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D5.7. Report on the use of multiple EBV data streams and derived indicators for cross-cutting assessments of biodiversity

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D5.7. Report on the use of multiple EBV data streams and derived indicators for cross-cutting assessments of biodiversity

07/05/2024

Lead beneficiary: Martin-Luther-Universität Halle-Wittenberg (MLU)

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Deliverable description	This report discusses the potential synergies of the EBVs developed in each showcase, in conjunction with existing environmental policies, for a comprehensive assessment of European biodiversity.
Keywords	Essential Biodiversity Variables; Birds Directive, Habitats Directive, Water Framework Directive, Restoration, real-time forecasting, Bioeconomy, Biodiversity indicators.

Contents

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1. Introduction

Lack of spatially comprehensive information on biodiversity status and trends remains a major constraint for conservation policies at all governance levels. The concept of Essential Biodiversity Variables (EBVs; Pereira et al. 2013) proposed a unified framework for developing spatially-explicit monitoring information ready to use for conservation assessments, planning and management. The EBV concept has significance for the global integration of the information produced by multiple biodiversity observation networks (e.g., Gonzalez et al. 2023). Furthermore, EBVs have been used for assessing biodiversity monitoring needs for policy (Moersberger and et al Submitted) and for shortlisting specific structural, compositional and functional biodiversity attributes to be monitored across realms (Junker et al. 2023).

The EBV framework was conceived as a means to harmonize spatiotemporal datasets describing the state of many different aspects of biodiversity, from genetic to ecosystem

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variability, and from compositional to structural and functional elements. The generation of transparent, evidence-based, consistently documented, and replicable workflows has been revealed as a key to the operationalization of the concept (Fernández et al. 2020). It seeks common elements that enable interoperability across multiple monitoring goals, schemes, and regions. Therefore, EBVs place a particular emphasis on developing systematic and reproducible workflows, from raw-data collection to assessment-ready information products (Kissling et al. in prep. D4.1). With sufficient spatiotemporal coverage, EBVs can hypothetically provide the data required for predicting, tracking, and assessing biodiversity consistently across space and scales (Navarro et al. 2017). However, the application of the EBV concept has yet to become mainstream, especially in meeting societal and policy needs.

The proposal for a European Biodiversity Observation Coordination Center (EBOCC; Liquete et al. 2024) relies on the operationalization of the EBV concept. Its primary goal is to reduce the spatial, temporal and thematic data deficiencies that hinder biodiversity assessments at the National and European Union (EU) levels. Assessments of biodiversity status and trends are mandatory under EU nature protection regulations, including the Habitats and Birds Directives (European Environment Agency. 2020). Furthermore, novel policies such as the proposal for a Nature Restoration Regulation (NRL) and a Directive on Soil Monitoring and Resilience, demand for more comprehensive spatially-explicit information and projections on biodiversity status and trends. Finally, timely spatiotemporal biodiversity data is increasingly demanded by multiple sectors of the economy and society, e.g., in reconciling economic activities with biodiversity conservation and promoting sustainable use of biodiversity resources by citizens (European Commission 2018).

A large share of biodiversity reporting produced in Europe responds to the reporting mandates under the Habitats and Birds directives. These reports largely rely on a combination of aggregated data and expert-based judgements (European Topic Centre on Biological Diversity n.d.), often guided by fragmentary information. The actual collected data, where available, is rarely accessible, there is not enough transparency regarding underlying data collection methods and reporting streams lack reproducible workflows that can be replicated and/or scaled-up. These limitations hinder re-use and comparability of the underlaying data, precluding the reproducibility of assessments (Figure 1).

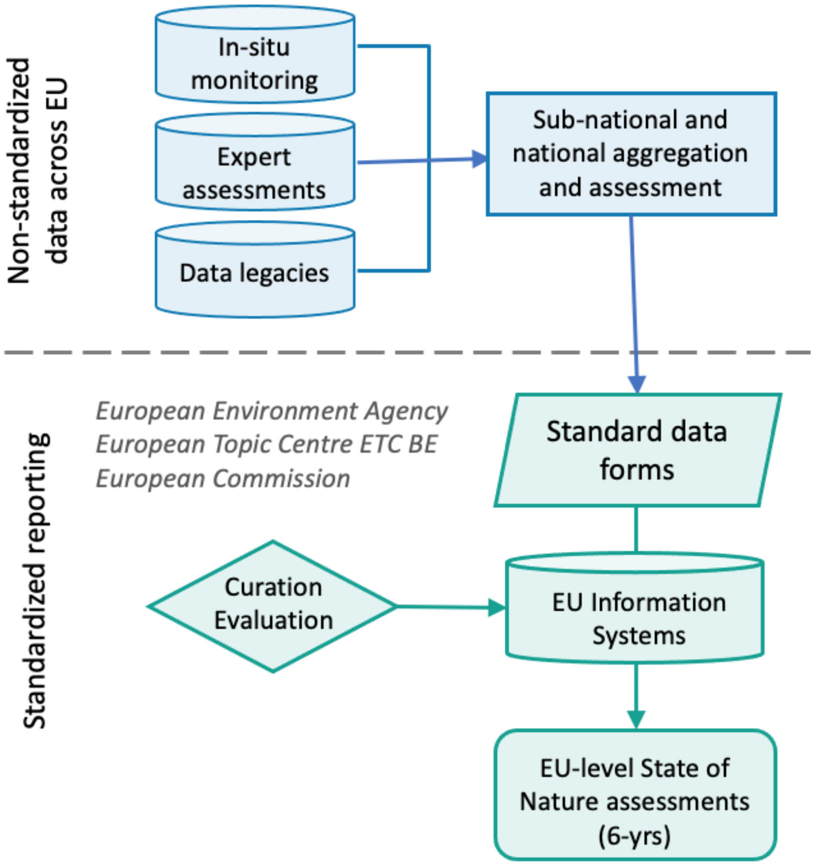

Figure 1. *Diagram of current data and information flows for assessing biodiversity state and trends in the EU for the Habitats and Birds Directives. The steps shaded in blue represent a collection of heterogeneous protocols and data difficult to access.*

Here, we analysed advances and breakthroughs towards mainstreaming the policy and societal use of EBVs. We address challenges and solutions across the EBV production workflows based on lessons learned in the *EuropaBON showcases* (Box 1). The showcases were designed to advance various elements of the EBV workflow, i.e., ranging from engaging long-term monitoring initiatives in modelling EBVs; the harmonization and integration of fragmented data sources; the production of spatiotemporal biodiversity data cubes with biodiversity models and remote sensing (RS); and developing biodiversity indicators. We also investigated areas of application for decision support according to the EBV data characteristics, differentiating among four broad uses: (1) EBVs used to produce spatiotemporal biodiversity trend indicators; (2) EBVs used to assess biodiversity condition compared to reference values; (3) forecasting short-term biodiversity dynamics with economic impact; and (4) projecting biodiversity change.

2. Essential Biodiversity Variables meet policy assessments

The EuropaBON Showcases (Box 1) were designed to encompass multiple facets of biodiversity, filling critical information gaps for regulatory assessments and addressing various spatial scales. We have used the EBVs framework to leverage and integrate the existing data from monitoring initiatives across the EU. By establishing explicitly defined workflows, each showcase aims to deliver data cubes for multiple biological entities (i.e., various taxonomic groups, habitat types and community metrics, respectively). Such EBVs aim to address the data needs along four main types of assessments: trends in biodiversity distributions (species, communities and habitat types); changes in habitat condition; fast-response monitoring systems; and future projections. Showcase EBVs were tailored to inform the following policies:

- The Birds (BD) and Habitats (HB) directives, cornerstones of the EU nature protection legislation, demand for periodic reports of the distribution and distribution changes of all listed species and habitats at 10-km grid resolution. The HD further extended to appraise quantitative (range and area) and qualitative (structure and function) habitat change for each of nine European biogeographic regions.
- The Water Framework Directive (WFD) aims to protect and restore water bodies to reach good chemical and ecological status. It requires ecological status assessments which compare the flora or fauna of degraded water bodies to reference undisturbed water bodies through selected biological quality elements (BQEs). This information is considered vital not only for biodiversity conservation but also for monitoring and predicting impacts on ecosystem services, people's livelihoods, and the economy.
- An upcoming directive focusing on Soil Monitoring and Resilience pursues the protection and sustainable use of soils. It aims to establish efficient soil health monitoring as defined by biological condition, among other components.
- The EU adopted the bioeconomy strategy to foster sustainable use of ecosystems and the services they provide. Monitoring ecological dynamics is key for the sustainable management of biological resources and renewable energies.

