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Signals from local and national monitoring will guide us to nature recovery

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Summary

Biodiversity and climate crises are globally recognised, and monitoring biodiversity is crucial for tracking progress toward conservation efforts. The UK has world-class national biodiversity indicators that document the state and change of species and habitats, but trends at these scales are not appropriate for all evidence needs, and do not respond quickly enough to inform rapid assessments or early signals of change that can guide adaptive management and policymaking. A local scale monitoring approach is detailed here to complement the national indicators to fulfil different evidence needs.

Local monitoring reduces measurement lags, offers early indications of change, and allows for targeted interventions. A local scale monitoring approach also provides context-specific data, which can be aggregated to help track progress towards global targets, but also inform decisions, and link ecological trends to specific policies, thereby improving the effectiveness of conservation actions.

We have identified where monitoring can help to answer specific needs. We have outlined categories of evidence needs that guide and assess policy, inform interventions and investments, support decision tools and modelling, assess the status of biodiversity, evaluate the roles of drivers and pressures, as well as policy-relevant research. Both local and national monitoring approaches are necessary to fill the different evidence gaps. Where local monitoring can be enabled and standardised, the increase in consistent monitoring will lead to greater data that will provide a critical nature evidence base beyond its local collection.

Finally, we demonstrate how citizen science, and remote sensing are efficient and cost-effective mechanisms to help address diverse evidence needs for additional and consistent local monitoring which can support informed decision-making in ecological conservation across multiple scales.

Future work should focus on mapping available evidence to fulfil the needs we have identified, followed by mobilising data to address these needs, including removing barriers for citizen science data and enhancing coordination among stakeholders. The integration of local and national-scale monitoring data, as well as the integration of multiple data sources, is necessary through the engagement of different stakeholders and support tools.

Contents

1. Introduction

1.1. Context

Biodiversity and climate are in crisis, with species and their habitats declining (Halley & Pimm 2023) and ecosystem processes collapsing (Valiente-Banuet & Verdú 2013). Many countries, working within the structures of the Convention on Biological Diversity, have collaboratively developed a set of targets under the Kunming-Montreal Global Biodiversity Framework to address the issue. To evaluate progress toward these targets and assess the overall health of nature, it is more critical than ever to monitor the state of nature using evidence-based approaches across different spatial and temporal scales (Geijzendorffer *et al.* 2017).

In the UK, national monitoring schemes using citizen science (CS) provide high-quality data that cover a wide geographical area and create long-term datasets. This monitoring underpins biodiversity indicators and official statistics, which report on the status and change of the environment and guide high-level policy making (Broughton & Pocock 2022).

One challenge with national indicators is the lag in response to policy decisions and management actions on the ground, yet policy teams are often working in short-term policy cycles and need to understand the likely outcomes of policies more quickly than the national indicators will allow. The larger the spatial scale, the longer it will be before outcome measures will be able to pick up any change as a result of the actions taken (Figure 1). This means that the national level indicators may not be best placed to inform progress towards national targets. It is however possible to use site-scale and landscape scale monitoring data (together called local scale) to obtain early indicators of change, which can be used to evaluate and inform national scale insight and policy.

Monitoring at the site-scale can reduce measurement lags as sampling of a selection of locations can provide the earliest possible measurement of species outcome (Way & Lightfoot, internal report). Similarly, landscape scale monitoring can provide the insight into the combined effect of actions intended to drive species abundance and composition before this can be detected nationally and may be more indicative of population-level changes. Increasing the sampling density of national species monitoring to detect change at this scale is not logistically or financially feasible, but local scale monitoring could be increased sufficiently to gain a robust signal that could also help meet national-scale evidence needs, as they will be able to evaluate the impact at an appropriate scale to interventions.

Likewise, since policy needs to assess whether existing commitments are likely to achieve target outcomes, models projecting species outcomes based on policy-driven actions are currently being used to inform policy design. These models are powerful tools to inform policy about action ahead of other metrics and potential outcomes but require relevant input data. The IPBES methodological assessment of biodiversity and ecosystem services scenarios and models found that global assessments typically overlook values and processes from sub-regional scales. Meanwhile, local scale scenarios are often designed for specific contexts, making it difficult to compare them across different regions (Rosa *et al.* 2017).

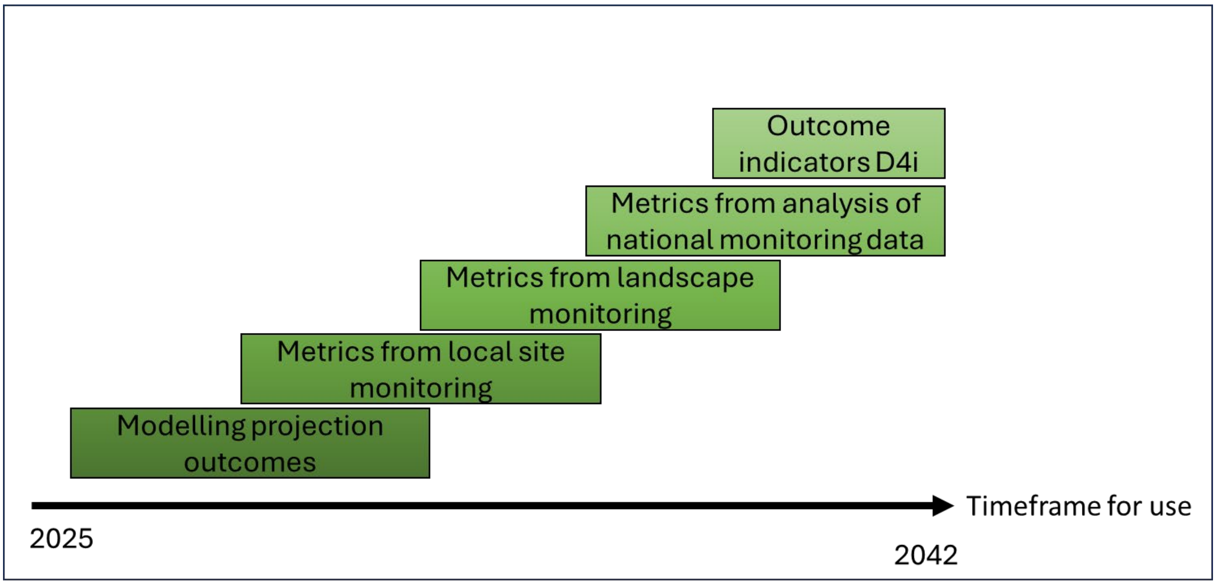

Figure 1: In England, the EIP set targets for 2042. Different outcomes and metrics are most appropriate for use at different timepoints to assess progress towards those targets, demonstrating that projections, site and landscape monitoring can provide early signals of change before national indicators, such as outcome indicator D4, detect them. Projections also rely on scale-appropriate data, which frequently is sub-national, so site and landscape monitoring also inform improved projection models.

Therefore, to better inform policy decisions, evidence is required that will:

(i) provide an early signal of change, which indicates outcomes of policy as a result of actions on the ground, and

(ii) support projections which can inform targets and the potential impact of policy levers to reach those targets.

Both require more fine-scale recording and insight than the national schemes can support, and to try and increase the schemes sufficiently to do so would be logistically problematic and prohibitively costly.

1.2. The local monitoring approach

Outside of the UK national schemes, there is wide interest in biodiversity and environmental monitoring. Local organisations and volunteers are already engaged in monitoring efforts through citizen science initiatives, but the variety of protocols and systems used can result in fragmented data that is hard to combine, compare, or scale up and thus hard to apply to national scale needs such as policy needs.

The local change approach aims to benefit both the local initiatives and the policy need by disseminating standardised methods and tools for environmental monitoring, building open data pathways and reducing barriers for uptake of those standards by local initiatives. The increased efficiencies and insight will further enhance the amount of local recording, leading to more environmental data collected at a resolution that can collectively fill the evidence gap to meet the policy need. The aim of the approach is to bridge this gap by promoting standardised, interoperable monitoring protocols that are suitable across scales — from local to national. This would allow local data collection to meet the specific evidence needs of communities and land managers, while also contributing meaningfully to wider-scale environmental assessments.

To achieve this a toolkit for local biodiversity monitoring is being developed, starting by building on existing national scheme protocols such as the Breeding Bird Survey (BBS) or the United Kingdom Butterfly Monitoring Scheme (UKBMS). These schemes already have well-structured methodologies and infrastructure that can support locally driven projects but may require additional components to be used in a local context, especially in terms of guidance for smaller-scale sampling and tailored feedback systems. Particular attention is being given to the entire data lifecycle — from recording and data storage through to collation, analysis, and feedback — ensuring the system is cost-effective, scalable, and produces open, reusable data. Some schemes, like those using stratified random sampling, show promise for flexible application across different scales but need further refinement to be practical for smaller areas. The ambition is for the resulting protocols and guidance to be adopted across the UK, supporting a more unified and effective approach to biodiversity monitoring nationwide.

