Submitted manuscript, not yet peer-reviewed

Towards a modern and efficient European biodiversity observation network fit for multiple policies

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Funding information

This work was funded by the European Union’s Horizon 2020 research and innovation programme (grant agreement No 101003553). Views and opinions expressed are those of the author(s) and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. A.M.O. was financially supported by the Biodiversa+ project PrioritIce (grant No 31BD30_209629), and L.B. and D.V. acknowledge funding from the European Union's Horizon Europe Research and Innovation Programme for the BioAgora project (grant agreement No. 101059438).

Open research statement

The following data are already publicly available:

- The list of selected Essential Biodiversity Variables (EBVs) as identified by the EuropaBON project is available from GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki)
- Descriptions of EBV workflows as collected during the EuropaBON online workshop on EBV workflows (February 2023) are available from the Zenodo repository (https://zenodo.org/doi/10.5281/zenodo.10680435)

The following data are not yet provided, but will be permanently archived on the open Zenodo repository if the paper is accepted for publication:

- Raw data and metadata used to generate Figure 3, 4, 6, 8, 9, and 11–15
- Raw data and metadata used for the cost estimation (Appendix S2 and S3, Table 5 & 6)

No code has been used for this study.

Abstract (349/350 words)

To address the biodiversity crisis, global and regional policy frameworks like the Kunming-Montreal Global Biodiversity Framework and the European Green Deal demand to monitor biodiversity. Despite these efforts, existing approaches for monitoring biodiversity remain fragmented and lack data integration. Here, we review and synthesize crucial information for developing an integrated European-wide biodiversity monitoring framework using Essential Biodiversity Variables (EBVs), with the aim to improve data coverage, enhance transnational coordination, adopt advanced technologies, and better inform environmental policies. Using a participatory approach involving over 1500 stakeholders, we prioritized EBVs for assessing biodiversity status and trends and supporting European policies, identified relevant monitoring technologies, developed recommendations for a spatial sampling design, and estimated the costs of implementing a continent-wide biodiversity observation network that covers terrestrial, freshwater, and marine ecosystems. A total of 84 EBVs addressing genetic, species, community and ecosystem-level biodiversity attributes were prioritized. A broad range of monitoring methods is required, especially structured in-situ monitoring schemes and satellite and airborne remote sensing, complemented with citizen science observations, DNA-based methods, digital sensors, and biological observations derived from weather radar. Our suggestions for a more effective spatial sampling design ensure a broad representation of European biodiversity, especially through stratified random sampling, incorporation of existing monitoring sites, filling of spatial gaps, and co-location of monitoring activities. Developing the prioritized EBVs will require to integrate multiple biodiversity data streams, apply advanced modelling techniques for gap-filling, and account for different sources of uncertainty. A digital infrastructure is required with supporting services, and with data being shared using interoperable standards and published on open platforms. The costs of such a European biodiversity observation network were estimated to be at least 5.7 billion Euro over 10 years, including initial investments and annual maintenance. A European Biodiversity Observation Coordination Centre (EBOCC) is needed to coordinate monitoring activities and data management. The network's benefits for addressing multiple policies, including improved ecosystem services, will by far outweigh the expenses involved in establishing and maintaining the entire network. The illustrated co-design offers a scalable model for developing biodiversity monitoring networks in other continents, with potential adaptations to local policies and conditions.

KEYWORDS (6–12)

biodiversity policy, community composition, cost effectiveness, data cubes, ecosystem functioning, ecosystem structure, genetic composition, monitoring, multi-taxa biodiversity assessments, species populations, stakeholder co-creation, stratified random sampling

INTRODUCTION

Drastic biodiversity declines have been documented over the last decades (Hallmann et al. 2017, Mancini et al. 2023, Rigal et al. 2023) which can significantly affect ecosystem services and the people that depend on them (Díaz et al. 2019). The political and societal awareness of the biodiversity crisis has led to a range of global, regional and national policies and initiatives aimed at reverting biodiversity loss, including the European Green Deal and the Kunming-Montreal Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD). However, efforts to monitor biodiversity are often spatially and temporally fragmented, taxonomically biased, and lack integration (Proença et al. 2017). Many policies, action plans, programmes and initiatives require unbiased, integrated and regularly updated biodiversity data, which are currently not available. There is thus a gap between the biodiversity data needs of policymakers and authorities responsible for policy implementation on the one hand, and the existing reporting streams and data sources on the other.

The European Union has responded to this need by giving the EuropaBON project the mandate to design an EU-wide framework for monitoring biodiversity (Pereira et al. 2022). The project harnesses the concept of Essential Biodiversity Variables (EBVs) (Pereira et al. 2013) to define a minimum set of variables for monitoring biodiversity from genes to ecosystems in freshwater, marine and terrestrial realms, and to increase the availability of data and knowledge for informing, implementing and evaluating environmental policies in Europe. This modern monitoring system should better integrate different biodiversity reporting streams and data sources, and improve existing monitoring schemes to become spatially and taxonomically more representative, and with a better temporal resolution. To achieve this, we have engaged a large amount and diverse group of stakeholders to identify user and policy needs for biodiversity monitoring. Moreover, we have identified a list of EBVs for monitoring biodiversity change, quantified current monitoring gaps and bottlenecks in data streams, and specified the costs of different monitoring networks. Here, we summarize how a cost-efficient European Biodiversity Observation Network could be developed that covers EBVs in the freshwater, marine and terrestrial realms, that builds on both in-situ and remote sensing data, and integrates novel technologies to deliver more complete and less biased biodiversity information with relevance for multiple EU policies. Below, we (1) first review the biodiversity monitoring landscape in Europe, (2) then present the framework for co-designing the network, (3) explain what should be monitored, why and how, (4) suggest recommendations for a spatial sampling design, (5) perform a comprehensive assessment of the staff and material costs in terms of data collection, workflows and coordination, and (6) finally discuss the scalability and transferability of the monitoring design to other continents.

BIODIVERSITY MONITORING LANDSCAPE IN EUROPE

EU policy context

The policy framework in the EU has been built over the past four decades with various legislations that are relevant for biodiversity monitoring and assessments (Figure 1a). These policies entail a wide spectrum of goals, legally binding or voluntary targets, and specific commitments at EU and global level in terms of financing and implementation (Table 1). The backbone of the biodiversity policy is formed by four main directives, namely the Birds Directive (BD), the Habitats Directive (HD), the Water Framework Directive (WFD) and the Marine

Strategy Framework Directive (MSFD). Those are among the first environmental laws in the EU (Figure 1a). These have been recently complemented with other main directives such as the EU Biodiversity Strategy for 2030 and the Nature Restoration Law (Figure 1a). In addition, several policies aim to preserve and maintain ecosystem services (e.g. the Pollinators Initiative) or require a monitoring framework for particular groups of species (Table 1), such as the Regulation on Invasive Alien Species (IAS), the Common Fisheries Policy (CFP), and the Common Agricultural Policy (CAP).

The BD and HD constitute the legal basis for the Natura 2000 network (Table 1). The reporting to these directives also supports the European Red List of Threatened Species, developed independently by the International Union for Conservation of Nature (IUCN) as an overview of the conservation status of species. At a global level, the CBD, the Ramsar Convention on Wetlands, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITIES), the Convention on Migratory Species (CMS), the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), and several Regional Seas Conventions play an important role for the conservation of species and habitats.

The WFD and the MSFD set quality objectives for freshwater and marine ecosystems. Together with other environmental policies —such as the National Emission Ceilings Directive (NECD) and the Proposed Directive on Soil Monitoring and Resilience (SML) (Table 1)— they focus on the ecological and chemical status of ecosystems and their services, i.e. on water, air and soil pollution and protection. Since these policies include biodiversity criteria and biological quality elements, they are also relevant for biodiversity monitoring and assessing the impacts of human pressures and measures to reduce pressures on species and ecosystems in rivers, lakes, transitional, coastal, and marine waters.

In 2024, a new nature restoration law (NRL) has been adopted with multiple binding restoration targets to achieve the recovery of nature across the EU's land and sea areas (Table 1). In addition, the European Commission is preparing a series of new policy initiatives which have been proposed in 2022–2023 (Figure 1a). This includes a regulation on ecosystem accounting (EEA-EA), a forest monitoring regulation (FMR), and a directive on soil monitoring and resilience (SML) (Table 1). The NRL and the proposed regulations and directives will make the monitoring of specific biodiversity and ecosystem indicators mandatory and further extend the existing monitoring framework.

Current challenges

Reporting reliable biodiversity trends across Europe is currently challenged by (1) monitoring gaps, (2) insufficient data integration, and (3) insufficient resources (Figure 1b). Monitoring gaps remain a key challenge because the spatial coverage, monitoring frequency, and representation of taxa and ecosystem types are insufficient for reliable assessments of status and trends (Morán-Ordóñez et al. 2023a, Santana et al. 2023, Moersberger et al. 2024). Although thousands of different monitoring schemes and programmes exist in the EU, the density of sampling sites and the temporal coverage of observations is currently too low to detect reliable trends (Santana et al. 2023, Valdez et al. 2023). Moreover, the taxonomic coverage is incomplete (Morán-Ordóñez et al. 2023a, Santana et al. 2023) and large gaps exist in occurrence information for policy-relevant species, especially in Eastern and South-eastern European countries (Wetzel et al. 2018, Santana et al. 2023). For many freshwater and terrestrial taxa (e.g. zooplankton, lichens, dragonflies, terrestrial arthropods, fungi, or crops pests), there are currently no coordinated monitoring programmes at the European scale. Monitoring data in European marine waters are also fragmented and regionalised (e.g., Northeast Atlantic region, Baltic Sea), and biodiversity data from Southern and Eastern European waters are limited (Morán-Ordóñez et al. 2023a).

The underlying data from different monitoring schemes, programmes, agencies and infrastructures are rarely integrated across Europe (Morán-Ordóñez et al. 2023a) and hence are not easily accessible (Wetzel et al. 2018). For regulatory monitoring —which is typically carried out by regional and national environment agencies that are responsible for the reporting to the BD, HD, WFD and MSFD— aggregated data and information from regional and national reports (e.g. qualitative indicators on status and trends of species and habitats) are compiled and made available by the European Environmental Agency (EEA), but the underlying raw data are not reported to the EU level. For instance, biological monitoring data from aquatic ecosystems are collected in the context of the WFD and are then aggregated by the national agencies before reporting to the EEA through the Water Information System for Europe (WISE, https://water.europa.eu/). The ecological status class data for each biological quality element are reported once every six years when the River Basin Management Plans (RBMPs) are updated for each River Basin District (RBD), which currently holds data from more than 100,000 water bodies in all EU countries and Norway. These data can be used to assess spatial variation of ecological status and change from one six-year cycle to the next, but are not suitable to use for trend analysis. EEA also requests more detailed and quantitative data annually on Ecological Quality Ratios, EQRs, including 13,000 waterbodies in 26 countries from the reporting years 2011–2021 (Moe et al. 2023). The EQR-values, which measure deviation from reference condition on a harmonised scale from 1 (no deviation) to 0 (totally damaged ecosystem), can be used to assess trends both between and within status classes for consistent time series. However, only a small fraction (ca. 10–15%) of the reported water bodies have such time series of EQR-data. This raises concerns about spatial representativity of the trends. While the reporting of EQRs follows strict guidelines and quality assurance rules, the underlying raw data (e.g. species, genus or family occurrence and abundance records of phytoplankton, macrophytes, phytobenthos, benthic invertebrates, and fish in rivers and lakes) are only stored at national or subnational/regional level. Hence, the lack of data flows, web tools and apps to facilitate raw data harmonization and integration remains a major bottleneck for making raw data from regulatory monitoring accessible and reusable (Morán-Ordóñez et al. 2023a).

Besides regulatory monitoring, a large number of monitoring programmes in the EU are effectively coordinated by NGOs, research organisations and governmental institutions (Morán-Ordóñez et al. 2023b). Such monitoring programmes typically use standardized sampling protocols for data collection and sometimes have data integration nodes at the sub-national, national, supra-national and European level (Morán-Ordóñez et al. 2023b). Prominent examples of monitoring schemes with European-level integration initiatives are the Pan-European Common Bird Monitoring Scheme (PECBMS), the European Butterfly Monitoring Scheme (eBMS), and the European Vegetation Archive (EVA) (Van Swaay et al. 2019, Morán-Ordóñez et al. 2023b, Rigal et al. 2023, Knollová et al. 2024). Such data are used to derive indicators and trends of common species or selected species in particular habitats (e.g. forest, farmland) and can thus inform policy makers about progress towards biodiversity targets and sustainable development goals of the EU. Despite such efforts, data sharing is often restricted due to a lack of long-term funding, especially for non-governmental organisations.

Insufficient resources and major funding limitations continue to be a key challenge for biodiversity monitoring in the EU, especially because no long-term funding is guaranteed for NGOs which effectively coordinate a number of monitoring programmes in the EU (Moersberger et al. 2024). In-situ monitoring is often labour-intensive and requires substantial human resources. This includes capacity building and training of volunteers, paying for the time, skills and knowledge of experts to maintain monitoring schemes, hiring specialists (e.g. technicians, taxonomists, Information Technology [IT] professionals) and creating and maintaining IT infrastructure and databases (Morán-Ordóñez et al. 2023a). Financial constraints (e.g. limited funding for long-term monitoring efforts) and a lack of human resources and technical capacities (e.g. regarding competence in specific methods, data analysis, and new technologies) are therefore a key challenge for biodiversity monitoring in many EU countries (Moersberger et al. 2024). Coordination at subnational, national and EU levels is currently insufficiently funded to support the harmonisation and sharing of data (Moersberger et al. 2024). This includes the lack of long-term policies on biodiversity monitoring in several countries. Many recent achievements of European-level integration initiatives have been funded via competitive calls (e.g., LIFE and BiodivERsA projects) or with sporadic and short-term contributions from private foundations (2–3 years), rather than through structural or permanent funds (Morán-Ordóñez et al. 2023a).

Major needs

Based on a comprehensive stakeholder engagement process (Moersberger et al. 2024), five major needs have been identified to address the challenges for building a European Biodiversity Observation Network. These are related to coordination, data, methods, capacity, and resources (Figure 1c). First, coordination and cooperation of monitoring efforts need to be enhanced to better unite the fragmented biodiversity data landscape in the EU. This may involve a better synchronisation of data collection, an improved coordination of biodiversity monitoring across EU member states, and a common platform that can integrate data and provide monitoring protocols and guidelines where needed (Moersberger et al. 2024). Second, data collection, integration and sharing needs to be improved at national and EU level. More data flows from local data collectors to (sub-)national agencies and European integration nodes need to be established with standardized data entries, harmonized data formats, and (semi-) automated data flows, enforcing technical interoperability and findable, accessible, interoperable and reusable (FAIR) data among different databases and platforms (Morán-Ordóñez et al. 2023a, Moersberger et al. 2024). Third, making use of novel methods and monitoring technologies is of vital importance to expand the extent and resolution of biodiversity monitoring (Besson et al. 2022). This can include microphones and digital cameras with artificial intelligence (AI) approaches, high-throughput sequencing of environmental DNA (eDNA), and various remote sensing approaches (e.g. weather radars, drones, satellites). Fourth, an increase in capacity building and human resources is urgently needed. This includes training of taxonomic experts and citizen scientists, knowledge exchange, and financial support of natural history societies (Moersberger et al. 2024). Finally, more financial resources and secured long-term funding are needed to allow the maintenance of monitoring programmes, expand the geographic coverage of monitoring, as well as its temporal resolution (Santana et al. 2023), and increase cross-country, cross-institutional, and cross-sectoral coordination (Moersberger et al. 2024). This can include public funding complemented by investments from the private sector to unlock public funds, and long-term public-private partnerships (PPPs) to help mobilising other financial resources.

