired outcomes of the activity. They should be closely linked with the overall organisational and programme goals while being contextualised within the broader current knowledge about the area, taxon of interest, and stressors. We suggest different steps to develop well-defined objectives that focus on "why" the monitoring is needed, "what" aspects of biodiversity will be measured with a focus on species and habitat, "how" the monitoring will be conducted (i.e. which method), and "where and when" this monitoring will take place. By following these steps, we encourage the different stakeholders interested in biodiversity monitoring to consider the various aspects of the monitoring process separately, but also as part of the same framework.

Contents

1. Background

Biodiversity monitoring is defined as the process of gathering information about the various aspects of biodiversity within a specific area and at different points in time (Yoccoz *et al*. 2001). It can be used across taxa and environmental components, can occur at different spatio-temporal scales, and can be applied to various fields (Schmeller *et al.* 2015). In the context of the global biodiversity crisis, effective biodiversity monitoring is crucial for making informed conservation decisions, evaluating the success of conservation initiatives, and more broadly understanding the impact of environmental changes (Lindenmayer & Likens 2010; Schmeller *et al.* 2015).

One key factor contributing to the effectiveness of monitoring is the establishment of clear objectives before initiating the monitoring process (Kühl *et al.* 2020; Stephenson 2019). Robust objectives are used to determine what aspects to monitor and how to monitor the system effectively (Yoccoz *et al.* 2001). Objectives also inform the spatial scale at which the monitoring needs to occur (Eyre *et al.* 2011), the temporal coverage of monitoring (Mihoub *et al.* 2017), the monitoring methodology (Marion *et al.* 2020), as well as the evaluation process following the monitoring (e.g. evaluating restoration success; Prach *et al.* 2019). Conversely, the formulation of poor monitoring objectives, or the absence of objectives altogether, can have significant consequences. For example, this may result in the selection of inappropriate monitoring methods and tools, leading to the collection of biodiversity data with little relevance, and poor allocation of time and resources. Therefore, the development of specific objectives is essential as it lays the foundation for initiating effective and successful monitoring programmes.

Although the need to define objectives seems obvious, explicit statements of objectives for many monitoring programmes are often challenging to find (Prach *et al.* 2019). The development of these programmes frequently seems to be underpinned by the assumption that additional information about any system will inherently be useful (Yoccoz *et al.* 2001). Similarly, many stakeholders find it challenging to set objectives. For example, a large landowner with monitoring needs may have difficulties expressing their diverse objectives across various spatiotemporal scales and thus not articulate those objectives. Another challenge of defining clear monitoring objectives is identifying what aspect of biodiversity needs to be monitored, as biodiversity can be characterised by various components (Gaston & Spicer 2013). Each of these components can be monitored using different metrics (e.g. abundance of species vs site occupancy, habitat quality vs quantity), at different spatio-temporal scales and using different methodological approaches. Monitoring biodiversity comprehensively is unrealistic in many contexts due to the resources that would be required, so decisions need to be made on which aspects of biodiversity can most pragmatically and informatively be monitored.

Well-established objectives can be challenging to define, but opportunities can arise from them. Such opportunities include, but are not limited to, supporting data flows, enhancing collaboration amongst users across different scales, and allowing efficient use of resources (Harris & Hoskins 2024; Yoccoz *et al.* 2001). For instance, when two stakeholders share an interest in the abundance of a particular species or when two use cases seek alpha diversity information for distinct purposes, defining and effectively communicating the specific data being recorded can foster collaboration. This allows for the potential of working together, rather than each programme solely gathering data for its isolated project.

Developing clear objectives is of importance in the literature (e.g. Prach *et al.* 2019; Ferraro & Pattanayak 2006; Harris & Hoskins 2024), but there is a lack of clarity about what monitoring objectives are and how to define them. Thus, this report aims to:

(1) outline what a well-defined monitoring objective is,

(2) set steps for developing biodiversity monitoring objectives, and

(3) identify the barriers and opportunities to developing monitoring objectives.

This work represents a first step in setting objectives when measuring biodiversity and is aimed to broad audiences (including academia, NGOs, large landowners, research centres, citizen science initiatives) that have interest in biodiversity monitoring. While we recognise that biodiversity includes species, genetic, and functional diversity, this work focuses solely on terrestrial species biodiversity and habitat monitoring as our intention is to reach a large audience at an introductory level.

2. What is a well-defined objective?

A well-defined objective is a concise and unambiguous statement that articulates the specific goals and desired outcomes of the activity (Ogbeiwi 2016). These objectives can be set using with care the framework SMART (Specific, Measurable, Achievable, Relevant, and Time-bound). This ensures that the objectives are clear, quantifiable, realistic, aligned with the broader goals of the programme, and have a defined timeframe for completion (Ogbeiwi 2017). For example, a programme might want to assess how their decision of reducing hedge strimming influences biodiversity in the long term. Thus, a SMART objective might be to estimate bullfinch (*Pyrrhula pyrrhula*) spatial distribution in hedgerows with different management in a local authority during spring and summer months with repetition over three years. In this example, we are being 'Specific' by focusing on the bullfinch populations specifically in hedgerows; 'Measurable' by focusing on the spatial distribution; 'Achievable' by selecting a local authority; 'Relevant' by deciding which bird (here bullfinch are known to use hedgerows as an habitat) might be a key population informed by the project's aim; and 'Time-bound' by constraining monitoring to spring and summer months with repetition over three years.

SMART objectives can be difficult to articulate and result in unattainable objectives (Ogbeiwi 2017; Prather 2005). Specifically, SMART objectives work well when the goal is to improve a well-known system, which might not be the case when developing biomonitoring programmes (Prather 2005). Thus, to articulate SMART objectives, we suggest focusing on a framework composed of four basic components: Outcome, Indicator, Target and Timeframe (OITT) (Ogbeiwi 2016). This approach develops the basis of SMART objectives by focusing on specific components of it. We suggest further adapting this SMART-OITT framework to biodiversity monitoring by focussing the Target component on methods used to monitor biodiversity, and by adding spatial constraints to the Timeframe component. Thus, our framework is composed of two pre-requisites and four steps (Figure 1):

Pre-requisites

a) A well-defined project aim.

b) An understanding of the current knowledge about the system

Steps

1) **Outcome**: *why* the monitoring is needed.

2) **Indicator**: *what* aspects of biodiversity will be measured.

3) **Target and Method**: *how* biodiversity will be measured.

4) **Timeframe and Location**: *where and when* this monitoring will occur.

These considerations are not mutually exclusive and often one will inform another. Thus, while we present a linear approach by setting numbered steps, each step can be taken in various orders depending on previous knowledge about a system, stakeholders' preferences, or other constraints. However, the combination of steps 1 to 4 should, in most cases, help define clear monitoring objectives. In the next section, we develop further each of these steps and provide more detailed explanation and guidance.

In Annex 1, we provide examples of well-defined objectives in relation to the different steps described in our framework.

