HEALTHY ECOSYSTEM RESTORATION IN OXFORDSHIRE (HERO)

MARCH 24 2022

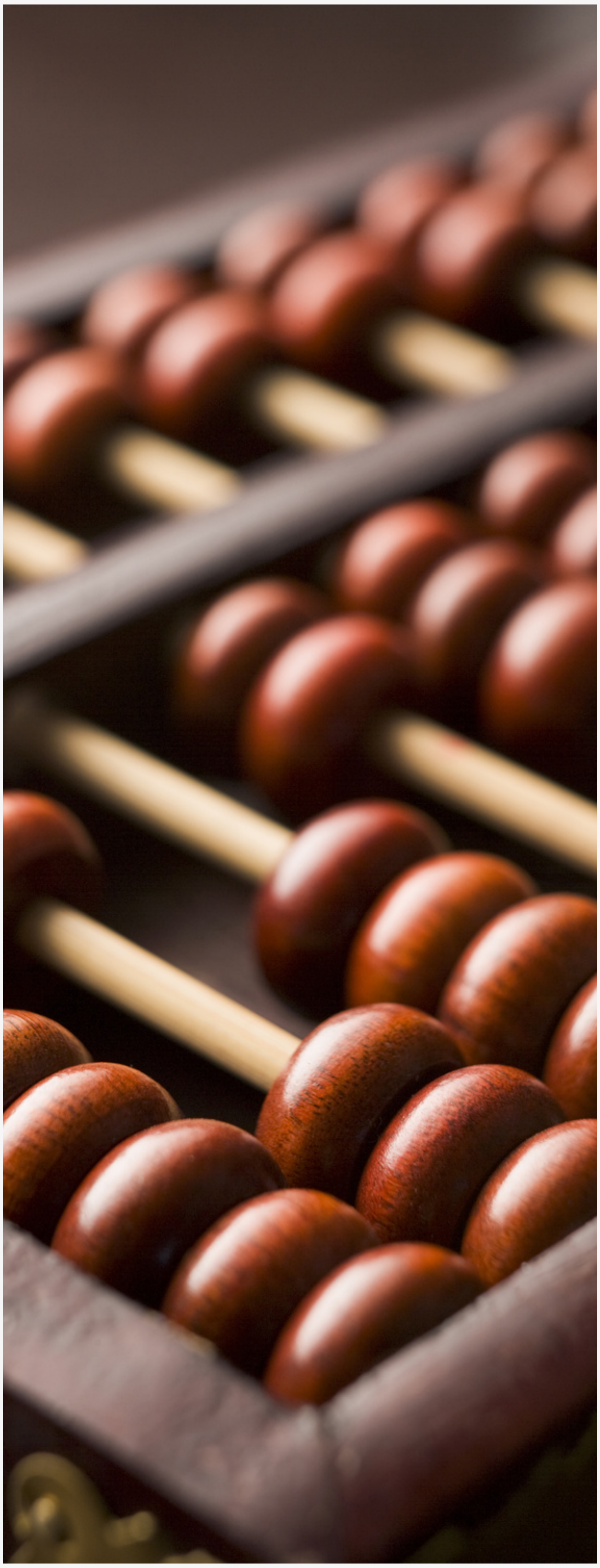
BEST PRACTICES FOR MONITORING BIODIVERSITY

OXFORD MARTIN SCHOOL

UNIVERSITY OF OXFORD

HERO WORKSHOP #5

HYBRID MEETING



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Participants:

In person: David MacDonald (WildCRU), Emma Gardner (UK Centre for Ecology and Hydrology), Cecile Girardin (University of Oxford), Isobel Hawkins (University of Oxford), Mark Hirons (University of Oxford), Keith Kirby (University of Oxford), Cecilia Larrosa (University of Oxford). Angela Liu (University of Oxford), Yadvinder Malhi (University of Oxford), Francesca Mancini (UK Centre for Ecology and Hydrology), Jasper Montana (University of Oxford), Emily Stott (University of Oxford), Martha Crockatt (Oxfordshire Treescape Project), May Chemais (Earthwatch Europe), Caroline Pilat (Earthwatch Europe), Giles Davis (STFC),

Online: Prue Addison (Berks, Bucks, and Oxon Wildlife Trust (BBOWT), Wallerand Bazin (University of Oxford / rapporteur), Stephanie Brittain (University of Oxford), Camilla Burrow (Wild Oxfordshire), Mike Clark (University of Oxford), Marta Dondini (Nature Based Insetting), Gus Fordyce (Nature Based Insetting), Daniel Hayhow (Earthwatch Europe), Andy Hector (University of Oxford), Rhosanna Jenkins (Natural Capital Research), Constance McDermott (University of Oxford), Henrietta Pringle (Oxfordshire County Council), Alexander Shenkin (University of Oxford), Michael Obersteiner (University of Oxford), Luke Ramsey (Nature Based Insetting), Sam Riley (Forestry Commission), Carlyn Samuel, (University of Oxford), Alison Smith (University of Oxford), Pete Sudbury (Oxford City Council), Beccy Wilebore (Natural Capital Research), Steve Wilkes (Thames Valley Environmental Records Centre, TVERC),

About HERO

Healthy Ecosystems Restoration in Oxfordshire (HERO) is a three-year programme (in the first instance) supported by the Oxford Martin School programme on Biodiversity and Society, and the Leverhulme Centre for Nature Recovery. HERO is exploring how Oxford University can play a role in efforts to restore ecosystems to health in Oxfordshire, by bringing the University's strengths in academic knowledge, research capacity and convening power to support ongoing and planned nature recovery activities by a range of local partners and stakeholders.