FRAMEWORK FOR CO-DESIGNING THE EUROPEAN BIODIVERSITY OBSERVATION NETWORK

Stakeholder network

To co-design the European Biodiversity Observation Network, we adopted the approach for developing coordinated Biodiversity Observation Networks (BONs) from the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Navarro et al. 2017, Gonzalez et al. 2023). This approach emphasizes the co-design with stakeholders at all stages of the BON development, from the assessment of current monitoring to the implementation of new designs. Specifically, we have engaged stakeholders from terrestrial, freshwater, and marine realms to (1) identify user and policy needs for biodiversity monitoring (Moersberger et al. 2024), (2) identify policy-relevant priority variables for monitoring biodiversity change across Europe (Junker et al. 2023), (3) assess current monitoring efforts to identify gaps and workflow bottlenecks (Morán-Ordóñez et al. 2023a, Santana et al. 2023), (4) specify the role of novel monitoring technologies (Dornelas et al. 2023), (5) develop EBV workflows with policy relevance (Lumbierres and Kissling 2023), (6) analyse cost-effectiveness of different monitoring schemes (Breeze et al. 2023), and (7) define the scope and tasks of a European Biodiversity Observation Coordination Centre (EBOCC).

Within just 3.5 years (2020–2024), we have developed an extensive stakeholder network (Figure 2a). More than 1500 members from >650 organisations have engaged with the project, especially from academia, but also representing governmental organisations, NGOs, private industry, citizens science and other occupational sectors (Figure 2a). The policy interest of members is focused on the main EU legislation on biodiversity, but also on ecosystem services policies and other EU policies (Figure 2a). The stakeholder network also represents a wide geographic coverage, with most members coming from western and southern European countries (Figure 2a). The stakeholder engagement process was comprised of conferences and expert meetings, online surveys, semi-structured interviews, and several expert workshops (Moersberger et al. 2024). Most workshop participants were typically from the academic sector, followed by representatives of governmental organisations, NGOs, and the private industry. Interviews and surveys were targeted to specific stakeholder groups, such as the national contact points of the European Environment Information and Observation Network (Eionet), EU policy bodies, or other relevant experts working at the interface of biodiversity monitoring and policy (Moersberger et al. 2024). Feedback and input were also obtained from high-level policy representatives in the EU, including the Commission's Directorate-General for Research and Innovation (DG RTD), the Directorate-General for the Environment (DG ENV), the Directorate-General for Agriculture and Rural Development (DG AGRI), the Directorate-General for the Maritime Affairs and Fisheries (DG MARE), the Directorate-General for Regional and Urban Policy (DG REGIO), the Joint Research Centre (JRC), the EEA and Eurostat.

Essential biodiversity variables

To identify priority variables for monitoring biodiversity change across Europe, we have adopted the concept of EBVs initially proposed by GEO BON (Pereira et al. 2013). The key idea of the EBV framework is to measure the state of species and ecosystems with biological variables that can capture the major dimensions of biodiversity change, i.e. a minimum set of measurements that are complementary to each other (Pereira et al. 2013). Major biodiversity dimensions are represented by six EBV classes (Figure 2b) which either cover similarities and differences within species (i.e. species-focused EBV classes such as genetic composition, species populations, and species traits) or within whole biological communities and ecosystems (i.e. ecosystem-focused EBV classes such as community composition, ecosystem functioning or ecosystem structure). We identified specific EBVs to measure Europe's biodiversity change across multiple dimensions in space and time, including species-focused EBVs (e.g. 'Genetic diversity of selected terrestrial taxa', 'Species distribution of marine turtles' or 'Phenology of migration of freshwater fishes') and ecosystem-focused EBVs (e.g. 'Community biomass of soil microbes', 'Harmful marine algal blooms' or 'Structural complexity of riparian habitats'). EBVs were separately identified for the freshwater, marine, and terrestrial realms (Figure 3a) because these components of the biosphere differ fundamentally in ecosystem organisation and function (Keith et al. 2022).

The specification of EBVs also included the spatial and temporal resolution for each EBV (Figure 2b), for instance, the grid cell size (e.g. 1 × 1 km), spatial unit (e.g. lake or river segment) and temporal frequency (e.g. annually or every 6 years) at which the modelled EBV data (not the raw observations) would be available (Junker et al. 2023). The EBVs were also chosen to represent a range of taxonomic groups and habitats (Figure 2b), including specific plant groups (e.g. vascular plants, trees, lichens, phytoplankton, macrophytes, macroalgae, phytobenthos), vertebrates (birds, mammals, reptiles, amphibians, fish), invertebrates (pollinators, dragonflies, zooplankton, bivalves etc.), other types of organisms (bacteria, fungi, protozoa, etc.), or a combination of taxa (e.g., alien invasive species, disease vectors, crop pests).

The identification and selection of specific EBVs within each EBV class and for each realm was based on a comprehensive stakeholder engagement process (Junker et al. 2023). This included two workshops, surveys, semi-structured interviews, consultations of experts and in-person meetings with representatives from relevant EU Commission Services and other EU agencies (Junker et al. 2023). In addition, one-to-one consultations with project-internal and external experts were held to add definitions and metrics for each EBV, to revise EBV names and their spatial and temporal resolutions, and to provide details on the taxonomic scope and ecosystem focus of each identified EBV. The EBV list also repeatedly underwent internal reviews to remove redundancies, achieve better balance of EBVs across classes, realms and taxonomic groups, match and extend essential variables to existing EU reporting streams (HD, WFD, MSFD, NRL etc.), and to ensure that the major policy missions of the EU Biodiversity strategy (BDS) for 2030 were addressed.

The potential use of the proposed EBVs to the monitoring and reporting obligations in the EU were carefully cross-checked by analysing the legal acts of 15 key EU policies (Table 1). Some of the EU policies comprise sets of directives and regulations (e.g. Common Agricultural Policy) while others have just been proposed or adopted (e.g. Forest Monitoring Regulation). For each EBV-policy combination, we described the concrete link between the policy requirements and the EBV and subsequently assessed whether the link is direct or indirect and complete or partial (Appendix S1: Table S1). A direct link was specified if the EBV can directly be used to respond to a reporting requirement whereas an indirect link reflects that the EBV provides underlying, complementary, or voluntary information for such reporting requirement. Both direct and indirect links can be complete (filling completely one specific reporting requirement, for example one indicator) or more commonly be partial (covering part of an indicator but still missing some conceptual, geographical, or temporal aspect). The links between EBVs and EU policies were derived from policy documents (Appendix S1: Table S2). Even though any EBV could provide useful information about EU ecosystems and their exploitation, we classified “no link” if the relationship had no clear operational application for the implementation (monitoring and reporting) of the EU policies. The specific details of all links between EBVs and EU policies are provided in the supplement (Appendix S1: Table S3–S5).

Design criteria

Developing the design for an EU-wide network of biodiversity monitoring sites across realms and diverse taxa and ecosystems is a formidable scientific challenge (Carvalho et al. 2016, Potts et al. 2021). This was beyond the scope of the EuropaBON project, but a range of design recommendations were identified for a European Biodiversity Observation Network. These represent aspects of the sampling network, the use of different monitoring methods, and considerations for data integration and analysis (Figure 2c).

Identifying design recommendations for the sampling network involved assessing the current state and gaps of monitoring EBVs in Europe with existing monitoring networks (Morán-Ordóñez et al. 2023a, Santana et al. 2023), as well as lessons learned from the designing of other European monitoring schemes that are being piloted for pollinator species (Potts et al. 2021) and biodiversity in agricultural areas (Sutcliffe et al. 2019, Anonymous 2021, Oppermann et al. 2021). A central point for the monitoring design is how differences of common and widespread versus rare and range-restricted species and habitats can be captured (Buckland and Johnston 2017, Pescott et al. 2019, Potts et al. 2021). Advantages and disadvantages of different spatial sampling designs were discussed with experts (EuropaBON workshop on showcases and co-design, April 2023 in Troia, Portugal). This included grid-based and site-based monitoring designs, stratification (e.g. by habitats, natural drivers, anthropogenic drivers, or policy aspects), and various combinations (e.g. stratified random sampling). Potential sample sizes of the monitoring network were identified by reviewing sample sizes and sampling densities from existing or new EU-wide monitoring networks (Sutcliffe et al. 2019, Potts et al. 2021, Santana et al. 2023) and simulations on the number of sites needed to detect trends (Potts et al. 2021, Valdez et al. 2023). The benefits and possibilities of co-locating monitoring activities for multiple EBVs were also explored, including sampling differences among taxa (e.g. timing of monitoring) and within realms (e.g. different water bodies, shoreline vs. deep water).

Considering the role of different monitoring methods for implementing EBVs was a key aspect for design recommendations (Figure 2c). EBVs should generally be measurable with available technologies and have a proven track record in on-going initiatives (Walters et al. 2013). However, EBVs may also become measurable at reasonable cost in the near future, e.g. with technologies that are not yet used for an operational and regulatory monitoring. For co-designing the European biodiversity observation network, various monitoring methods were broadly distinguished (Figure 2c): (1) structured in-situ monitoring, (2) DNA-based methods (e.g. AFLP/microsatellite, SNPs, and eDNA metabarcoding), (3) digital sensors (e.g. cameras, acoustic devices, GPS tags), (4) remote sensing (including satellite remote sensing, airborne remote sensing with drones and airplanes, and weather radar), and (5) citizen science observations. During the EuropaBON workshop on EBV workflows (online, February 2023), participants were asked to fill out an online survey (Google form) to assess whether a specific monitoring method is of central importance for a particular EBV (Lumbierres and Kissling 2023). To better understand the overarching needs for implementing each monitoring method at a European scale, additional break-out sessions with online (Miro) boards were organized to identify emerging tools and future needs for implementing specific monitoring techniques (Lumbierres and Kissling 2023).

Another key aspect for the monitoring design were considerations for data integration (Figure 2c). Generating EBVs requires specifying and developing workflows for integrating primary observations from multiple data streams into aggregated and harmonized datasets that can then be modelled to derive spatially explicit EBV products with a specific spatial and temporal resolution (Kissling et al. 2018, Fernández et al. 2020, Boyd et al. 2023). Through the comprehensive involvement of experts in the EuropaBON workshop on EBV workflows (Lumbierres and Kissling 2023), key aspects of data aggregation and harmonisation were collected for each EBV and the needs for statistical analysis and modelling (e.g. types of models and software) were identified (Lumbierres et al. 2024). Moreover, a web-based database on biodiversity monitoring initiatives at the European level was created (Morán-Ordóñez et al. 2023b) to describe national or EU-wide integration nodes, i.e. institutions, projects or initiatives that integrate biodiversity data for use at the European level. Finally, information on the needs for digital infrastructure (e.g. data portals, use of European research infrastructures, data storage, central repositories, scalable computing, cloud services) and aspects of interoperability (e.g. access to and sharing of primary data, metadata standards, open access licences, machine readability) were collected from a broad range of stakeholders (Lumbierres and Kissling 2023, Morán-Ordóñez et al. 2023a).

Cost estimation

Evaluating the full economic costs of implementing a transnational and continental-scale monitoring scheme is challenging and requires obtaining the best possible cost estimates for monitoring each variable in terms of staff (e.g. to undertake field work, analyse the samples to identify species and their abundance or develop data integration tools) and materials (e.g. traps, fuel and computers). To estimate the costs of a European Biodiversity Observation Network, we performed a comprehensive assessment of the staff and material costs in terms of data collection, workflows, and coordination (Appendix S2: General cost estimation & Table S1). For each of these three components (Figure 2d), the establishment costs (e.g. one-off expenses to set up activities such as materials to establish field sites) were separately calculated from the maintenance costs (e.g. recurring expenses for maintaining the monitoring such as consumables for field data collection). All costs were estimated over a 10 years timespan and, where possible, for each EU member state. Cost estimates were derived for sampling networks that combine multiple EBVs (Appendix S2: Sampling networks and monitoring methods) as well as for each EBV individually (Appendix S3: Table S1–S4). These cost estimates were based on data collection protocols from national schemes or literature, from prices of commercial suppliers, obtained through comprehensive expert interviews, or through information available from various organizations or EU research projects (Appendix S2: Table S2). The cost estimates were generally based on specific methods used in biodiversity monitoring and on comprehensive assessments of monitoring schemes and EBV workflow needs (Breeze et al. 2023, Lumbierres and Kissling 2023, Morán-Ordóñez et al. 2023a, Santana et al. 2023). The cost estimates were based on the best available data and are conservative because they do not include the costs of current monitoring schemes. Since a wide range of EBVs and monitoring methods are involved, the cost estimates should be regarded as indicative and further improved for specific EBVs through dedicated collaborations with experts and researchers.

We first estimated the costs for each EBV individually and then combined for sampling networks that simultaneously record data for multiple EBVs (Figure 2d, middle). The cost assumptions and calculations for individual EBVs (Appendix S3: Table S1–S4) assume that the sampling and data processing is completely independent from other EBVs. This reflects a basic, low-efficiency scenario which was used as the basis for comparison with a more cost-efficient biodiversity monitoring using sampling networks. Since there is considerable overlap in monitoring methods across EBVs, the same data could be used in many cases to generate multiple EBVs (e.g. ‘Species abundances of selected terrestrial bird species’ and ‘Phenology of migration of terrestrial birds’ based on point counts). We therefore explored a potential cost-efficiency by grouping EBVs into sampling networks based on their taxonomic and methodological focus (Table 2). These sampling networks could use similar methods for generating multiple EBVs and would benefit from collaborative approaches among multiple organizations and initiatives. For example, surveys of marine mammals, birds and turtles could be conducted within the same sites of a sample network, but subsequently passing the data to separate workflows for modelling and management purposes. Where a sampling network crosses realms, we assumed that a portion of the sites would be distributed to give equitable coverage.