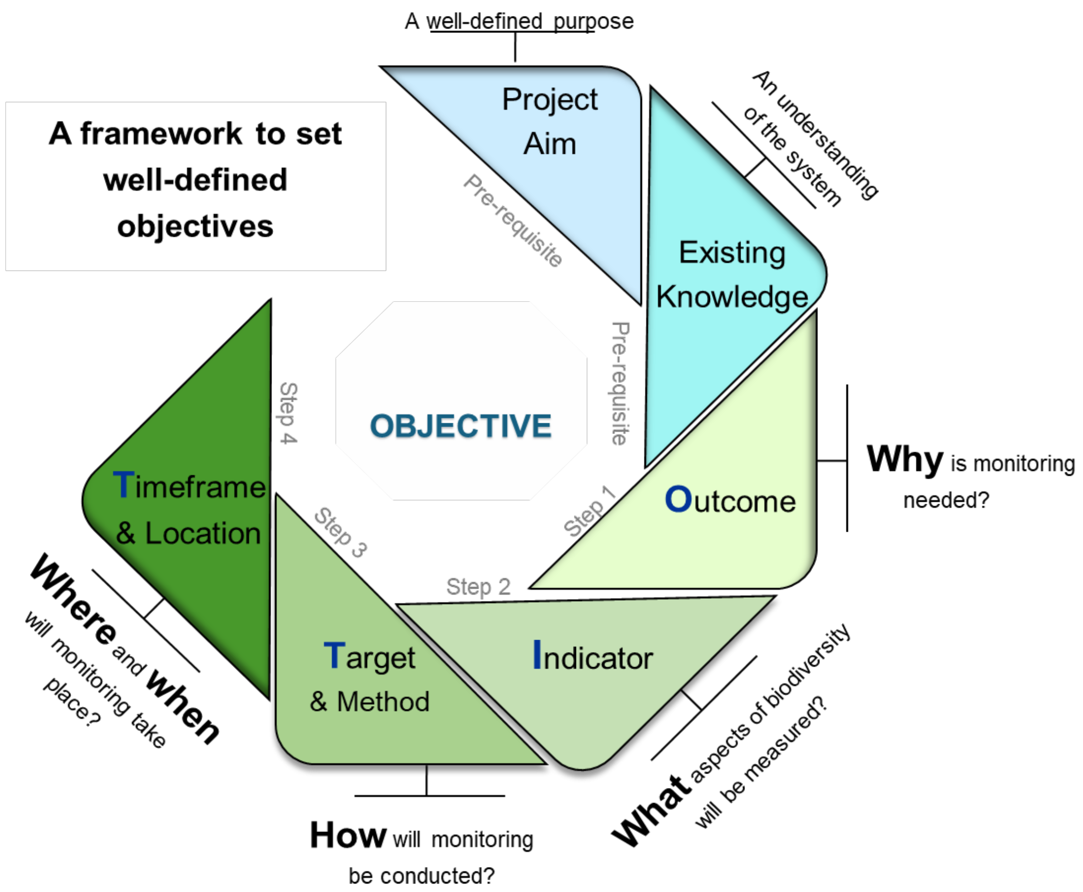

Figure 1: Overall framework allowing to set well-defined monitoring objectives. Stakeholders interested in setting monitoring objectives need to consider project aim, current knowledge, why, what, how, where and when, and what aspects of monitoring need to be considered. Each step is illustrated by an example (see main text for full description of each step and Annex 1).

3. Defining objectives

3.1. Pre-requisite a: define programme and project goals.

One of the key elements to ensure the development of well-defined monitoring objectives is a clear link between the monitoring objectives and the project and programme goals (Stephenson 2019). A hierarchy can be identified where monitoring objectives are driven by project goals, themselves driven by programme goals, themselves driven by organisational goals (Stephenson 2019). Thus, a programme is defined as a group of two or more projects, often driven by organisational goals. Therefore, the formulation of the project goal should reflect and share language with that of the programme in order to aggregate results and evaluate programme efficiency (Stephenson 2019).

Programme and project goals are not necessarily focused on monitoring, however, to understand progress towards those goals, monitoring is likely be required. Programme and project goals are more general and open-ended, while monitoring objectives are specific and measurable. A programme goal might be to improve biodiversity understanding, while the project aim might be to understand the local plant community, while its monitoring objective may be to measure the abundance of plants in a well-defined area over a specific period. Moreover, programme and project goals are used to identify the main problem or area of inquiry, while objectives define the specific outcomes that the project manager is looking to achieve. For example, a programme aim might be to improve urban biodiversity; one project aim might be to improve habitat quality in urban garden while the monitoring objective will be to measure the habitat quality in gardens.

3.2. Pre-requisite b: Investigate the current knowledge.

This step presents an opportunity to investigate other ongoing projects or those previously undertaken with similar aims, focusing on the same taxon or area. Such work is necessary to avoid duplicating efforts and to learn from the successes and failures of past projects. Identifying projects with similar aims would help in recognising objective opportunities and limitations, as well as understanding how the monitoring fits into the broader picture. For this preliminary step, one might want to explore resources such as academic and non-academic literature, engage with local authorities, and connect with various research centres and existing monitoring initiatives. Together these resources should be able to offer guidance on current knowledge and provide additional information about past successes and failures in monitoring programmes. We advise that each step outlined in our framework should be examined within the larger context of monitoring. For instance, in Step 1, 'why', one should investigate which other monitoring programmes have posed similar questions; in Step 4, 'where', one should investigate what monitoring has already been conducted around interest and for what objectives.

3.3. Step 1: Why is monitoring needed?

To clearly define monitoring objectives, it is essential to first establish why the monitoring is necessary. This section focuses on the outcome of the monitoring. Developing from Sparrow *et al.* (2020), we have identified questions that can be applied to different monitoring types. Each question relates to understanding why the monitoring is needed and can be used to build objectives:

- **What is the status of biodiversity?** This question might be used when new monitoring is taking place in an area where little is known about the composition of an ecosystem or the different species and habitat status in this ecosystem. Examples of monitoring objectives might be (list not exhaustive):

  - Understand the abundance or presence of bird/plant/mammal species present in an area.
  - What is the density of non-native species present in a site.
- **What is the impact of an action or intervention on biodiversity?** This question might be used to develop monitoring objectives that aim to monitor the long- and short-term impacts of positive and negative action such as creation of habitat or anthropogenisation. This question might be followed by a more targeted one (see below for the directionality of environmental change). Examples include:
  - Monitor the status of endangered or threatened species to assess the effectiveness of conservation efforts and identify potential recovery needs (Campbell *et al.* 2002).
- **What elements within the environment are changing?** This question is more appropriate to be used when projects already understand the past historical status of biodiversity (see question 1). Examples of monitoring objectives might be:
  - Track changes in the number of species present within a specific habitat (Shtilerman *et al.* 2014).
  - Understand the abundance of key species to explore population dynamics and potential ecological shifts (Hall *et al.*1992), including the use of indicator species (Terrigeol *et al.* 2022).
- **What is the direction and magnitude of that change?** Relating to or following from the first question, examples of monitoring objectives that focus on the direction and the magnitude of the changes may be:
  - How many species are being lost (or gained) due to climate changes in a specific area (Kappelle *et al.* 1999).
  - How is habitat fragmentation in a specific landscape changing due to anthropogenisation (Brauer & Beheregaray 2020)
  - What is the abundance of an endangered or threatened species in comparison to past records (Lewis *et al.* 2022).
- **Where is environmental change occurring in the landscape?** Monitoring objectives focusing on this might want to understand species and habitat spatial and temporal distribution and the drivers of distribution changes. For example:
  - Identify hotspots of plant diversity to select and evaluate protected areas (Bonn & Gaston 2005).
  - Identify where and when humans and wildlife interact in protected areas to mitigate human-wildlife conflict (Warrier *et al.* 2021).
  - Comparing habitat quality in urban areas to identify priority areas for rewilding (Sweeney *et al.* 2019).
- **When is environmental change occurring and is the rate of change increasing or decreasing?** Monitoring objectives trying to answer this question might relate to understanding temporal distribution of species and habitat evolution. For example:
  - Estimate key indicators of species population size over time to obtain long-term trends (e.g. BTO's indicators).
  - Identify when a population is at risk of local extinction depending on different environmental pressures (Boakes *et al.* 2018).
- **What is the cause of the environmental change we are observing?** Monitoring objectives trying to answer this question might relate for example to

    - Understanding the drivers of population changes.