With its active network of nature recovery groups, Oxfordshire presents a compelling opportunity to test and showcase a portfolio of different ecosystem restoration strategies, to become a model county for nature recovery. HERO aims to build a community of practice between the University and local practitioners and will also form a resource for the University and its constituent Colleges within broader institutional sustainability goals.

The HERO network brings together researchers from the natural and social sciences with local authorities, environmental organisations, landowners and community groups who are already working on a range of initiatives to help support nature's recovery and enhance the multiple benefits that nature provides in Oxfordshire.

HERO aims to holds a regular series of workshops and seminars to examine key opportunities, challenges and evidence gaps around nature recovery in Oxfordshire, and also provides a limited amount of research resource to help fill evidence gaps.

Previous workshops have included:

1. Inception workshop (July 2021): identified the priorities for nature recovery across Oxfordshire and produced a strategic overarching plan for the HERO work.
2. Mapping workshop (September 2021): identified available mapping tools and challenges for reliable habitat mapping.
3. Evidence needs (November 2021): presented a summary of existing datasets on habitats and species, and defined further evidence needs for a nature recovery strategy.
4. Social science (February 2022): defined the social science research agenda of HERO and outlined the socio-economic and cultural barriers to effective change in Nature Recovery.

About this workshop

This note summarises the fifth HERO workshop, on the 24th of March 2022, which focused on monitoring and evaluating biodiversity restoration. It was attended by 37 participants (16 in-person and 21 on-line). Cécile Girardin introduced the main questions surrounding monitoring and evaluation of biodiversity. Francesca Mancini, Mike Clark, Cecilia Larrosa and Emma Gardner then presented their insights into suitable methodologies and frameworks, and discussed the function and relevance of different biodiversity metrics. Finally, a panel discussion between Prue Addison, Camilla Burrow and Steve Wilkes explored the practicalities of implementing monitoring in Oxfordshire.

Three main themes emerged from the discussion:

1. More local monitoring is needed, which will require additional financial and human resources.
2. Citizen science provides a cost-effective monitoring tool but requires correction for spatial bias and variation in sampling effort, and must be verified by environmental record centres to ensure data reliability and legitimacy.
3. It is important to maintain coherence between local, regional, and national monitoring schemes.

INSIGHTS INTO METHODOLOGIES AND FRAMEWORKS

(1) FRANCESCA MANCINI ON BIODIVERSITY INDICATORS FROM BIOLOGICAL RECORDS

For over 50 years, the Biological Records Centre has pioneered citizen science for biodiversity monitoring and evaluation, working with eight structured monitoring schemes and 85 national recording schemes – mostly volunteer-led – to collect species records and produce vast quantities of data. In 2014, there were 96 million observations available on the National Biodiversity Network gateway. A total of 120 distribution atlases have been published, covering over 10,000 species.

Although this data is a great resource to monitor biodiversity by analysing multiple species over decades, there is an unevenness in the way the data is collected. Due to the opportunistic nature of data collection processes, occurrence records are biased in space and time. For instance, a disproportionate number of observations are skewed to certain regions of England and although some sites have never been observed, others have been visited multiple times over a decade. Moreover, the number of species recorded did not grow in tandem with increasing observations since data collectors tend to focus on certain species, which are then over-represented. In addition, different levels of effort of data collectors can explain qualitative differences in the output of citizen science. Considering how data is collected (e.g. time spent collecting) is therefore a crucial methodological concern, along with considerations of which species were observed, where and when. Finally, it is difficult to assess the nature of non-detection, i.e. whether species are genuinely absent or just not observed and recorded..

To address these issues, the occupancy-detection-model (Figure 1) reverse-engineers the observation process by accounting for biases along the collection phase, to improve ecological inference and fine-tune policy guidance. This includes a state model, which describes the ecological processes supporting the observed species, and an observation model which estimates the probability of error detection as a function of different variables (e.g. a proxy for effort) in order to account for different biases. This was used in the State of Nature report's assessment of the change in the distribution of priority species in the short and long-term.[1]