The local change approach aims to support standardised place-based monitoring at the appropriate scale and promote effective sampling designs to answer the evidence needs effectively. This approach can operate at the site-based scale—focused on small areas such as a single wetland or forest patch—or at the landscape scale, which covers larger areas ranging from several square kilometres to extensive regions. The chosen scale is determined by the monitoring objectives and the reasons for conducting monitoring in that particular area (Marion *et al.* 2024).

1.3. Aim

This report seeks to define how local change monitoring can be used to provide early signals of change and support modelling projections by addressing different evidence needs and complementing national scale monitoring. It outlines an approach that offers valuable insights for local initiatives. As this approach is widely adopted, the collective evidence generated enhances our understanding of how local actions contribute to nature recovery at broader scales, while also supporting policy and evidence requirements.

We begin by outlining the advantages of a local change monitoring approach. We then define the different evidence needs and explain how the local change approach is complementary to the national scale monitoring approach. Finally, we show examples of how —using an integrative method of citizen science and new technologies such as earth observation (EO) — we can address these needs.

Box 1: Definition of terms used in the report

Natural Capital Ecosystem assessment (NCEA): is a science innovation and transformation programme. It has been set up to collect data on the extent, condition and change over time of England's ecosystems and natural capital, and the benefits to society.

Natural Capital (NC): A stock of assets that nature provides to people. These assets are wide-ranging and essential for a thriving society and economy (Bell & Craven 2024).

Earth Observation (EO): process of gathering information about the Earth's surface, waters and atmosphere via ground-based, airborne and/or satellite remote sensing platforms.

Ecosystem services (ES): Ecosystem Services are the direct and indirect contributions ecosystems (known as natural capital) provide for human wellbeing and quality of life (NatureScot).

2. Local change monitoring advantages

The need for monitoring and data collection at regional and local levels is increasing (e.g. for Protected Landscapes, and Local Nature Recovery Strategies in England). Many organisations are investing in nature recovery and need to be able to evaluate effectiveness and track progress. These data are also required to support financial investment in nature. Greater standardisation with open data pathways will enable robust data collection and better insights across different spatial scales. This will better support adaptive land management and inform early evaluations within policy cycles in a range of ways:

2.1. Insight from local monitoring provides broader insights

At the landscape scale monitoring enhances national or regional monitoring programmes by providing consistent, detailed and mass produced data that can be aggregated or scaled up (Maas-Hebner *et al.* 2015). The accumulation of evidence about species status and drivers can then be used to understand progress towards national and global environmental targets before the availability of the national reporting results. Similarly, reporting on targets at the local scale helps provide a broader understanding by considering context dependency. At the national scale, interventions can take a long time to influence nature while at local scales recovery can be more responsive. Site-scale monitoring allows for increased sampling density at small spatio-temporal scales, increasing monitoring resolution.

2.2. Contributing to modelling impacts and investment in policy

Finer-scale evidence about biodiversity and natural capital can be integrated into models for projecting the impacts of investments or policies, understanding conditions, and informing local nature recovery strategies. It contributes to producing sub-national trends and provides insights into land use change, which is a key threat to biodiversity and ecosystem services. This benefits local stakeholders by allowing them to compare their local trends with national trends, helping them understand their context within the broader picture (Harris & Hoskins 2024).

2.3. Inform decision-making by understanding if interventions and conservation management will be effective in increasing biodiversity and natural capital over the long term (Danielsen *et al.* 2005; Watts *et al.* 2020)

Monitoring tracks biodiversity state and change but critically needs to relate to specific drivers and pressures of changes to inform tailored decision making. Local monitoring helps link ecological trends to specific policies or land management actions, providing clearer insights into cause-and-effect relationships. This informs localised planning and management strategies, such as habitat restoration, species reintroduction, or pollution mitigation. It also helps policymakers understand the practical implications of their decisions at the local level and further consideration at national scale (including by informing models and projections, as above), ensuring that policies are more effective and impactful.

2.4. Understanding natural capital and ecosystem service benefits

Similarly, NC and ES benefits at large spatial scales can be diluted or hard to estimate due to multiple factors influencing NC and ES. At a fine scale, particularly in multi-functional landscapes such as farms, understanding the benefit of different interventions and funding is necessary for the long-term success of nature recovery by integrating it within land use decision making (Parkin 2022). Comparing NC across scales can be valuable for local stakeholders seeking to maximise potential benefits; however, such comparisons require standardised protocols. The local change monitoring approach can support this by drawing on the standardisation knowledge developed through national monitoring schemes.

2.5. Relating monitoring to multiple objectives

Local scale monitoring can address several objectives simultaneously, such as biodiversity conservation, climate resilience, ecosystem service provision, and community development. This ensures complementarities with other initiatives and stakeholders through coordinated efforts. Large-scale monitoring might struggle to align with multiple goals, given the diversity of stakeholders and data cycles.

2.6. Holistic ecosystem monitoring

Local scale monitoring allows for a more comprehensive understanding of ecosystem functioning and can support more accurate decision tools and modelling by considering all components of an ecosystem and further enables the identification of early indicator species — those that respond to environmental pressures, drivers, or management interventions before other species.

2.7. Engaging stakeholders and local communities

The local change approach is beneficial for local stakeholders and communities, as working at local scale helps engagement with those stakeholders (e.g. landowners, communities, conservation organisations) by providing actionable data relevant to their context while learning from experienced national monitoring schemes. It supports collaborative efforts and ensures that decisions resonate with those directly affected. Local knowledge, such as insights about rare or endemic species, can complement national monitoring. Engaging with local communities raises awareness about biodiversity challenges and creates a positive feedback loop for local biodiversity conservation, as well as the benefits to the communities and people from increasing their engagement with nature.

3. How national and local monitoring contributes to evidence needs

In ecology and conservation, an evidence-based approach is essential for making informed, effective, and adaptive decisions to preserve ecosystems and biodiversity (Sutherland, 2022). Evidence needs arise when there is insufficient information to support decision-making by various stakeholders, including policymakers. While often used interchangeably, here we distinguish evidence needs from data gaps, where a data gap refers to missing information about a specific taxon or in a specific area. Evidence needs take a top-down approach by identifying broader contextual goals and determining what information is necessary to address those goals.

Three categories of evidence needs are identified and set out below:

(i) decision making,

(ii) supporting tools, and

(iii) assessing and reporting change (Figure 2).

Decision making needs are informed by the supporting tools category, which in turn is shaped by the evidence needs of assessing and reporting change. It is important to note the direct link between the bottom category - assessing and reporting change - and the top category, decision making. Within each category, we have identified sub-categories that are interconnected.