For the different sampling networks, we estimated the differences in costs for a low site-number scenario (e.g. 10,000 terrestrial sites) and a high site-number scenario (e.g. 100,000 terrestrial sites). The specific numbers for the low and high site-number scenarios (see Table 2 and Appendix S2: Site numbers) were a compromise between the current practice (based on ongoing EU monitoring efforts) and what would be needed to reliably detect trends in biodiversity. In most cases (except large lakes), the low site-number scenario corresponds to ~1% of the total number of sample sites across Europe and the high site-number scenario to ~10%. A ‘site’ is here defined as a grid cell of 2 × 2 km (terrestrial and cross-realm) or 10 × 10 km (marine) size, or a lake or river segment (freshwater). Total site numbers were proportionally divided among EU member states and low and high site numbers were separately chosen for river segments, lakes, marine sites, terrestrial and cross-realm sites, and validation sites for remote sensing, respectively (Appendix S2: Table S3). Several assumptions were made for site selection, amount of training, travel distances, number of sites per collector, time for data management, workflow tasks and coordination (Appendix S2: Assumptions & Table S4–S6). For each sampling network (Table 2) the costs for establishment and maintenance are separately provided to illustrate what is required for initial investments versus continued funding (e.g. annual costs). Our costs also include the activities of a European Biodiversity Observation Coordination Centre (EBOCC) to support the coordination, data collection, workflows, and reporting for transnational biodiversity monitoring in the EU (Liquete et al. 2024). This includes costs for activities of the EBOCC such as data integration, capacity building, workflow development, interoperability, and modelling (Appendix S2: Costs for a European Biodiversity Observation Coordination Centre & Table S7–S9). Similar costs were calculated for each EU member state to ensure engagement with the EBOCC for European integration activities (Appendix S2: Member state interoperability & Table S10).

WHAT SHOULD BE MONITORED, HOW AND WHY?

The EBV identification and selection process resulted in a list of 84 EBVs, of which 36 (43%) are in the terrestrial realm, 26 (31%) in the freshwater realm and 22 (26%) in the marine realm. In each realm, the EBVs cover all six EBV classes, i.e. genetic composition, species populations, species traits, community composition, ecosystem functioning and ecosystem structure. Of the 84 variables, 43 are species-focused EBVs and 41 community or ecosystem-focused EBVs. The full EBV list with all specifications is available from GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

Most EBVs (80%) should become available with a grid cell size of 1 km or 10 km resolution (Figure 3a). The remaining EBVs (20%) should be provided within other spatial units such as catchments, lakes, and river segments (e.g. freshwater EBVs), or monitored only at specific sampling sites (populations) across the geographic range of selected taxa (e.g. genetic diversity of terrestrial, marine, or freshwater taxa). The regulatory reporting of most EBVs (51%) should be at a temporal resolution of 3 to 6 years (Figure 3a) which aligns with the legal requirements for the EU member states (e.g. to the HD and WFD). One third of the EBVs (33%) should be reported annually to sufficiently capture interannual or spatial variability. For some of these EBVs (e.g. phenology-related EBVs, 'Harmful and non-harmful freshwater algal blooms' or 'Species abundances of selected terrestrial animal disease vectors'), the underlying metric needs to be based on a finer temporal resolution (e.g. the day of arrival). This effectively requires daily or weekly observations, even if the spatial resolution of the reporting can be coarse (e.g. 50 × 50 km, or eutrophic lakes). About one tenth of the EBVs (12%) will require a weekly or daily temporal resolution (e.g. ‘Aerial biomass of migrating insects’ and ‘Harmful marine algal blooms’). The genetic diversity of selected taxa (3 EBVs, 4%) can be reported every 10 years.

Species-focused variables

The species-focused EBVs provide information about the status and trends of individual species, including their distribution (e.g. geographic occurrence of invertebrates), abundance (e.g. counts of vertebrates), phenology (e.g. timing of migration, flowering or fructification), and genetic composition (e.g. allelic richness and heterozygosity of selected taxa). Due to differences in monitoring feasibility, species distribution EBVs are most often represented, followed by EBVs of population abundance, phenology, and genetic diversity (Figure 3b left). Besides species distributions and abundances, phenology was included as a key species trait for monitoring the response of taxa to climate change, including migration phenology of birds, fishes and mammals, as well as the phenology of fructification, flowering and emergence for plants, mushrooms and butterflies. In addition, a set of freshwater, marine and terrestrial species is proposed to be monitored genetically in selected populations. This can only be done for a subset of species of conservation interest, as genetic monitoring is typically more expensive than species distribution or population monitoring.

The taxonomic focus of the species-focused EBVs includes all species listed in the BD and HD. Most prevalent are birds and insects/invertebrates (covered by 8 and 7 EBVs, respectively), followed by fishes, mammals, plants, reptiles, and invasive alien species (3–5 EBVs each; Figure 3c left). Other groups such as amphibians, animal disease vectors, crop and forest pests, fungi, and lichens are at least represented with one EBV. For some taxonomic groups, all species are proposed to be monitored, going beyond the current regulatory requirements of the HD, as it was deemed to be feasible based on existing or near-ready scientific and technical capacity (e.g. most of the freshwater EBVs). For other taxonomic groups, only a subset of the taxa is proposed for monitoring (i.e. priority or selected species). This included, for instance, species that are listed in the HD or European Red List of threatened species (e.g. marine reptiles, freshwater mammals, invertebrates, terrestrial reptiles and mammals), those that are of particular EU interest or concern (e.g. commercial marine fish species, invasive freshwater species of concern), or those with a particular role for ecosystem functions or ecosystem services (e.g. lichens as indicators of air pollution, wild mushrooms of recreational significance, key pollinators as specified by the EU pollinator monitoring scheme, harmful algal blooms).

Ecosystem-focused variables

The ecosystem-focused EBVs provide information about the status and trends of habitats and whole ecological communities, including the taxonomic and functional composition (e.g. ‘Community composition of phytoplankton’), biomass (e.g. ‘Community biomass of soil microbes’, ‘Aerial biomass of migrating birds’, or 'Standing and lying deadwood'), ecosystem distribution (e.g. 'Ecosystem distribution of terrestrial EUNIS Habitats' or 'Ecosystem distribution of marine seagrass habitats'), physical structure (e.g. 'Vertical structure of vegetation' or 'Connectivity of terrestrial ecosystem habitat types') and functioning (e.g. 'Terrestrial ecosystem productivity', ‘Harmful marine algal blooms’, or 'Rate of decomposition'). EBVs of community composition are the most prevalent variable type (Figure 3b right), followed by EBVs of ecosystem distribution, biomass, and productivity. Community composition EBVs quantify aspects such as species composition and/or total biomass or total abundance of a taxonomic community or group, or functional composition and diversity based on morphological, physiological, or behavioural similarities among taxa. Measurements of community composition can therefore be used to assess the condition and ecological status of habitats, such as the Ecological Quality Ratios (EQRs) of the WFD which quantify the community composition of phytoplankton, macrophytes, phytobenthos, fishes, and zooplankton in rivers and lakes relative to a reference state.

The ecosystem-focused EBVs are particularly relevant for assessing the distribution, structure and function of EU habitats. In a policy context, habitats in the EU are either defined by the European Nature Information System (EUNIS) or in the annexes of the HD. Due to the inclusion of various community composition EBVs, a large diversity of taxonomic groups is represented in the ecosystem-focused EBVs (Figure 3c right). Best represented are insects/invertebrates, plants, phytoplankton and microorganisms (3–5 EBVs each; Figure 3c right), but corals, fungi, macroalgae, oysters, phytobenthos and zooplankton are also included (one EBV each). In addition, for each realm (freshwater, marine, terrestrial) one ecosystem productivity EBV and one disturbance EBV are included, complemented by ecosystem phenology and/or rate of decomposition EBVs. These EBVs are relevant for assessing the impacts of climate change (e.g. via ecosystem productivity and community structure) or the effects of other pressures and disturbances such as nutrient pollution (causing harmful and non-harmful algal blooms) or fire regimes (affecting habitat condition, or decomposition rates).

Methods for monitoring

A broad range of monitoring methods are required to derive the raw data for generating EBVs. The monitoring for most EBVs (~75%) requires in-situ observations, using structured monitoring programs, citizen science observations and genetic monitoring (Figure 4a). This includes, for instance, the species distribution, population abundance, community composition and genetic composition EBVs in the freshwater, marine and terrestrial realm. Sampling methods for in-situ observations are diverse (Pereira et al. 2017) and include point counts, area-based surveys and transects (e.g. birds, mammals, amphibians, reptiles, plants, marine turtles, butterflies and other pollinators), electrofishing (freshwater fish), sampling from boats (phytoplankton, zooplankton, macrophytes), soil samples (terrestrial arthropods), trawling surveys (freshwater and marine fishes), ship and aircraft surveys (marine mammals), various traps (pollinator insects, crop and forest pests), and opportunistic observations contributed by citizen scientists. Structured monitoring programs are the most important primary monitoring technique for EBVs (Figure 4a). For instance, breeding surveys of 168 common bird species in Europe are conducted with national monitoring schemes (with professionals and volunteers) in the context of the Pan-European Common Bird Monitoring Scheme (PECBMS), using standardized field methods (e.g. point counts, territory mapping, line transects and 60–120 min surveys in 10 km^2 squares). The data come from 30 European countries covering 42 years (1980–2021), are aggregated by sub-national, national and European integration nodes and are currently used with statistical models to create species trends at national level and tentative distribution EBVs at 10 km resolution for some species (Keller et al. 2020). Most freshwater and coastal water EBVs are also monitored by structured monitoring programmes requested by the WFD, e.g. surveillance monitoring programmes and operational monitoring programmes, which are mostly based on conventional sampling methods, but gradually supplemented with new methods.

Nearly one quarter of the EBVs (~25%) depend on remote sensing as the primary monitoring technique (Figure 4a). Most important is satellite remote sensing which offers great potential for monitoring ecosystems from space, including the distribution, phenology and productivity of marine, freshwater and terrestrial ecosystems (Skidmore et al. 2021, Timmermans and Kissling 2023). The Copernicus land monitoring service from the EU already provides some datasets that either match directly a specific EBV (e.g. the Copernicus Vegetation Phenology and Productivity Parameters for the EBV 'Terrestrial ecosystem phenology') or can be further integrated into a biodiversity monitoring system (e.g. Copernicus riparian zones, CORINE land cover, and small woody features). Satellite remote sensing can further support the monitoring of algal blooms in lakes and coastal waters based on their chlorophyll-a concentration (Matthews et al. 2012). Besides satellite remote sensing, data from operational weather radar networks across Europe can monitor biomass flows of migratory birds (Shamoun-Baranes et al. 2021), and airborne laser scanning with aircrafts and drones can provide high-resolution details on vegetation height, cover, and structural complexity (Valbuena et al. 2020, Boucher et al. 2023).

Primary monitoring techniques alone are often insufficient for implementing EBVs across Europe and can therefore be complemented with additional approaches that automate and expand the extent and resolution of biodiversity monitoring (Figure 4b). For instance, structured monitoring programs that underlie many species-focused EBVs could benefit from citizen science observations (Figure 4b, left), e.g. through dedicated volunteer programmes that are organized by natural history societies and research institutes and complemented by various apps. Similarly, digital recorders such as microphones, cameras and other mobile and stationary sensors can complement structured monitoring programs for species distributions (Figure 4b, left), e.g. with audio recordings for bats and marine mammals or camera traps for terrestrial wildlife species. Together with artificial intelligence (AI) approaches, this allows scaling-up of monitoring for specific species groups (Besson et al. 2022, Tuia et al. 2022). High-throughput sequencing of environmental DNA (eDNA) extracted from water, soil, air or bulk samples has also reached a high level of scientific and technical maturity and provides opportunities for complementing the monitoring of both species-focused and ecosystem-focused EBVs (Figure 4b, left and right). Finally, all remote sensing techniques need to be complemented with ground truth data on land and in aquatic environments. Hence, ecosystem-focused EBVs require additional data from in-situ monitoring (Figure 4b, right), e.g. through the collection of soil and water samples, vegetation plots, land surveys, portable chlorophyll fluorometers or in-situ measurements of plant phenology, physical structure, colour and metabolism.

Workflows for data integration and modelling

The raw observations from in-situ monitoring and remote sensing —together with emerging tools such as digital sensors, citizen science apps, eDNA sampling and AI species identification— will provide the basic input for the EBV workflows of a European Biodiversity Observation Network (Lumbierres et al. 2024). These EBV workflows integrate heterogeneous, multi-source data sets across space, time, taxa, ecosystems and different sampling methods to produce EBV cubes that capture space, time, biological entities, and uncertainties (Kissling et al. 2018, Fernández et al. 2020, Boyd et al. 2023). Key components of such EBV workflows are data integration of raw observations and subsequent modelling and analysis (Figure 5a). This requires addressing variation in sampling effort and harmonizing different spatial and temporal resolutions in the data and measurement units (Kissling et al. 2018). EBV workflows therefore benefit from standardized data entry protocols, data quality assurance and control, automation of data streams (e.g. via APIs) and machine-readable (meta)data (Figure 5a). Such coordination related responsibilities and data integration efforts are already supported by several EU-wide integration initiatives (Morán-Ordóñez et al. 2023a), e.g. the Pan-European Common Bird Monitoring Scheme (PECBMS), the European Butterfly Monitoring Scheme (eBMS), the Water Information System for Europe (WISE), and the European Marine Observation and Data Network (EMODnet) (Figure 5a). After data integration, statistical models for spatial inter- or extrapolation need to be applied (Figure 5a) to derive spatially contiguous information from different time periods (Kissling et al. 2018, Fernández et al. 2020, Boyd et al. 2023). This can be achieved by applying regression and machine learning techniques such as species distribution models (Figure 5a). Estimating uncertainties is crucial because biases and variation in raw data, covariates, model fitting and parameter estimation can propagate and reverberate through the

EBV production chain (Kissling et al. 2018, Boyd et al. 2023). Statistical models may also include trend analysis and forecasting (Figure 5a), e.g. to derive changes from population time-series (Rigal et al. 2023) or short-term ecological forecasts to predict ecological phenomena at temporal resolutions shorter than a year (Tulloch et al. 2020).

Three simplified EBV workflows are illustrated to provide examples for current data integration and modelling (Figure 5b). Raw observations of butterflies abundances are obtained by the eBMS through a large network of volunteers and scientists (>100,000), using systematic transect counts with standardized protocols several times per year, currently at about 5,800 sites in 30 EU countries for >312 butterfly and moth species (Morán-Ordóñez et al. 2023a, Santana et al. 2023). The data are complemented with a new app enabling citizen scientists to record species observations and abundances using 15-min counts (Figure 5b). Data integration at the EU-level is achieved by the NGO Butterfly Conservation Europe which harmonizes national data into a European database. A combination of models and R-packages (e.g., 'rtrim', 'rGAI', 'rbms') is then used to derive multi-species trends of butterfly abundances (Dennis et al. 2016).

In the marine realm, the distribution of seagrass habitats is mapped by compiling data from the HD reporting and different monitoring programs (Morán-Ordóñez et al. 2023a). The collection of imagery from drones and satellites together with in-situ validation data is currently being tested in several projects (e.g., SeaBee, BiCOME, OBAMA-NEXT). Different seabed habitat classification systems have been integrated through the European Marine Observation and Data Network (EMODnet) and habitat modelling is done with geographic information systems and deep learning (Figure 5b).