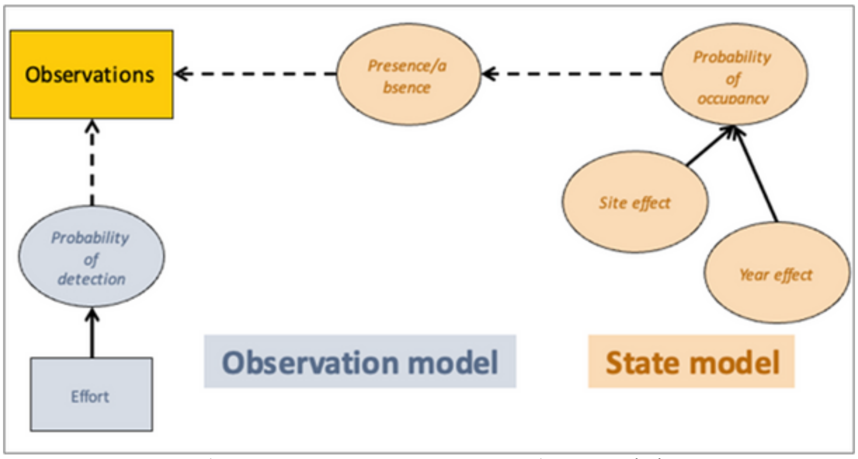

Figure 1: Occupancy-Detection-Model

[1]Hayhow et al. (2019) "The State of Nature", Report

Isaac and colleagues (2014)[2] tested different correction methods for their ability to extract robust trends over time from biased datasets. They used simulated datasets which included observation biases caused by different factors (variation in sampling effort, spatial coverage, sampling effort per visit and detectability) as well as a simulated change in species composition over time. They found that simple correction methods performed poorly but a sophisticated method that combined the Occupancy Detection Model with three other methods (in bright pink on the far right of the charts in Figure 2) performed best, i.e. had the lowest occurrence of type I errors (when the model detects a false trend).

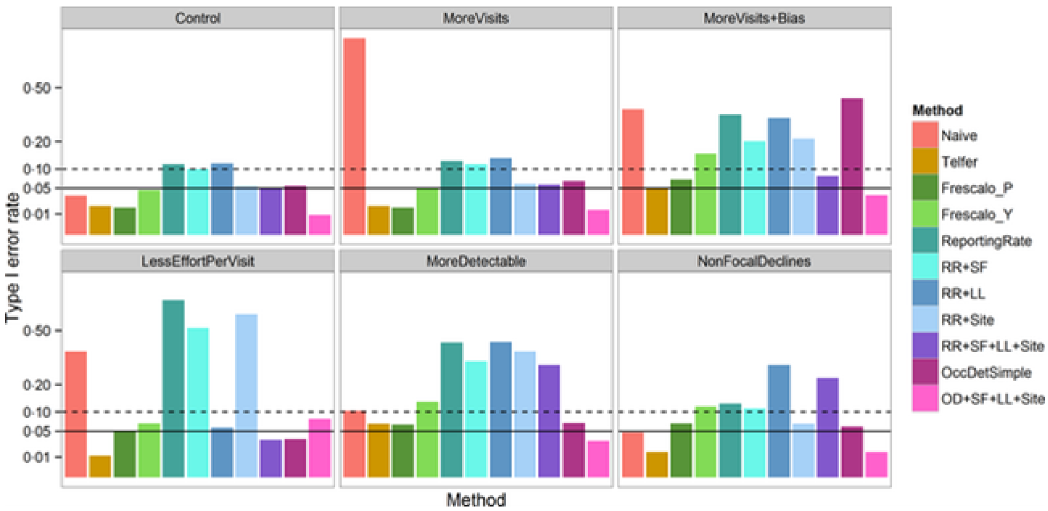

Figure 2: Testing methods for correcting bias due to different levels of recorder activity in Citizen Science observations (Isaac et al., 2014).

(2) MICHAEL CLARK ON GLOB2LOC, A BIODIVERSITY MODELLING APPROACH

Michael Clark presented a biodiversity model, Glob2loc, that measures the impact of various human activities on levels of biodiversity at multiple spatial scales. This model contributes to a gap in the research since most studies tend to focus only on one biodiversity stressor, most often land use change or climate change. However, 80% of vertebrates are functionally impacted by at least two stressors (e.g., invasive species, water quality, species overexploitation). Moreover, these multiple stressors tend to impact biodiversity in synergistic ways. For instance, a 5% reduction in "habitat loss" and in "climate change" can lead to a 15% increase in "species well-being". In addition, existing approaches with large geographical ranges typically focus on cells with an area of 100 km2 to 2,500 km2. However, approximately 93% of terrestrial conservation actions are smaller than 100 km2, with 99% being smaller than 2,500 km2. This means that existing metrics rarely account for scalar differences of impacts on biodiversity. As a result, metrics cannot adequately guide conservation interventions that range from small-scale interventions led by individuals to community-led actions that are orchestrated internationally.

[2]Nick J. B. Isaac, Arco J. van Strien, Tom A. August, Marnix P. de Zeeuw, David B. Roy (2014) "Statistics for citizen science:extracting signals of change from noisy ecological data", British Ecological Society https://doi.org/10.1111/2041-210X.12254

With this in mind, Glob2loc's objective is to identify, in a specific habitat range, the human activities that are occurring or that are likely to occur in the future, whether species can exist with and benefit from these activities and, if not, whether they can migrate to patches within the species habitat range (Figure 3).