Box 1. *The EuropaBON showcases.*

The Farmland Birds Showcase (Herrando et al. 2024) aims to produce wall-to-wall EBV species distribution cubes at the European scale with frequent updates. It leverages *in-situ* data collected by broad observer networks. Such data is unique for its spatial coverage and for using harmonized sampling protocols, therefore illustrating the EBV potential from large-scale systematic observations. Site-level monitoring data from the Pan-European Common Bird Monitoring Scheme (PECBMS; Brlík et al. 2021) was used generate weighted Ensemble Model Predictions from statistical and machine learning models for two time spams: 2013–2017 and 2018–2022. Independent data from the European Breeding Bird Atlas (EBBA2) was used to validate predictions. The modelled EBV matches the spatiotemporal specifications of the EuropaBON species distribution EBVs according to systematic user & policy needs assessments (Junker et al. 2023). Uses of the EBV not only include higher-resolution conservation status assessments of the BD listed species, but it also can help monitor restoration progress in agricultural ecosystems under the provisions the proposal for an EU regulation on nature restoration.

The EUNIS Habitats showcase targets prevailing information gaps on the distribution of threatened habitat types requiring protection under the HD. Despite habitat extent assessments are key to the implementation of the EU conservation legislation, no harmonized methodology exists to map the area covered by these habitats, and methods used can greatly differ between countries and ecosystem types. The showcase demonstrates state-of-the-art hierarchical habitat mapping and monitoring through integrating in-situ data with remote sensing and abiotic limiting factors such as topography and climate. Although a comprehensive EU level result has proved not possible at the required accuracy level, the showcase was developed on a regional scale encompassing 15.000 km^2 in the Atlantic bioclimatic region of Northern Spain. The analysis targeted mapping habitat classes in three hierarchical levels at 10-m pixel size of resolution, reaching 22 habitat types in the lowest level (EUNIS level 3), representing a rich variety of grasslands, shrubland and forests.

The freshwater biodiversity showcase aimed to demonstrate two complementary approaches. The first consists in leveraging ecosystem condition indicator data produced at the level of water bodies across Europe to gain understanding on the state of ecological communities from regulatory reporting. The goal was to demonstrate the data mobilization capacities trough exploiting biodiversity data reported to the Water Information System for Europe (WISE) (Moe et al. 2023). The second was to produce novel EBV distribution and community data of macrophytes across Fennoscandian lakes though the aggregation of systematic data collected over a 30-years span. The approach demonstrates the application of species distribution models for predicting species and community metrics under varying environmental conditions to compensate for low monitoring frequency and monitoring gaps. Both approaches have clear applications for enhancing the availability and quality of freshwater biodiversity information in support of both the WFD and the HD.

The short-term ecological forecasts showcase (Ceia-Hasse et al. 2024) produces large-scale, near real-time monitoring EBV products for rapid decision support. Using a novel automated workflow with species data retrieval from GBIF, this approach shows the potential to forecast distinct intra-annual variation phenomena with economic relevance, including wild mushroom fructification and the adult stage of an agriculture pest species. Machine-learning algorithms are used to produce daily EBV data of such phenomena at 0.25° resolution. Another application directly uses radar data from weather stations to monitor the biomass of migratory birds, a community-level EBV with important applications for monitoring important conservation areas, anticipate bird mortality threats on the short term, and to improve aviation safety and reduce damage to aircrafts and delayed flights.

The soil restoration showcase aims to map a wide array of soil based EBVs (Smith et al. 2021, Zeiss et al. 2024) and test the capacity of current datasets to project future scenarios for those same EBVs. Additionally, this showcase also provides a conceptual and material application of an indicator related to the potential for soil restoration considering multiple related to taxonomy, species composition and ecosystem functions. We leverage the standardized European wide dataset on soil properties (LUCAS; Orgiazzi et al. 2018) with powerful statistical approaches to obtain wall to wall spatial representations of several EBVs and their projections to the future. The resulting soil restoration indicator has a direct link to current EU policy and targets (namely for biodiversity and climate) but also provides an important baseline for the current political discussions related to the proposed Soil Health Law.

3. Operational EBV workflows: from observation networks to EBV data cubes

3.1. Participatory design of EBVs

The EBV design process aimed to ensure that research outputs are valid, applicable, and broadly accepted among the relevant stakeholders' groups (Figure 2). The initial EBV design and the synergies between showcases were structured through two workshops that took place in Leipzig (Germany) in November 2021 and in Tróia (Portugal) in April 2023. These involved >70 and 60 participants, respectively, and included scientists and stakeholders from European, subnational and national policy bodies and agencies, and NGOs. In addition, each showcase organised separate seminars and workshops addressing design topics including identification of data and models; strengthening observation networks; or exploring specific user needs and policy applications, among other topics.

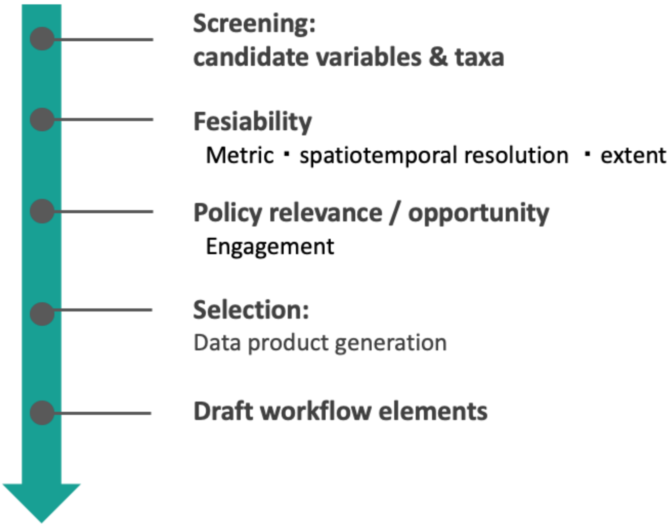

Figure 2. *Common procedure followed by the showcases to select the Essential Biodiversity Variables and their characteristics during the 1st workshop in Nov. 2021.*

The participatory design revealed very different starting points across showcases: while some of the workflows built on previously established stakeholder networks (e.g., for 'farmland birds' and freshwater biology EBVs), other workflows required novel participatory processes and thus set the stakeholder network from the beginning of the EuropaBON project (e.g., the generic forecasting workflow developed for the mushroom fructification and invasive pest's phenology). Therefore, the means of involving stakeholders and the intensity with which they participated varied across showcases.

We organized the participatory processes along four overarching topics (Figure 3):

1. *Policy processes*. The engagement with the EU science-policy bodies, notably the Directorate-General for Environment of the European Commission (DG ENV), the Joint Research Centre (JRC), and the European Environmental Agency (EEA), has been critical in aligning the showcase outcomes with environmental directives and the environmental policy agenda form the EU. Their involvement ensured that the EBV design adhere to the key legislative frameworks (BD, HD, NRL) and contribute to increase reproducibility and transparency of the transnational assessments. This proactive alignment by EU policy bodies catalysed the refinement of EBVs particularly promoting their practicality for policy decisions and management strategies. Attempts were also made to engage with National and regional agencies

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responsible for periodic reporting. Such attempts revealed challenging due to a high fragmentation of governance and monitoring responsibilities in Europe and the lack of EU-level coordination.

The private industry played a significant role in the bird migration showcases. Energy companies and grid operators contributed to future developments, focusing on the practical applications of forecast models, particularly in relation to wind energy curtailment and other industry-related operations. This underscores interest in the usability of research outcomes for operational decision-making.

2. *Input data management.* Stakeholders of the different showcases stressed the importance of leveraging readily available data and monitoring networks, including already existing authority data curation such as the European Soil Data Centre (ESDAC) for developing soil biodiversity EBVs and the European Topic Center Biodiversity and Ecosystems (ETC BE) freshwater biodiversity data. Furthermore, the participation of transnational voluntary networks with well-established governance such as the European Bird Census Council (EBCC) and the Pan-European Common Bird Monitoring Scheme have demonstrated instrumental since they allowed leveraging already curated data collected using standardized protocols. As an alternative model, the Water Information System for Europe (WISE) allowed a platform-based approach to EQR data aggregation from various National nodes as part of the requests for regulatory reporting. In both cases, the data management governance was instrumental to achieve extensive national-to-European *in-situ* data coverage.

   In contrast, in-situ vegetation data mobilization for habitats mapping was extremely limited. Few countries surveyed vegetation data as part of the HD monitoring. When data existed, data property rights precluded its compilation across countries. Under the absence of well-established in-situ monitoring, the participatory process was constrained to aspects such as identifying relevant data sources available together with experts (e.g., mushroom forecasts EBV) or employing specific efforts to compile data collected in research projects (lake macrophytes EBV). In such cases where there is a lack of coordinated networks, the capacity to engage with representatives and experts of the various National and sub-national monitoring initiatives was further constrained.