For European freshwater systems, a large effort has gone into developing consistent biological indicators of the ecological status of aquatic ecosystems (especially rivers and lakes), which is required by the WFD (Birk et al. 2012). The data are generated through structured monitoring programs requested by the WFD and comprise phytoplankton, phytobenthos, macrophytes, benthic invertebrates and fish. For instance, phytobenthos is currently monitored in >13,000 rivers (16% of total) by 25 EU countries (Santana et al. 2023), with information being aggregated at the EU-level in the WISE database of the EEA (Figure 5b). The current biological indicator of community composition of all the above-mentioned biological taxa groups are given as EQR values, which measure the deviation from a reference condition on a harmonised scale from 1 (no deviation) to 0 (massive deviation) (Moe et al. 2023). The data are used to model trends based on consistent timeseries. The indicators can be aggregated to ecological status class, which are used to show spatial variation in maps. Models are being developed to cover spatial gaps using land-use variables (e.g. % agriculture or % urban land use in the river or lake catchments) or nutrient concentrations, which affect the EQR-values. Identification of phytobenthos and phytoplankton-species with eDNA is increasingly becoming feasible, while DNA metabarcoding of fish species and to a lesser extent of benthic invertebrates and macrophytes being ready for implementation, although reference databases still need extensive improvements for some taxa (e.g. diatoms). Furthermore, APIs are developed to deliver sequence data from repositories such as the European Nucleotide Archive (ENA) to the Global Biodiversity Information Facility (GBIF).

Policy relevance

The policy relevance of the identified EBVs was mapped for the various policies that manage the natural environment in the EU (Table 1). The most prevalent link is with the main EU legislation on biodiversity (yellow in Figure 6), specifically the direct links with the HD and BD (species-focused and ecosystem structure EBVs), the WFD (freshwater community composition EBVs), the MSFD (marine species-focused and ecosystem-focused EBVs), the NRL and the BDS (various EBVs). More than 50% of the 84 EBVs have direct relationships with at least one policy. EBVs including pollinators, deadwood, or terrestrial and marine habitats are examples with many direct connections to EU policies. When both direct and indirect relationships are considered, >75% of the EBVs have policy-relevant applications, also including many of the freshwater EBVs (Figure 6). Several EBVs show links to ecosystem service policies in the EU (green links in Figure 6), especially various terrestrial species-focused and ecosystem-focused EBVs in relation to the FMR, the Land Use, Land Use Cover and Forestry Regulation (LULUCF), the SML, and the Pollinators Initiative (PI), but also marine fishes for the Common Fisheries Policy (CFP). For other EU policies (blue links in Figure 6), several EBVs are important, but often with an indirect link. For instance, the community composition EBVs of freshwater algae and higher plants (i.e. phytoplankton, macrophytes and phytobenthos) can indirectly contribute to the CAP by indicating the nutrient content of water bodies and thus the gross nutrient balance for nitrogen and phosphorus in agricultural areas. Similarly, many species-focused EBVs (and some various community composition EBVs) could indirectly contribute to the monitoring under the NRL (e.g. by measuring habitat quality for species), to assessing target 4 of the BDS (i.e. no deterioration in conservation trends and status), or to collecting and recording data on the occurrence of invasive alien species for the IAS. A comprehensive overview of the direct and indirect, partial, and complete links between EBVs and EU policies is provided in Appendix S1 (Table S3–S5).

DESIGN RECOMMENDATIONS

To facilitate the operationalisation of the monitoring of EBVs across Europe, we identified several recommendations for (co-)designing a modern and efficient European Biodiversity Observation Network. This should build on already existing large-scale or pan-European monitoring networks and integration nodes in Europe and form a monitoring backbone to support evidence-based findings on trends and driver attribution analyses to inform the realisation of policy and management goals.

Spatial sampling designs

The design of a European Biodiversity Observation Network must ensure that monitoring sites are spatially, environmentally and thematically representative across Europe. To achieve this, a spatial sampling design is suggested that combines an EU-wide stratified sampling with local sampling designs for field surveys (Figure 7). This ensures a representative sampling across different environments, human impacts and policy or management interventions.

For an EU-wide stratified random sampling (Figure 7a), the region of interest (e.g. the EU + Norway, Iceland, Switzerland and the Balkan countries) is first divided into smaller geographic units, e.g. using a grid of equally sized cells (e.g. 2 × 2 km) as it has been implemented in the Land Use / Cover Area frame Survey (LUCAS) across Europe. The geographic units are then spatially intersected with stratification layers, based on available environmental and socio-political information. A representative subset is then selected for monitoring, using a stratified random selection approach (Figure 7a). For the marine realm, the geographic units can also be grid cells, but possibly with a coarser cell size (e.g. 10 × 10 km). For freshwater, geographic units for sub-sampling can be catchments, lakes, or river segments instead of being situated within grid cells, following ECRINS (European Environment Agency 2012), the European functional elementary catchments (Globevnik et al. 2017) or a global hydrological network (Amatulli et al. 2022). However, grid cells can also be used for sampling freshwater biodiversity to ensure a monitoring network that is geographically representative (including also small streams, lakes, and ponds across Europe). Moreover, the monitoring network for freshwater biodiversity should also reflect the actual distribution of ecological status classes according to WFD reporting. The latter is important to prevent bias towards monitoring mostly unimpacted or mostly impacted water bodies.

For a European Biodiversity Observation Network, three types of stratification could be considered (Figure 7a), based on environmental, anthropogenic, and political characteristics. First, environmental stratification can divide large-scale environmental gradients into convenient units for selecting representative monitoring sites across a continent (Jongman et al. 2006, Keller et al. 2008). Environmental variables can include climate or environmental zones, but also other variables such as biogeographic regions, geomorphology, soil, geology, elevation, ocean depth, seabed characteristics, river and lake types, biomes, habitat types, and physical or chemical ocean parameters (Metzger et al. 2005, Thorpe et al. 2016, Costello et al. 2018, Lyche Solheim et al. 2019). Environmental stratification can thus ensure that biodiversity monitoring is representative for the broad-scale spatial, environmental and biogeographic variability across Europe (Jongman et al. 2006). Second, anthropogenic stratification can be used to map and monitor how human transformation of ecosystems reshapes biodiversity (Ellis 2015). This stratification can include variables such as land cover and land use, climate change velocity, nitrogen deposition, or nutrient pollution from wastewater or from agricultural areas, and ensure that biodiversity change is attributable to specific drivers (Carvalho et al. 2013, Newbold et al. 2015). Third, policy stratification can be used to measure the effectiveness and impacts of policy interventions and protected area management (Santini et al. 2016, Bakker and Svenning 2018). This can allow spatial comparisons of biodiversity (including condition indicators) exposed to different types of policy interventions. Relevant variables may include geospatial layers of protected areas, political/administrative boundaries, exclusive economic zones (EEZs) of regional seas, spatial planning units, agri-environmental schemes, or barriers in rivers. To optimise the representativeness of selected sites with multiple stratification layers, a number of statistical techniques can be applied, including multivariate geographic clustering (Keller et al. 2008), generalized dissimilarity modelling (Guerin et al. 2021), or optimization methods from systematic conservation planning approaches (Carvalho et al. 2016).

For the selected geographic units (e.g. grid cells, catchments, lakes, river segments), local sampling designs for field surveys can be implemented, using a variety of complementary methods (Figure 7b). The selection of local sampling locations can be random or systematic, or in combination with stratification, such as random locations in different habitat types or systematic sampling with clusters or transects (Figure 7b). Local stratification layers may not only include habitats, but also intensity of land use (e.g. nutrient additions, pesticide treatments), variation in water quality or ecological status, management measures, and restoration efforts (e.g. large herbivore exclosures, structure of riparian areas along rivers). A wide range of methods is required for sampling, including traps, transect walks, plot surveys, water and soil samples (e.g. for conventional and/or eDNA analyses), and digital sensors (e.g. micro- and hydrophones, fish tags or cameras) (Figure 7b). For instance, monitoring cetaceans in European waters can be done with a combination of visual or acoustic recordings, fixed stations and mobile platforms (e.g.

ferries and whale-watching boats), line transect surveys and mark-recapture methods using photo-identification of recognizable individuals (Evans and Hammond 2004). For pollinators, the proposal for an EU Pollinator Monitoring Scheme (EU PoMS) suggests a combination of transect walks and pan traps (for bees, butterflies and hoverflies) complemented with light traps (for moths) (Potts et al. 2021). Similarly, the LUCAS monitoring in the EU uses transects (for recording land use/land cover and tree height), mapping of landscape features, photointerpretation and soil samples in local sub-plots of 100 × 100 m size (https://ec.europa.eu/eurostat/en/web/lucas/overview). These LUCAS sub-plots are located within a sub-set of 2 × 2 km grid cells across Europe and have been selected using a land cover stratification (based on aerial photos or satellite images). The European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL) has also used the 2 × 2 km grid from LUCAS to select grid cells with at least 10% agricultural use, and then applied a random stratified sampling to identify areas of 500 × 500 m size for the ground-based field surveys (EFTAS et al. 2021).

Number of monitoring sites needed across Europe

To ensure that trends in biodiversity can be detected, it is crucial to have sufficient sample sizes for monitoring biodiversity change (Nielsen et al. 2009, Potts et al. 2021, Valdez et al. 2023). Previous studies indicate that thousands of sites are required for trend detections in diverse taxonomic groups over large geographic areas. For instance, power analyses for detecting declines in local species richness suggest that several thousands of sites are needed as a minimum, especially if trend detection is required over time intervals of a few years (Valdez et al. 2023). Similarly, power analyses suggest that the proposed EU PoMS requires a minimum network of at least 3,000 sites to detect a 1% annual change in major pollinator groups and a 3% annual change for individual species across Europe (Potts et al. 2021). This may be enough for common and widespread species, but sill insufficient for rare and threatened species which often have small geographic ranges and therefore require a more targeted approach for monitoring population trends (Potts et al. 2021). For example, the eBMS currently focuses on monitoring butterflies in transects at 5,800 sites in Europe, but the sampling design of the eBMS lacks power to detect declines in rare or localized butterfly species due to biases in site selection and limited sample sizes. The required number of sites will depend on the focal taxonomic group, the commonness and rarity of species, the effect size of interest (i.e. the level of precision to detect a change), how representative the sites are and on the amount of variability across sites and years. Sample sizes of <10,000 might generally be limited for detecting biodiversity trends of diverse taxonomic groups across large geographic areas such as Europe.

To ensure detectability of biodiversity trends, a European Biodiversity Observation Network should therefore be supported by a large monitoring site network. As a minimum, we recommend at least 10,000 sampling locations in the terrestrial and freshwater realm, respectively. However, sample sizes of up to 100,000 or more would be desirable. These sample sizes correspond to ~1% and ~10% of the terrestrial 2 × 2 km grid used by LUCAS if only one sampling location per grid cell was used (usually more). Existing EU-wide monitoring schemes for common birds (PECBMS) and vegetation (EVA) or land cover (EMBAL, LUCAS) already have sample sizes of >10,000 transects, plots or survey points (Figure 8). However, currently only ground-based field surveys for land cover (LUCAS, EMBAL) reach sample sizes of >100,000 (e.g. numbers of sampled landscape elements or land cover polygons, Figure 8). Surveys of land cover (e.g. mapping parcels, recording landscape elements, transect photographs) are generally less time consuming than methods for sampling diverse species assemblages, and the obtained data are especially intended for Earth Observation training and validation rather than monitoring biodiversity trends. In the freshwater realm, most of the current regulatory monitoring for the WFD already includes sample sizes of >10,000 sites (Figure 8). However, this mainly applies to river segments, whereas the number of sampled lakes ranges between 1,000–8,000 depending on the taxonomic group that is monitored (Figure 9). For rivers, the current WFD monitoring of the different biological quality elements ranges from 16,000–32,000 water bodies, corresponding to ca. 20–40% of all river water bodies (total ca. 86,400), while for lakes, ca. 5–40% of all lake water bodies are monitored for the different biological quality elements (total ca. 19,000). However, the water bodies included are only rivers with catchments >10 km^2 and lakes with a surface area >50 ha (0.5 km^2). When also including smaller water bodies, there would be a need to increase the sample size considerably, as 10,000 and 100,000 corresponds to only ~0.7% and ~7% of the inland water bodies if one assumes 1,348,163 river and stream segments and 70,847 lake polygons with >25 ha size (based on the European catchments and rivers network system, ECRINS). For transitional and coastal water bodies, sample sizes are usually <1,000 (Figure 9). In the marine realm, sample sizes of monitoring efforts were difficult to obtain. We therefore used the exclusive economic zones (EEZs) of the mainland EU member states (plus the Azores, Madeira and Canaries) to delineate the European regional seas. This amounts to a total of 5.5 Mio km^2 of which between 550 (1%) and 5,500 (10%) grid cells of 10 km^2 size are recommended to be monitored.

Filling of gaps

The spatial sampling design of a European Biodiversity Observation Network should be built on already existing large-scale or pan-European monitoring networks and integration nodes in Europe (examples in Table 3). Monitoring sites from such networks should be incorporated as much as possible, with missing taxa being added and spatial gaps being covered by new sites, using a stratified random selection design as outlined above. Current biodiversity monitoring in Europe shows pronounced gaps (examples in Figure 10), including not only spatial gaps but also gaps in temporal and taxonomic coverage (Santana et al. 2023). These gaps need to be filled to make EBVs and derived trend estimates and indicators across Europe more reliable, representative, and informative. Moreover, a major gap exists in the monitoring of genetic diversity across Europe (Santana et al. 2023, Pearman et al. 2024). It is crucial for EU member states to fill this gap in the context of measuring progress on global policy commitments such as the CBD (Hoban et al. 2022, Gonzalez et al. 2023).

Spatial gaps in terrestrial biodiversity monitoring exist in several EU countries, and are particularly pronounced in Southern and Eastern Europe (Santana et al. 2023) where capacity is weaker and site access more difficult and often more costly. For instance, even though butterfly monitoring through the eBMS is one of the best examples of terrestrial insect monitoring in Europe, the number of monitored transects is concentrated in central Europe, with large gaps in other parts of the EU (Figure 10a). Minimum networks with representative sites across Europe for different habitats or similar geographic units (e.g. grid cells or river basins) therefore need to be developed, for instance as it is currently designed for the EU pollinator monitoring scheme (Potts et al. 2021).