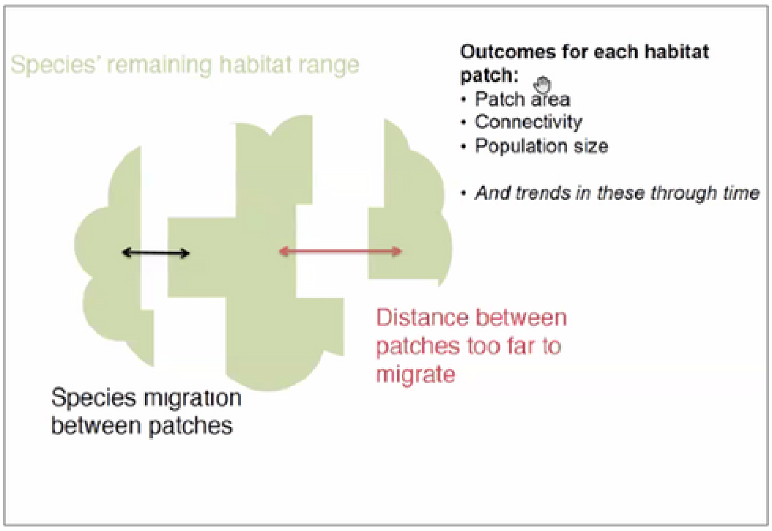

Figure 3: Glob2Loc output on connectivity between habitat patches

The output of the model therefore analyses the number of individuals and remaining habitat for each patch of approximately 30,000 terrestrial vertebrates, at a resolution of 2 km2, as well as the connectivity of each patch. These outputs can be summarized across space, levels of biodiversity, populations, species, communities, landscapes and countries, etc. The results will be reported using indicators embedded in existing decision-making processes including extinction risk and IUCN Red list status, with some flexibility to report other indicators.

The scientific aim is to identify how different stressors (Climate Change, Agricultural Transition, urban land cover change, habitat fragmentation, and possibly more) individually or interactively stress biodiversity. Although preliminary and approximate, the results could provide an integrative and holistic understanding of which stressors are most important in certain biodiversity hotspots (c.f. Figure 4). A participant asked how applicable the model's outputs would be to inform decisions at local scales. Michael has been building the model so that the 2 km2 cells can be downscaled to 300m2 for case studies. However, taking the example of the Biodiversity Intactness Index,[3] participants agreed that using global models at smaller scales is often difficult.

In summary, the approach could measure biodiversity outcomes from different activities, highlight populations, species, or communities most at risk of severe losses in the next decades, and communicate outcomes in the language used by decision-makers. However, Michael recognized that the model's focus on biophysical dynamics excludes social outcomes (i.e., wellbeing, livelihoods, cultural acceptability) and feasibility assessment (i.e., political, social, and economic costs).

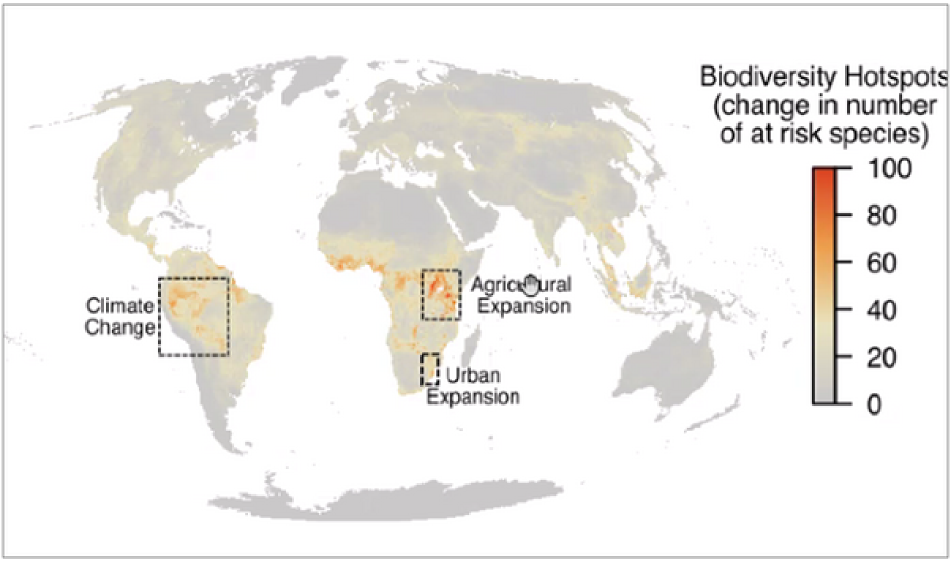

Figure 4: Main stressors in Biodiversity Hotspots

[3] https://www.nhm.ac.uk/our-science/data/biodiversity-indicators.html




(3) CECILIA LARROSA ON BENCHMARK FOR NATURE: SCIENCE-BASED INDICATORS AND INDICES FOR INVESTORS

Benchmark for Nature is a framework tailored to the financial sector that allows companies to assess risks to nature of different investment options. It responds to the increasing awareness surrounding financial, economic, legal, and criminal risks for businesses resulting from biodiversity loss. Organizations are increasingly expected to disclose their extra-financial performance, and they need stronger biodiversity metrics that can identify, measure and reduce the environmental impacts of their business activity. For instance, the Sustainable Finance Disclosure Regulation (SFDR) imposes mandatory Environment, Social, and Governance (ESG) disclosure obligations for asset managers and other financial markets participants.