- **What action can be taken to ameliorate deleterious change and/or encourage positive change?** After changes have been identified through biodiversity monitoring, the next set of monitoring objectives might involve identifying different actions to halt or manage these changes.

To set a well-defined objective, one might think about which type of questions they are interested in answering. Projects are unlikely to have only one objective and there are often links between them. For example, it is likely that someone wanting to understand which elements of the environment are changing would also want to understand the direction and magnitude of this change and where this change is occurring.

Most of these questions also rely on monitoring biodiversity against a baseline or counterfactual (e.g. you need to have a baseline about a specific population to understand its trends overtime). Thus, one might investigate which baseline is appropriate to use for their specific context.

3.4. Step 2: What aspects of biodiversity are being measured?

A clearly defined objective will specify which aspect(s) of biodiversity are being measured. Stakeholders undertaking monitoring need to decide which aspect of biodiversity they want to monitor; multiple options are available, and some might want to focus on multiple aspects. Adapting from Walters and Scholes (2017), we have categorised these different components as **species monitoring** and **ecosystem and habitat monitoring** (Figure 2). Below, we will first describe these two components, followed by presenting consideration points to aid in the decision-making process regarding which one on which the monitoring should focus.

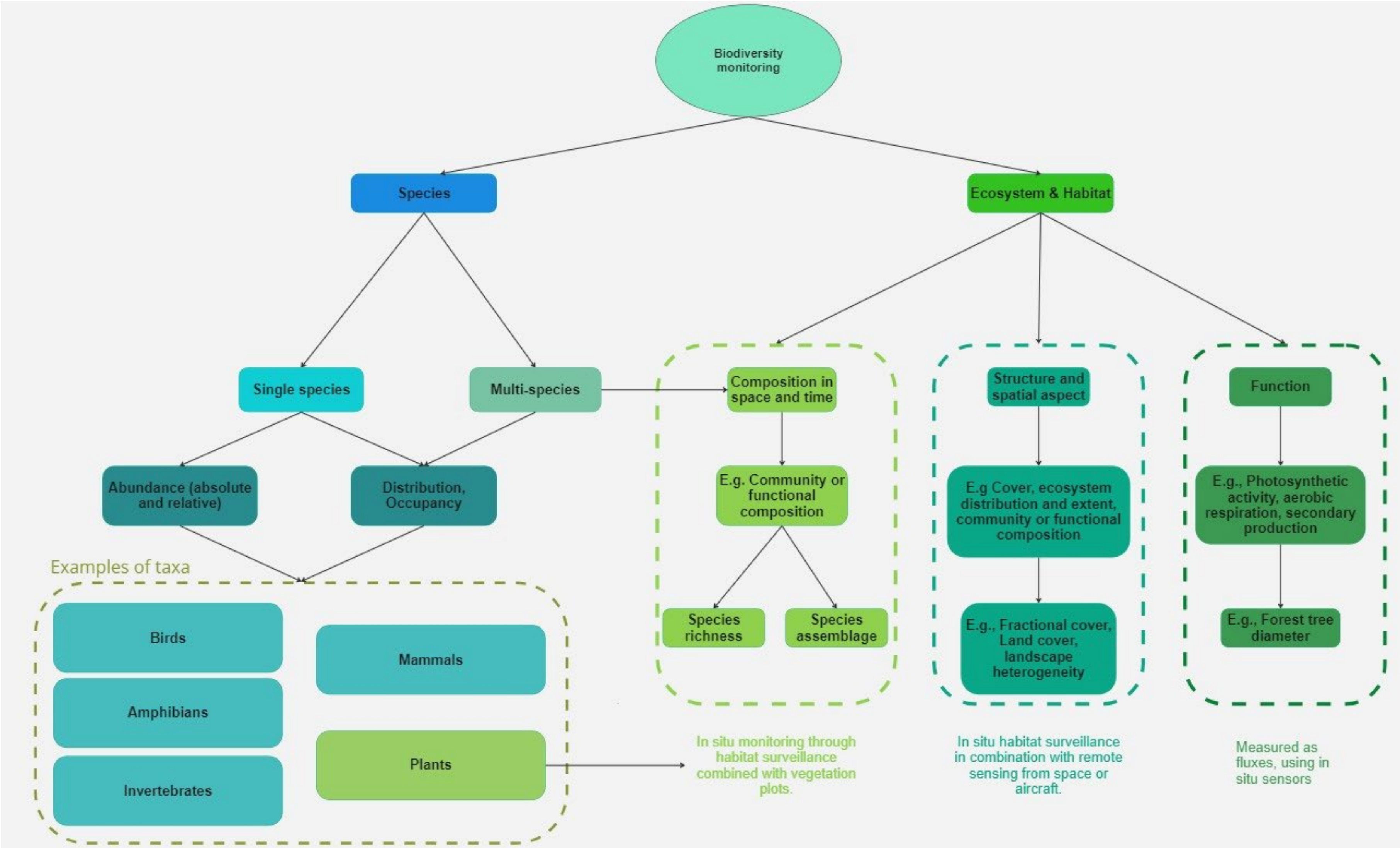

Figure 2: A framework to describe which aspects of biodiversity are being measured.

3.4.1. Species

Species monitoring is defined as the repeated, systematic collection of data to detect changes in the populations of wild species (Moussy *et al.* 2022). Species can be identified at different taxonomic levels or by different ecological functions, and clustering species by genus or family or by habitat affiliation may be necessary (see below single vs multiple species). Thus, one first step for species monitoring is to consider if one or multiple species are being monitored or if clustering need to be done.

Single species monitoring

Single species monitoring will specifically focus on species abundance and distribution (occupancy and occurrence). Monitoring objectives that focus on abundance will typically want to understand the sum total of individuals from a given species for a specific location (Tittensor *et al.* 2014). Monitoring objectives that focus on abundance will be appropriate for:

(i) understanding endangered species' population status,

(ii) understanding the drivers of change in the targeted population,

(iii) following species over time to identify trends.

For example, official statistics on species of birds are annually produced by the British Trust for Ornithology (BTO) to track population trends by counting birds individually at different locations. Thus, BTO monitoring objectives are "to generate robust and long-term evidence describing changes in the populations of birds and other wildlife, which in turn prompts further research and conservation action". While this monitoring is multi-species (i.e. multiple bird species are being monitored at the same time), each species abundance is calculated separately, and the resulting individual trends are aggregated during the reporting.