3. *Workflow and indicators design*. The design of workflows and indicators across various showcases involved facets from the identification of predictive variables and metrics to the optimisation of modelling processes and validation of results. The research community was pivotal in shaping novel workflows. Research institutions served dual roles as data custodians and developers of models and workflows, particularly in the showcases where no formal organisational structure was present, such as the generic forecasting workflow developed for the mushroom fructification or future projections of modelled soil showcases. In such showcases, workflows were co-developed involving researchers and experts that pinpointed the desirable properties of the EBVs, identified the key metrics and appropriate models, and evaluated practical aspects of workflow implementation. Again, the Farmland Birds showcase was particular case since a Spatial Modelling Group of the EBCC was already established and took a leading role supervising the modelling framework. For a majority of EBVs, similar and well-established modelling methods were identified by the experts, often including machine learning methods and ensemble model predictions (farmland birds, EUNIS habitats and mushroom fructification and beetle pest forecasts)
4. *Future needs and developments*. Discussions on future needs and developments were centred on refining modelling techniques to expand applications and ensure alignment of EBVs with evolving policy requirements. In the aerial biomass forecasting showcase, key stakeholders from the private sector, including energy companies and aviation sectors, were engaged in developing models for aerial biomass flow forecasting. These models are intended for use as early warnings and to improve aviation safety. In the farmland birds showcase, the JRC was working to incorporate farmland species into their studies into the implementation of the proposed Nature Restoration Law, focusing on ensuring that future policy impacts are comprehensively addressed.

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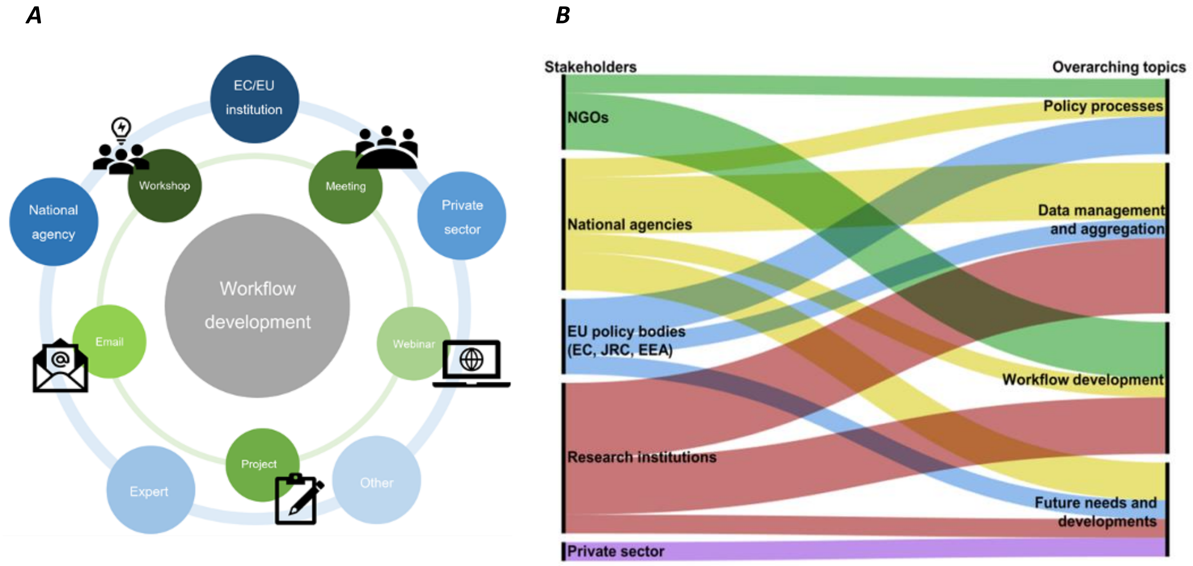

Figure 3. *Summary of the stakeholder engagement process and methodologies*. **A:** *The participatory design process involved engaging stakeholders from across sectors and using different means. EU policy bodies and a wide variety of researchers were involved in all showcases. Participation of National agencies and the private sector were also engaged, although comprehensive representation of the different EU member states was not possible. Showcase-specific and cross-cutting workshops were the primary engagement method.* **B:** *Flows of stakeholder contribution in the EuropaBON showcases. The width of each stream represents the number of stakeholders engaged in each overarching topic, such as policy processes, data management and aggregation, workflow development, and future needs and developments.*

3.2. Operationalizing EBV workflows

EBV design characteristics

The workflows developed focus on the terrestrial and freshwater realms, and include EBVs from the classes *Species populations*, *Species traits*, *Community composition*, and *Ecosystem structure* (Table 1; see also Fernández et al. 2022). The EBVs characteristics regarding spatial resolution range from 10-m for the EUNIS habitat distribution at sub-National scale to 0.25° for near-real time forecasts, and range from daily (forecast) to sexennial (farmland birds) temporal resolution, for some EBVs we could produce data for only one time period (EUNIS habitats and lake macrophytes).

While estimation of each EBV has its own characteristics, they used similar workflow approaches seeking for reproducibility. These were defined by raw data collection, curation and integration, and the development of a modelling or data analysis framework to obtain predictions, projections and trends. Figure 4 provides an overview of the major workflow's steps. See Table 2 for more details of each workflow.

Table 1. EBVs for which a complete workflow was developed, classified by realm and EBV class. ECRINS stands for European catchments and rivers network system, and EQR for Ecological Quality Ratio. Showcase names reflect the target entities (e.g., 'birds' for the showcase targeting the EBV "Species distributions of terrestrial birds") or products ('forecasts' for the showcase developing forecasts) and aim at more easily identifying the showcases throughout the text.

Realm	EBV class	EBV name	Spatial resolution	Temporal resolution
Terrestrial	Species populations	Species distributions of terrestrial birds	10–km	6 years
		Species abundances of selected terrestrial crop pests	0.25º	Daily
	Species traits	Phenology of fructification of mushroom species	0.25º	Daily
	Community composition	Community biomass of soil microbes	1–km	1–year snapshot
		Functional composition of soil biota	1–km	1–year snapshot
		Taxonomic diversity of soil biota	1–km	20 years (present and future projections)
		Aerial biomass of migrating birds	0.25º	Daily
	Ecosystem structure	Ecosystem distribution of terrestrial EUNIS Habitats	10x10m	1–year snapshot
Freshwater	Species populations	Species distributions of freshwater macrophytes	As in ECRINS and selected smaller lakes (<4 ha)	3-6 years
	Community composition	River benthic invertebrates EQRs	As in ECRINS	2-3 years
		Lake phytoplankton EQRs	As in ECRINS	1 year, weekly-monthly in growing season

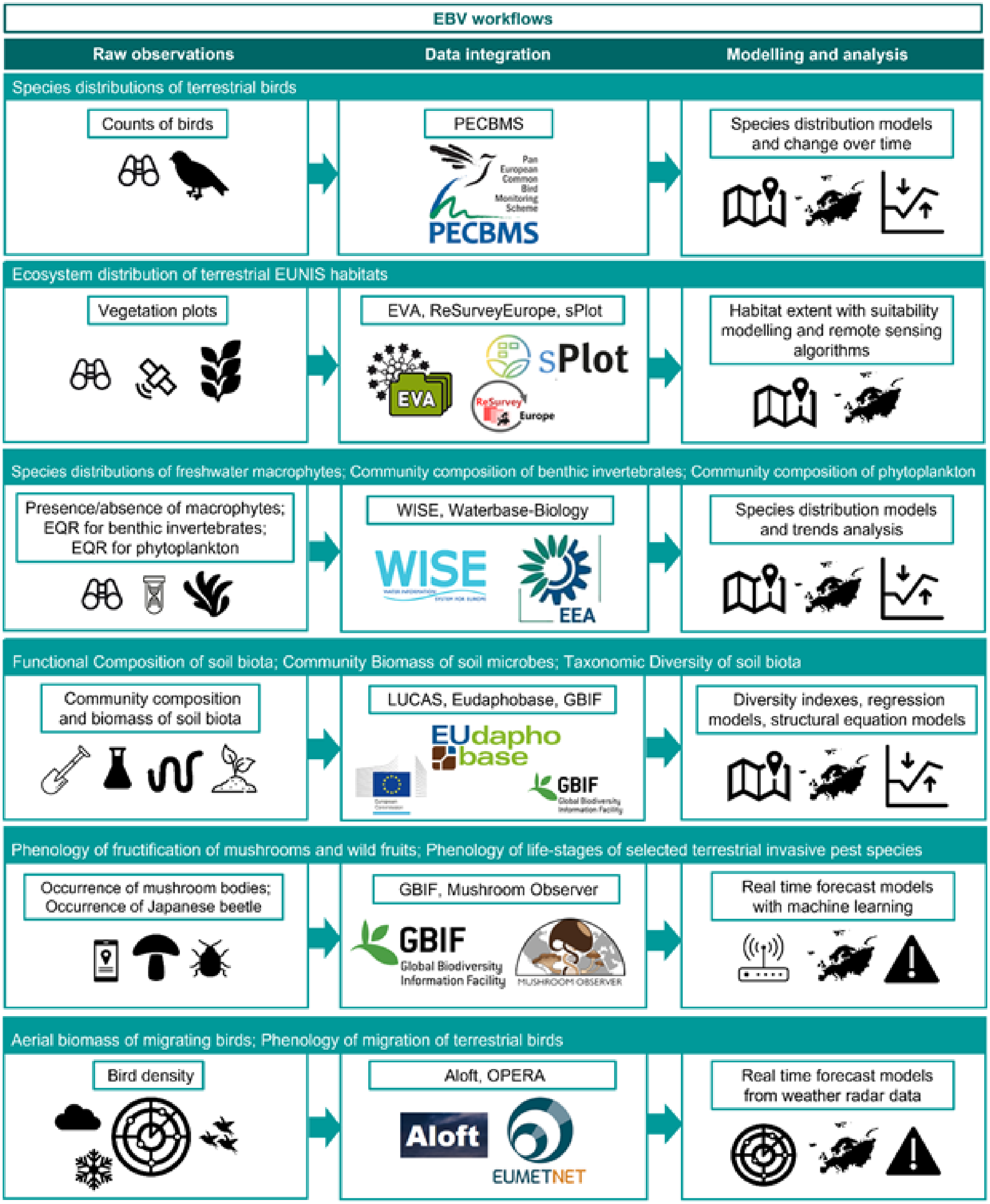

***Figure 4**. Overview of the workflows developed in the showcases for producing the EBVs, from raw observations to data integration and modelling and analysis (left to right). The different EBVs represented in each row were produced in the following showcases (from top to bottom): 'birds', 'habitats', 'water', 'soil', 'forecasts' (EBVs phenology of mushrooms and invasive crop pests), and 'forecasts' (EBVs bird biomass and migration phenology).*