In this context, Cecilia and their team first reviewed 17 approaches or frameworks used by businesses and financial institutions which rely on quantitative indicators to estimate impacts on biodiversity.[4] Barring two approaches that have their own distinct methodologies (Trase and STAR), these seventeen frameworks can be split into site-level (24%) or scorecard approaches (17%) as well as models using collected, proprietary or open-source data to represent the link between economic activities and pressures with biodiversity (60%). Benchmark for Nature attempts to complement existing data to address shortfalls of current ESG assessment approaches. It seeks to be AI-enabled (automated and real time), open-access, available for academic review, with low data requirements, and incorporating impact mechanisms. As a result, it will be a framework for organisations to identify, manage and report on their impacts and dependencies on nature. As a screening tool, it will aid in the appraisal of nature-related risks and opportunities and help redirect global and regional financial flows away from nature-negative and towards nature-positive outcomes.

After an initial phase of prototype development, the benchmark is now at its second phase of scaling. It is based on the DAPSIR conceptual framework, which links drivers and actions with the consequent pressures, state, impact, and responses, which result in a biodiversity risk score (Figure 5). The indicators used for each element of the framework are shown in Table 1.

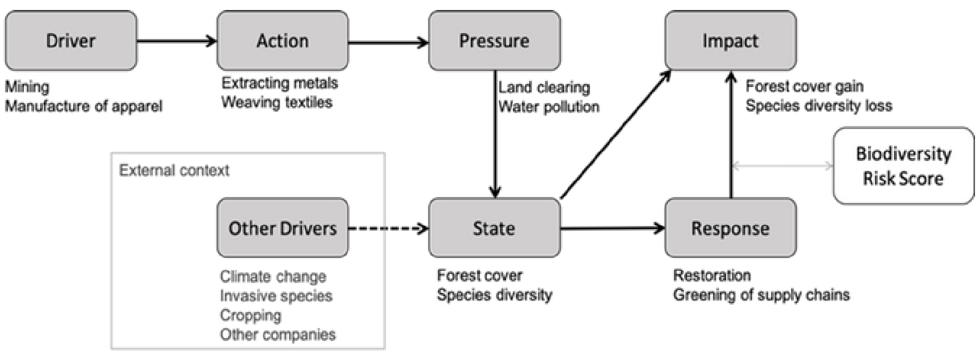

Figure 5: DAPSIR Framework

[4] These include the Corporate Biodiversity Footprint (CBF), Biodiversity Footprint for Financial Institutions (BFFI), Global Biodiversity Score for Financial Institutions (GBSFI), Global Biodiversity Score (GBS), Biodiversity Impact Analytics (BIA), BioScope, Species Threat Abatement and Restoration (STAR), Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE), Trase, Biodiversity Indicators for Site-based Impacts (BISI), Biodiversity Impact Metric (BIM), LIFE Key, Product Biodiversity Footprint (PBF), Biodiversity Footprint Methodology (BFM), Biodiversity Net Gain Calculator (BNGC), BIRS & Ecosystem Services Assessment, and ReCiPe2016

Table 1: DAPSIR element description and indicators

	Definition	Classification used
Driver	Sector in the economy to which the company belongs (e.g., mining)	FTSE Industry Classification Benchmark (ICB)-sectors of the economy
Activity	Specific activities the company is linked to across its value chain (e.g., extracting non-ferrous metals)	FTSE Industry Classification Benchmark (ICB)-subsectors of the economy
Pressure	Biodiversity threats linked to the action (e.g., land clearing)	IUCN - CMP Unified Classification of Stresses v1.1
State	State of components of biodiversity in the area (e.g., natural vegetation cover fraction)	Essential Biodiversity Variables, Biodiversity Indicators Partnership
Impact	Likely impacts of the pressure on the state of biodiversity (e.g., loss of species)	Essential Biodiversity Variables + change term
Response	A company policy targeted at mitigating specific impacts or proactive conservation (e.g., vegetation restoration)	CMP Conservation Actions Classification v2.0

To assess company performance within this framework, the team collects data that captures various aspects of the sustainability performance of the company using a multi-media and big-data analytics approach (searching news, company reports, social media, report sensing, academic articles, patents databases, etc). They developed a list of search terms (Table 2) to identify all relevant articles in the Global Database of Events, Language and Tone. This was chosen as an easy-to-access data source that includes "reputable" news sources, and therefore has elements of both scientific evidence and public opinion.