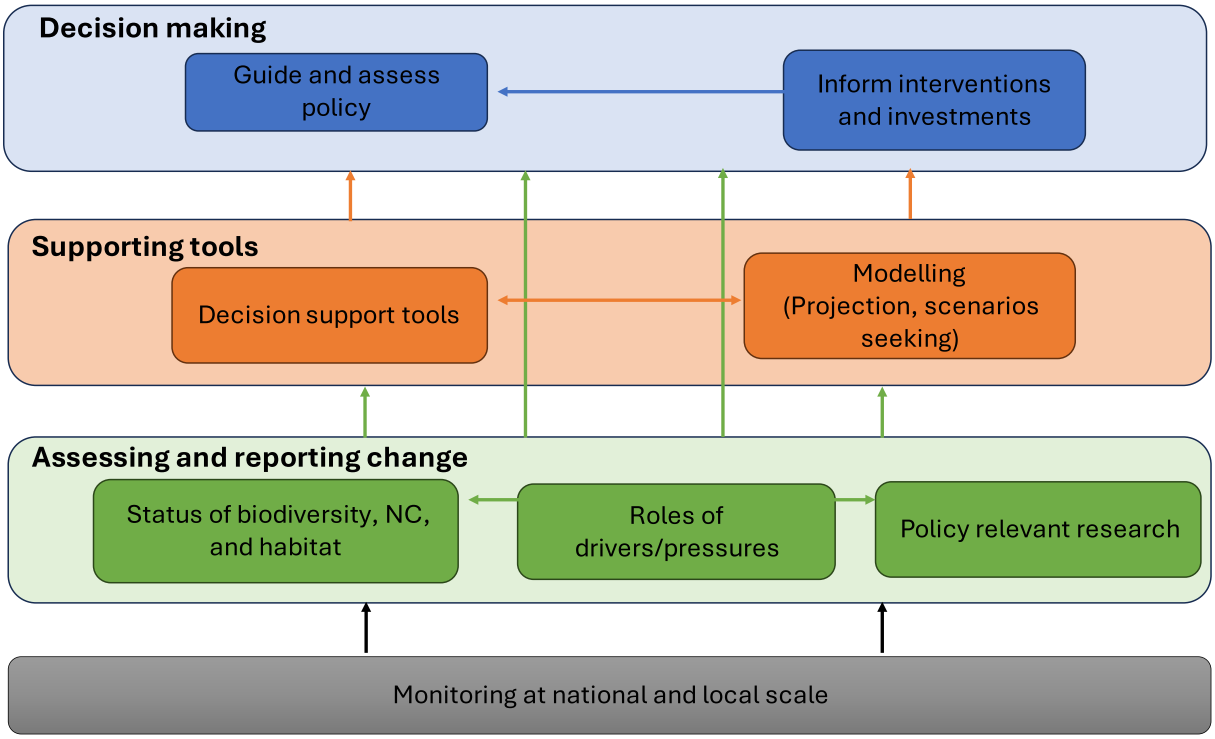

Figure 2: Evidence needs categories and sub-categories and their connections.

3.1. Decision making evidence needs

The UK's public environmental bodies use biodiversity and natural capital information for statutory reporting, operational needs (e.g. planning advice and regulation), and strategic needs (e.g. influencing policymaking and assessing the impact of policy) (Pocock, 2018). Thus, the broader context of evidence needs can be sub-categorised into:

(i) guiding and assessing policy, and
(ii) informing investments and interventions.

These categories are not independent of each other; guiding and assessing policy is closely linked to informing investment, particularly when investment is publicly funded. Similarly, guiding policy is related to informing intervention when those interventions are led by public bodies or informed by the results of previous intervention.

These categories align with the policy cycle such as The Green Book UK government. The policy cycle is a framework used to understand the stages involved in the development and implementation of public policy:

(1) Agenda setting,
(2) Policy formation,
(3) Decision making,
(4) Implementation, and
(5) Evaluation.

Guiding and assessing policy corresponds to steps 1 and 2, informing investment and intervention corresponds to steps 3 and 4, and assessing effectiveness aligns with step 5 (Figure 3).

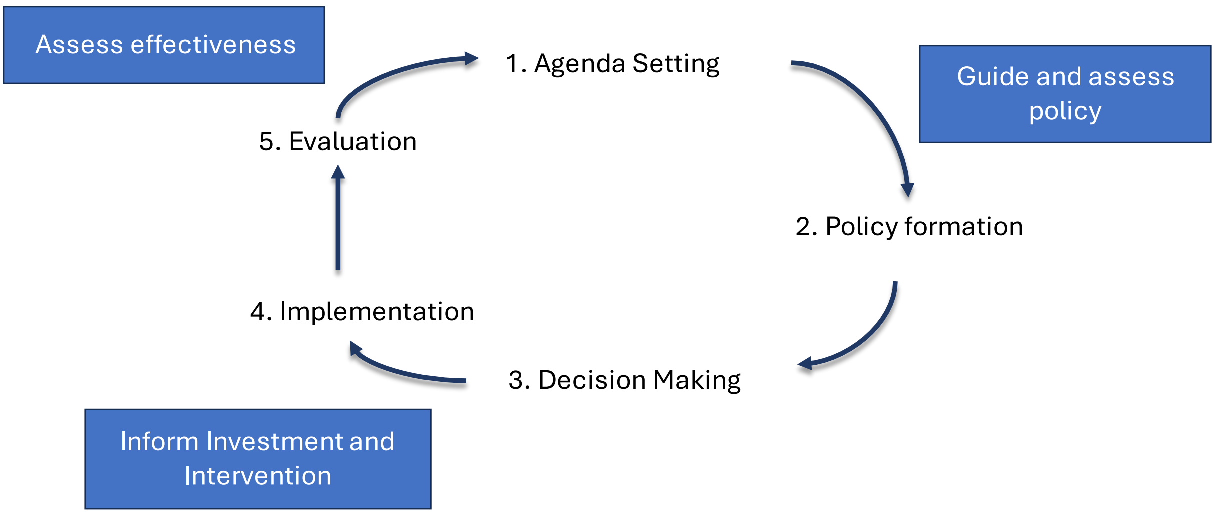

Figure 3: Umbrella needs in the context of the policy cycle.

3.1.1. Guide and assess policy

Policymakers rely on evidence to create regulations, allocate funding, and set conservation priorities (Pocock 2018). Creating and adapting policies that will have a positive impact on nature requires a large amount of evidence to support decisions that can be controversial and sensitive. Evidence is necessary to assess how governments are performing against targets; at the national scale, England's Environmental Improvement Plan (EIP) sets 10 goals that aim to improve nature Environmental Improvement Plan 2023: Executive summary - GOV.UK . While targeting and policy reporting often occur at the national scale, local scale monitoring is necessary to improve our understanding of progress toward these targets at the local level and may be more appropriate for reporting against specific targets (see Table 1).

3.1.2. Inform interventions and investments

Interventions and investments tightly relate to each other, as an intervention can be an investment (money, time, process) and an investment can lead to one or multiple interventions.

As investment can come from different sources linked to various spatial scales, it is crucial to understand how investment is viewed by different stakeholders. At larger scales, investment can help achieve significant (and easier) wins, while at the local scale, investment can be more targeted and relevant to local stakeholders (Table 1 and see Section 2). Likewise, interventions are often implemented through the control of pressures and drivers of change. Monitoring is crucial at all scales for conservationists to assess the impact of their interventions (Danielsen, Burgess & Balmford 2005).

Financial resources for conservation are often limited. Evidence helps allocate them, through interventions, where they can have the greatest impact on both the environment and the economy.

A key component of interventions and investments is to assess their impact and success (Pocock 2018). Successful land/water management interventions include habitat and natural process restoration (e.g. sowing native plants, increasing tree cover, enhancing habitat connectivity, pond creation), site management (e.g. grazing reduction, adding mulch to soils), and invasive or problematic species control (Bowgen *et al.* 2022). Understanding the circumstances under which different types of interventions succeed (or fail) requires effective monitoring of managed and control areas or monitoring of managed areas both before and after an intervention (Danielsen, Burgess & Balmford 2005).

3.2. Supporting tools

The supporting tools level is positioned at an intermediate level between policymaking, and the evidence needs arising from assessing and reporting change. Supporting tools require evidence of changes and monitoring data from the base level to help guide decision-making at the top level. For clarity, we have separated decision support tools and modelling. However, it can be argued that modelling can serve as a decision support tool, and decision support tools can incorporate modelling to assess effectiveness, inform investment and guide policy.

3.2.1. Decision support tools

Decision support tools are designed to answer specific questions that policymakers and stakeholders might have. For example, JNCC has been developing a spatial prioritisation approach under England's Farming and Countryside Programme (FCP) to help decision-makers identify the '*right intervention*, in the *right place* and at the *right scale'* and deliver greater environmental benefits through land management. The approach aims to systematically identify and rank possible interventions from the Environmental Land Management (ELM) schemes that could be implemented on a land parcel, based on their suitability and potential impact on the delivery of locally important ecosystem services. To achieve this, evidence is needed about the location, quantity, and quality of natural capital and how this may impact ecosystem service delivery. For instance, lowland fields in a flood zone with a potential for habitat creation may deliver different benefits compared to fields directly upstream of a protected area that is in poor condition due to pollution. The spatial prioritisation work uses a range of data and evidence to identify priority locations for delivering ecosystem services and reducing pressures on natural capital at a national scale but aims to contribute to these priorities through decisions made at a local scale. Thus, evidence is needed at both scales to appropriately support decision-making, with more localised monitoring data and advice necessary to guide more specific local questions about where to implement land management interventions.

3.2.2. Scenario modelling

A challenge facing nature conservation agencies, policymakers, and reserve managers is prioritising actions that will contribute to the positive vision for nature in the face of uncertainties, while providing a robust, evidence-based understanding of what constitutes an effective intervention (Bowler *et al.* 2024). One way to prioritise actions for a nature-positive future is to build models capable of describing potential biodiversity trajectories under alternative future scenarios.