Input biodiversity data

National coordinated monitoring programs coordinated at the European level provided some of the highest density of long-term in-situ observations. Examples include PECBMS contributing data to the Farmland Birds EBV from >16 000 sites monitored yearly; and > 54000 data points of benthic invertebrate's species composition from National monitoring schemes reporting to EIONET. Despite the EU-level coordinated LUCAS Soil monitoring program encompasses ~20 000 soil locations sampled every 3 years, biodiversity attributes were measured only in a small fraction of them (885 sites in 2018 and 1500 sites in 2022, respectively).

To effectively allow the implementation of use-ready EBVs, standardisation of data collection methods is crucial. This ensures that data collected across different regions and times are comparable, providing a reliable basis for long-term biodiversity monitoring. The LUCAS soil surveys in Europe are an example of such large-scale standardised data collection that offers invaluable insights into soil health and its temporal dynamics. These surveys highlight the diversity and distribution of soil properties and organisms, creating a comprehensive database from which EBVs can be extracted.

For less monitored biodiversity, the analyses strongly relied on open science platforms such as GBIF (i.e., opportunistic mushroom species observations for mushroom phenology forecasts and invasive arthropods for the crop pest's phenology forecasts; Fig. 4 & Table 2). Research projects were another key resource that allowed a novel aggregated dataset of macrophytes distributions from samples collected in >2000 Scandinavian lakes over a 40-years period. In all these cases, the spatiotemporal resolution of the input data was much lower, translating into low downstream EBV resolution in the temporal or spatial dimensions (e.g., macrophyte predictions comprised one single 40-year period and temporal resolution of 0.25° for mushroom and invasive pest forecasts).

Data access

An important constraint to the reproducibility of EBVs is limitations to data access. The showcase EBVs were largely built based on in-situ data with restricted access, with the only exception of the forecast EBVs, whose design was founded on open-access to primary sources

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of data. The access to the primary observations from the birds monitoring programs varied from free access in some countries to available upon request and restricted in others, despite being largely based on voluntary networks and solid data governance structures. A particular case is the freshwater biology data underpinning freshwater biology assessments: despite the EQR values themselves being open access through the EIONET data facilities, underlying raw data on species occurrences and community composition is typically not accessible. Unlocking this data would realise the potential to estimate various metrics for species populations and community composition EBVs, beyond the local quality assessments relative to a baseline. At present, LUCAS soil data is the only EU-level dataset that will become open access. Therefore, open access to in-situ, standardised data reveals as a major breakthrough for the estimation and full reproducibility of the EBVs.

Table 2. Overview of the characteristics of the workflows developed in each showcase for the target EBVs produced, regarding observation networks, data accessibility, modelling and analyses, and needs highlighted regarding IT infrastructure.

Showcase	EBV	Observation networks	Data accessibility	Modelling and analysis	IT infrastructure
'birds'	Species distributions of terrestrial birds	PECBMS	Restricted access, under request	Species distribution modelling	Incorporate casual observations
'habitats'	Ecosystem distribution of terrestrial EUNIS habitats	EVA; ReSurveyEurope; sPlot; sPlotOpen	Open or under request	Remote sensing framework to detect change	Annotated training dataset to detect change
'water'	Species distributions of freshwater macrophytes	Individual projects and publications; WFD related monitoring; WISE; Waterbase-Biology	Dependent on dataset (open, restricted, restricted but opening with this project)	Species distribution modelling	Resources for data curation and automated data flow

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	EQR of benthic freshwater invertebrates; EQR of phytoplankton in lakes	National monitoring based on the WFD	Monitoring raw data stored in national or regional databases, not reported to the European level. Only EQR estimates are open access	Calculation of normalised EQR values, Interpolation, Trend analysis	Further automation and harmonisation of software and workflow fully within a common workspace
'soil'	Functional Composition of soil biota; Community Biomass of soil microbes; Taxonomic Diversity of soil biota	LUCAS Soils; Eudaphobase; GBIF	Open access (with and without registration)	Species distribution modelling, diversity indexes	Increased data validation (species identification) and curation prior to modelling
'forecasts'	Phenology of fructification of mushrooms; Phenology of life-stages of selected terrestrial invasive pest species	GBIF; Mushroom Observer	Open access (with and without registration)	Forecast model with machine learning and real-time implementation	Increased automation and upstream data inventorying and integration; Open access to high quality weather data
	Aerial biomass of migrating birds; Phenology of migration of terrestrial birds	Aloft; OPERA	Bird density from weather radars publicly available	Migration intensity from bird density using ensemble models	

Modelling and analysis

Modelling has been instrumental in all showcases to realize spatiotemporal EBV cubes filling data gaps. The underlying purposes may vary, but are often associated with the spatial and temporal resolution of the reporting. For example, the water framework showcase recurred to linear interpolations to estimate the missing EQRs from unreported years to perform trend

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analysis. Similarly, the species distribution of macrophytes on 3693 non-surveyed lakes in the Fennoscandian region was conducted by linking specific chemical and physical covariates.

For predicting occurrences, species distribution modelling has been instrumental to generate updated occurrence maps of bird species, macrophytes, soil biota. In the Birds showcase, for example, ensemble model predictions enabled the generation of updated distribution maps for birds occurring at the EU for 2018-2022 data, while enabling comparison with past occurrences modelled data on occurrence (2013-2017) to estimate distribution changes. In the water framework showcase, the macrophytes distribution in Fennoscandian lakes was estimated by linking specific chemical and physical covariates. In the soil showcase, a space-by-time substitution approach was used to model the distribution of 19 earthworm species and to map updated and future perspectives of these species, therefore providing a wider perspective on the soil compositional and functional responses to climate change.

The EUNIS Habitats Showcase demonstrates a data fusion approach based on machine learning. It combined remote sensing vegetation phenology products with modelled climatic surfaces and static topography data to simultaneously predict the distribution of 22 different habitat types. Given the limitation of the exclusive use of remote sensing products to directly detect certain habitat types, such model-based approach reveals promising to detect habitat changes and threats (Álvarez-Martínez et al. 2018). Soil biotic indicators including microbial biomass, respiration quotient and respiratory potential have also been modelled by using structural equation modelling for soil status assessments.

Integrating multiple data sources is another pivotal aspect for the implementation of these indicators. By combining traditional field data with innovative data collection techniques such as remote sensing and citizen science projects, a more complete picture of biodiversity emerges. For example, remote sensing technology provides large-scale data on land cover changes that affect soil biodiversity, while citizen science projects often fill gaps in ground-based data collection, especially in hard-to-reach areas. Developing statistical and spatial models to interpret EBVs and translate them into actionable indicators is the next critical step. These models aid in understanding complex interactions within ecosystems and predicting future trends under various scenarios.

It is particularly relevant how integrating statistical models with state-of-art algorithms including machine learning, can unveil the hidden potential to forecast in almost real-time ecological events of societal and economic value, fostering proactive and timely decisions. The forecast showcase has combined these two approaches in tandem with automatic routines to collect updated weather variables to predict the occurrence of fruiting Chanterelle mushrooms and adults of the invasive Japanese beetle and Migratory bird Biomass using weather variables.

Information and technology (IT) infrastructure

A common challenge identified among all showcases is the need for increased data curation and better data interoperability and integration. In the birds showcase, non-standardised monitoring and the lack of a common workflow for data harmonisation caused by a diverse monitoring scheme's landscape were significant roadblocks in the creation of the EBBAFL EBV. In the habitat showcase, the need for better data curation and workflows was reflected in the lack of a common key defining habitat types across the EU or the lack of taxonomic knowledge to identify the species of interest, as shown for earthworms and mushrooms in the soils and fast-response monitoring showcases, respectively. Similarly, the fast-response monitoring showcase points out to improve data inventorying and integration to collect and harmonise ecological and biological data efficiently.