In the freshwater realm, larger streams and rivers (> 10 km^2 catchment area) and large lakes (>50 ha) are relatively well monitored for the WFD, but the density of sampling varies widely across Europe (Santana et al. 2023). For instance, for both rivers and lakes, the percentage of water bodies monitored for the most well-studied taxonomic groups (i.e. benthic invertebrates in rivers and phytoplankton in lakes) is high in several European countries, e.g. with >90% of those rivers monitored in small countries like Belgium, the Netherlands, Slovenia and Luxembourg, and >90% of those lakes monitored in Slovenia, Belgium and Portugal. However, the percentage of monitored water bodies is especially low in Northern European countries (that have vast areas with very small human impact) and intermediate in several Southern and Eastern Europe countries (Figure 10b,c). Thus, spatial coverage needs to be improved to make current monitoring for the WFD more representative for all types of water bodies in each of the water categories (rivers, lakes, transitional and coastal waters) and for all ecological status classes (high, good, moderate, poor, bad). Moreover, groundwater as well as small waterbodies such as small streams, ponds and ditches are currently not covered, albeit their high importance for biodiversity and ecosystem services (Biggs et al. 2017). The WFD does not require these smaller streams (representing the highest share in river network length) and the high number of ponds and smaller lakes to be monitored and reported as separate water bodies.

In the marine environment, the deep sea is heavily under-sampled as it has been technically challenging (Patrício et al. 2016). Spatial coverage and distribution of marine monitoring programmes is also highly uneven across European regional seas (Figure 10d). The North Sea and the Baltic Sea are the two most densely monitored European regional seas, whereas only few spatial data are available from other areas such as the Mediterranean Sea and Black Sea (Jessop et al. 2022). Moreover, marine monitoring data with a fine spatial resolution are largely concentrated around national coastal areas (Jessop et al. 2022), so gaps in non-coastal monitoring (except for the North and Baltic Seas) need to be filled. The spatial resolution and coverage of off-shore marine waters could be lower than that of the coastal waters, as the former is usually more homogenous and less impacted than the latter.

Besides filling the spatial gaps, the temporal frequency of monitoring also must be improved. The frequency of sampling (e.g. several times per year, once per year, or only once every 3 or 6 years) differs from the desired temporal frequency of the modelled EBV (e.g. annually) or the frequency of reporting required for policy purposes (e.g. every six years). Currently, monitoring frequency is insufficient for the majority of the EBVs (Santana et al. 2023). For instance, monitoring frequency for the WFD mostly follows the minimum requirement, i.e. 1–2 samples once every 6 years or even only every 18 years in low-impact water bodies. This is insufficient to capture trends for most of the biological quality elements in many water bodies. Operational monitoring for the WFD for more impacted water bodies should therefore ideally be done annually or at least once every 3 years. For EBVs that show large temporal variation, such as phytoplankton (including algal blooms), insect populations and various marine invertebrates and fish in both freshwater and marine areas, sampling should be done annually with multiple sampling times per year to separate population fluctuations from long-term trends, at least in a subset of sites. For EBVs that only change slowly and do not have large fluctuations, such as the EBV 'Standing and lying deadwood' or the EBV ‘Ecosystem distribution of oyster reef habitats’, a much lower temporal frequency of sampling can already give important insights.

Taxonomic coverage also needs to be expanded because existing biodiversity monitoring schemes in Europe do not sufficiently cover all taxonomic groups (Potts et al. 2021, Santana et al.

2023). For instance, although freshwater monitoring in the EU in the context of the WFD covers all species of fish, macrophytes and most species of phytoplankton, benthic algae and benthic invertebrates, other taxonomic groups such as zooplankton (cladocerans, copepods, rotifers) as well as amphibians are not required to be monitored. In addition, most of the invertebrate, phytoplankton and phytobenthos taxonomic groups are monitored not at the species, but a higher taxonomic level, i.e. genus, family or order, in most EU member states (Weigand et al. 2019). Another gap is the disease vectors in lakes and ponds/wetlands, e.g. malaria mosquitoes and the swimmers itch parasite (*Austrobilharzia variglandis*), for which there is no systematic monitoring. More generally, the best covered organism groups monitored in the EU are typically those that have historically been monitored by NGOs with professional and citizen scientists (mostly birds and butterflies) or those that are of economic interest (e.g. fish). This means that several taxonomic groups —such as terrestrial and marine invertebrates, zooplankton, amphibians, fungi, and terrestrial plants— require major investments into expanding current monitoring efforts in Europe. However, even for taxonomic groups that already have well-established monitoring schemes across Europe, taxonomic coverage is often insufficient because they focus on common and widespread species and habitats for which indicators have been derived with a relatively small number of sites, e.g. the Common Bird Indicator (Gregory et al. 2005) and the Grassland Butterfly Indicator (Van Swaay et al. 2019). Within each taxonomic group, there are many species which are rare, geographically localised (e.g. endemic), or highly specialised in terms of their habitat use. These are often of conservation and policy interest. Standardised European monitoring schemes are unlikely to sample these species with sufficient frequency to be able to detect changes in their status (Potts et al. 2021). Hence, different surveying and monitoring approaches are needed that are tailored to the specific ecology and biology of these rare and specialised species (Potts et al. 2021).

Co-location

It is pivotal to plan monitoring activities at the same sites (co-location). Such co-location can allow comparing multiple aspects of biodiversity, contribute to reducing costs (e.g. travel, resources, and time), and simplify logistics and coordination efforts (Thorpe et al. 2016, Wägele et al. 2022). We therefore recommend to co-locate the sampling of multiple EBVs (ranging from species populations to community composition) as much as possible to improve cost-effectiveness and multi-taxa biodiversity assessments. However, the specific choice of sampling locations and sampling methods differs widely among taxa, which can limit the actual co-location of monitoring activities at a specific site. This is also true for monitoring rare and threatened species which may require sampling sites that are different from those for common species (Potts et al. 2021). Even if challenging, it will be highly valuable to co-locate sampling efforts to achieve synergies and arrive at opportunities to assess the interaction of different species with their environment and with each other.

For freshwater EBVs, most variables can be sampled at the same water bodies (Moe et al. 2023), with the exceptions of the EBVs 'Phenology of migration of wetland birds', ‘Ecosystem distribution of freshwater EUNIS Habitats’, and 'River Connectivity/Free river flow'. However, co-location of monitoring activities may not necessarily mean that different taxa are sampled at the same locations, as this will depend on the monitoring methods deployed and how sampling is conducted. For instance, pelagic EBVs like phytoplankton, zooplankton and planktivorous fish species are sampled in the pelagic zone of lakes and large rivers, while macrophytes, benthic invertebrates, benthic algae and benthivorous fish are surveyed in the littoral zone of lakes and in rivers. For freshwater ecosystems, it is crucial to monitor different types of water bodies, including small water bodies like ponds, streams, and temporary water bodies, which are currently not covered by the WFD. For wetlands, it is important to define whether they belong to the freshwater or the terrestrial realm, and which EBVs can thus be co-located.

For terrestrial EBVs, the co-location would depend on the monitoring technique and the EBV class. Four groups could be distinguished. The first group includes species distribution and species abundance EBVs, as well as some of the community composition EBVs. These are generally monitored with in-situ sampling designs (Pereira et al. 2017) and can leverage digital sensors and genetic monitoring methods (Besson et al. 2022, Wägele et al. 2022), making them highly adaptable to various locations and environments. The second group includes phenological variables. Although these can be integrated with the previous monitoring methods, they require specific timing and techniques due to the time-sensitive nature of phenological changes, as they should be adapted to the life cycles of organisms (Elmendorf et al. 2016, Thorpe et al. 2016). The third group includes species abundance of selected terrestrial disease vectors and species abundance of selected terrestrial crop pests. These EBVs are of importance for human health and food and fibre production, respectively. Monitoring these variables would require specialized approaches in both space and time (Lumbierres et al. 2024), as their monitoring needs to include an early detection system and spread control. The fourth group includes remote sensing enabled EBVs. The sampling design of ground truth data for calibration and validation may differ from the first group due to the unique aspects of remote sensing (Thorpe et al. 2016, Musinsky et al. 2022, Rapinel et al. 2022), which can limit the co-location of monitoring activities for other EBVs.

For marine EBVs, boat surveys are costly and co-location strategies will depend on cost effectiveness and on how well the monitoring effort and sampling of different EBVs can be performed during the same survey campaign (Patrício et al. 2016). Several groups of EBVs can be differentiated depending on the location and methodology for data collection. The first group consists of EBVs that need to be monitored from a boat. Examples include genetic diversity of selected marine taxa, species distributions of marine fishes, taxonomic and functional composition of marine phyto/zooplankton, sea grasses and benthic invertebrates on soft-bottom habitats. The second group includes EBVs that can be sampled from the shoreline, potentially through the establishment of coastal stations, or using aerial surveys with drones and aircraft (McIntosh et al. 2018). These EBVs include 'Species distributions of marine birds', 'Species distributions of marine mammals', and 'Species distribution of marine turtles'. By using shore-based stations and aerial surveys, it is possible to monitor these EBVs without the extensive use of boats, which can be more cost-effective. The third group relates to EBVs from deep-water locations and those based on satellite remote sensing. Examples include the EBVs 'Ecosystem distribution of hard corals habitats', 'Ecosystem distribution of marine macroalgae canopy cover', 'Harmful marine algal blooms', and 'Marine ecosystem productivity'. Finally, also estuaries (the so-called transitional waters according to the WFD) are required to be monitored concerning phytoplankton biomass, seagrass abundance, community composition of macroalgae in hard-bottom habitats along the shores, benthic invertebrates in soft-bottom habitats, and fish.

DNA-based methods

DNA-based methods such as DNA metabarcoding and analysis of population genetic markers have great potential for biodiversity monitoring (Schwartz et al. 2007). In the last decade, they have reached a high level of scientific and technical maturity. For instance, DNA metabarcoding identifies species with unique sequence identifiers (i.e. DNA barcodes) which allows measurement of biodiversity change even for poorly studied groups such as flies (order Diptera) or sawflies, wasps, bees, and ants (order Hymenoptera) for which many species remain taxonomically undescribed or otherwise difficult to distinguish. In particular, the application of DNA-based methods is enabling a rapid expansion of the taxonomic range of data included in open biodiversity platforms such as GBIF, especially through the sampling of invertebrates, e.g. from insect traps (Buchner et al. 2024). We therefore recommend to apply DNA-based methods for complementing the routine monitoring of terrestrial, freshwater, and marine biodiversity (e.g. for the WFD, MSFD and SML, Table 1) and to scale up the spatial, temporal, and taxonomic resolution of biodiversity monitoring with DNA-based assessments. The coupling of DNA-based methods with morphotaxonomic or imaging-based methods also holds great potential to upscale taxonomic assessments of difficult taxa (Høye et al. 2021, Hartop et al. 2022). However, there is still an urgent need to curate DNA-barcode reference libraries and substantially expand them for several algal groups as well as poorly studied invertebrates (e.g. nematodes) to allow species identification at a level that is comparable to, or better than, conventional methods. A short-coming of DNA metabarcoding is that it mainly can give presence/absence information but not abundance, which is a problem for abundance-related EBVs. Contamination of samples through DNA traces of food items in wastewater (e.g. through human faeces) or pet species ending up in rivers and lakes is another problem which can provide misleading results. It is therefore important to be aware of these potential pitfalls and to take control samples that are analysed by taxonomists using conventional methods.

DNA-based methods can potentially be used for the cost-effective monitoring of a range of EBVs, especially for EBVs in the EBV classes genetic composition, species populations and community composition (Figure 11). Population genetic markers (e.g. for measuring allelic richness, nucleotide diversity and heterozygosity) are crucial for monitoring the genetic richness (number of alleles in a population) and genetic evenness (expected proportion of heterozygotes in a population at equilibrium) of taxa (Schwartz et al. 2007), i.e. the three EBVs of genetic diversity of selected terrestrial, freshwater and marine taxa. DNA-based methods also allow characterizing the effective population size, a key indicator for the Kunming-Montreal GBF of the CBD. Furthermore, DNA captured from the environment (eDNA) can be directly used across realms to monitor the distribution of endangered, invasive and pest species and their diets, and to estimate the composition and diversity of biological communities. Other species-focused EBVs potentially monitored through DNA-based methods include phenology, with for instance spatial and temporal changes in DNA-based detection of species potentially providing information on the timing of reproduction and migration. For ecosystem-focused EBVs (including community composition EBVs), DNA-based methods are especially promising for biodiversity assessments and inventories. Existing examples are assessments of fish communities in freshwater and marine habitats with DNA metabarcoding (Miya 2022) or insect and invertebrate diversity from terrestrial and aquatic bulk or eDNA samples (Yu et al. 2012, Leese et al. 2021, Buchner et al. 2024, Remmel et al. 2024). It is worth noting that the costs and technical complexity of these techniques have been decreasing quickly, allowing the fast production of massive amounts of biodiversity data with relatively low budgets (e.g. Buchner et al. 2024).

Technology readiness levels of many DNA-based methods are already high and official national roadmaps for the implementation of DNA and eDNA methods have been outlined in some European countries (Norros et al. 2022). Standardized and automated DNA metabarcoding workflows are now also increasingly in place (Buchner et al. 2021, Buchner et al. 2024), a European standard for eDNA sampling exists (EN 17805:2023), standards and technical specifications for methods in the freshwater and marine realm are actively developed by European (CEN TC 230/WG28) and international (ISO TC147/SC5/WG13) organisations, and guidelines for publishing DNA and eDNA-based occurrence records in GBIF have been made (Nilsson et al. 2022). However, comparatively little effort has been put into the development of international standards for DNA-based monitoring. Consequently, the lack of transnationally standardized approaches and quality assurance and quality control (QA/QC) frameworks is an important gap hindering the implementation of DNA-based methods within regulatory frameworks (Meissner et al. 2020, Blancher et al. 2022). Implementing DNA-based methods for a European Biodiversity Observation Network therefore requires coordinating the development of agreed minimum standards for sample collection procedures, QA/QC laboratory procedures, and resulting species lists. This should ideally be based on the initial efforts of existing official working groups from ISO (International Organisation for Standardization) or CEN (European Committee for Standardization). Furthermore, standardization work should include and integrate national advances and cooperate with non-profit organisations that work towards harmonized methods (e.g. the Biodiversity Information Standards TDWG or the International eDNA Standardization Task Force). A second priority for advancing European efforts of DNA-based monitoring is to identify laboratory expert centres, i.e. reference laboratories that are accredited to perform laboratory analysis according to the international QA/QC guidelines. Their role would be to oversee the implementation of QA/QC laboratory procedures and act as the certifying bodies that issue compliance certificates. Besides lab facilities, computational infrastructures for standardised bioinformatic processing may be required, and the national implementation of sample processing workflows should be coordinated with a central European entity (e.g. through EBOCC). A third priority is to agree on criteria defining valid taxonomic assignments, e.g. through a central reference database for taxonomic assignment to allow for comparable data to be derived from DNA-based monitoring.

Digital sensors

Digital sensors such as wildlife and insect cameras, microphones and hydrophones, radars and sonars, or GPS tags are already widely used to study the distribution, abundance, behaviour, and movements of animals. Recent technological advancements make high-throughput digital sensors increasingly affordable and together with AI approaches enable the automated monitoring of species and ecological communities (Besson et al. 2022, Tuia et al. 2022, Wägele and Tschan 2024). Digital sensors have several advantages over traditional survey methods, including being less invasive, covering larger and more remote areas, and recording high-resolution metrics in a repeatable and standardised way. We therefore recommend complementing structured in-situ monitoring schemes with digital sensor networks to scale up the spatial, temporal, and taxonomic resolution of terrestrial and aquatic biodiversity monitoring across Europe. This will be beneficial for a broad range of EBVs (Figure 12).