Monitoring abundance might not be realistic due to the size of the area of interest, species-specificity (e.g. elusive species) or financial limitation. Thus, understanding distribution and occupancy might be a more realistic aim. Monitoring objectives that focus on occupancy and distribution will be interested in investigating species use of space and identifying critical habitat characteristics associated with species occurrence (Peterman *et al.* 2013). Occupancy sampling can be used to assess the status of species at multiple points in an area (e.g. species presence/absence or distribution), and how those change over time. It can provide measures of detectability, increasing the confidence that a species is truly absent when not detected. However, these approaches do not provide information about the number of species per area. Therefore, monitoring objectives focused on single species distribution and occupancy might revolve around the understanding of:

(i) drivers of a species spatial and temporal distribution (Basille *et al.* 2009),

(ii) areas of high conservation priority due to a species' space use (Chapron *et al.* 2003), or

(iii) a species spatial niche adaptation to external stressors (e.g. niche change due to climate change) (Charmantier *et al.* 2015).

Multi species monitoring

While more easily applicable to single species, monitoring occupancy and distribution is also being used more and more to understand multi species spatiotemporal distribution and occurrence patterns (Mihaljevic *et al.* 2015). Monitoring objectives might be similar to the above for single species occupancy, with the addition of understanding species interactions (Singh *et al.* 2022), and community-level responses to environmental variables (Zipkin *et al.*

2023). Beyond species interaction and community responses, multi-species monitoring simply provides more insights of environmental impact on multiple species within or across taxonomic groups.

Species richness is the number of species in a community, which consists of interacting species inhabiting a particular location at a specific time. A measure of the abundance of each species is usually described by an index (e.g. Shannon's Index H'. Species). Monitoring objectives that focus on species richness might be interested in having an overall understanding of the various species in an area and might want to compare this to a different area. Species richness can be defined at different spatial scales, and the suitable scale of species richness is sometimes captured through either alpha, beta, or gamma diversity. Examples of applications of biodiversity monitoring for each metric are:

- Alpha diversity is well-suited for monitoring objectives that involve determining the number of species within a specific local habitat (e.g. counting the number of bird species in a designated forest/area). This type of metric is also highly relevant to identify and monitor the presence of species unique to a particular region (endemism); (e.g. track the occurrence of plant species endemic to a specific island ecosystem).
- Beta diversity is more suited to monitoring priorities such as understanding changes in community composition and examining how species composition changes between different habitats or over time. For example, comparing the plant species composition in a riparian zone to that in an adjacent upland area. It is also highly relevant to understanding biodiversity patterns, for example measuring beta diversity in fragmented versus contiguous forest patches.
- Gamma diversity is more suited to larger spatial scale monitoring. Monitoring objectives that are concerned with gamma diversity are suited to regional biodiversity assessments, such as evaluating the impact of habitat fragmentation on the turnover of species between habitat patches.

Single vs multiple species

The choice between monitoring a single species or multiple species may be informed by considering specific points:

- Has a taxon of interest already been identified? This may be the case if monitoring specifically targets an endangered species aligned with the project's overall aim, due to a general interest in a particular taxon, or because of expertise in a specific taxon or monitoring method associated with that taxon; as described in Table 1, some species are easier to monitor or have existing data available.
- What will be gained from monitoring multiple species? For example, monitoring a single species that can reveal the status of the environment, also known as an indicator species, is a cost-effective way in which to assess ecosystem health without collecting data about the entire ecosystem (Gerhardt 2002). However, focusing on a single species might not be able to reveal complex ecosystem processes, which might be necessary to meet the study objectives. For example, bird populations respond differently to stressors which is difficult to capture if focusing on a specific species (Hasui *et al.* 2024).
- Is an understanding of the community-level overview of biodiversity change of importance for the programme? Monitoring species' population variables across entire assemblages provides a community-level overview of biodiversity change (Dornelas *et al.* 2014). Such broad surveys may capture population trends of abundant species but may fall short of providing precise abundances for rare species. Instead, rare species

may require targeted sampling schemes, both in terms of spatial sampling and field methodology (Thompson 2013).

- Which metric (abundance, occupancy, diversity) will be used to assess the population, and does the project team have the analytical skills required to monitor this metric? (e.g. occupancy can be more challenging to determine in comparison to other metrics such as abundance)
- Would the sample size adequate for monitoring a single species obtain meaningful information about the species, particularly in a monitoring programme occurring at multiple scales (Stephenson & Carbone 2021)?
- What is the sampling scale? When working across multiple sites, the monitoring programme may choose to aggregate data at a higher taxonomic level, such as genus, family, or order, to simplify the monitoring process and facilitate inter-site comparisons.
- As well as single vs multiple species, it might also be worth considering the above points to consider if they have advantage and capacity in monitoring single taxonomic group vs multiple. For example, if interested in changing farmland biodiversity, whether to monitor farmland birds as a proxy, or monitor a wider range of farmland taxa.

Walters and Scholes (2017) also proposed that the selection of taxa and metrics is guided by several considerations:

(1) Monitoring should have a minimal impact on the targeted organisms (e.g. on fitness, spatio-temporal distribution, behaviour)

(2) The monitoring protocol (e.g. number of sampling points, temporal aspect, method) must be reliable and repeatable.

(3) The variable (e.g. abundance of a species) should exhibit a strong correlation with the concerned driver.

(4) The variable should possess ecological significance, where its impacts hold meaning at either an ecosystem level or localised impacts are significant enough to warrant concern.

3.4.2. Ecosystem and habitat monitoring

The overall objective of habitat monitoring is to describe and understand habitat condition and extent (Lengyel *et al.* 2008). Monitoring objectives that would aim to focus on habitat might include variables such as habitat composition in space and time (quality assessments), structure (spatial aspect), and function (Walters & Scholes 2017). Thus, the first step of habitat monitoring involves selecting which of these variables need to be prioritised. However, note that one might want to focus on multiple variables.

The objectives of monitoring habitat **condition (quality)** are to understand trends within a habitat, for example, to guide conservation and assess interventions and management efforts. Traditionally, condition is often achieved by assessing vegetation community composition and structure at stationary sampling units (Lengyel *et al.* 2008). However, habitat quality is a complex concept, and different stakeholders might have contrasting expectations of what constitutes a high-quality habitat. For example, farmers might not consider land with a high plant species richness as a high-quality habitat but instead, might consider quality in terms of the overall annual productivity of the piece of land. In the context of biodiversity conservation, we are interested in a high-quality habitat for biodiversity which itself can be defined differently for different species. A high-quality habitat might be relevant for a particular endangered species but not for the rest of the community.

Monitoring objectives that focus on habitat **structures (extent)** will aim to understand spatial distribution and dynamics of the studied habitats. This can be achieved by looking specifically at metrics such as land cover, landscape heterogeneity or connectivity. Overall, these objectives focusing on habitat structures aim to understand more holistic processes underlying a change. For example, understanding habitat heterogeneity or connectivity in urban areas might explain why some populations of invertebrates are decreasing. Habitat structure can be assessed using traditional field mapping and remote sensing techniques (i.e. satellite imagery) which are increasingly being used as a cost-effective way to obtain habitat maps (see 3.5). By integrating these monitoring approaches, we can gain a holistic understanding of ecosystem and habitat structures, informing conservation and management efforts effectively.