Table 2: List of Search Terms

Pressures

Category	Search term
(H) Habitat Loss	clear-cutting
(H) Habitat Loss	land-clearing
(H) Habitat Loss	water management/use
(H) Habitat Loss	ecosystem disturbance
(P) Pollution	seepage from mining
(P) Pollution	nutrient loading
(P) Pollution	soil erosion
(P) Pollution	sedimentation
(O) Overexploitation	overgrazing
(O) Overexploitation	habitat degradation
(C) Climate Change	sea-level rise

Response

Category	Search term
Site/Area Stewardship	safeguarding critical habitat
Ecosystem & Natural Process (Re)Creation	reforestation
Ecosystem & Natural Process (Re)Creation	habitat restoration
Better Products & Management Practices	Green supply chains
Better Products & Management Practices	zero deforestation commitments
Direct Economic Incentives	agri-environment schemes
Policies & Guidelines	convention on biological diversity
Internal Manag. & Admin.	sustainability strategy/policy/reporting
Internal Manag. & Admin.	biodiversity strategy/policy/reporting
Internal Manag. & Admin.	corporate responsibility
Internal Manag. & Admin.	offsetting
Internal Manag. & Admin.	no net loss
Internal Manag. & Admin.	net zero
Internal Manag. & Admin.	natural capital assessment
Internal Manag. & Admin.	climate change mitigation

This data feeds into a supervised machine-learning model implementing a Bayesian approach (Figure 6). This is a causal chain model which links the elements of the DAPSIR model (company activities, likely biodiversity impacts and policies designed to mitigate those impacts). The data is filtered by sector, geography, companies, etc., and the model assigns probabilities to each causal link by looking for pairwise co-occurrence of the search terms in the dataset. It then combines these probabilities to get the probability of impacts via different pathways (combinations of Pressure and Response). Sentiment analysis is used to determine the direction of each link (positive or negative). The output of the model is an indicator for end users, that acts as a proxy for the likely biodiversity impact risk and the extent to which it is being effectively mitigated by the company. The team corrects the model by assessing its performance with sectors that team members know very well.

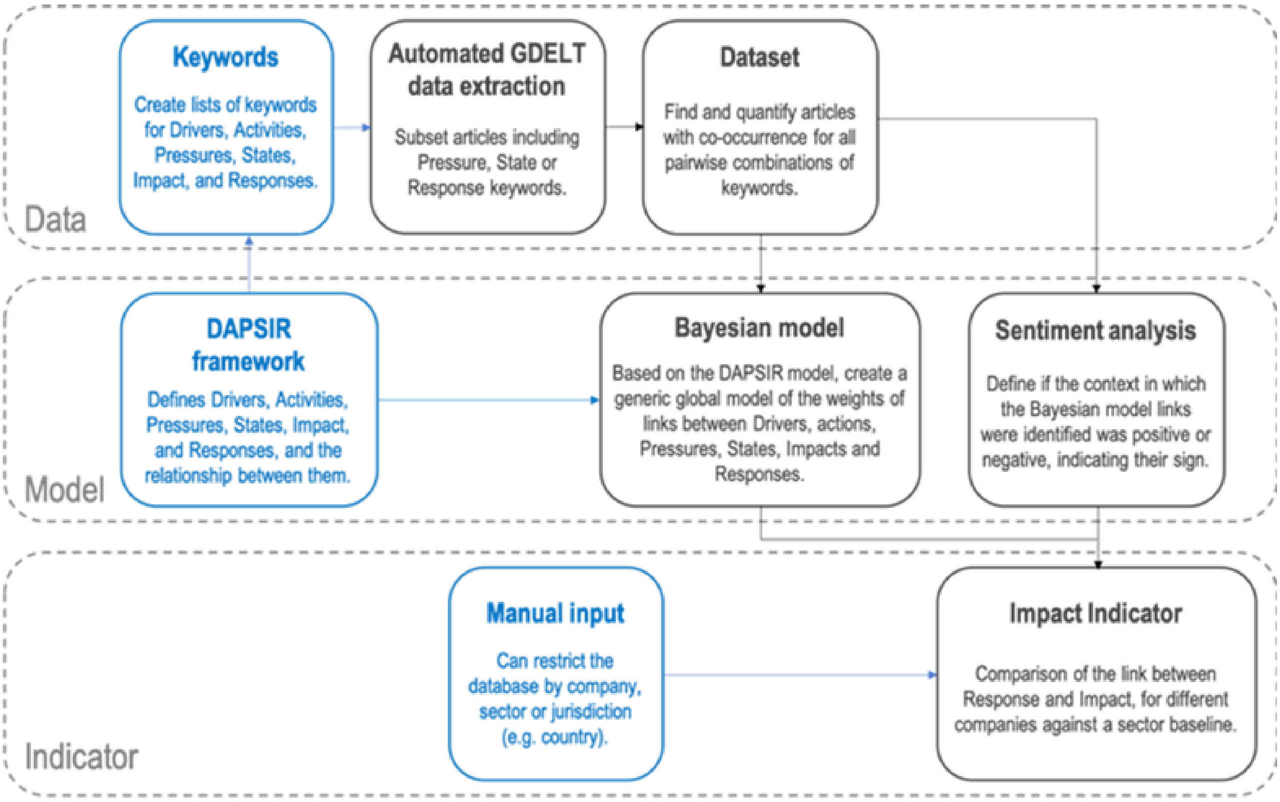

Figure 6: Summary of the Benchmark for Nature Model

(4) EMMA GARDNER ON BIODIVERSITY METRICS FOR LANDSCAPE DECISION-MAKING: HOW CURRENT HABITAT ACCOUNTING APPROACHES CAN FAIL TO REPRESENT THE NEEDS OF LOCAL BIODIVERSITY