Digital sensors are especially relevant for monitoring EBVs that capture the distribution, abundance, and phenology of species (Figure 12). For instance, the monitoring of wildlife populations with camera traps across Europe is currently improved by the ENETWILD project which is implementing international standards for data collection and providing guidance on wildlife density estimation (ENETWILD-consortium et al. 2022, ENETWILD-consortium et al.

2023). Similarly, the European Tracking Network (ETN, https://www.europeantrackingnetwork.org) has emerged as a key network for aquatic researchers using acoustic telemetry to investigate the ecology and movement behaviour of aquatic species in relation to their environment. For insects, several monitoring projects with acoustic devices and insect cameras are currently pioneered in Europe (van Klink et al. 2022). For some digital sensors, centralized data management systems have already emerged for the scientific community, such as Movebank for animal tracking data (https://movebank.org/), ETN for acoustic telemetry of freshwater and marine mammals (https://lifewatch.be/etn/), and Agouti for terrestrial wildlife camera traps (https://agouti.eu). Such efforts are promising, but require additional funding and support for developing standardized data collection protocols, data integration and harmonization procedures, machine-readable metadata, improved AI species identification algorithms, repositories and services for data storage, robust privacy policies, and platforms for handling digital media files and their annotations. Major investments are therefore needed into a digital infrastructure that supports a European Biodiversity Observation Network.

Remote sensing

Remote sensing with satellites, drones and airplanes can play a major role for monitoring EBVs (Lumbierres et al. 2024). We therefore consider the monitoring of EBVs with Earth Observation (EO) data as a key component of a European Biodiversity Observation Network.

Current satellite remote sensing with the European Copernicus Sentinels and the American Landsat data archives can support EU-wide monitoring with a spatial resolution of up to 10 m, a broad spatial extent (Europe-wide or even near-global) and a high temporal resolution (weekly up to daily). This is particularly relevant for ecosystem-focused EBVs in the EBV classes ecosystem structure (e.g. 'Ecosystem distribution of terrestrial EUNIS Habitats') and ecosystem functioning (e.g. 'Harmful marine algal blooms' and 'Harmful and non-harmful freshwater algal blooms') (Figure 13). However, to achieve assessments of habitats and ecosystem conditions across Europe there is a need to map ecosystem types more finely than land cover classes, to update EBV products more frequently, and to enhance the availability of ground-based (in-situ) data on land and in marine and freshwater environments (Camia et al. 2023). A major constraint for operationalising EBVs with satellite remote sensing at broad spatial scales is the lack of in-situ reference data. Such ground-based measurements are indispensable for monitoring biodiversity with an Earth Observation (EO) platform. However, in-situ data collection is time-consuming and costly, and often collected in a way that it is not usable with EO. Consequently, in-situ data is often not available in sufficient volume to calibrate (train) and validate the remote sensing enabled EBVs. This is relevant for machine learning models (particularly deep learning) because they require many high-quality in-situ data for model training. In-situ data need to be consistent over time, but not necessarily being as frequently sampled as in structured in-situ monitoring schemes. However, they should cover the taxonomic detail that can be discovered through EO, have a geolocation precision as required by the spatial resolution of the EO signal, include information on the size and diversity of the observation, and preferably coincide with the EO platform’s overpass to address specifics of biophysical and biochemical parameters.

Several developments have been identified to extend the use of EO for biodiversity monitoring in the future (Table 4). This includes, for instance, new terrestrial models for monitoring habitats and invasive species through the use of deep learning models with hyperspectral data from satellites (Omeer and Deshmukh 2022) or multi-satellite combinations to detect vegetation height (Perez et al. 2022). Defining protocols for a harmonized in-situ collection of ground-based measurements with a harmonized European classification scheme (e.g. EUNIS habitats) applied by experts in all EU member states together with a multi-disciplinary expert group for data quality control would improve the collected in-situ data. Applications of satellite remote sensing to habitat monitoring and classification would further benefit from the in-situ collection of additional physical properties such as vegetation height, colour during flowering, specific textures (standing patterns), soil properties (including wetness), phenological cycles, and non-natural features. This would improve the training data for hierarchical classification approaches for various remote sensing domains (optical, radar, lidar) and signal content (vegetation structure, volume, water content, height). Moreover, the geospatial location accuracy of the sampling plot is highly relevant for model accuracy. The position accuracy of the ground truth data should therefore be at or better than the resolution of the imagery, e.g. a position accuracy of 5 m for a habitat classification at 10 m spatial resolution. Not all habitat types can be directly classified by remote sensing. For instance, hard to distinguish habitats defined only by their understory (e.g. Central European lichen pine forests vs. blueberry pine forests) will need auxiliary inputs.

Besides satellites, data collected with crewed aircraft through (sub)national airborne laser scanning surveys as well as imagery and LiDAR point clouds collected with affordable unmanned aerial vehicles (UAV, i.e. drones) will be required to complement satellite remote sensing with habitat condition assessments at scales useful to land managers (e.g. site-specific Natura 2000 monitoring). This may specifically include monitoring of vegetation structure and landscape characteristics which are relevant for the EBVs ‘River Connectivity/Free river flow’, ‘Structural complexity of riparian habitats’, ‘Vertical structure of vegetation’, ‘Connectivity of terrestrial ecosystem habitat types’ and ‘Standing and lying deadwood’. For drone surveys, major challenges include the lack of standardisation of flight surveys, little guidance for standardised data generation, the absence of standardised metadata, and the use of proprietary software during data pre-processing. Similar challenges exist for harmonizing weather radar data, which have great potential for monitoring aerial biomass (birds, bats, and insects). New meteorological data exchange policies further pose a risk for the sharing and standardizing of continent-wide weather radar data, as they render data useless for biodiversity monitoring (Shamoun-Baranes et al. 2014). A European Biodiversity Observation Network there needs to foster better coordination, integration, and harmonisation of local and national data collection efforts with airborne UAV-based platforms.

Citizen science

Through the participation of volunteers (novices or experts), citizen science has great potential to complement data collection by biodiversity monitoring professionals (Chandler et al. 2017, Fritz et al. 2019, Sheard et al. 2024). Citizen science is particularly important for species-focused EBVs in the EBV classes genetic composition and species populations but can also strongly contribute to various ecosystem-focused EBVs (Figure 14). In the terrestrial realm, numerous examples exist where citizen science can contribute to monitoring EBVs such as 'Species abundances of selected terrestrial bird species' and 'Phenology of migration of terrestrial birds' (Sullivan et al. 2009, Jetz et al. 2019) or ‘Species distributions of selected terrestrial plants’ (van Strien et al. 2022). In fact, much of the bird-related EBVs are currently monitored by dedicated volunteer programmes, organized by natural history societies and NGOs, and complemented by various apps (e.g. EuroBirdPortal). In the freshwater realm, citizen science can contribute to monitoring algal blooms (Bloomin’ Algae, ceh.ac.uk), invasive species or species traits such as the EBV ‘Phenology of migration of freshwater fishes’ (Collins et al. 2023). Within the marine realm, citizen science could also support a range of EBVs, for instance monitoring the EBV 'Ecosystem distribution of marine seagrass habitats' (Rock and Daru 2021). In addition, citizen science can be used to identify the impact of environmental drivers, such as climate change (Devictor et al. 2012), pesticides in rivers and small streams (Collins et al. 2023, von Gönner et al. 2023) or the impact of urbanization (Svenningsen et al. 2022).

Although numerous existing citizen science data streams could already contribute to generating EBVs, there is great potential for additional innovation in this field. We recommend promoting the use and integration of citizen science with other emerging tools and technologies for biodiversity monitoring. For instance, the advent and rapid development of artificial intelligence (AI) algorithms in computer vision combined with digital sensors such as camera traps, audio records and radar provide unprecedented possibilities for advancing large-scale biodiversity monitoring with citizen science (Schiller et al. 2021, Besson et al. 2022, van Klink et al. 2022, Sheard et al. 2024). This could contribute to multiple EBV classes across realms, including EBVs of species populations and species traits. Similarly, citizen science has the potential to contribute to eDNA-based surveys, e.g. for monitoring fish and other animal diversity in streams, especially in small water bodies currently not covered by the WFD (Clarke et al. 2023). To ensure improvements in citizen science data coverage, it is recommended to shift incentives from numbers of records and species collected to value of records contributed (Oliver et al. 2021). Here, well designed recording schemes and apps can help to implement semi-structured recording schemes and thereby increase the accuracy and usefulness of citizen science data (Kelling et al. 2019). Moreover, new methods for data integration are being developed to combine structured monitoring data and opportunistic citizen science data (Isaac et al. 2020). Understanding potential biases in citizen science data can further help to adapt data analyses and deal with uncertainties (Bowler et al. 2022). Employing behavioural nudges can further improve biodiversity data derived from citizen science (Callaghan et al. 2023), while species trends can be detected reliably even when recording behaviour can be accounted for (Bowler et al. 2022, Pocock et al. 2023).

Data integration and modelling

The EBV framework allows producing standardised, spatiotemporal EBV data cubes that can form the basis for automatically assessing the status and trends of species and habitats. However, this requires developing standardised and reproducible workflows for integrating multiple biodiversity data streams, and advanced modelling techniques for gap-filling and producing wall-to-wall EBV cubes, while accounting for different sources of uncertainty. We therefore strongly recommend facilitating and expanding the capacity for data integration at the EU level and modelling for EBV generation.

For data integration, the most important needs for developing EBV workflows are multi-source data integration, improved accessibility and availability of data, implementation of data and metadata standards, and the expansion and improvement of European integration nodes (Figure 15a). Multi-source data integration refers to integrating data from different sampling methods (Isaac et al. 2020), digitizing and mobilizing historical datasets such as 'long-tail data' (Vanderbilt and Gries 2021), better aligning the collection of in-situ data for model training (e.g. EBV satellite remote sensing products), and providing data machine-actionable exchange mechanisms between various web portals. Closely connected is the improvement of databases (e.g. reference databases for metabarcoding and genomes, databases for training and validating AI algorithms), transnational data repositories, and the harmonization of different national databases, including the harmonization of taxonomic nomenclature for taxa (e.g. diatoms) that have different traditions of morphological identification across the EU. A major challenge remains access to data, even if they have been collected with public funding. In many cases, data access is restricted to the derived data rather than the raw data, e.g. access to normalised EQR values from the WFD monitoring through the EEA rather than to the collected raw data of species distributions and abundances (Moe et al. 2023). Some data, such as national forest and fishery inventories, have no public access. It is therefore paramount to increase data sharing between organizations, administrations, and countries, and to develop data sharing agreements. A major bottleneck is the implementation of human- and machine-readable data and metadata standards which would facilitate an automated data integration process (Hardisty et al. 2019, Morán-Ordóñez et al. 2023a). Finally, the expansion of European integration nodes and an improvement in communication and coordination support for national coordinators, volunteers and paid experts is crucial.

For modelling, the development of spatially explicit models together with indicator development and driver attribution (i.e. models that connect EBVs to drivers of biodiversity loss) is seen as the most important need for developing EBV workflows (Figure 15b). The most widely used spatially explicit models in biodiversity assessments are species distribution models (Araújo et al. 2019). For applications with EBVs, such models need to be extended to make spatially explicit predictions not only of species distributions but also of population abundance, community composition, taxonomic diversity, microbial biomass, pest prevalence and biological quality elements of the WFD, to name a few. For some species, such as freshwater mussels that need a suitable fish species to complete their life cycle, joint species distribution models can be applied that estimate distributions of multiple species simultaneously (Pollock et al. 2014). More broadly, new modelling techniques that include biotic interactions (predator-prey interactions, parasites, diseases, etc.) should be explored (Kissling et al. 2012, Wisz et al. 2013). Spatially explicit models in rivers also need to consider the dendritic hierarchical structure of stream networks and connectivity (e.g. presence of dams and other obstacles), rather than using species distribution models borrowed from terrestrial environments. For most EBVs (and indicators), the development of baselines such as historical reference conditions or the level of diversity that should be maintained to optimize conservation efforts is needed to assess current condition and put current and future biodiversity metrics into context. The EQR-values for freshwater community composition are good examples of indicators that are based on deviation from reference conditions (Moe et al. 2023). Similar approaches have been suggested for ecosystem accounting of forest condition (Maes et al. 2023). Model accessibility should also be improved, such as open code, user-friendly software, easy-to-use tools for spatially explicit modelling and the automated calculation of geospatial information.

Digital infrastructure

A European Biodiversity Observation Network should as much as possible make use of existing infrastructures, standards and pipelines to avoid duplicating efforts and re-inventing solutions that were already developed by the biodiversity informatics community. We therefore recommend that a digital infrastructure should be supported by existing EU infrastructures and services that provide data, platforms and cloud-based hosting and processing solutions (Figure 16). Since data processing and EBV data integration and modelling often involve data from multiple sources, advanced computing and network infrastructure is needed to allow access to remote data sources, automated processing pipelines, and data storage of intermediate and final data products. Expanding and integrating existing platforms and portals such as GBIF, the EBV portal of GEO BON and the Biodiversity Information System for Europe (BISE), Water Information System for Europe (WISE) and leveraging re-configurable EBV workflows in European infrastructures such as the European Open Science Cloud (EOSC), LifeWatch, and ELIXIR further requires a web of FAIR data and supporting services and developing digital tools for knowledge sharing, dissemination, and data integration (Figure 16). The value of data being shared with interoperable standards and published on open platforms such as GBIF is that they can be integrated into a global knowledge base and repurposed for a wide variety of other uses, including the Kunming-Montreal GBF of the CBD and the associated reporting requirements for the EU and its member states.

For the monitoring of species, existing (meta)data standards such as the Darwin Core (DwC) are readily available for ensuring interoperability (Wieczorek et al. 2012). GBIF provides the tools and exchange protocols that enable such data to be formatted, published, discovered, accessed, and re-used. The simplification and ‘flattening’ of raw data into exchange formats for species occurrence datasets in GBIF has resulted in key information on species populations and trends being lost in the sharing process. Recent developments such as the Event Core or sampling-event datasets have enabled the sharing of richer contextual information provided by the grouping of species observations around specific sampling events at particular locations and time periods, including detailed description of methodologies, protocols and sampling effort in the metadata, as well as quantitative information on individual numbers or volume of biomass, and even absences when target species are not found in surveys or censuses. Nevertheless, existing data exchange standards are not sufficient to represent the full richness of raw data from a range of monitoring methods. GBIF has therefore initiated a process to diversify its existing data model, encouraging development of a variety of use cases to test a new, universal data model capable of capturing more complex associations and ontologies. Involvement of the European biodiversity monitoring community in support of this process will be fundamental for the success of a European Biodiversity Observation Network, e.g. through submitting use cases and testing the model to provide a solid and fit-for-purpose data infrastructure capable of integrating a wide range of monitoring data.