Solving this initial hurdle incurs in significant use of resources that vary depending on the taxonomic and geographic scale, but can be improved with automated routines for more cost-effective data streams as stated by the water framework showcase. Automation is also required for operational procedures that currently need manual implementation, as it is the case of the model periodic recalibration of weather variables based on new daily updated data to enable near real-time forecasts.

The workflows development in the showcases allowed for progress towards achieving the minimum requirements for EU-scale EBVs. Figure 5 represents the status before and after developing the showcases with regards to data collection networks, in-situ data access, spatial extent and resolution, temporal extent and resolution, in-situ data integration, data coverage, and model uncertainty.

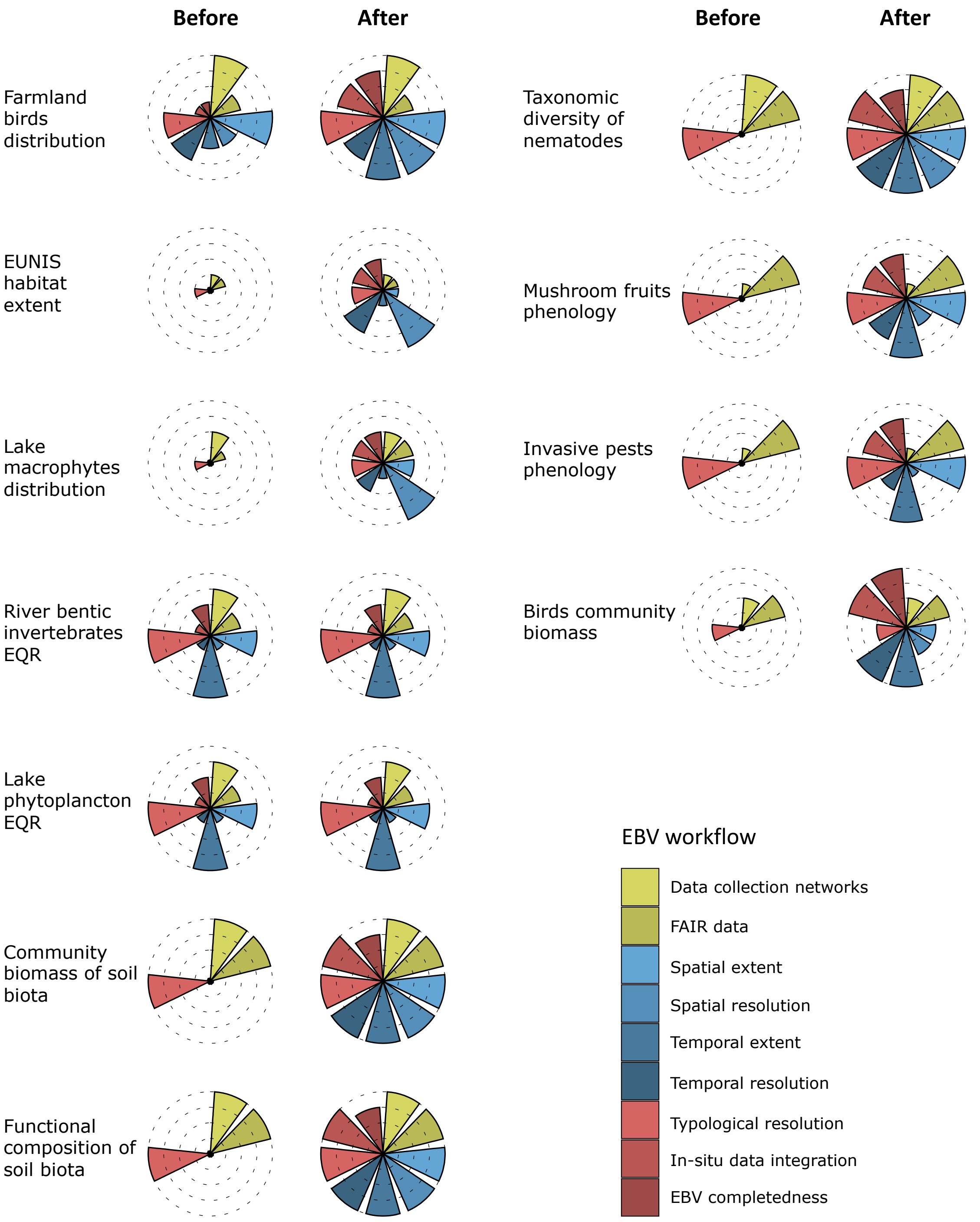

***Figure 5**. Progress in the Development of Essential Biodiversity Variables (EBVs). The spy-charts illustrate the progress on data collection (represented by metrics in green), EBV specifications (represented by metrics in blue), and data integration (represented by metrics in red), at the beginning (left) and at the conclusion (right) of each showcase. The inner dotted-circle indicates a score ranging from 1 to 4 for each metric. A score of 1 suggests that the available data significantly*

deviates from the specifications required to produce an EBV for a given metric. Conversely, a score of 4 indicates complete alignment with the specifications. Scores are presented in the Appendix.

4. Decision support: from Essential Biodiversity Variables to indicators

In order to fit its purpose of informing biodiversity assessments, the data contained in EBV cubes typically requires to be further processed to meet the demands of the different management and policy targets. Building on lessons learned in each of the EuropaBON showcases, we outline the use of EBVs under three broad categories: indicators aimed at detecting trends in the state of biodiversity; assessments that judge the condition (or status) of communities and ecosystems; and support for rapid-response decisions.

4.1. Assessing biodiversity trends

Trends in the spatial distribution of species and ecosystems may capture conservation threats and undesired biodiversity change. This principle is central to conservation objectives defined in terms of no-deterioration and recovery of species populations, such as in Goal A of the Kunming-Montreal Global Biodiversity Framework. The Habitats and Birds directives both draw on this principle since they require periodic reporting on the distribution of the listed species, so that changes in the distribution extent can be directly estimated to inform conservation progress assessments. Similarly, a reduction in the area of occupancy of listed habitats types may directly result in changes in the habitat conservation status. In all these cases, trend indicators can be directly derived at any spatial aggregation unit from the species and ecosystem distribution EBVs.

Farmland Birds Spatial Indicator

Trend assessments for European farmland birds exemplify the demand for more granular spatiotemporal information. Biodiversity trends indicators are often built through the aggregation of local change analyses repeated in space. The information they generate is bonded to the level of spatial aggregation (e.g., National, continental or global) and the indices typically cannot be disaggregated. The Farmland Bird Index (Gregory et al. 2005) is widely adopted to report on multi-species bird conservation status as one of the Streamlining

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European Biodiversity Indicators (SEBI) and it has been proposed for reporting on the restoration of agricultural systems under the European Nature Restoration Regulation proposal. However, the data aggregation makes its applicability limited when it comes to inferring spatial trends below the country level. The Farmland Birds EBV can cover this gap by adjusting the spatial and taxonomic scope for trend analysis addressing multiple needs.

This pilot showed that the existing network of bird monitoring could be used to update the breeding distributions of farmland birds at 10x10 km resolution by means of spatial distribution modelling techniques. This is the most important outcome of this showcase, which suggests that, at least for this group of species, the EBV distribution of terrestrial birds can be updated periodically. Modelling is essential as a procedure to update distributions since the comparison with the reference European Atlas (EBBA2; Keller et al. 2020) showed that maps based exclusively on monitoring data do not allow to generate observed distributions in a satisfactory manner, even at a coarse resolution of 50x50 km. Data gaps are identified, especially in the south-east of Europe, where further efforts to boost bird monitoring would be necessary. Robustly assessing changes in the probability of occurrence between consecutive periods of 5 years is more challenging than updating distributions. The results indicate that this can be also assessed using monitoring data, although probably not for species with restricted distribution or mostly occurring in areas of low monitoring data such as the south-east of Europe.

Moving forward, updated spatial information for farmland species included in the Farmland bird indicator would be the first step towards the availability of an indicator of farmland quality based on the combined relative abundance of farmland birds in Europe. However, the assessment of temporal changes in space requires extensive validation to disentangle observed local changes in abundance from changes in abundance derived from correlations with environmental variables related to species distributions. This distinction has an important relevance from a policy point of view and will require the deployment of spatial indicators of temporal change to develop clear interpretation guidelines allowing to assess the reliability in the changes inferred.

Towards ecosystem extent indicators

The Ecosystem EUNIS habitats EBV demonstrates successful mapping of the spatial distribution of community-level entities as binary presence/absence map or in terms of probability of occurrence (Álvarez-Martínez et al. 2018). However, beyond the current mapping capabilities, there is a need of establishing an additional framework related to monitoring short-term dynamics and trends of conservation status. This multiscale challenge lies on the availability of massive Earth Observation data collections. Remote Sensing (RS) has the capability of leveraging critical indicators to detect ecosystem disturbances and threats, vegetation dynamics, structural properties and functional traits, informing conservation strategies and tracking their effectiveness over time. The EuropaBON workflow includes a Change Detection Module that uses time-series of EO data to identify changes in the habitat extent at the pixel level, performing a temporal monitoring of structural and function variations of habitat types mapped. In this context, changes in the EBV can signal shifts in ecosystem dynamics, species composition, or habitat quality, providing valuable insights into emerging threats and allowing for timely intervention and restoration actions. The European Copernicus program represents a significant asset by providing readily available data for land dynamics assessment from Sentinel missions, including high-resolution datasets of biophysical measurements tailored for mapping EU habitats. For longer time series, NASA's satellite imagery and products may be used for retrospective change trend analysis, as their space missions date from the 1970s and 2000s.