As a research fellow on NERC's Landscape Decisions programme, Emma Gardner brings together stakeholders and researchers to try and better represent the needs of biodiversity when decisions are made about changes in land-use for development or restoration.
Emma explained that although the terms 'indicators' and 'metrics' tend to be used interchangeably, in ecology science they are different. Indicators are trends based on observations of species abundance or absence that indicate how populations are changing over time, while metrics are ways of measuring biodiversity. Metrics therefore involve subjective decisions on how to combine indicators from multiple recording schemes as well as simplified assumptions, such as in habitat accounting, where habitats are weighted by the amount of biodiversity they are assumed to support. In short, indicators are closer to observational data, and they measure species, tracking past and current situations. In contrast, metrics are increasingly distanced from observational data and tend to measure concepts that can frame decision-making moving forward.

Using a broad definition of biodiversity as all species in a landscape, measuring biodiversity means understanding the different needs, habitat preferences, level of mobility, and landscape use of each species. Biodiversity metrics are therefore calculated quantities that reduce this diversity to a single number. Hence, before using any biodiversity metric to inform decision-making – whether for development or restoration – researchers must ask three questions:

1. What is this metric actually measuring?
2. What data has gone into it and what might be missing?
3. How well does it represent the needs of local and national biodiversity?

To illustrate the complexity of accurate biodiversity monitoring, Emma used DEFRA's Biodiversity Metric as a case study for assessing two examples of interventions, both for site-level and landscape-level biodiversity.

In the first example, a development project tried to assess which available land between a meadow and a woodland would be most suitable for development in a way that limited biodiversity loss, specifically toad populations. The proposal was to replace some of the existing woodland with human dwellings and to off-set habitat loss by creating additional meadows. Using the DEFRA metric to measure the national distinctiveness of each area of habitat – based on how rare this habitat is nationally – project developers argued that the small area of highly distinctive meadow provided a higher score on the metric than the larger area of existing mixed woodland. However, the metric did not account for the fact that woodlands score higher than meadows for toads, which use woodlands for habitat. As a result, the development project reduced the site's ability to support local species of toad. Moreover, the chances of species moving into newly created mitigation habitats and replacing species lost by the development are low.

The second example looked at a study that investigated biodiversity offsetting' markets, by Needham and colleagues (2020).[5] Given that developers need to pay more in offsetting credits if they develop on high biodiversity areas, biodiversity metrics are important in assessing how an area scores on these issues. The choice of metric affects the scale and distribution of development but also disproportionately affects some species over others. The study created metrics for protecting birds that are endangered but not nationally protected, including curlews. One metric predicted curlew abundance based on landcover, based on data observing the correlation between landcover and curlew observations in June. However, the metric did not account for the different habitats of curlews according to the season, namely coastal in winter, short pasture in summer, long grass, and damp areas for nesting. Given that the metric was not habitat-sensitive, it did not capture the species' reliance on a mix of specific grassland habitats.

[5] Needham et al. (2020) "Understanding the performance of biodiversity offset markets: evidence from an integrated ecological–economic model", Land Economics.

To better account for biodiversity in decision-making, Emma highlighted important considerations.

1. **We need to think about species, not just habitats**. It is dangerous to assume that habitat restoration will necessarily increase the abundance of species, since mobile species depend on multiple habitats. We cannot assume that species will be present because a habitat is present.
2. **Connectivity for what species?** Increasing connectivity for one species may decrease connectivity for another. For instance, increasing woodlands to improve connectivity for woodland birds decreases connectivity for farmland birds.
3. **Seasonal habitat dependencies.** As shown in the case study on curlews, metrics must simulate how different species use landscapes and their habitats throughout the year.
4. **Local knowledge.** Metrics must always integrate local knowledge and on-the-ground survey data because species do not always do what models and metrics predict.Their capacity to do the opposite should not be underestimated.
5. **Biodiversity = all species.** The metric must ensure the needs of under-recorded and unpopular taxa are not overlooked.

In summary, researchers must remain critical of what metrics are measuring, what data has gone into metrics and what may be missing, and whether metrics balance national conservation priorities with the needs of local species. Good metrics should evolve to reflect a three-way dialogue between data recorders, stakeholders advocating for the metrics and modellers, to decide what questions we should be asking and what data can/needs be collected to answer them. Emma concluded with a plea to consider uncertainty, as the metric may conceal important opposing trends in its components. If we do detect changes in the metric, can we determine what's causing them? Usually, we need information on all the underlying components before we can make well-informed decisions. In conclusion, researchers need to avoid making decisions that preserve biodiversity metrics at the expense of biodiversity itself.