In recent years, multiple models have been developed to inform how different management and policy actions can be implemented to support nature recovery. These models can be used for a range of actions, depending on the biological processes of interest and the desired management outcomes. However, to provide reliable projections, these models need to be based on data that are both reliable and up to date. The data required for projections include general biodiversity metrics, such as abundance metrics for one or more species, as well as information about habitats, drivers, and pressures (see Section 3.3.2).

Those models aim to project biodiversity change under different scenarios such as different management and interventions. To do that, there is a need to aggregate different local effects, as well as understand their effect size. National trends can inform some scenarios where drivers impact at a large spatial scale, but local data aggregation brings granularity to national models by providing details about effect and scale of the uptakes. Understanding how specific actions — such as local spatial prioritisation, harvest management, connectivity, reintroduction/translocation, ecosystem restoration, or control of disease/invasive species — can affect conservation outcomes. Similarly, different taxa will be influenced by management action differently at different places. However, national scale monitoring schemes' survey designs do not always overlap, making it difficult to predict the impact of interventions and investment across taxa. Local scale monitoring can facilitate the monitoring of multiple species in one place which then can be used to predict different species trends under various scenarios.

3.3. Assessing and reporting change

At the bottom of our framework, as described in Figure 1, is the evidence need for assessing and reporting change. This broad category of needs can be roughly divided into understanding the spatiotemporal status of biodiversity, habitats, and NC, the roles of drivers and pressures, and policy relevant research. Again, these sub-categories are not independent of each other; research often aims to understand how species and habitats are influenced by different environmental drivers or pressures.

3.3.1. Understand spatio-temporal status of the ecosystem

Monitoring change over time is a key aspect of nature recovery. To determine whether nature is improving, monitoring at different spatiotemporal scales is necessary. Monitoring species, NC, and habitats is essential to establish their baseline, which can then be used to evaluate and compare ecosystem changes against this baseline. For example, to assess the effectiveness of interventions (Mihoub *et al.* 2017), repeated measurements of the same components over time can be used to characterise these changes. Shorter intervals between measurements can help identify early indicators of change (Vos, Meelis & Ter

Keurs 2000) while long-term monitoring, over a span of decades, is useful for measuring longer term processes or interventions like habitat creation or recolonisation. The optimal duration for monitoring depends on stakeholders' requirements and the ecological processes of interest. White (2019) showed that 72% of time series of biodiversity population trends required at least 10 years of continuous monitoring to achieve a high level of statistical power. Monitoring biodiversity is necessary to assess progress toward targets, but the monitoring design must consider that the response to interventions intended to advance those targets may be delayed due to ecological, implementation, and measurement lags. This can be especially problematic where project and funding cycles supporting interventions are short term and based on activity, yet monitoring for the outcomes of those activities requires a much longer timeframe.

3.3.2. Roles of drivers and pressures

In addition to understanding where and when biodiversity exists, there is a need to comprehend the various pressures and drivers that influence it. Understanding these drivers and pressures is essential across all categories of evidence needs, particularly for decision-support tools and modelling frameworks. For instance, the Biodiversity Pathways Project - a recently launched initiative between JNCC, BTO, UKCEH, and Cambridge University—aims to understand future biodiversity changes under a range of environmental and socioeconomic scenarios. The project's first step involved mapping out the different drivers and pressures that stakeholders are interested in, to understand their roles.

Understanding the environmental drivers and pressures that influence biodiversity, and nature is necessary to inform interventions aimed at reducing these pressures or leveraging nature recovery. At the national level, understanding drivers and pressures is crucial to gaining a full picture of which factors are most important to influence. Policies are often implemented at larger spatial scales, so understanding these pressures and drivers can inform policymakers about available levers for influencing environmental change.

The local change approach has the advantage of relating the scale of impacts to the scale of the drivers/pressures. For instance, national bird trends are hard to relate to specific sources of pollution. By monitoring at local scale, we can relate local bird trends to a specific source of pollution (and the amount of that pollution) which can then be aggregated to multiply source pollution which impacts on the overall bird trends. However, other drivers are not site specific such as larger or national scale pressures such as climate change; thus, a complementary monitoring approach at national and local scale is necessary to capture the overall picture of pressures occurring at local scale and those occurring at national scale.

3.3.3. Supporting policy relevant research

This type of research differs from long-term assessments, as it often aims to answer specific scientific questions about species or ecosystems' responses to certain drivers (both positive and negative), assess the impact of specific interventions on ecosystems, or evaluate short term trends and patterns in ecological processes. These form the foundation of evidence used in many of the other categories of evidence needs. These studies are often conducted by non-public bodies or industry-led scientific inquiries, such as academic research or consultancy, and require data at both local and national scales. They rely on evidence and data that are actively monitored and serve as a bridge between different categories of evidence needs. Such inquiries analyse evidence, generate new data, and develop tools that can be used by policymakers. Using monitoring data, researchers may employ or develop models to understand the influence of specific pressures on species abundance, which can then be reused by policymakers.

At the core of most research is the use of field evidence, literature, and prior research. This work spans multiple scales, and examples of evidence needs at both global and local levels are abundant. There is a strong connection between existing conservation policies, scientific information, research priorities, and public concerns (Martín-López *et al.* 2009).

Table 1: Evidence needs at different scales.

Sub-category	National and landscape scale	Local Scale
Guide and assess policy	- Targets and major policy levers are made at the national scale, so evidence at this scale is necessary to inform the ambition behind these. - Annual indicators at the national scale are essential to report against these policies and targets. However, national scale outcomes can be slow (e.g. species trends) while responses can be faster at local scale.	- Monitoring and reporting at smaller spatial scales can help improve our understanding of the broader picture. Some local areas may perform differently against targets, and understanding this context dependency could help guide national policies more effectively. - National policy steers overall ambition but is reliant on local policy to develop a deployment mechanism, including monitoring to assess individual success and combined success.
Inform investment and management	- Funding that supports interventions may be disseminated from the national scale (e.g. agri-environment schemes), so evidence that can be generalised or applied at this scale is necessary. - Policymakers often seek large-scale impact (i.e. identifying which actions (and where) will have the greatest impact and thus monitoring informs cost-benefit). - National guidance is required for interventions, such as in the case of new national policies that influence large-scale drivers or pressures.	- Encouraging investment by local stakeholders, who may relate more closely to local scale monitoring and see the direct benefits of ecosystem service (ES) provision. - Investment and intervention at the local scale is more likely to have a greater impact, as it accounts for the specific constraints and context dependencies of the local area. - Analysing how investment and management impact biodiversity and nature across multiple local areas can help build a broader understanding of key drivers by combining individual findings. - Effectiveness can be assessed more rapidly due to smaller lag of implementation and measurement - As with the national scale, a local scale monitoring approach is needed to estimate the best cost-benefit investment at the local scale.

Sub-category	National and landscape scale	Local Scale
Decision support tools	- Decision support tools require evidence that can be applied to different conditions. Datasets, such as those obtained through national monitoring, provide a range of evidence for various taxa and habitats, which can be used for different purposes. - It is necessary to understand the broader context in which the local context fits. For example, comparing habitat conditions. - These scales require consistency of evidence, so local decisions are comparable/equally well informed (or better if they have additional local data).	- Decision tools, such as spatial prioritisation, can be more easily applied at smaller spatial scales, where the scope of decision-making is narrower. They can be tailored to meet the specific needs of local stakeholders. - Applied decisions likely to be taken at local level (e.g. specific intervention decisions of what and where etc).
Modelling	- Modelling requires large datasets to provide accurate predictions, which often implies working at a larger spatial scale. Data at high resolution are not always available to model at local scale while data at larger resolution can be more easily apply to broad scales. - It often requires historical data, which are typically more accessible at the national scale than at smaller spatial scales.	- Similarly, it is easier to monitor all the different components of an ecosystem at the local scale rather than at a large spatial scale. - Validation of predictions is easier at smaller spatial scales (e.g. if a model predicts that increasing hedgerows will boost bird populations by 10%, it is easier to validate this prediction at a small spatial scale than at a large one (i.e. at a scale appropriate to the response)). - Multi-species monitoring is easier at small spatial scale which can be then used for modelling to compare the output of different scenarios.
Understand spatio-temporal status of biodiversity, NC, and habitat	- Large-scale monitoring is necessary to gain an overview of trends across different species and to remove context dependency, providing a general picture of trends and status. This information can be used, by policymakers and applied in a broader context.	- Local scale monitoring allows for a holistic approach, increasing sampling size per area over time. It can, therefore, be used to test different intervention and managements more rapidly using a before/after intervention monitoring

Sub-category	National and landscape scale	Local Scale
Understand the roles of drivers/pressures	- Evidence at large spatial scales regarding drivers and pressures is highly relevant for policymakers and for achieving "big wins." For instance, policies aimed at reducing pressures or alleviating drivers require evidence of their effectiveness, particularly when applied at large spatial scales.	- A local understanding of the drivers and pressures that influence biodiversity and nature is essential for informing local stakeholders about actions that are tailored to their specific context.
Supporting policy relevant research	Policy relevant research spans various scales, from global to local studies. To conduct this research effectively, evidence is needed at each scale regarding species, habitats, pressures, and levers.	