One challenge is that the operational use of remote sensing for ecosystem monitoring lies in the complexity of data interpretation and integration. Additionally, the spatial and temporal resolutions of RS imagery may not always align with the scale of ecological processes, posing challenges in accurately capturing dynamic ecosystem changes. Habitats are not expected to change quickly; however, the current cycle of monitoring every six years is found to be too restrictive and mostly provides few details. In order to avoid regenerating each habitat map yearly, the EBV module identifies target areas where a change has been detected at the pixel level by using temporal series. Changes can be categorised in (i) abrupt changes (e.g. fires, harvested areas, deforestation, flooding) and (ii) gradual changes (e.g. due to climate change, invasive species or secondary succession dynamics of vegetation types). To this end, the time dimension must be taken into account and regular (monthly to seasonal) detection is required which is facilitated by the use of EO remote sensed data streams. Moreover, given that different sensors can capture different ecosystem processes and disturbances, multi-sensor information may facilitate the detection different changes.

One caveat is that noise and redundant information in RS data may lead to detecting irrelevant changes or even changes with no actual interest for change assessments (e.g., brightness, shadow casts not corrected typographical or colour differences). Therefore, ensuring the accuracy and reliability of EBVs derived from remote sensing data requires continuous validation and calibration efforts, which demand significant resources and expertise. Finally, interoperability issues among different data sources and platforms may impede seamless integration and standardization of monitoring protocols, limiting the scalability and effectiveness of such EBV-based ecosystem monitoring initiatives.

4.2. Assessing status

Status (or condition) assessments establish the conservation status of species and ecosystems as the distance between the current state and a pre-defined baseline state. For example, Ecological Quality Ratio (EQR) assessments can give information about water body quality for different biological groups. EQR-values are given on a gradient between 1 and 0 ranging from a system with undisturbed flora and fauna (EQR=1; baseline or reference conditions) to a fully degraded system (EQR=0; bad condition). Thus, EQR-values > 0.6 represent rivers and lakes which are considered in good or high status for a biological community, e.g., benthic invertebrates in rivers or phytoplankton in lakes. In those rivers and lakes, the biological communities mainly consist of species found in undisturbed conditions. In contrast, EQR-values < 0.6 represent rivers and lakes with moderate, poor or bad status, in which the biological communities are dominated by species that are more tolerant to disturbance by pollution or hydro-morphological habitat alteration.

In contrast with the previous group of indicators, ecological quality values cannot be interpreted independently from judgement-based decisions to define reference conditions. The spatiotemporal data cubes contain indicator values and not EBV metrics of community composition. Therefore, these EQR-based indicators cannot directly monitor trends in biodiversity metrics such as species richness and species turnover (Hillebrand et al. 2017).

Instead, locally collected species turnover data is used to calculate the community level deviation from the reference (baseline) state. This way, the reference quality approach allows comparing the status of very different water bodies on a common scale using data from the different water body monitoring programs that may come from different taxonomic groups (Moe et al. 2023). In principle, the same approach can be used also for assessing ecosystem condition for terrestrial biological groups, as long as the baseline can be identified.

Data aggregation-based condition indicators

The EQR-based EBVs measures the current condition of different biological communities in rivers and lakes. The community structure (= species composition) is measured by national indices developed from knowledge on species occurrences and preferences along pollution gradients, e.g., nutrient gradients in different types of rivers and lakes. These national indices and their thresholds between the high & good, as well as good & moderate status classes have been intercalibrated across countries sharing common types within a European geographical region, e.g., Northern, Central, Eastern, Mediterranean. This intercalibration provides comparable EQR-data across countries. This way, a series of data products have been developed by the ETC-BE showing the spatial distribution of status classes for each biological community and trends over time, including the amount of change over a certain period (2015-2021) (Moe et al. 2023). The spatial distribution of status classes is shown as interactive maps allowing the user to select the area and year, as well as water category (rivers or lakes for example) and the biological community of interest. These community structure EBVs have recently shown to correlate well with land-use variables, showing deterioration (lower EQR-values) with increasing proportion of agriculture and urban areas in the catchment of the rivers and lakes. Through regression tree analysis, the actual proportion of such areas that would decrease the EQR-values can be quantified. This would in the next step facilitate modelling of EQR-values based on land-use data in areas without biological observations.

Model-based condition indicators

The macrophytes species distribution EBV in Fennoscandian lakes was estimated using species distribution models (SDMs) based on lake area, alkalinity, water colour, total phosphorus (TP) and climate data (annual sum of degree-days) (Lyche-Solheim and et al. 2024). Such models may be used to estimate the optimum and tolerance of the species for individual co-variates

(Demars and Trémolières 2009). Starting with this data, three different types of spatially explicit indicators may be estimated sequentially:

Species status: SDMs allowed to estimate the probability of occurrence of macrophytes under varying pressures each stressor, such as under current TP conditions and optimum TP conditions for the species from water quality and climate variables. From such modelled data, species status indicators (Si) can therefore be estimated as the probability of species occurrence under current TP conditions relative to species optimum conditions:

$$S_i = \frac{O_i(current)}{O_i(optimum)}$$

with Oi the number of projected occupancies of species i under current TP conditions and optimum TP conditions in lake j. The geographical loss of a species due to non-optimal TP conditions can easily be mapped, highlighting which lake might benefit from a phosphorus abatement program.

Habitat status: predictions of geographical species loss would further allow to estimate the conservation status of habitats defined by reference macrophyte species. More robust habitats assessments may be reached by aggregating species status data for multiple characteristic species.

Lake status. The WFD defines lake status relative to reference conditions. SDMs allows to project individual species map of occurrence (Fig. 6). The stacking of these maps for current and reference TP conditions allows to produce list of species per lakes, from which weighted average indices may be calculated (Demars and Trémolières 2009). The ratio of the two indices (current / reference) provides an ecological quality ratio (EQR). Stacking the maps also allows to reveal changes in species richness and turnover (Fig. 6).

Major breakthroughs. The EBV cubes developed here works with continuous co-variates rather than lake typologies, removing some inherent uncertainties from categorical grouping. The species distribution approach can be used to characterise (i) species status assessment, habitat status assessment (HD, EUNIS) and lake status assessment. While the statistics may be complicated, simple maps may be produced readily usable for assessments.

Limitations. The species distribution models are empirical models based on the concept of realised niche and cannot be applied beyond the spatial extent and environmental space. Uncertainties of SDMs can be large. The most outstanding challenge at European extent is to have sufficient resources to increase data coverage with field surveys, curation (national databases) and sharing. The lack of access to the raw species data, used to calculate the (voluntarily) reported EQRs in WISE-2 EU portal, remains a major deadlock preventing novel EBVs to be developed.

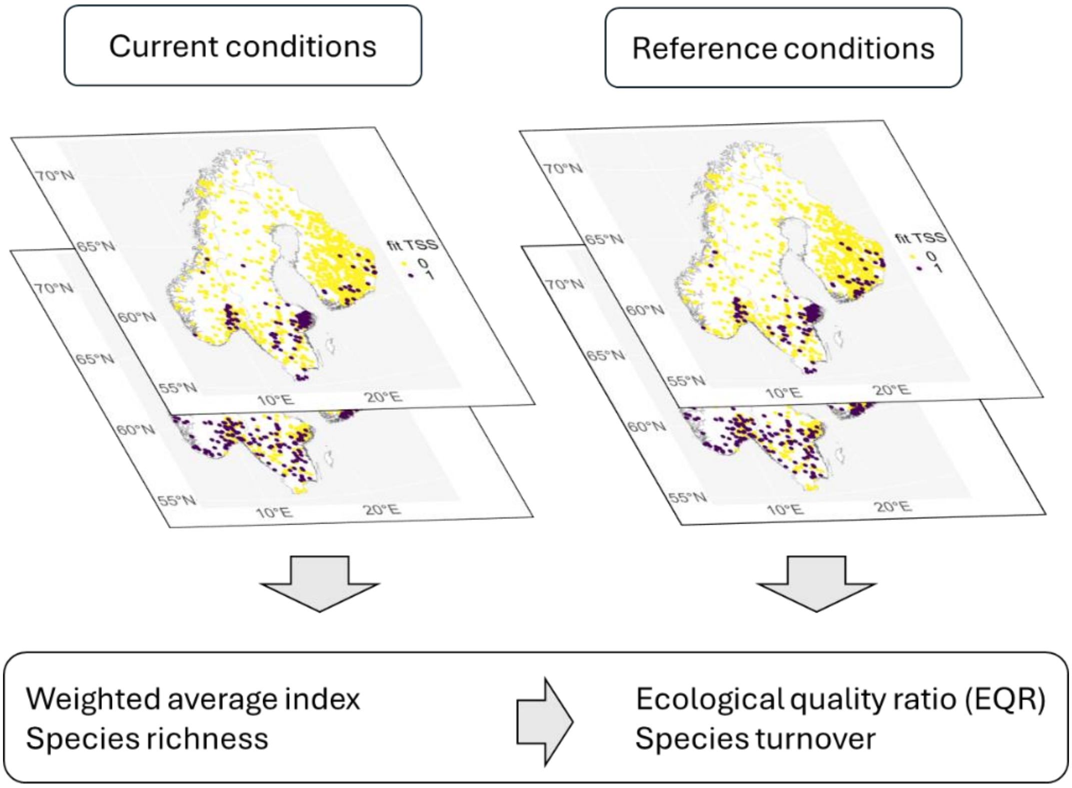

Figure 6. *Lake status assessment indicator. Stacking of species distribution models to produce a list of species per lake for current and reference conditions, from which weighted average indices and species richness may be calculated. The current/reference ratio of weighted average indices provides an ecological quality ratio (EQR), sensu EU WFD or community EBV (EuropaBon). The same ratio could be calculated using species richness. Another possible community indicator is the species turnover between the current and reference conditions.*