(5) PANEL DISCUSSION ON MONITORING BIODIVERSITY ACROSS OXFORDSHIRE: BALANCING PRAGMATIC SOLUTIONS WITH ECOLOGICAL INTEGRITY

Steve Wilkes, Camilla Burrow and Prue Addison discussed the challenges of the implementation of biodiversity reporting in Oxfordshire.

Steve Wilkes presented the biodiversity reporting efforts of TVERC, the Thames Valley Environmental Record Centre, which helps local authorities in their annual biodiversity reporting. TVERC covers species, habitats, and local wildlife site data for the counties of Berkshire and Oxfordshire. They produce reports for the Local authorities, who can use the data to assess how their annual biodiversity indicators such as areas of Local Wildlife Sites and priority habitats, change over time. Steve mentioned some key datasets such as BBOWT's water vole records, other Priority Species observations, condition of SSSIs and BTO farmland bird distribution and status. According to Steve, these crude measures are a good starting point for designing nature recovery strategies. However, some challenges exist, including monitoring the 400 Local Wildlife Sites (LWS) which cover 3% of the county. TVERC provide advice on maintaining and enhancing key features of the LWS but they can only survey 10% each year, and some are not easily accessible as they are on private land. Steve also noted recording biases.

Camilla Burrow presented Wild Oxfordshire's work with community groups, who are running an increasing number of wildlife monitoring projects for their local patches. Wild Oxfordshire has been encouraging volunteers to use nationally established recording scheme methods, and to share their data with TVERC. Given that recorders tend to be volunteers from the general public rather than experts, the species recorded are more often those that are easily identifiable or that come out in good weather. Referencing the Chilterns AONB (Area of Outstanding Natural Beauty) programme "Chalk, Cherries and Chairs", Camilla Burrow pointed to the rising monitoring efforts at local scales. However, supervising volunteer recorders can be almost as costly as employing a professional ecologist. WO are calling for more funding for local recorders. Camilla also asked if the University could help to set up more field stations in Oxfordshire to obtain in-depth studies, e.g. for the floodplain meadows near Little Wittenham.

Prue Addison presented the perspective of BBOWT (Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust), which has a team of five staff members to monitor 86 nature reserves across the three counties, usually through a 3-to-5-year monitoring cycles. One of the five members is a designated coordinator for their hundreds of volunteers, which is quite unique for a wildlife trust since that role tends to be first cut when resources are lacking. The team always makes sure that an evaluation and monitoring officer is appointed when applying for funding. The officer ensures that all recorded data goes to the local recording centre. Funding is one of the main obstacles to keeping their rich datasets updated, including valuable long term monitoring, e.g. 20 years of data on water voles showing that the population has increased due to mink control. They monitor nature reserves and Local Wildlife Sites, but it is harder to monitor the wider countryside. However, the Local Nature Recovery Strategy offers an opportunity to push for more monitoring and evaluation. Another challenge, mentioned above, is the decoupling between local recording and the wider regional big picture. Hence, a county-wide monitoring scheme is paramount and must be aligned with national recording schemes.

Prue emphasised the importance of maintaining coherence between monitoring schemes so that monitoring at local scales line up with statistically robust national coverage. For example, the Chilterns AONB conservation project "Tracking the impact", with JNCC, is consistent with the National Biodiversity Network approach. Finally, it is important to recognize that what is protected will boil down to values of decision makers. Although ecology science will be paramount to assess which species is monitored, practical trade-offs linked to cost-factors will also influence decisions.

DISCUSSION

The discussion emphasised three main points:

- **More local monitoring is needed**, which will require additional financial and human resources (including taxonomists to verify records). Participants agreed that it was vital to demonstrate the value of monitoring to decision makers and volunteers, to channel more funding into evaluation and monitoring. Moreover, younger people need to be engaged in monitoring, to increase the number of volunteers.

- **Citizen science** provides a cost-effective monitoring tool: there are an increasing number of publications on its legitimacy and the cost savings it can incur. However, some volunteers are more expert than others. Some policy makers (such as in an European Commission report) challenge citizen science on the grounds that indicators based on volunteer data are not robust, while others support it because it is free. Citizen Science therefore requires correction for spatial bias and variation in sampling effort, and must be verified by environmental record centres to ensure data reliability and legitimacy and provide assurance to policy makers. Skills training is needed for under-recorded taxa. Recorders could also help with teaching the new GCSE on Natural History in schools, helping to build a community of young recorders. New technologies such as remote sensing and eDNA can complement citizen science data.

- **It is important to maintain coherence** between local, regional, and national monitoring schemes

ABOUT HERO

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The Oxford Martin School is a world-leading research department of the University of Oxford. Its 200 academics, work across more than 30 pioneering research programmes to find solutions to the world's most urgent challenges. It supports novel and high-risk projects that often do not fit within conventional funding channels, with the belief that breaking boundaries and fostering innovative collaborations can dramatically improve the wellbeing of this and future generations. Underpinning all our research is the need to translate academic excellence into impact – from innovations in science, medicine and technology, through to providing expert advice and policy recommendations.