Species vs habitat

When establishing monitoring objectives, one must decide whether to focus on monitoring species or habitats. This decision can be guided by the aim of the project, which could be to understand changes in biodiversity, or identify the drivers of these changes. However, these objectives are often intertwined, as monitoring one aspect often sheds light on the other. The choice between monitoring species versus ecosystem and habitat can be achieved by weighing up the advantages and disadvantages of each approach. Species monitoring, whether single or multi, is well-suited for examining how specific taxa are changing spatially and temporally, as well as their responses to drivers, impacts and pressures. However, focusing solely on species may overlook the complexities of the ecosystem. Hence, those seeking a more holistic perspective may opt to examine various habitat components, such as composition and structure. Similarly, habitat monitoring might be more appropriate for providing faster answers to conservation projects regarding their actions. Species such as birds may not (re)populate an appropriate habitat as soon as it becomes available. Thus, habitat monitoring can provide insights into the success of interventions at a faster pace. Moreover, the choice between species and habitat monitoring is influenced by practical considerations, such as financial resources and technical skills, as well as the chosen metric.

3.5. Step 3: How

A well-defined monitoring objective will identify which monitoring method is to be used during the monitoring. This choice might be inherent to the project objectives, driven by the species being monitored, or limited by the surveyor's ability. Monitoring methods can be broadly categorised as:

Field survey: sampling is conducted by restricting surveys to certain locations and by making inferences from these locations to non-surveyed areas. Objectives focusing on field surveys might be interested in site scale or comparison between areas or understanding inferences and drivers of biodiversity state. Collated site-scale information can then be used to understand biodiversity at a larger spatial scale. These surveys might be used to collect data on species diversity, population size, or species distribution. They can be conducted by professional ecologists or citizen science schemes can be used to perform field surveys, for example, on vegetation, insect surveys, bird, and bat populations (Dickinson *et al.* 2010). We can distinguish different methods of field surveys:

- Direct observation: Field surveys that directly involve the counting and recording of different taxa as well as environmental variables. This can include traditional monitoring methods where a professional ecologist or a citizen scientist survey a site by focusing on specific taxon (i.e. bird, plants). As this method has been used for decades, it is important for obtaining population trends and understanding local changes. However, to obtain inference and statistical significance, this method can be time and resource consuming, especially when applied at large spatial scale. This explains the extensive involvement of citizen scientists for large surveys such as the Breeding Bird Survey organised by BTO and used every year to produce population trends using volunteer-recorded data (de Sherbinin *et al.* 2021). Similarly, at the site scale, citizen science can also be used to perform field surveys in local areas, leveraging local knowledge.

- Camera Trapping: Camera traps are widely used to monitor wildlife populations, mostly mammals, by capturing images or videos (O'Connell *et al.* 2011). This non-invasive method helps ecologists estimate species abundance, behaviour, and distribution patterns (Bridges & Noss 2011; Nichols *et.al.* 2011). Objectives that aim to use camera trapping might seek to understand multispecies distribution over different areas, as a potential advantage of camera traps is that they are not species specific.
- Biotelemetry tracking: Animal-borne sensors and bio-loggings for location-based tracking in terrestrial systems are traditionally used to understand movement responses to environmental changes (Katzner & Arlettaz 2020). These traditionally expensive methods are becoming more affordable and accessible to different audiences. However, these methods can still be invasive for species and require extensive skills. Objectives that aim to use biotelemetry might want to focus on mammals and birds, at large spatial scale (beyond site scale), aim to understand animal movement.
- Acoustic Monitoring: automated audio recorders are specifically used to record the sounds of animals such as birds, small mammals, or orthoptera (Sugai *et al.* 2019). Acoustic monitoring is relevant to any objective aiming to detect animal presence and absence rather than abundance. It is highly relevant to study elusive species such as bats. As acoustic monitoring captures a soundscape, it is not species-specific and can be used to monitor multiple species. It can identify multiple bird species at the same location and time as mammals or human activities. It is also becoming more accessible for different users, including citizen science. Yet, this method is not relevant for silent taxa such as plants.
- Environmental DNA (eDNA): Similarly to acoustics, eDNA is particularly relevant to study elusive species while being non-invasive and non-selective (i.e. can be used for multispecies monitoring) (Mathieu *et al.* 2020). It involves sampling water, soil, air or biological materials to understand species' presence using DNA extraction. It has become more affordable and used by ecologists and, more recently, by citizen scientists (Biggs *et al.* 2015; Chave 2013). Thus, objectives using eDNA might want to have an overview of the biodiversity present in a small area or compare two different areas' species composition without necessarily looking at estimating biodiversity abundance.

Satellite imagery: A broad range of satellite imagery data sources are used for habitat monitoring, including panchromatic or colour photography, multispectral imaging, laser scanning, and radar imaging (Corbane *et al.* 2015). These methods are typically limited to professional ecologists and geographers due to their technical complexity and computational demands. They are particularly useful for monitoring objectives focused on large spatial scales, remote or inaccessible areas, or when monitoring environmental variables such as temperature, moisture, or radiation.

Data processing: This involves collating information previously collected from various sources to obtain insights about a system, which can be a cost-effective monitoring method. For example, with the rise of the "big data" era and sharing information among scientists, opportunities can arise from previously collected data (Hampton *et al.* 2013). Various open-access libraries of data can be identified, such as Dryad, as well as on government websites. GIS (Geographic Information Systems), mapping methods, and modelling approaches can help enhance the analysis of monitored data and answer specific questions. Objectives that focus on data analysis might aim for a large spatial scale (across a continent), focus on multi-species analysis, or be limited financially.

Thus, the choice of the method is driven by the needs to have monitoring that is species-specific (single vs. multiple species vs. habitat), requires extensive field collection, and is appropriate for different spatial scales (site-based vs. large scales).

3.6. Step 4: Where and when the monitoring will take place

3.6.1. Spatial scale

A clearly defined objective will specify a particular survey area where the data will be collected. Different sampling scales can be considered: site-based, landscape, and regional.

Site-based scale refers to a small spatial scale where targeted monitoring is often used (Eyre *et al.* 2011). The monitoring area of interest is generally well-defined due to stakeholders' needs to monitor their specific area. The choice of this scale might also be influenced by the spatial distribution of species, which might be limited to a small area. For example, some bat populations are spatially constrained to specific areas. At this scale, monitoring can occur over short or long periods of time, and both species and habitat monitoring can be used. For the latter, traditional methods such as plant community monitoring assessments might be more appropriate, as satellite imagery may not have the appropriate resolution for small-scale monitoring. Thus, monitoring objectives focusing on this scale are very specific to the needs of stakeholders, species, and areas.

Landscape scale is larger than the site-based scale, ranging from several square kilometres to large areas spanning multiple counties. The choice of this scale might be influenced by stakeholders such as policymakers with interests across different counties. Similarly to site-based scale, this choice might also be driven by species-specific needs, such as their spatial distribution. However, this scale requires careful consideration of the survey design to capture the appropriate resolution and obtain a statistically significant sampling size. This scale is likely to provide indications of change over an area related to larger-scale interventions or drivers, such as a reduction in pollution pressure or habitat restoration initiatives.

Regional scale often refers to large areas. It is unlikely that monitoring objectives at this scale would be comprehensive but rather indicative of the different ecological processes in focus. The choice of this scale might be driven by large-scale policymakers, data-driven approaches (e.g. summary/collation of data from smaller areas), or holistic thinking. Both species and habitat monitoring might be used at this scale, but satellite imagery is more likely to capture large-scale complexity adequately. Large-scale monitoring can be challenged by landscape and sampling heterogeneity, which might create analytical complexity.