4.3. Forecasting biodiversity phenomena

Fast-response monitoring systems emerge as an alternative to optimise cost-efficient data management processes for end-users. For example, they allow for preparation and planning for economically relevant natural events, such as the arrival of migratory birds for birdwatching and ecotourism. They can also reduce food production costs by enabling early planning and management of pests and invasive species, thereby reducing the need for expensive mitigation processes of control and eradication. These systems aid in developing management plans around seasonal foraging on edible resources, providing alternative sustainable sources of income, particularly benefiting rural areas.

Short-term ecological and biological forecasts provide crucial insights for policy objectives, benefiting society by informing decisions across multiple sectors. Specifically, forecasts of Essential Biodiversity Variables (EBVs) and Essential Ecosystem Service Variables (EESVs) enable stakeholders to anticipate ecological changes and make proactive, informed choices that support conservation, economic activities, and human well-being. Highly sought-after forecasts include phenology stages of problematic species such as agricultural and forest pests, commercially valuable wild species like peak berry or mushroom production, and the activity levels of taxa relevant for air and road traffic safety. EBV-based near-real-time monitoring demonstrated the capacity to produce these forecasts using correlative-based approaches, leveraging the increasing streams of biodiversity observation data available. When coupled with gridded weather forecast data, the models demonstrated a confirmed ability to predict these phenomena several days into the future.

Despite their significant potential in decision-making and societal benefits, the development and operationalization of short-term ecological forecasts face substantial challenges. A central issue is the availability of data for calibrating computational models that predict ecological phenomena. Most models use complex process-based approaches, requiring in-depth mechanistic knowledge of the factors driving the dynamics of forecasted phenomena. However, this approach heavily relies on detailed experimental-based knowledge, which is only available for a limited number of taxa. Additionally, these models suffer from scalability issues, being species-specialized and of limited reusability, thus requiring significant resources for each new model developed. As a result, the vast majority of biological or ecological phenomena of interest for forecasting remain unaddressed.

The workflows demonstrated should be able to proceed for operational use across a high number of phenomena and regions, but a few challenges persist for their wider and sustained use. Key limitations include the coarse spatial resolution and limited forecast horizon of the produced forecasts (up to 10 days), primarily due to constraints in available input data like weather forecasts. Model uncertainty can also be significant and should be clearly communicated to end-users, for instance through reports of inter-model variability accompanying each forecast. Increased automation in data collection and pre-processing would enhance operational efficiency, as essential components like model calibration updates remain manually executed. Moreover, integration of high-quality, but restricted-access weather data from ECMWF could improve forecasts, yet current workflows do not include these data due to accessibility issues. Additionally, the sustainability and operational functionality of these workflows critically depend on the availability of dedicated personnel and robust IT infrastructure.

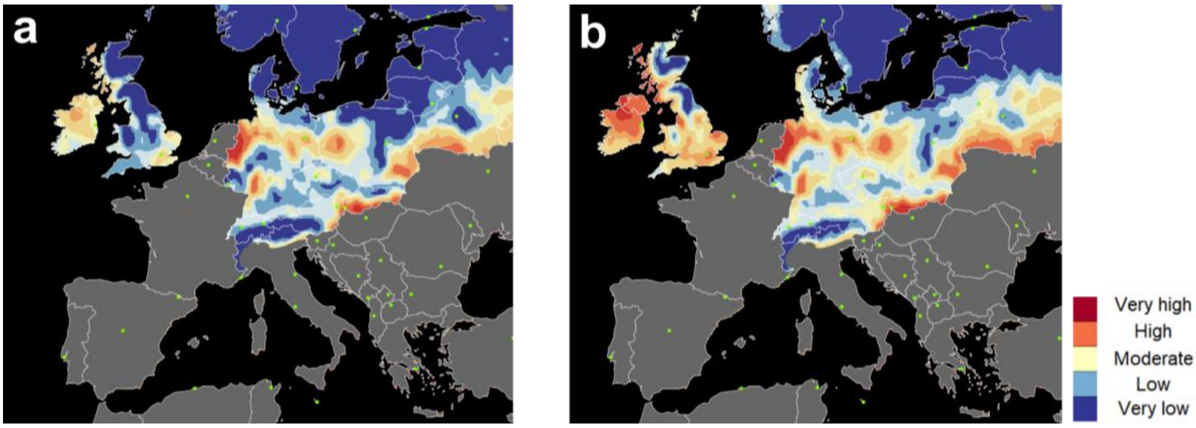

Figure 7. Forecasts of the probability of occurrence of the garden lupine (Lupinus polyphyllus), an alien invasive plant in the EU, in its flowering stage. The forecasts refer to the average probabilities predicted for April 29, 2024, to May 1, 2024 (a), and from May 2, 2024, to May 4, 2024 (b). The forecasts were produced on April 26, 2024.

4.4. Projecting biodiversity

Transitioning from EBVs to actionable indicators that support policy requires a focus on representing and quantifying the status and trends of biodiversity, especially in soil ecosystems due to its complexity and ecological importance in terrestrial systems. Soil EBVs, derived from direct observations and measurements, reflect key aspects of biodiversity such as taxonomic diversity, functional diversity, soil basal respiration, and microbial biomass, and provide insights into the health and sustainability of soil ecosystems, which are critical for biodiversity conservation. These EBVs can be directly translated into indicators that inform policy decisions by assessing ecological conditions, changes, and impacts of management interventions. The process involves standardising data collection methodologies, integrating multiple data sources, developing statistical and spatial models, engaging stakeholders, and aligning indicators with specific policy goals, as the ones outlined in the EU Biodiversity Strategy for 2030 but also in the EU climate neutrality policy for 2050. Soil EBVs provide a robust framework for monitoring and evaluating the biological richness and ecological health of soil, which is fundamental to ecosystem services such as carbon storage, water filtration, and plant growth support.

Spatial modelling can be used to predict how future changes in land use or climate might impact soil biodiversity and ecosystem functions (Figure 8), thereby informing conservation strategies and land management policies. Stakeholder engagement, including policymakers, conservationists, land managers, and the scientific community, is then fundamental in this process to ensure that the data produced is relevant and practically applicable. This engagement also facilitates the dissemination and implementation of findings, enhancing the likelihood of achieving biodiversity conservation goals.

Aligning the design of biodiversity indicators with policy goals is essential for their effective implementation and monitoring. To effectively apply these indicators, they must be tailored to support specific policy objectives, enabling policymakers to make informed decisions using accurate and up-to-date information. Based on a wide array of soil EBVs, we developed a soil restoration indicator that can be easily used to identify soil restoration needs and, more importantly, which variables require special attention. While the integration of EBVs into policy frameworks faces several challenges, including the complexity of data collection and analysis, existing data gaps, and the uncertainties associated with predictive models, our framework accounts for at least part of these uncertainties by using probabilistic models to infer the restoration potential. Furthermore, by regularly assessing the impact of various conservation strategies through the monitoring of specific EBVs, policymakers can make necessary adjustments to enhance their effectiveness, ensuring that conservation and restoration efforts are both responsive and adaptive. By evaluating the resilience and recovery potential of ecosystems, particularly soil systems, stakeholders can identify areas that are most likely to benefit from restoration activities, optimise resource allocation, and implement effective conservation strategies. Our indicator is based on a range of soil properties and ecological dynamics, including biodiversity metrics, such as taxonomic and functional diversity, soil stability and fertility, and other biological or chemical processes crucial to ecosystem functioning. The restoration potential indicator helps by providing a quantifiable measure of an ecosystem's ability to return to a functional state after disturbance, thus guiding policy and conservation actions to where they can be most effective. These projections enable policymakers and conservationists to anticipate changes in the proposed indicators but also at the level of individual EBVs due to various factors like climate change, land-use change, and other anthropogenic pressures. By understanding these dynamics, it is possible to implement proactive land management approaches that can mitigate potential risks and capitalise on opportunities to enhance ecosystem resilience and functionality.