3.4. A case study of evidence needs

Here, we illustrate how different evidence needs interact with each other. The Biodiversity Pathways case study aimed to assess the potential impact of the UK's 30 by 30 target on bird abundance (Figure 4) (Border *et al.,* in prep). There is a clear link to the evidence need for guiding policy and informing intervention (i.e. how 30 by 30 can be implemented by testing four different scenarios). To achieve this, researchers assessed the likely outcomes of different planning scenarios through predictive species distribution modelling, using a supporting tool.

The evidence originated from multiple sources: citizen science, with data from the Breeding Bird Survey (BBS) used to derive bird abundance; Earth Observation (EO), with land cover layers included; and research, with effect sizes relevant to the different scenarios extracted from conservation evidence (i.e. systematic reviews and meta-analyses).

The BBS is a national-scale monitoring programme (non-local scale monitoring data) while data from conservation evidence are extracted from different studies, some of them at local scale. Therefore, the case study described here used a mix of national and local scale monitoring. Using the local scale approach in this case study is a way to increase the model's predictive power and accuracy, by providing effect size of pressure and drivers on species abundance.

This case study also focuses on a single taxon. While birds are good indicators of environmental change, other taxa might respond differently to interventions and management—such as the establishment of protected areas. Local change monitoring can address this limitation by enabling multi-species monitoring (e.g. Tracking the Impact) within the same landscape and at precisely the same locations. Monitoring multiple species can help identify early indicators of change, which can then be used in modelling frameworks to more accurately and promptly predict the impacts of different scenarios.

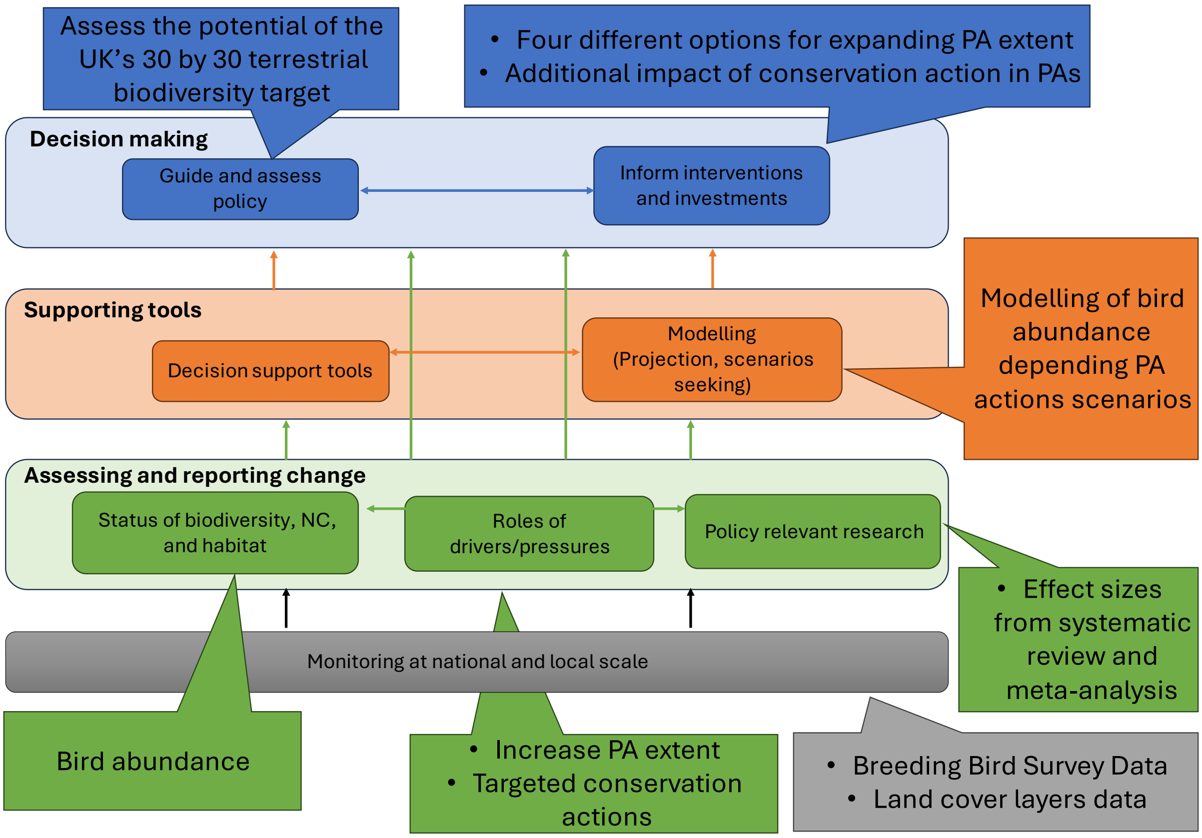

Figure 4: Case study of evidence needs for the Biodiversity Pathways project. This takes the different evidence needs described in Figure 2 and explain how biodiversity pathways tested different scenarios to implemented protect areas (PA) in the context of the UK's 30 by 30 target using evidence from citizen science (Breeding Bird Survey), EO (Land cover layers data) and research (effect size of drivers).

4. Methods to fill evidence needs

In light of the different type of evidence needs, a holistic approach to biodiversity monitoring and natural capital assessment is required, as measuring one species and/or one habitat is unlikely to provide evidence required by different stakeholders as well as being unlikely to capture the ecosystem complexity. Yet, as financial and human resources can be limited, holistic monitoring shouldn't be confused with measuring everything, everywhere all the time. Monitoring must allow a holistic understanding of the ecosystem and underlying ecosystem processes. While it is understood that there is a need for greater monitoring and a growing appetite to do so, monitoring can be resource intensive and there is a need to focus on cost-effective mechanisms to do so. Citizen science and earth observation have the potential to fulfil those needs, individually and together.

4.1. Local Scale Citizen Science to Complement with National Scale Schemes

We have demonstrated how both local and national scales are necessary and complementary in fulfilling evidence needs (Table 1). Specifically, we highlighted the advantages and value of each spatial monitoring approach for different evidence needs. We advocate for an integrated approach to monitoring across scales rather than relying on a single scale in isolation (Figure 5).

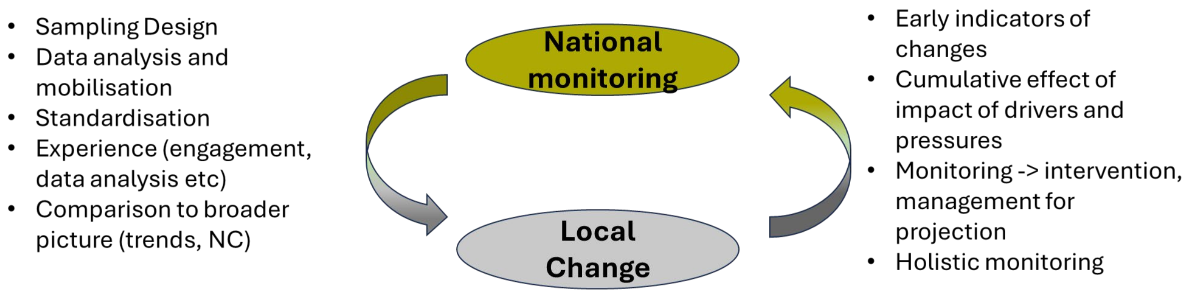

Figure 5: Complementarity between national and local scale monitoring.

This complementary approach aims to enable local monitoring initiatives to benefit from the experience of national monitoring schemes in sampling design, data collection, and stakeholder engagement. In turn, local scale monitoring can support national efforts by providing early indicators of change, insights into the cumulative impacts of drivers and pressures and more holistic monitoring.

4.2. How to enable the complementary approach

To be useful, biodiversity data must be collected, collated, processed, managed, and analysed appropriately. Engaging citizen scientists in data collection also requires providing meaningful feedback to maintain their motivation. Additionally, the data must be made accessible to policymakers, land managers, and other stakeholders. Achieving this requires a single, standardised pathway to ensure consistency and interoperability across scales and over time.