While an effective digital infrastructure for biodiversity monitoring will inevitably involve new networks of sampling sites and investment into additional data collection efforts, a key component of such an infrastructure involves a process of ‘unlocking’ existing data. Thus, an important part of a European Biodiversity Observation Network will be the rescuing and mobilizing of raw data that is generated for the purposes of EU reporting, but that is currently discarded, lost, or inaccessible (Morán-Ordóñez et al. 2023b, Santana et al. 2023). Such raw datasets are not routinely shared because there is no mandate for national authorities to do so, as the obligation is typically restricted to more aggregated data requested for the reporting formats, for example to the EEA, that include no requirements for sharing the underlying observation data, or even indicating where it may be found. An effective European monitoring system will provide both the mandate and the means to ensure that original source datasets are compiled using common exchange standards and shared through interoperable data platforms. Support services for handling such datasets are currently provided through national GBIF nodes, and these should be supplemented by technical services at a European level to support data standardization and sharing. A centralized service, acting as a component of the EBOCC, is required to a) account for the fact that GBIF nodes are not present within all European states, and b) provide support and guidance to existing GBIF national nodes on the best practices for mobilizing raw datasets from EU reporting workflows.

For the operational implementation of EBV workflows, a digital infrastructure must provide data storage and hosting services, cloud and high-performance computing (HPC) services, data management tools, virtual research environments and dashboards and knowledge sharing platforms (Figure 16). This will allow to host the modelling routines and to handle tasks such as predictor data retrieval, processing, storage, and EBV generation. Dedicated personnel are required to monitor and resolve technical issues that may arise with the infrastructure. Ideally, model calibration should be periodically updated, which requires the availability of specialised technical staff. Developing, maintaining, and updating EBVs operationally therefore requires specialized personnel who can perform model development, quality control and maintenance of the IT infrastructure. Moreover, specialized personnel are required for front-end and web development.

COSTS

Total costs of a European Biodiversity Observation Network

We estimated the total costs of establishing and maintaining a European Biodiversity Observation Network by calculating staff and material costs in terms of data collection, workflows, and coordination for 84 EBVs over a 10-year period for each EU member state and with activities of a EBOCC to support the coordination in the EU (Appendix S2). For the sampling networks that simultaneously record data for multiple EBVs (Table 2) we distinguished a low site-number and a high site-number scenario. For the low site-number scenario with 10,000 river sections, 2,000 lakes, 550 ocean cells of 10 km^2 size, 100,000 terrestrial sites, and remote sensing validation in 1 site per 500 km^2 (Table 2), the total costs over 10 years for the eighteen sampling networks were estimated at 5.7 billion EUR (Table 5). Across EU member states, this includes 506 million EUR for initial establishment and 460 million EUR/year for annual maintenance of the sampling networks. Costs were calculated per monitoring method involved in each sampling network (Appendix S2: Table S2). At the EU-level, establishment costs for an EBOCC were estimated to be 68 million EUR, with an annual maintenance of 56 million EUR/year, representing ~11% of the total costs in a low site-number scenario. Costs for the EBOCC included activities for standardisation, power analysis, capacity building, modelling, metadata, central repositories, citizen science apps, and automated pipelines (Appendix S2: Table S7). Similar activities were costed for EU member states to actively contribute to the European data integration (Appendix S2: Table S10).

Using a high site-number scenario with 100,000 river sections, 20,000 lakes, 5,500 ocean cells of 10 km^2 size, 100,000 terrestrial sites, and remote sensing validation in 1 site per 50 km^2 (Table 2), the total costs over 10 years for the eighteen sampling networks increased sevenfold to 39.7 billion EUR (Table 6). Across EU member states, this included 2,865 million EUR for initial establishment and 3,623 million EUR/year for annual maintenance of the sampling networks. At the EU-level, establishment, and maintenance costs for an EBOCC were the same as in the low site-number scenario, and thus relatively lower (~1.5% of the total costs of the overall network).

Cost variation among sampling networks

The most expensive sampling network was the ‘terrestrial invertebrate monitoring’ with a total cost of 1.5 billion EUR and 14.4 billion EUR for a low and high site-number scenario, respectively (Table 5 & Table 6). The monitoring of terrestrial invertebrates with various traps (malaise traps, pitfall traps, sticky traps, light traps, tick cloth drags) includes high annual fuel costs for repeated site visits and high costs for identifying the large numbers of insects collected by traps (Appendix S2: Table S2). This sampling network covers three EBVs, namely 'Species abundances of selected terrestrial animal disease vectors', 'Species abundances of selected terrestrial crop and forest pests', and 'Community biomass of selected functional groups of terrestrial arthropods (e.g. predator, decomposer)'. An improved monitoring system that requires less regular field visits, takes advantage of digital sensors with AI species identification and automated invertebrate sample sorting (Høye et al. 2021), and makes use of eDNA metabarcoding (Buchner et al. 2024) would greatly reduce the fuel and staff costs of this network.

The sampling network for ‘mainland mammal monitoring’ was also estimated to be expensive, with a total cost of ~1 billion EUR and 8.9 billion EUR for a low and high site-number scenario, respectively (Table 5 & Table 6). This sampling network aims to monitor the distribution and abundance of terrestrial and freshwater mammals and included costs for digital sensors (camera traps and acoustic devices), genetic analysis of faecal/spraint samples, and traditional monitoring methods such as transect counts and live trapping capture-recapture (Appendix S2: Table S2). The high costs derive from the annual fuel costs for repeated site visits and the time taken to identify animals from digital media (images and sound files). Efforts to reduce the amount of field data collection and manual species identification, e.g. through sensor networks with automated data streams and machine learning for automated species identification

(Porter et al. 2005, Steenweg et al. 2017, Tuia et al. 2022) can greatly reduce the long-term costs of such sampling networks (Kissling et al. 2024).

The costs for freshwater sampling networks (rivers and lakes) were higher than some terrestrial sampling networks (Table 5 & Table 6). This is due to the time-consuming nature of many freshwater monitoring methods, particularly for sampling fish and identifying invertebrates and plankton (Appendix S2: Table S2). This is offset by the less frequent sampling (each site is sampled once per three years), which greatly reduces the staff effort required. However, lowering the frequency of monitoring risks missing key inter-annual trends among certain key taxa, particularly under climate change conditions (e.g. O'Donnell et al. 2023).

In contrast to most other sampling networks, the sampling networks in the marine realm (i.e. for fish, invertebrates & plankton, and marine habitats) had higher establishment costs than annual maintenance costs (Table 5 & Table 6). The set-up of marine sampling networks requires considerable investment into technology and workflows during establishment, but then becomes much less expensive annually. However, it should be noted that the site numbers in the marine sampling networks were several orders of magnitude smaller than those of terrestrial and freshwater sampling networks.

The least expensive sampling networks were 'mainland habitat monitoring', 'vegetation monitoring', 'citizen science apps' and 'LiDAR' (Table 5 & Table 6). Mainland habitat monitoring and vegetation monitoring is time consuming due to the (re)surveying of vegetation plots (Knollová et al. 2024), but once completed it requires less data processing and archiving than other sampling networks. The citizen science apps network is very cost-effective due to the low labour cost within the network, even when including the development of apps for individual EU member states. We applied this monitoring method only to EBVs where data are best collected entirely by citizen scientists. Examples include the phenology of fruits and mushrooms (EBVs 'Phenology of fructification of wild fruits' and 'Phenology of fructification of mushrooms') and river barrier mapping (EBV 'River Connectivity/Free river flow'). However, citizen science apps can add considerable value to other sampling networks for relatively little investment and maintenance costs. The LiDAR sampling network had relatively low costs because it only included costs for processing workflows and not for data collection which is usually done through national LiDAR flight campaigns in various EU member states (see e.g. Kissling et al. 2022). Two EBVs were included in the LiDAR sampling network, namely the EBVs 'Structural complexity of riparian habitats' and 'Vertical structure of vegetation'.

Satellite remote sensing costs were mainly driven by the costs for data validation because we assumed that existing Earth Observation data can be used to generate EBVs. We included three forms of data validation in our cost estimation (Appendix S2), i.e. phenocams (to validate ecosystem phenology EBVs), flux towers (to validate ecosystem productivity EBVs), and image flow cytometry (to validate marine algal bloom EBVs). Without these costs for validation the overall costs were reduced by ~20% over 10 years (i.e. 69 less than 368 million EUR in the low site-number scenario, Table 5). Nearly 80% of the validation costs were from the flux towers due to the high material and staff costs involved (1 full time staff member per tower). However, a significant challenge in developing Earth Observation models is the availability of reliable ground truth data for model validation. We included EBVs for which there are already some models available, but a significant investment will be needed to develop models for other EBVs, such as EUNIS habitats.

Cost efficiency

Previous work on the costs of European monitoring schemes (Breeze et al. 2023) indicated that the cost-efficiency of data generation from biodiversity monitoring schemes could be increased through collecting data for multiple EBVs at once, reducing the use of contractors and increasing participation from citizen scientists. The sampling networks used here to illustrate costs (Table 2) were designed to reduce redundancy in data collection efforts, especially where (1) observations for one taxa can be used to develop multiple EBVs (e.g. species distribution of terrestrial birds and phenology of terrestrial birds), (2) data for multiple EBVs can be collected at the same time (e.g. species distributions of plants and species distributions of lichen), or (3) where the monitoring methods are identical among EBVs (e.g. species distributions of wetland birds and species distribution of terrestrial birds). If each of the 68 EBVs for which individual cost calculations could be made were to be monitored by a separate network, using the same general methods and assumptions, the total cost would range from 14.6 billion EUR (low site-number scenario) to 117.4 billion EUR (high site-number scenario) over 10 years (details in Appendix S3). This corresponds to an increase of 256%–296% of the total costs of all sampling networks combined. Much of the cost savings arise from reducing the staff effort and fuel costs from travelling to sites to collect multiple data types, and from a more centralised coordination effort at a member state level.

We have used the most widely applied methods for biodiversity monitoring as part of this cost estimation. However, several emerging technologies could further reduce these costs. For example, fully autonomous camera traps for mammal monitoring could greatly reduce the staff and fuel required to change batteries and memory cards and, combined with AI assisted identification of species, can collectively reduce camera trap costs by over 40% (Kissling et al.

2024). Environmental DNA (eDNA) analysis can greatly reduce the need for site visits to detect a number of freshwater (e.g. Smart et al. 2016), marine (e.g. Bowers et al. 2021) and terrestrial taxa (e.g. Lyet et al. 2021). Aerial remote sensing also offers the possibility not only to reduce data collection efforts for species-focused EBVs (e.g. McIntosh et al. 2018, Michez et al. 2021), but also to detect standing and lying deadwood (Zielewska-Büttner et al. 2020). Finally, as noted above, remote sensing technologies are inexpensive relative to biodiversity monitoring with in-situ data collection and other EBVs could be generated with such remote sensing data in the future, including distributions of freshwater macrophytes (Espel et al. 2020), macroalgae (Marquez et al. 2022) and terrestrial EUNIS habitats (Rapinel et al. 2022). However, developing applications of these technologies for an operational monitoring system will require a significant up-front investment in data collection to develop, validate and update the underlying models. As such, biodiversity monitoring can be self-improving, increasing in efficiency as data allow new methods to emerge.

Citizen scientists can generate large volumes of data with very little cost (Estes-Zumpf et al. 2022). We assumed a minimum citizen science engagement to keep our cost estimates conservative. However, thousands of citizen scientist already contribute to biodiversity monitoring efforts (European Environment Agency 2020) and a wide range of local initiatives have been launched to monitor specific taxa across Europe, including freshwater invertebrates (Jarić et al. 2020), coral reefs (Branchini et al. 2015) and priority beetles (Zapponi et al. 2017). However, managing citizen scientists effectively is a demanding effort that should be properly resourced at both national and EU level to maximise volunteer engagement and retention (Breeze et al. 2023).

The establishment of a European Biodiversity Observation Coordination Centre (EBOCC) —recently supported with a grant from the European Parliament in the form of a preparatory action— can play a crucial role in improving cost-efficiency by supporting capacity building among and between EU member states (Liquete et al. 2024). This can be (1) directly through developing data collection standards, workflows and data hosting solutions, and (2) indirectly by providing contacts and forums for coordinators in EU member states to learn from one another, and by supporting connections with business and finance which could potentially provide revenue (Liquete et al., 2024).

Finally, although the costs for the proposed network might appear to be high, the benefits stemming from effective biodiversity monitoring and the proper targeting of conservation and restoration measures that result from this are likely to be much higher than even the highest cost network. As European business and finance increasingly consider their impacts on biodiversity, good quality data will be essential to developing effective conservation action. This remains a significant bottleneck for the uptake and effectiveness of green financial measures and nature-based solutions (zu Ermgassen et al. 2022, World Economic Forum 2023). Regardless of the optimal efficiency of the monitoring network, funding the development of expertise through biodiversity monitoring will represent a significant investment in improving the efficiency of wider biodiversity conservation, restoration, and management into the future.

SCALABILITY AND TRANSFERABILITY OF THE EUROPEAN MONITORING DESIGN AND COSTS

Our synthesis provides the most comprehensive framework to date for establishing a modern and efficient European biodiversity observation network (Figure 2). We address a comprehensive set of relevant policies in the EU (Table 2, Figure 6), propose EBVs to represent multiple dimensions of biodiversity (i.e. genetic composition, species populations, species traits, community composition, ecosystem functioning and ecosystem structure), cover the terrestrial, freshwater and marine realms, include a broad range of monitoring techniques (Figure 4, Appendix S2: Table S2), and provide costs estimates at the EU level and for all EU Member States based on the best knowledge currently available (Appendix S2, Appendix S3). This framework could be a blueprint for biodiversity monitoring in other regions of the world, as many of the recommendations are generic and go beyond the specific European situation. This is particularly timely, now when the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is carrying out the first global methodological assessment on monitoring biodiversity (Decision IPBES/10/1). Application to other regions may, however, require fine-tuning to match policies as well as considering additional taxa and ecosystems that occur outside the European continent. Likewise, the cost estimation for the European monitoring network can not be readily transferred to other continents, as the costs are dependent on a country’s socio-economic conditions, technological development, and organisational structures. However, the underlying methodology for cost estimation remains applicable, if adjustments are made for differences in policies, personnel and material costs, training and capacity building requirements (e.g. for taxonomy, citizen science set-up, and co-ordination), and the development level of transnational or national digital infrastructures.