The overall choice of a spatial scale might be defined by external constraints discussed in Section 4. For example, local authorities and policymakers might want to investigate biodiversity in their area of jurisdiction, thus the spatial extent is automatically defined. Alternatively, access to private land might be restricted, which might exclude some specific sampling areas, limiting the scale of the survey. However, the choice of the spatial extent of monitoring can be challenging as ecosystems are not constrained to specific scales and pressure can take place across different scales (Harris & Hoskins 2024). For example, site monitoring of birds might be necessary to understand the impacts of an intervention at a particular location. However, as birds are not spatially constrained, an external stressor to this area might not be identified unless you also considered information from a larger spatial scale. Thus, one might want to consider if they want to only focus on their intervention area (study area) or also consider the direct and indirect influence of a broader spatial scale. In this context, considering a multiscale approach might be beneficial to understand multiscale ecological processes (e.g. pressure), inform decision making across scales, and increase sampling size (Harris & Hoskins 2024). Different decisional tools and analytical techniques such as GIS, models and meta-analysis, are available to understand the different layers of complexity of the monitoring area and help identify sampling areas.

3.6.2. Temporal period

Similarly, a well-defined objective will also specify the timeframe for the monitoring. Considerations might include:

- What is the seasonality of the species monitored? Biodiversity monitoring at different periods of the year might reveal different trends depending on wildlife seasonality, human activity, and changes in environmental stressors. Thus, monitoring objectives might specify a timeframe such as “understanding bird populations in a specific area in winter vs. summer, considering migration patterns”.
- What are the different biological timescales that need to be considered? For example, habitat restoration process might be long processes occurring over multiple years that need to be considered when setting monitoring objectives.
- For how long does the monitoring need to occur to have a realistic understanding of biodiversity? Biodiversity monitoring occurring only for a short period of time (e.g. one day) might not capture the different complexities of an ecosystem.
- Does the monitoring need to be repeated multiple times across different periods of the year, for example, every month, every year? For example, butterfly monitoring is weather-dependent (Kral-O’Brien *et al.* 2021), implying that different monitoring periods need to be considered to have an overview of population.
- What are the time constraints of the projects? For example, until when is the funding available, and does it allow for continuous monitoring? Additionally, when are people available to perform monitoring?
- What is the legacy and long-term perspective of the project? While short-term projects might be pragmatic to match the length of funding grants, long-term monitoring programmes should be favoured when possible. Long-term projects are beneficial for a wide range of purposes, including assessing the long-term impact of stressors on biodiversity, identifying and creating trends, participating in historical data recording, and detecting changes in ecosystems that might not be observed through short-term projects (Symstad *et al.* 2003). Thus, a multiscale approach can be considered where different short and long-term impacts of the monitoring objectives might be appropriate.

Sampling effort (e.g. using power analysis) is also relevant when considering the temporal aspects of monitoring design and can help in setting a well-defined objective. In ecology, sampling effort refers to the amount of time, resources, and energy invested in collecting data from a particular area or population (Azovsky 2011). It encompasses the intensity and duration of the sampling activities conducted to gather information about the ecological characteristics of a specific habitat, community, or species, influencing the “Achievable” part of the objective.

4. Limitations and constraints

Different constraints and limiting factors need to be considered when setting monitoring objectives. Funding availability is often a constraint for various monitoring programmes, as well as the associated human resources. For example, monitoring the different aspects of an ecosystem (e.g. species abundance and habitat quality) might seem like a good option to have a holistic view of the system; however, the resources available (including money and time) may limit monitoring to a specific part of the ecosystem. Similarly, the duration for which monitoring can be conducted while respecting financial and human resources needs to be considered, especially when monitoring objectives are labour-intensive.

We also suggest reflecting on the different monitoring techniques, and the expertise required to use such tools. Some objectives can only be achieved when using specific monitoring techniques, for example, understanding habitat quality changes at large spatial scales is often more appropriate using remote sensing. This might require specific technology and expertise in accessing and analysing earth observation data and satellite imagery. On the other hand, using specific monitoring techniques might drive objectives. Some might have specific expertise or have data available using some specific technologies which might influence the way they articulate their objectives. For example, one might want to understand some of the changes occurring in local areas and have access to a large dataset of camera trap detections. This technology is specifically aimed at detecting multi-animal spatial and temporal detection, thus what we described in step 1 would be directly data-driven rather than goal-oriented. This aligns with the first point of step 1, which involves understanding the local context and analysing if precedent data can be used to set monitoring objectives.

Thus, after setting what, when, how, and where, it is important to reflect on the feasibility of such monitoring objectives in relation to the different constraints mentioned above and readjust their expectations accordingly.

5. Conclusion

We have highlighted the importance of having well-defined monitoring objectives – a clear and concise statement of the outcome, indicator, target, method, timeframe, and location. We have developed a framework that uses different steps to develop biodiversity objectives. We suggest that different stakeholders use those steps as a starting point to develop their monitoring strategies. They can be used as a checklist of consideration points when developing monitoring projects; different projects might have different approaches to monitoring, such as methods or taxa already identified. In such cases, some steps might be irrelevant, but the link with other steps might be relevant, which is why we suggest this non-linear framework. Finally, limitations and constraints are various when setting monitoring objectives, but various tools such as modelling approaches and other options exist to overcome these challenges.

References

———. 2017. 'Why Written Objectives Need to Be Really SMART'. British Journal of Healthcare Management 23 (7): 324–36. https://doi.org/10.12968/bjhc.2017.23.7.324.

Azovsky, A.I. 2011. 'Species–Area and Species–Sampling Effort Relationships: Disentangling the Effects'. *Ecography* 34 (1): 18–30. https://doi.org/10.1111/j.1600-0587.2010.06288.x

Basille, M., Herfindal, I., Santin-Janin, H., Linnell, J.D.C., Odden, J., Andersen, R., Høgda, K.A. & Gaillard, J.-M. 2009. 'What Shapes Eurasian Lynx Distribution in Human Dominated Landscapes: Selecting Prey or Avoiding People?' *Ecography* 32 (4): 683–91. https://doi.org/10.1111/j.1600-0587.2009.05712.x .

Biggs, J., Ewald, N., Valentini, A., Gaboriaud, C., Dejean, T., Griffiths, R.A., Foster, J., *et al.* 2015. 'Using eDNA to Develop a National Citizen Science-Based Monitoring Programme for the Great Crested Newt (*Triturus Cristatus*)'. *Biological Conservation*, Special Issue: Environmental DNA: A powerful new tool for biological conservation, 183 (March):19–28. https://doi.org/10.1016/j.biocon.2014.11.029.

Boakes, E.H., Isaac, N.J.B., Fuller, R.A., Mace, G.M. & McGowan, P.J.K. 2018. 'Examining the Relationship between Local Extinction Risk and Position in Range'. *Conservation Biology* 32 (1): 229–39. https://doi.org/10.1111/cobi.12979.

Bonn, A. & Gaston, K.J. 2005. 'Capturing Biodiversity: Selecting Priority Areas for Conservation Using Different Criteria'. *Biodiversity & Conservation* 14 (5): 1083–1100. https://doi.org/10.1007/s10531-004-8410-6.

Brauer, C.J. & Beheregaray. L.B. 2020. 'Recent and Rapid Anthropogenic Habitat Fragmentation Increases Extinction Risk for Freshwater Biodiversity'. *Evolutionary Applications* 13 (10): 2857. https://doi.org/10.1111/eva.13128.