Drawing from the experience of national monitoring schemes, we have developed a data pathway that highlights the support mechanisms and processes needed for monitoring schemes to function effectively. (Figure 6).

National recording requires standardisation and consistency in monitoring to enable comparisons across space and time. This level of robustness is also essential at the local scale, where it enables comparison and centralisation of outputs from different areas. However, national level sampling designs are not always tailored for local use. While local users can adopt national protocols, the sampling design and subsequent analysis must be adapted to address specific local questions (O'Reilly et al., in prep).

A standardisation between protocols at national scale and local scale enables a single data pipeline that supports the use of locally collected data for broader evidence needs. This approach benefits both national and local monitoring efforts: local data can benefit national schemes by increasing sampling coverage, and local initiatives can compare their findings against national benchmarks.

Despite these benefits, challenges remain in integrating local and national monitoring efforts (see Figure 6: Barriers). Some challenges are shared by both national schemes and local monitoring, such as volunteer recruitment, recorder location bias, and data verification. Others are specific to the integration process, including data format compatibility. Data storage presents a challenge, as some existing tools (such as protocols and databases) will need to be adapted to accommodate additional local data while remaining distinct from existing datasets. In cases where adaptation is not feasible, entirely new tools will need to be developed to provide appropriate solutions. For example, some requirements include the ability to retrieve project-specific or spatially clipped data or ensuring that verification pipelines are in place and functioning effectively.

Addressing these common and specific barriers will enhance the overall utility of biodiversity data, supporting broader evidence needs. Ultimately, this will improve early detection of environmental changes and inform modelling efforts.

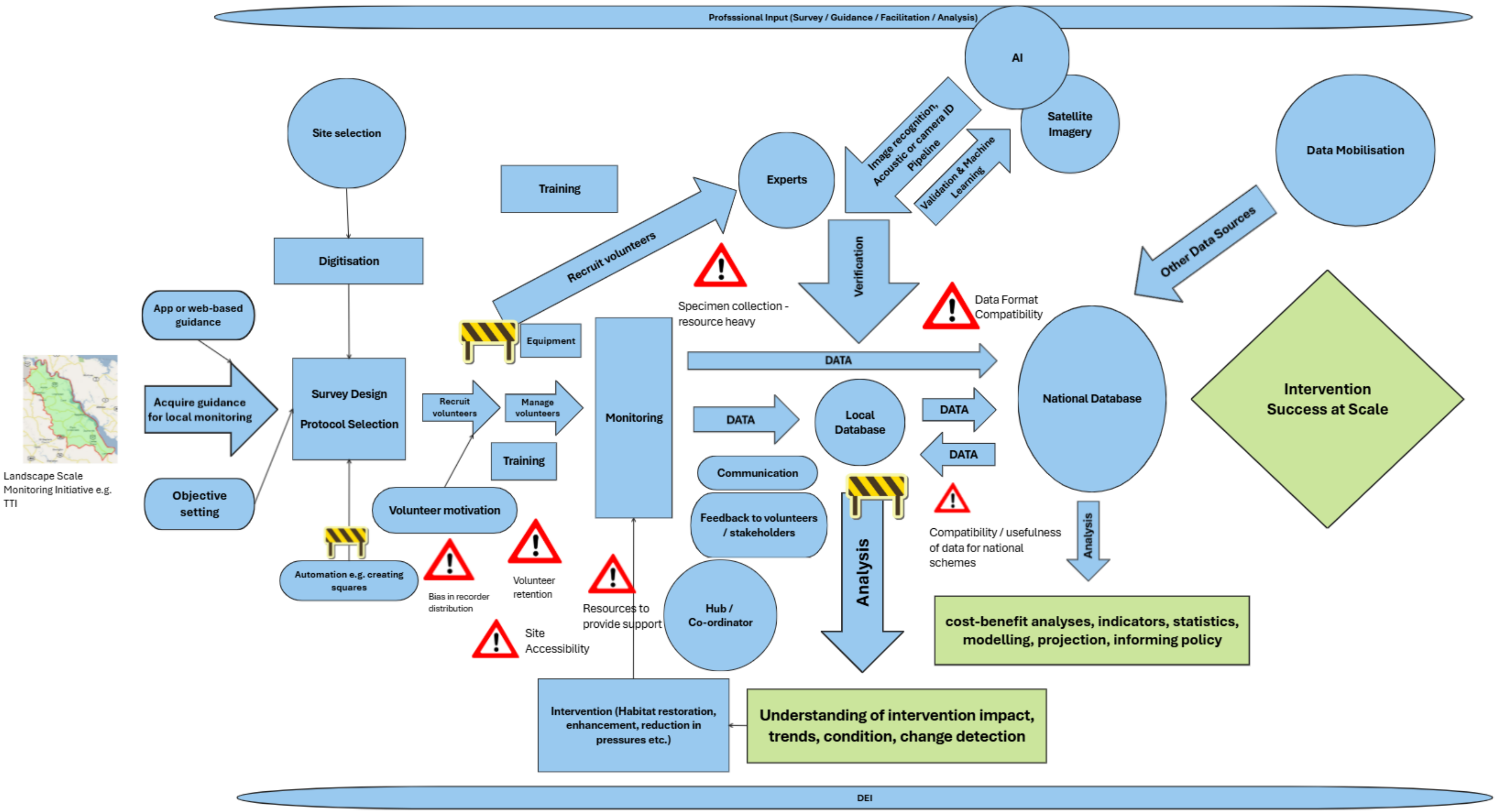

Figure 6: Processes and steps necessary for effective monitoring. The figure shows the flow of monitoring data throughout a scheme pathway, surrounded by the processes necessary to support the scheme's functioning. Hazard symbols represent common issue.

4.3. Earth Observation

Beyond CS, remote sensing and Earth observation (EO) has attracted a lot of interest due to their potential for collecting large datasets efficiently which can help with fulfilling different evidence needs. Satellites are currently collecting regular data (multiple observations per month), at a range of resolutions with complete spatial coverage of the UK. Much of these data are freely available and therefore there is a large dataset which can be used to gain inference on habitats and their changes over time. While EO therefore provides very comprehensive monitoring, EO data products cannot replace on the ground monitoring. As well as being limited to what is observable from space, most EO-derived datasets and products rely on field records for training and/or verification.

EO has been widely utilised to produce habitat extent maps and detect habitat change, with habitat condition mapping being an evolving area of focus (Burke *et al.* 2023). Effective fine-scale monitoring using EO data requires high-resolution, cloud-free imagery, good quality training data, and time-series data to monitor changes over time.

EO data is used in conjunction with various auxiliary datasets to produce national habitat extent maps such as the Living England Map, produced by Natural England. This is an England-wide habitat map derived from Sentinel-1 and Sentinel-2 imagery, together with ancillary datasets on topography, geology and climate. The map is based on raster data with a resolution of 10 m and has an overall habitat probability level of 88%. The modelled data are validated using reference data, including that from field surveys. Similar habitat mapping work is undertaken in Scotland and Wales with work currently ongoing for producing a habitat map for Northern Ireland (See Appendix 1 for more detail).

In addition to mapping habitat extent as well as monitoring change and condition, EO data have been used to assess a variety of environmental pressures, processes and hazards; fulfilling the evidence needs of understanding drivers and pressures. The Copernicus programme (i.e. the initiative responsible for the Sentinel 1 and Sentinel 2 missions) alone collects an array of data on atmospheric composition, sea level rise, global temperatures, and ocean dynamics. Further studies have used EO data to measure water and air quality (Malings *et al.* 2021; Adjovu *et al.* 2023), landslides (Tzouvaras, Danezis & Hadjimitsis 2020), flooding (Planque *et al.* 2020), wildfires (Blake *et al.* 2021), tidal stages and coastal erosion (Fitton *et al.* 2021), coastline detection (Seale *et al.* 2022). Satellite data from geostationary sources such as the Meteosat satellite arrays are also built into meteorological forecasting models by organisations such as the MetOffice.

Thus, EO and remote sensing have the potential to help with evidence needs by providing data and filling knowledge gaps but also can help with understanding the roles of drivers and pressures. The spatial resolution that EO provided is increasingly able to provide detailed information which will allow us to use those data at local and national scales. At local scale, combining EO techniques with citizen science could offer valuable opportunities to broaden the scope and scale of habitat monitoring (Harris *et al.* 2024). Citizen science could contribute to this by providing valuable training data for model validation and manual image classification (See *et al.* 2016), complementary records such as species occurrence data for habitat suitability mapping, and aiding in the collection of data through innovative smartphone technology (Burggraaff *et al.* 2020). Below and in Appendix 2 we show different opportunities that CS and EO integration (i.e. EO and CS used together to complement each other) can bring to monitoring.