Moving forward, spatial data on biodiversity variables allow for the mapping of biodiversity hotspots and areas of ecological significance. This capability is particularly important in the European context, where diverse landscapes and diverse ecological zones exist across the continent. The integration of such projections into spatial planning and policy development further supports the EU's commitment to sustainable development and climate action, particularly when related to soils.

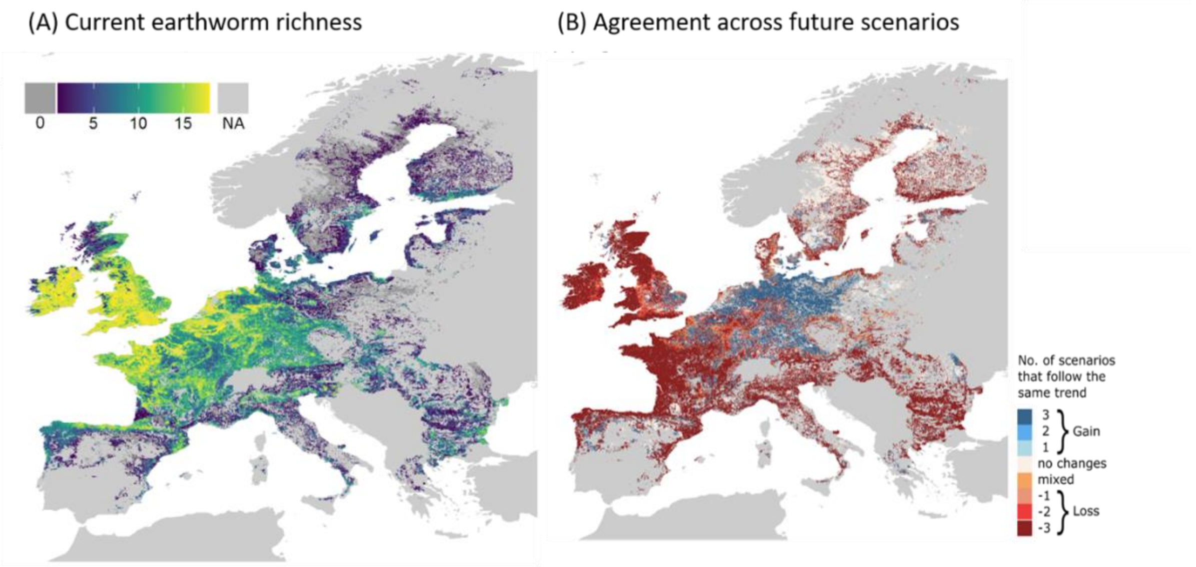

Figure 8. Output map for the EBV Taxonomic diversity of soil biota represented by earthworm species richness. (A) Spatial distribution of the current predicted overall species richness calculated as the number of species present with a probability higher than the species-specific threshold with maximum TSS value. Dark grey areas indicate species richness values of 0. (B) Agreement across the 3 different Shared Socioeconomic Pathway (SSP) scenarios used to anticipate and mitigate the effects of climate change on the range of specific earthworm species. Gain represents areas in which gain of species richness is predicted in 3/2/1 scenarios, while remaining scenarios predict no change; loss represents areas in which loss is predicted, and mixed represents areas in which different scenarios predict gain and loss. Light grey areas were not predicted based on the extent of the environmental dataset. Modified from (Zeiss et al. 2024).

5. Concluding remarks

Together with experts and stakeholders, EuropaBON have identified a thorough list of EBVs with their respective specifications to comprehensively monitor and assess European biodiversity change (Junker et al. 2023). The showcase EBVs represent a benchmark against which the current capacities to advance such EBV products can be evaluated (Table 1). The following conclusions can be extracted:

- European-scale coverage with sufficient spatial and temporal resolution matching the needs can be readily achieved for species distributions of selected terrestrial birds, as demonstrated with the Farmland Birds EBV. The EBVs monitoring fructification phenology of mushrooms and the aerial biomass of migrating birds similarly cover most of these specifications. However, the capacity to extend the taxonomic coverage using similar workflows may be constrained by reduced availability of in-situ data. For example, PECBMS includes only common terrestrial and wetland birds, while bird distribution EBVs are required encompassing threatened and rare species listed under the BD. Mushroom data accessible in GBIF is strongly biased towards species best known to the public and therefore reliable forecasts may be limited to those.

- Regional wall-to-wall habitats mapping could be achieved at sufficient resolution through in-situ and remote sensing data fusion thanks to a dense collection of systematic vegetation survey data. However, upscaling the approach at the European level requires breakthroughs in the collection and mobilization of data, as well as in harmonizing habitat definitions, which currently do not exist.
- Indicators such as the WFD Ecological Quality Ratios are produced at National and subnational levels using large amounts of systematic collected data on aquatic plant, invertebrate, and plankton communities. Although this georeferenced data holds great potential to produce species and community composition EBVs, only EQRs are openly available. The raw data are normally stored in National or regional databases not publicly available. Unlocking such data holds great potential to develop novel EBVs and biodiversity indicators as illustrated with the Macrophyte Species EBV.
- Given a generalized lack of time-series and re-survey biodiversity data, space-by-time modelling substitution approaches represent an alternative to generate spatiotemporal EBV cubes. Such approaches allow for projecting biodiversity change driven by climate change, as illustrated with the soil taxonomic diversity models (Zeiss et al. 2024). Uncertainty associated to the critical assumption, i.e., that temporal biodiversity responses to environmental change are analogous to spatial species–environment patterns, needs thorough evaluation.

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Appendix

Table A1. Scoring criteria used to assess the maturity of the EBV workflows (see Figure 5)

SCORING CRITERIA	**1 Low maturity**	**2 Proof of concept**	**3 EBV vision partly achieved**	**4 EBV vision fully achieved in EU**
IN SITU DATA COLLECTION				
Data collection networks	Most data comes from uncoordinated initiatives (e.g., research projects, local isolated monitoring etc)	Partial coordination of data collection already exists. E.g., in some regions or countries, among certain institutions, etc	National and/or sub-national coordination already exists in =>50% of the EU area	EU-level coordination of data collection
FAIR data	Most raw data has restricted access and does not follow any data and metadata standard	Raw data may be findable and/or accessible, but lacks standards and/or it is predominantly not interoperable among multiple sources	Data adheres to FAIR principles	In addition to FAIR, the data is open-access (e.g., linked open-access with persistent identifiers so that anyone can reuse the data)
EBV CHARACTERISTICS				
Spatial extent	Subnational (including also sub-regions within one or several countries)	Full national coverage in one or several countries	Supra-national coverage in => 50% of the EU area	Full EU coverage
Spatial resolution	Lower than the specification of the EBV list by one order of magnitude or more	Lower than the specifications of the EuropaBON EBV list	Partly meets the specifications of the EuropaBON EBV list (e.g., in most but not all of the spatial extent)	Meets the specifications of the EuropaBON EBV list
Temporal resolution	Snapshot (i.e, no time series)	Lower than the specifications of the EuropaBON EBV list	Partly meets the specifications of the EuropaBON EBV list	Meets the specifications of the EuropaBON EBV list
Typological scope and resolution	Low taxonomic or typological resolution (i.e., information is taxonomically /typologically aggregated and cannot be extracted at the highest taxonomic or typological levels that the EBV may address)	Lower than the specifications of the EuropaBON EBV List, with only one or few biological entities included at the moment	Entity meets the specifications of the EuropaBON EBV list including => 50% of the relevant biological entities	Entity meets the specifications of the EuropaBON EBV list

Table A1 *(Continued)*

SCORING CRITERIA	1 Low maturity	2 Proof of concept	3 EBV vision partly achieved	4 EBV vision fully achieved in EU
DATA INTEGRATION				
in-situ data integration	The available in-situ data lacks integration, or ithas serious limitations precluding harmonisation	Partly comparable and harmonised data exists in some countries or regions	Fully comparable and harmonised data for => 50% EU	Fully comparable and harmonised data covering EU and stored in authoritative repositories
EBV completedness	No wall-to-wall EBV cube has been produced	Some model-based integration has been used but insufficient to cover both spatial and temporal information gaps and biases	Spatiotemporal information gaps and biases addressed, e.g., using model-based EBV estimation. Partial coverage of the biological entities as described in the EuorpaBON EBV list	Spatiotemporal information gaps and biases addressed, e.g., using model-based EBV estimation. Full coverage of the biological entities as described in the EuorpaBON EBV list
EBV usability	The EBV is not currently usable to assess biodiversity change and condition	Readily usable EBV cube for estimating one or few particular types of indicators. Performance for monitoring change has not been systematically assessed	Readily usable EBV cube for multiple types of indicators, including uncertainty estimates. The performance for monitoring change has not been systematically assessed	Readily usable EBV cube for multiple types of indicators, including undertainty estimates. The performance for monitoring change has been systematically assessed

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