Bridges, A.S. Noss, A.J. 2011. 'Behavior and Activity Patterns'. In *Camera Traps in Animal Ecology: Methods and Analyses*, edited by Allan F. O'Connell, James D. Nichols, and K. Ullas Karanth, 57–69. Tokyo: Springer Japan. https://doi.org/10.1007/978-4-431-99495-4_5.

Campbell, S.J., Crampton, C.L., Guerry, A., Hatch, L., Hosseini, P., Lawler, J. & O'Connor, R. 2002. 'AN ASSESSMENT OF MONITORING EFFORTS IN ENDANGERED SPECIES RECOVERY PLANS'. *Ecological Applications* 12 (June):674–81. https://doi.org/10.1890/1051-0761(2002)012[0674:AAOMEI]2.0.CO;2.

Chapron, G., Legendre, S., Ferrière, R., Clobert, J. & Haight, R.G. 2003. 'Conservation and Control Strategies for the Wolf (Canis Lupus) in Western Europe Based on Demographic Models'. *Comptes Rendus Biologies* 326 (6): 575–87. https://doi.org/10.1016/S1631-0691(03)00148-3.

Charmantier, A., Doutrelant, C., Dubuc-Messier, G., Fargevieille, A. & Szulkin, M. 2015. 'Mediterranean Blue Tits as a Case Study of Local Adaptation'. *Evolutionary Applications* 9 (1): 135–52. https://doi.org/10.1111/eva.12282.

Chave, J. 2013. 'The Problem of Pattern and Scale in Ecology: What Have We Learned in 20 Years?' *Ecology Letters* 16 (s1): 4–16. https://doi.org/10.1111/ele.12048.

Corbane, C., Lang, S., Pipkins, K., Alleaume, S., Deshayes, M., García Millán, V.E., Strasser, T., Vanden Borre, J., Toon, S. & Michael, F. 2015. 'Remote Sensing for Mapping

Natural Habitats and Their Conservation Status – New Opportunities and Challenges'. *International Journal of Applied Earth Observation and Geoinformation*, Special Issue on Earth observation for habitat mapping and biodiversity monitoring, 37 (May):7–16. https://doi.org/10.1016/j.jag.2014.11.005.

De Sherbinin, A., Bowser, A., Chuang, T.-R., Cooper, C., Danielsen, F., Edmunds, R., Elias, P., *et al.* 2021. 'The Critical Importance of Citizen Science Data'. *Frontiers in Climate* 3 (March). https://doi.org/10.3389/fclim.2021.650760.

Dickinson, J.L., Zuckerberg, B. & Bonter, D.N. 2010. 'Citizen Science as an Ecological Research Tool: Challenges and Benefits'. *Annual Review of Ecology, Evolution, and Systematics* 41:149–72.

Dornelas, M., Gotelli, N.J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C. & Magurran, A.E. 2014. 'Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss'. *Science* 344 (6181): 296–99. https://doi.org/10.1126/science.1248484.

Eyre, T.J., Fisher, A., Hunt, L.P & Kutt, A.S. 2011. 'Measure It to Better Manage It: A Biodiversity Monitoring Framework for the Australian Rangelands'. *The Rangeland Journal* 33 (3): 239. https://doi.org/10.1071/RJ10071.

Ferraro, P.J. & Pattanayak, S.K. 2006. 'Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments'. *PLOS Biology* 4 (4): e105. https://doi.org/10.1371/journal.pbio.0040105.

Gaston, K.J. & Spicer, J.I. 2013. *Biodiversity: An Introduction*. John Wiley & Sons.

Gerhardt, A. 2002. 'Bioindicator Species and Their Use in Biomonitoring'. *ENVIRONMENTAL MONITORING*.

Hall, C.A.S., Stanford, J.A. & Hauer, F.R. 1992. 'The Distribution and Abundance of Organisms as a Consequence of Energy Balances along Multiple Environmental Gradients'. *Oikos* 65 (3): 377–90. https://doi.org/10.2307/3545553.

Hampton, S.E., Strasser, C.A., Tewksbury, J.J., Gram, W.K., Budden, A.E., Batcheller, A.L., Duke, C.S. & Porter, J.H. 2013. 'Big Data and the Future of Ecology'. *Frontiers in Ecology and the Environment* 11 (3): 156–62. https://doi.org/10.1890/120103.

Harris, M. & Hoskins, H. 2024. 'Review of Monitoring Biodiversity Effectively at Differing Scales'. JNCC Report 756 (Guidance Report). Peterborough: JNCC. https://hub.jncc.gov.uk/assets/145a3536-acae-4fad-8242-85b52cfe8c05.

Hasui, É., Camargo Martensen, A., Uezu, A., Guerra Pimentel, R., Nunes Ramos, F., Ribeiro, M.C. & Metzger, J.P. 2024. 'Populations across Bird Species Distribution Ranges Respond Differently to Habitat Loss and Fragmentation: Implications for Conservation Strategies'. *Perspectives in Ecology and Conservation* 22 (1): 43–54. https://doi.org/10.1016/j.pecon.2023.11.003.

Kappelle, M., Van Vuuren, M.M.I. & Baas, P. 1999. 'Effects of Climate Change on Biodiversity: A Review and Identification of Key Research Issues'. *Biodiversity & Conservation* 8 (10): 1383–97. https://doi.org/10.1023/A:1008934324223.

Katzner, T.E. & Arlettaz, R. 2020. 'Evaluating Contributions of Recent Tracking-Based Animal Movement Ecology to Conservation Management'. *Frontiers in Ecology and Evolution* 7 (January). https://doi.org/10.3389/fevo.2019.00519.

Kral-O'Brien, K.C., Harmon, J.P. & Antonsen, A.K. 2021. 'Snapshot Observations Demonstrate Within- and across-Year Weather Related Changes in Butterfly Behavior'. *Climate Change Ecology* 1 (July):100004. https://doi.org/10.1016/j.ecochg.2021.100004.

Kühl, H.S., Bowler, D.E., Bösch, L., Bruelheide, H., Dauber, J., Eichenberg, D., Eisenhauer, N., *et al.* 2020. 'Effective Biodiversity Monitoring Needs a Culture of Integration'. *One Earth* 3 (4): 462–74. https://doi.org/10.1016/j.oneear.2020.09.010.

Lengyel, S., Déri, E., Varga, Z., Horváth, R., Tóthmérész, B., Henry, P.-Y., Kobler, A., *et al.* 2008. 'Habitat Monitoring in Europe: A Description of Current Practices'. *Biodiversity and Conservation* 17 (14): 3327–39. https://doi.org/10.1007/s10531-008-9395-3.

Lewis, D.J., Kling, D.M., Dundas, S.J. & Lew, D.K. 2022. 'Estimating the Value of Threatened Species Abundance Dynamics'. *Journal of Environmental Economics and Management* 113 (May):102639. https://doi.org/10.1016/j.jeem.2022.102639.

Lindenmayer, D.B. & Likens, G.E. 2010. 'The Science and Application of Ecological Monitoring'. *Biological Conservation* 143 (6): 1317–28. https://doi.org/10.1016/j.biocon.2010.02.013.

Marion, S., Davies, A., Demšar, R., Irvine, J., Stephens, P.A. & Long, J. 2020. 'A Systematic Review of Methods for Studying the Impacts of Outdoor Recreation on Terrestrial Wildlife'. *Global Ecology and Conservation* 22 (June):e00917. https://doi.org/10.1016/j.gecco.2020.e00917.