4.4. Earth Observation and citizen science integration: A Case study of DigVentures, an NCEA CS Local Pilot

DigVentures is a crowd funded platform that primarily aims to give people the opportunity to participate in archaeology and heritage projects. Their DeepTime crowd-science platform recruits citizen scientists ('futurenauts') to identify features from EO data, on their own laptops and smartphones, in their own homes. It has trained more than 1,000 citizen scientists to identify and map archaeological features from EO satellite, drone and Lidar imagery, across a 700 km^2 area. Funding from Natural England through an NCEA citizen science local pilot project has extended it to also explore whether the model could be applied as a scalable methodology to identify habitats and monitor ecosystem change in Northumberland. Results from the pilot could help landowners to have the evidence they need to take a natural capital approach to land management which can be used to understand different investments needs and those undertaking restoration projects to monitor and verify the impacts that their actions are having.

The pilot includes five discrete 'missions,' each taking place over one month and focusing on a different aspect of habitats and ecosystems, and so are relevant to answering different ecological questions:

- Identification of open/standing water across the Pennines (in partnership with North Pennines National Landscape).
- Identification of multiple habitat types from coast to coast along the Hadrian's Wall Corridor (in partnership with Northumberland Wildlife Trust).
- Baseline monitoring for a reforestation project in Wallington (in partnership with the National Trust).
- Identification of wetland features such as palaeochannels at Ricknall and Bishop's Fen in Brightwater (in partnership with Durham Wildlife Trust).
- Identifying invasive species from medium to fine scale drone survey data along the Northumberland Coast (in partnership with the Northumberland Coast National Landscape).

Each mission is providing baseline monitoring data at a local scale, which, in the future could inform our understanding of local change and fulfil different evidence needs by collecting monitoring data. For instance, the baseline monitoring of reforestation could help to identify early indicators of positive change following reforestation. The integrated approach is useful because of the volume of EO data that are produced. Recruiting and training citizen scientists is likely to enable a far greater amount of data to be analysed than if only the project team themselves were involved. EO provides a simple and low effort way that people can make useful contributions to science and conservation. The fact that it can be done from a desk is likely to make this form of citizen science particularly accessible to those who are unable to participate in field-based monitoring.

To truly understand the costs and benefits of this integrated approach, it would be necessary to perform tests to check for within- and between-user variation in habitat classification (to ensure accuracy), and also to compare human outputs with machine-derived outputs (to ensure people's time and goodwill is being put to most efficient use).

5. Next steps

The local monitoring approach addresses the need for more detailed, local scale biodiversity data to inform policy and interventions effectively. Existing national schemes provide valuable species trends at broad scales, while the local change approach can fulfil the need for more local scale data to inform policy on early indicators of changes and use of projection. Having monitoring standards and enabling uptake and consistency at a mass scale (because it also meets local monitoring needs) is a cost-effective way of sourcing data to meet evidence needs at different scales.

Here, we showed that the local change monitoring approach can provide the information required for different evidence needs. We also demonstrated that this evidence is complementary to national-scale monitoring, highlighting the need for integration between the two monitoring scales and the datasets they respectively produce; thereby obtaining the advantage of both monitoring scales, as they complement each other.

Local stakeholders often collect useful data, but inconsistent protocols and systems limit the integration and comparability of this information at larger scales. To overcome this, the approach focuses on standardising monitoring protocols and ensuring they are interoperable across local and national efforts. By building on established national schemes the aim is to adapt these methods for local use, including appropriate guidance, tools, and feedback mechanisms.

For future work, we recommend:

5.1. Identification of evidence and data sources for each evidence-need category

A clear mapping of the evidence already fulfilled by national monitoring vs missing evidence where the local change approach could help is necessary. For example, mapping which policy needs national indicators currently can't support and where the local change approach could help with this. This will help identify where opportunities exist for the local change approach to work in collaboration with the national monitoring approach.

5.2. From data to evidence

Once evidence needs have been mapped out, the next steps are to:

(i) enable evidence collection (e.g. through CS and EO)

(ii) enable evidence use by modellers and decisional makers tools to

(iii) inform policy makers on clear conservation and management action on the ground that improve biodiversity and meet targets.

To do this, in Figure 1, we have demonstrated the interlinks between the different evidence need categories (i.e. arrows); however, identifying how these arrows are applied and how they can be enhanced is necessary. Engagement with different stakeholders from the different evidence needs category can help this. This might involve more centralised data processing (such as data sharing platform, open access), as well as increased collaboration and coordination across stakeholders to avoid working in isolation.

5.3. Support place-based monitoring to facilitate coordination among local stakeholders, researchers, and policymakers

Evidence gathered at multiple spatial scales can help obtain early signals of change, assess the impact of pressures and drivers, and understand the effects and scale of interventions. Pilot programmes at the local level allow governments to test global conservation policies in real-world conditions, assess their effectiveness, and refine them before national implementation. This approach reduces risks, ensures policies are adaptable to regional needs, and fosters community engagement. Successful pilots can serve as models for broader adoption, demonstrating feasibility and impact while building stakeholder support.

5.4. Enabling local and national monitoring alignment

The local scale monitoring approach can complement the random stratified sampling design of national monitoring schemes, through the use of their monitoring protocol while adapting their sampling design to match local context. Similarly, improving data-sharing platforms can increase local scale monitoring data accessibility and thus maximise the impact and use of monitoring data across scale. This will be obtaining information required to understand effect sizes necessary for modelling, such as effect size of overgrazing or reforestation.

5.5. Improving data integration and multiscale monitoring

This can be achieved by fostering collaboration across taxon-specific monitoring schemes and encouraging monitoring efforts to assess multiple species within the same landscape. This will help with obtaining a range of outcomes over the same area of interest to have a more holistic understanding of the impact of interventions. We demonstrated that both EO and CS have their advantages, and integrating both monitoring methods is possible; however, more work is required to understand how this integration can be maximised for evidence needs. Similarly, other monitoring methods or evidence-gathering techniques are available, such as systematic reviews and meta-analyses, as demonstrated in the case studies. Understanding the best practices to integrate all possible evidence sources is essential.

5.6. Increasing stakeholder engagement in monitoring

This can be achieved by promoting monitoring initiatives (including CS but also more generic monitoring) to increase local participation in biodiversity monitoring. This includes engaging with landowners, national parks and landscape sub-areas. Working with local authorities can also help secure funding by demonstrating the direct benefits of local scale monitoring for regional conservation goals. Finally, local initiatives should be encouraged to align conservation aims with both national priorities and local ecological needs.

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Appendix 1: More details about EO monitoring opportunities

NatureScot – Scotland Landcover map

In 2019, NatureScot worked with an external contractor to produce the 'SLAM-MAP', a Scotland-wide map, which was subsequently updated in 2020 and 2022 (Black *et al.* 2023). The map was created using optical data from Landsat and Sentinel-2 satellites combined with Synthetic Aperture Radar data from the ALOS PALSAR and Sentinel-1 satellites. The data from these were analysed using a machine learning method that incorporated reference data from the HabMoS dataset – a compilation of field survey data from a range of habitat datasets – together with expert interpretation of high-resolution satellite data, feedback from local experts and a review of published literature relevant to the region.

Following its latest update in 2022, the map currently presents the distribution of 28 habitat classes at a spatial resolution of 20 m, with the map provided in two levels (Black *et al.* 2023). The Level 1 land cover map describes 5 broad habitat classes, and the Level 2 map presents the distribution of 28 more detailed land cover classes. The contractors report accuracy levels of 92% and 80% for the Level 1 and Level 2 maps respectively.

Living Wales

The Living Wales Programme have been funded to produce land cover and habitat maps for Wales using EO methods. Based on a combination of Sentinel-1 and Sentinel-2 and LiDAR, the map has a resolution of 10 m and is validated using field survey data including that collected via the EarthTrack App; an application designed for a broad user base to record information on land cover and land cover change.

UKCEH Land cover map

The UKCEH Land Cover map (UKCEH, 2024) is derived from Sentinel-2 imagery combined with terrain, saltmarsh and OS data using random forest classifiers. The map was validated using field survey data from the GB countryside survey, open-source data from the National Forest Inventory data, and Rural Payment Agency data together with some bespoke manual image interpretation and field surveys. The map has an overall accuracy of 83%. The UKCEH landcover map was used by Andries *et al.* (2021) in conjunction with very high resolution (VHR) imagery and species occurrence data from a range of organisations (e.g. Butterfly Conservation and Surrey Bird Club) to develop habitat suitability maps in the context of the monitoring, reporting, and verification (MRV) of Environmental Land Management (ELM) schemes.

Unlike the data listed above, the UKCEH dataset is not freely available. However, data has been made available periodically since 1990.

JNCC work

Landscape Evaluation tool

The Landscape Evaluation tool currently under development by JNCC presents time series satellite data for each Living England Map habitat polygon alongside associated vegetation indices derived from Sentinel-1 and Sentinel-2 time series data, allowing for the interpretation of environmental change over time (Lightfoot *et al*. 2021). It is anticipated that national habitat and land cover maps listed above will work towards creating equivalent products to the Land Evaluation tool (Burke *et al.* 2023).

Crick Framework

The Crick Framework is a resource developed by JNCC that presents suitable EO methodologies for mapping the extent of Annex I and Biodiversity Action Plan habitats (Medcalfe *et al.* 2013). It is currently under review to expand its scope to cover habitat condition and change of priority and non-priority habitats. Previous work by Aberystwyth University in partnership with JNCC developed a pressure/impact matrix to identify how each of the habitats outlined in the Crick Framework responded to various pressures. Future work on the Crick Framework aims to also build this matrix in.

Saltmarsh and Intertidal mudflat extent mapping

Ongoing work by JNCC and NatureScot is assessing the use of EO data to map the extent of saltmarshes as well as intertidal mud and sand flats in Scotland. Work to date has identified a range of limiting factors including the influence of tidal stage, and a lack of suitable ground truth data.

Habitat remote sensing

Aerial photography and UAVs: With specific reference to habitat monitoring using non-satellite remote sensing techniques, aerial photography and Unmanned Aerial Vehicle (UAV) imagery offers great potential for assessing the nature and condition of current as well as historic habitats, particularly in areas that are difficult to access such as remote coastal and upland regions (Castellanos-Galindo *et al.* 2019). The high-resolution imagery collected using UAVs can be analysed to assess habitat condition, change and monitor management schemes (Villoslada Pesiña *et al.* 2021) and, when compared to historic aerial imagery, it can be used to assess long-term change. UAVs can be equipped with a variety of sensors including LiDAR which can be used to derive datasets that are fed into habitat mapping such as canopy height models, Digital Terrain Models (DTMs) and Digital Surface Models (DSMs).

LiDAR: The Environment Agency (EA) have a national LiDAR Programme that carries out LiDAR surveys using aircraft rather than UAVs. The surveys provide elevation data at a 1 m spatial resolution covering the whole of England; LiDAR data is also available for the whole of Wales, and is due to be updated across Scotland.

Thermal imaging: Temperature differences between caves and surrounding land can be picked up using thermal imaging and subsequently used to detect cave locations (Wynne *et al.* 2021). Wynne *et al.* (2021) used a thermal imaging camera hosted on an aircraft. However, UAV-hosted thermal sensors are also used, particularly for wildlife surveys (Hu *et al.* 2024).

Soundscapes: ‘Biophony’ or ‘ecoacoustics’ is a growing area of research whereby acoustic recordings are collected in a land- and/or seascape and used to infer ecosystem health. The method has been successfully applied to a range of environments including forests (Sangermano 2022), urban areas (Zhao *et al.* 2022), and coral reefs (Lamont *et al.* 2020). Recording of soundscapes could provide an opportunity for citizen science engagement with apps such as BirdNET already utilising AI-powered bioacoustic methods to aid bird species identification from recordings - although not without errors.

Remote sensing at JNCC – marine habitats

Satellites are not currently able to collect data about deep submerged areas. In order to collect data on offshore marine habitats, JNCC carry out a programme of marine surveys using a variety of remote sensing technologies. These include drop-frame and chariot-mounted cameras for collecting still and video images of the seabed, Remote Operated Vehicles (ROVs) for collecting images on transect surveys and of features of interest, multibeam echosounders (MBES) and side scan sonar to collect information on water depth and seabed morphology, and sub-bottom acoustic profilers to collect data on shallow geology and benthic sedimentary structure.

Remote sensing of environmental variables affecting habitat

Water quality: As part of Defra's Demonstration Test Catchment (DTC) platform, remote riverine monitoring was undertaken using bankside monitoring stations; with a network of automated sensor technologies established to collect high-resolution data (measurements taken every 30 minutes year-round) on surface water, soil water, groundwater and meteorological parameters between 2011 and 2018 (Cooper *et al.* 2020). This network of sensors allowed for the impact of agri-environment interventions on water quality to be measured (Old *et al.* 2020).

Under the Environment Act 2021, in England water companies responsible for wastewater assets are legally required to continuously monitor water quality up- and downstream of treatment works and storm overflows (Defra, 2023). Recording water quality every hour, or every 15 minutes at high-risk times, is undertaken using remote sensors in the field recording information on dissolved oxygen levels, temperature, pH, turbidity, and levels of ammonia (Defra, 2023).

Air quality: The Environment Agency have around 300 air quality monitoring sites (automatic and non-automatic) across the UK collecting information on various pollutants. As of 2021, 170 of these sites form the Automatic Urban and Rural Network (AURN), first set up in 1998 to record levels of oxides of nitrogen, sulphur dioxide, ozone, and fine particulate matter.

Weather: The MetOffice have a network of over 200 ground weather stations located across the UK that collect data on temperature, humidity, precipitation, atmospheric pressure and visibility. The organisation also has a network of 'Weather Observers', a community of citizen scientists who provide data from personal weather stations to the MetOffice via the *Weather Observations Website (WOW)*. JNCC currently rely on the ground and air temperature data collected by MetOffice ground weather stations for the Severe Weather Scheme, a scheme established to reduce disturbance of cold weather on waterfowl populations, although provision of this data is currently under review with alternative EO sources being explored.

Marine environment: The Centre for Fisheries and Aquaculture Science (CEFAS) operate a network of autonomous moored systems called SmartBuoys that collect continuous data on a range of marine parameters that influence pelagic habitats including salinity, temperature, oxygen saturation and turbidity (Parker 2021).

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Appendix 2: Other examples of CS and EO integration

eBird

The eBird platform, run by the Cornell Lab of Ornithology, collects bird observation data from citizen scientists worldwide. These observations can be integrated with satellite imagery (such as from MODIS or Landsat) to, for example, assess confidence, model habitat preferences, track migratory patterns, and assess how land-use changes affect bird populations.

Whilst eBird is a global platform, accepting data from anywhere around the world, more specific local change analyses can be undertaken in ‘hotspot’ areas where data are commonly submitted.

The eBird platform itself does not set out to integrate citizen science and EO data; it is primarily a citizen science project. However, many projects have used data collected through eBird in combination with remote sensing data to draw conclusions that would not have been possible using either citizen science data or EO data alone.

Citizen science data from eBird have been combined with MODIS satellite data. estimating spring greening dates to improve understanding of phenological mismatches (Mayor *et al.* 2017; La Sorte *et al.* 2014). This is important to gain knowledge of, because such mismatches are increasing with climate change, and has led to the insight that different trophic levels are shifting their phenologies at different rates, leading to disruption of food webs and life cycles at local scales.

As a final example, the BirdReturns project brings together citizen science data from eBird predicting the likely locations of birds throughout their migration period, with Landsat satellite data documenting areas where water collects (Radcliff & Ng 2015). In the areas with the biggest overlap, incentives were offered to farmers to reflood their fields during the migration period, to provide ‘pop-up’ habitats where birds can stop and feed on their way. Previously, this habitat would have been available, but with conversion to agriculture it has become more difficult to find. This example is a direct illustration of how bringing together citizen science data and EO data can lead to practical, local scale conservation action.

Geo-wiki

Geo-wiki uses citizen scientists to analyse satellite data and aerial details. From their phone or computer, they can participate in campaigns and games that classify various geographical features and/or phenomena, such as flooding, land cover and risks of urban heat islands from the imagery. This is similar in concept to the DigVentures project explored in detail above, whereby citizen scientists are being used to classify satellite imagery, rather than algorithms.

Floating Forests

The Floating Forests project is an online citizen science project aiming to assess the abundance of giant kelp around the world through the use of satellite imagery. Whilst the original project focused on the global scale, a relaunch project in 2017 focused on specific local areas of interest, such as kelp range edges in the Falkland Islands. Again, this is making use of citizen scientists to classify satellite imagery from their own device, rather than linked to citizen scientists collecting data in the field.

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