Mathieu, C., Hermans, S.M., Lear, G., Buckley, T.R., Lee, K.C. & Buckley, H.L. 2020. 'A Systematic Review of Sources of Variability and Uncertainty in eDNA Data for Environmental Monitoring'. *Frontiers in Ecology and Evolution* 8 (May). https://doi.org/10.3389/fevo.2020.00135.

Mihaljevic, J.R., Joseph, M.B. & Johnson, P.T.J. 2015. 'Using Multispecies Occupancy Models to Improve the Characterization and Understanding of Metacommunity Structure'. *Ecology* 96 (7): 1783–92.

Mihoub, J.-B., Henle, K., Titeux, N., Brotons, L., Brummitt, N.A. & Schmeller, D.S. 2017. 'Setting Temporal Baselines for Biodiversity: The Limits of Available Monitoring Data for Capturing the Full Impact of Anthropogenic Pressures'. *Scientific Reports* 7 (1): 41591. https://doi.org/10.1038/srep41591.

Moussy, C., Burfield, I.J., Stephenson, P.J., Newton, A.F.E., Butchart, S.H.M., Sutherland, W.J., Gregory, R.D., *et al.* 2022. 'A Quantitative Global Review of Species Population Monitoring'. *Conservation Biology* 36 (1): e13721. https://doi.org/10.1111/cobi.13721.

Nichols, J.D., Ullas Karanth, K. & O'Connell, A.F.. 2011. 'Science, Conservation, and Camera Traps'. In *Camera Traps in Animal Ecology: Methods and Analyses*, edited by Allan F. O'Connell, James D. Nichols, and K. Ullas Karanth, 45–56. Tokyo: Springer Japan. https://doi.org/10.1007/978-4-431-99495-4_4.

O'Connell, A.F., Nichols, J.D. & Karanth, U. (eds). 2011. *Camera Traps in Animal Ecology*. Tokyo: Springer Japan. https://doi.org/10.1007/978-4-431-99495-4.

Ogbeiwi, O. 2016. 'Defining Goal Terms in Development and Health'. *British Journal of Healthcare Management* 22 (11): 544–50. https://doi.org/10.12968/bjhc.2016.22.11.544.

Peterman, W.E., Crawford, J.A. & Kuhns, A.R. 2013. 'Using Species Distribution and Occupancy Modeling to Guide Survey Efforts and Assess Species Status'. *Journal for Nature Conservation* 21 (2): 114–21. https://doi.org/10.1016/j.jnc.2012.11.005.

Prach, K.I, Durigan, G., Fennessy, S., Overbeck, G.E., Torezan, J.M. & Murphy, S.D. 2019. 'A Primer on Choosing Goals and Indicators to Evaluate Ecological Restoration Success'. *Restoration Ecology* 27 (5): 917–23. https://doi.org/10.1111/rec.13011.

Prather, C.W. 2005. 'The Dumb Thing about SMART Goals for Innovation'. *ProQuest*, 2005. https://www.proquest.com/openview/066bfc391063c0fb25d2ec04cdfaffc9/1?pq-origsite=gscholar&cbl=37905.

Schmeller, D.S., Julliard, R., Bellingham, P.J., Böhm, M., Brummitt, N., Chiarucci, A., Couvet, D., *et al.* 2015. 'Towards a Global Terrestrial Species Monitoring Program'. *Journal for Nature Conservation* 25 (May):51–57. https://doi.org/10.1016/j.jnc.2015.03.003.

Shtilerman, E., Thompson, C.J., Stone, L., Bode, M. & Burgman, M. 2014. 'A Novel Method for Estimating the Number of Species within a Region'. *Proceedings of the Royal Society B: Biological Sciences* 281 (1779): 20133009. https://doi.org/10.1098/rspb.2013.3009.

Singh, H., Sharief, A., Joshi, B.D., Kumar, V., Mukherjee, T., Chandra, K., Bhardwaj, N., Thakur, M. & Sharma, L.K. 2022. 'Multi-Species Occupancy Modeling Suggests Interspecific Interaction among the Three Ungulate Species'. *Scientific Reports* 12 (1): 17602. https://doi.org/10.1038/s41598-022-20953-7.

Sparrow, B.D., Edwards, W., Munroe, S.E.M., Wardle, G.M., Guerin, G.R., Bastin, J.-F., Morris, B., Christensen, R., Phinn, S. & Lowe, A.J. 2020. 'Effective Ecosystem Monitoring Requires a Multi-Scaled Approach'. *Biological Reviews* 95 (6): 1706–19. https://doi.org/10.1111/brv.12636.

Stephenson, P.J. 2019. 'The Holy Grail of Biodiversity Conservation Management: Monitoring Impact in Projects and Project Portfolios'. *Perspectives in Ecology and Conservation* 17 (4): 182–92. https://doi.org/10.1016/j.pecon.2019.11.003.

Sugai, L.S.M., Silva, T.S.F., Wagner Ribeiro, J. & Llusia, D. 2019. 'Terrestrial Passive Acoustic Monitoring: Review and Perspectives'. *BioScience* 69 (1): 15–25.

Sweeney, O.F., Turnbull, J., Jones, M., Letnic, M., Newsome, T.M. & Sharp, A. 2019. 'An Australian Perspective on Rewilding'. *Conservation Biology* 33 (4): 812–20. https://doi.org/10.1111/cobi.13280.

Symstad, A.J., Chapin, F.S., Wall, D.H., Gross, K.L., Huenneke, L.F., Mittelbach, G.G., Peters, D.P.C. & Tilman, D. 2003. 'Long-Term and Large-Scale Perspectives on the Relationship between Biodiversity and Ecosystem Functioning'. *BioScience* 53 (1): 89–98. https://doi.org/10.1641/0006-3568(2003)053[0089:LTALSP]2.0.CO;2.

Terrigeol, A., Ebouele, S.E., Darveau, M., Hébert, C., Rivest, L.-P. & Fortin, D. 2022. 'On the Efficiency of Indicator Species for Broad-Scale Monitoring of Bird Diversity across Climate Conditions'. *Ecological Indicators* 137 (April):108773. https://doi.org/10.1016/j.ecolind.2022.108773.

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D., Butchart, S.H.M., *et al.* 2014. 'A Mid-Term Analysis of Progress toward International Biodiversity Targets'. *Science* 346 (6206): 241–44. https://doi.org/10.1126/science.1257484.

Walters, M. & Scholes, R.J. (eds.) 2017. *The GEO Handbook on Biodiversity Observation Networks*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-27288-7.

Warrier, R., Noon, B.R. & Bailey, L.L. 2021. 'A Framework for Estimating Human-Wildlife Conflict Probabilities Conditional on Species Occupancy'. *Frontiers in Conservation Science* 2. https://www.frontiersin.org/articles/10.3389/fcosc.2021.679028.

Yoccoz, N.G., Nichols, J.D. & Boulinier, T. 2001. 'Monitoring of Biological Diversity in Space and Time'. *Trends in Ecology & Evolution* 16 (8): 446–53. https://doi.org/10.1016/S0169-5347(01)02205-4.

Zipkin, E.F., Doser, J.W., Davis, C.L., Leuenberger, W., Ayebare, S. & Davis, K.L. 2023. 'Integrated Community Models: A Framework Combining Multispecies Data Sources to Estimate the Status, Trends and Dynamics of Biodiversity'. *Journal of Animal Ecology* 92 (12): 2248–62. https://doi.org/10.1111/1365-2656.14012.