The monitoring methods presented here should also be transferable, as far as the human capacity to apply new technologies is available. Indigenous knowledge about species and habitats, which is very valuable, especially in tropical areas, could also be incorporated in regulatory in-situ monitoring programmes, potentially creating win-win benefits. The spatial and temporal resolution proposed for each EBV could also be used as a reference, but the spatial number and density of monitoring sites will likely need scaling based on the region's size and environmental conditions. Most of the other recommendations given above would also be adoptable in other areas. These include:

- Co-location of monitoring activities for several EBVs at the same sites, adding missing taxa and filling spatial gaps, as that would enable holistic assessments of biodiversity change across multiple dimensions.
- Using standardised and reproducible workflows for integrating multiple biodiversity data streams all the way from monitoring, data reporting, quality checking and data processing to data analysis and publication of data and products, e.g. spatial distributions of species and habitats on maps and assessments of trends.
- Using a digital infrastructure that is supported by existing infrastructures and services, and with data being shared using interoperable standards and published on open platforms.
- Using advanced monitoring and modelling techniques for gap-filling and producing wall-to-wall EBV data cubes, while accounting for different sources of uncertainty.

The feasibility of implementing our recommendations benefits from the development of transnational integration among countries and from subnational integration within countries (e.g.

among federal states, provinces, and counties). The capacity and level of biological, ecological, and technical expertise in addition to sufficient financial resources is crucial. High-level integration comparable to the EU-level would facilitate the transferability of the European design. In the absence of such integration, our framework can still be of value for improving national biodiversity monitoring in countries in other continents, but will need to be adapted to policies, capacities, funding, and organisation of monitoring systems in each country. We therefore recommend applying our framework in other parts of the world to test its wider applicability for advancing modern and efficient biodiversity observation networks that contribute to local, national, and global conservation efforts.

ACKNOWLEDGEMENTS

We are grateful to Jan-Erik Petersen (European Environmental Agency) for contributing to the EBV-policy mapping and to Stacy Shinneman (University of Amsterdam) for support with GIS mapping. We acknowledge the contributions of all EuropaBON members, external experts and officials from the European Commission and EU agencies who participated in EuropaBON conferences, expert meetings, workshops, online surveys, and interviews.

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TABLE 1 The policy framework of the European Union (EU) which drives the development of biodiversity and ecosystem monitoring and assessments, and fosters management measures for the conservation and sustainable use of EU ecosystems. The policies are ordered by publication year.

EU policy	Abbreviation	Year	Description	Weblink
Birds Directive	BD	1979	Requires the EU member states to monitor and report on the conservation status of all wild bird species natural occurring within and outside protected areas. It includes the assessment of population size, trends and species distributions.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31979L0409
Habitats Directive	HD	1992	Requires the EU member states to monitor and report on the conservation status of habitats. This includes the assessment of the extent and condition of 200 habitat types and over 1000 animals and plant species within and outside of the Natura 2000 protected areas.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31992L0043
Water Framework Directive	WFD	2000	Requires EU member states to monitor and report on the ecological and chemical status of water bodies, including a wide range of biological quality elements in rivers, lakes, transitional and coastal waters.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32000L0060
National Emission Ceilings Directive	NECD	2001	Establishes the emission reduction commitments for the EU member states anthropogenic atmospheric emissions. EU countries need to measure in situ the impact of air pollution on terrestrial and freshwater ecosystems.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32001L0081
Marine Strategy Framework Directive	MSFD	2008	Requires EU member states to monitor and report on the environmental status of all marine EU waters, including environmental status and biodiversity criteria covering all species groups and broad habitat types.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0056
Common Fisheries Policy	CFP	2013	Establishes rules for sustainably managing European fishing fleets and conserving fish, including a monitoring framework targeting population sizes of various marine fish stocks.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R1380&qid=1686913584860
Regulation on Invasive Alien Species	IAS	2014	Requires EU member states to set up a surveillance system which collects and records data on the occurrence of invasive alien species of EU concern.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014R1143#d1e1376-35-1

EU Biodiversity Strategy for 2030	BDS	2020	Provides high-level ambitions of the EU to halt biodiversity decline and to put biodiversity on the path towards recovery by 2030. Includes more than 100 actions with headline indicators linked to 16 targets. Those indicators have different sources and do not necessarily depend on official reporting obligations of EU member states.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380
Common Agricultural Policy	CAP	2021	Aims to help tackling climate change and the sustainable management of natural resources in rural areas and landscapes across the EU. This requires a monitoring framework targeting selected species in agricultural areas. Farmland birds are reported as indicator under this monitoring and evaluation framework.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021R2115
Proposed Regulation on Ecosystem Accounting	EEA-EA	2022	Sets out a common framework for collecting, compiling, transmitting, and evaluating European environmental economic accounts. Includes accounts on forests and other ecosystems.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022PC0329
Proposed Forest Monitoring Regulation	FMR	2023	Sets out a common monitoring framework for the consistent collection and sharing of accurate and comparable forest data to ensure a coherent high-quality monitoring of EU forests and other wooded land.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0728
Pollinators Initiative	PI	2023	Develops and tests an EU-wide pollinator monitoring sampling scheme that includes bees, butterflies and hoverflies while also increasing taxonomic capacity and expertise in countries.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023DC0035
Land Use, Land Use Cover and Forestry Regulation	LULUCF	2023	Requires the monitoring of change in carbon stocks in managed forests, croplands, grasslands, and wetlands. Aims to remove annually 310 million tonnes CO_2 equivalents from the atmosphere by 2030.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018R0841-20230511
Proposed Directive on Soil Monitoring and Resilience	SML	2023	Sets out a soil monitoring framework for all soils across the EU and aims to achieve and maintain healthy soils by 2050, so that they can supply multiple ecosystem services.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0416&amp%3Bqid=1706624227744
Nature Restoration Law	NRL	2024	Multiple binding restoration targets and obligations to achieve the continuous, long-term, and sustained recovery of biodiverse and resilient nature across the EU's land and sea areas. Aim is to restore ecosystems and to contribute to achieving Union climate mitigation and climate adaptation objectives and meet its international commitments.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1728024382866

TABLE 2 Overview of sampling networks into which Essential Biodiversity Variables (EBVs) were grouped. The sampling networks were used as the basis for calculating the costs of a European Biodiversity Observation Network, assuming shared methodologies and a specific taxonomic focus within a sampling network. The EBV IDs refer to the EBV identifiers on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki). Additional details on methods and sources are provided in Appendix S2.

Sampling network	Description	Methods	Sites (low and high site-number scenario)	EBV IDs
Freshwater				
River monitoring[1]	Monitoring of rivers at a catchment scale >10 km^2, using methods employed in biodiversity sampling for the Water Framework Directive (e.g. WISE-2), with additional surveys to capture river barriers	Electrofishing, macrophyte transects, diatom and other benthic algae sampling, kick sampling of benthic invertebrates, barrier mapping	10,000 or 100,000 river sections, proportionally divided among EU member states based on the number of rivers as given by Lyche Solheim et al. (2019).	Spp_SP_dis_fish_FW, Spp_SP_dis_inve_FW, Spp_SP_dis_mphy_FW, Spp_ST_phe_fish_FW Eco_CC_com_mphy_FW, Eco_CC_com_pben_FW, Eco_CC_com_inve_FW, Eco_CC_com_fish_FW, Eco_CC_com_fung_FW,
Lake monitoring[2]	Monitoring of lakes (>50 ha), using methods employed in biodiversity sampling for the Water Framework directive	Dip sampling (phytoplankton, cyanobacteria and zooplankton), pump/core sampling for invertebrates, macrophyte survey, gillnetting, trawling, hydroacoustic survey for fish	2,000 or 20,000 lakes, divided proportionally among EU member states based on the number of lakes as given by Lyche Solheim et al. (2019).	Eco_CC_com_mphy_FW, Eco_CC_com_ppla_FW, Eco_CC_com_pben_FW, Eco_CC_com_fung_FW, Eco_CC_com_zoop_FW, Eco_CC_com_inve_FW, Eco_CC_com_fish_FW, Eco_EF_phe_ppla_FW

[1] We assume that each site in this sampling network is sampled once every 3 years.

[2] We assume sampling once every 3 years for phytoplankton (monthly samples in the growing season) and fish, and every 6 years for macrophytes. Some EBVs will require both river and lake sampling and hence are named in both networks

Marine				
Marine fish monitoring	Active and passive monitoring of marine fish, e.g. as implemented by the European Tracking Network (ETN) or for the Marine Strategy Framework Directive	Trawling surveys, acoustic sensors	550 or 5,500 ocean cells of 10 km^2 size, representing 1% and 10% of the total Exclusive Economic Zone (EEZ) of EU member states around continental Europe.[3]	Spp_SP_dis_fish_MA, Spp_SP_abn_fish_MA, Spp_ST_phe_fish_MA
Other marine vertebrate monitoring	In-situ monitoring of marine bird colonies, mammals and turtles, e.g. as implemented for the Helsinki Commission (HELCOM), Oslo and Paris Conventions (OSPAR), and the Italian Institute for Environmental Protection and Research (ISPRA).	Ship transects, aerial transects	550 or 5,500 ocean cells of 10 km^2 size, representing 1% and 10% of the total Exclusive Economic Zone (EEZ) of EU member states around continental Europe.[3]	Spp_SP_dis_bird_MA, Spp_SP_abn_bird_MA, Spp_SP_dis_mamm_MA, Spp_SP_dis_rept_MA, Spp_ST_phe_bird_MA, Spp_ST_phe_mamm_MA
Marine habitat monitoring[4]	Monitoring of marine habitat distribution (oyster reefs, coral reefs, macroalgae forests and seagrass forests)	Marine habitat surveys, sediment core sampling	550 or 5,500 ocean cells of 10 km^2 size, representing 1% and 10% of the total Exclusive Economic Zone (EEZ) of EU member states around continental Europe.[3]	Eco_ES_dis_cora_MA, Eco_ES_dis_malg_MA, Eco_ES_dis_plan_MA, Eco_ES_dis_oyst_MA, Eco_EF_dtb_habi_MA
Marine invertebrate & plankton monitoring	Monitoring of marine invertebrates and plankton	Plankton trawling, Autonomous Reef Monitoring Structure (ARMS) and Artificial Substrate Unit (ASU) sampling with genetic metabarcoding, marine video transects	550 or 5,500 ocean cells of 10 km^2 size, representing 1% and 10% of the total Exclusive Economic Zone (EEZ) of EU member states around continental Europe.[3]	Spp_SP_dis_inve_MA, Eco_CC_com_micr_MA, Eco_CC_abn_inve_MA
Terrestrial				

[3] These are divided among EU member states based on the relative size of their EEZ. We include the overseas territories of Madeira, the Azores and the Canary Islands.

[4] Following existing schemes, we assume that each site in this network is sampled every 5 years

Terrestrial invertebrate monitoring	Monitoring of insects, also including some pollinators and other important terrestrial invertebrates (e.g. European Food Safety Authority guidelines)	Malaise traps, pitfall traps, sticky traps, light traps, tick cloth drags	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Spp_SP_abn_dise_TE, Spp_SP_abn_pest_TE, Eco_CC_bio_inve_TE
Vegetation monitoring	Monitoring of trees, plants, lichen and dead wood (e.g. European vegetation Archive (EVA)	Vegetation plots, tree transects, lichen sampling, dead wood transects	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Spp_SP_dis_plan_TE, Spp_SP_dis_lich_TE, Eco_ES_bio_habi_TE
Soil monitoring[6]	Monitoring of soil biodiversity, including invertebrates as e.g. suggested for the Land Use / Cover Area frame Survey (LUCAS)	Soil metagenomics, soil invertebrate sampling	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Eco_CC_bio_micr_TE, Eco_CC_com_micr_TE
Cross-realm				
Mainland bird monitoring	Monitoring of terrestrial and wetland birds, e.g. as implemented by Birdlife International, the European Breeding Bird Atlas (EBBA), Wetlands International, and the European bird ringing schemes (EURING)	Point counts, constant effort ringing, bird transects	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5]. For these EBVs, we assume 50% of sites are monitored by volunteers	Spp_SP_abn_bird_FW, Spp_SP_dis_bird_TE, Spp_SP_abn_bird_TE, Spp_ST_phe_bird_TE, Spp_ST_phe_bird_FW

[5] We divide these proportionally among EU member states based on their total land area. For cross-realm sites, it is assumed that these sites will be distributed between freshwater and terrestrial sites, but the methods used are the same.

[6] Following the Land Use / Cover Area frame Survey (LUCAS), we assume each site in this network is sampled once every 6 years

Mainland mammal monitoring	Monitoring of terrestrial and freshwater mammals, e.g. as suggested by the European Observatory of Wildlife (EOW), the European Mammal Foundation (EMF) and the Agreement on the Conservation of Populations of European Bats (EUROBATS)	Camera traps, passive acoustic sampling, live trapping capture-recapture, genetic barcoding of faecal/spraint samples, mammal transects	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Spp_SP_dis_mamm_FW, Spp_SP_abn_mamm_TE, Spp_SP_dis_mamm_TE
Herpetology monitoring	Monitoring of terrestrial and freshwater reptiles and amphibians, e.g. as suggested by the Amphibian and Reptile Conservation Trust (ARC)	Amphibian transects, reptile transects	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Spp_SP_dis_amph_FW, Spp_SP_dis_rept_FW, Spp_SP_dis_rept_FW
Priority insect monitoring[7]	Monitoring of pollinators and dragonflies, e.g. as implemented by the European Butterfly Monitoring Scheme (eBMS) and as suggested by the proposal for an EU Pollinator Monitoring Scheme (EU PoMS)	Butterfly transects, other insect transects, Flower-Insect Timed (FIT) counts, pan traps, light traps	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5]. For these EBVs, we assume 25% of sites are monitored by volunteers	Spp_SP_abn_inse_TE, Spp_SP_dis_inve_TE, Spp_ST_phe_inse_TE, Spp_SP_abn_inse_FW, Spp_SP_dis_inse_FW, Eco_CC_abn_inse_TE
Mainland habitat monitoring	In-depth monitoring and habitat classification of freshwater and terrestrial habitats of the European Nature Information System (EUNIS)	Large habitat plot sampling (10km)	10,000 or 100,000 sites, representing 1% and 10% of the 2 × 2 km grid cells used as the basis for the Land Use / Cover Area frame Survey (LUCAS) sampling[5].	Eco_ES_dis_habi_FW, Eco_ES_dis_habi_TE

[7] Pollinators and dragonflies are separated from other terrestrial invertebrates because they use more observational methods, many of which are non-lethal.

Genetic sequencing[8]	Monitoring the genetic diversity of rare and threatened species across realms	Full genome sampling	10,000 or 100,000 populations across species listed in the Habitats Directive, sampled once per 10 years.	Spp_GC_div_unsp_TE, Spp_GC_div_unsp_FW, Spp_GC_div_unsp_MA
Citizen science apps	Setting up and maintaining citizen science photographic apps that are used as the primary source of data collection	Citizen science	10,000 or 100,000 sites submitting ~10 images per year.	Spp_SP_dis_alie_FW, Spp_SP_dis_alie_MA, Spp_SP_dis_alie_TE, Spp_ST_phe_fung_TE, Spp_ST_phe_frui_TE, Eco_ES_con_habi_FW,
LiDAR[9]	Monitoring habitat structure using LiDAR	Airborne LiDAR	These networks take advantage of existing LiDAR data collection by EU member states but could be accompanied by ground truth data.	Eco_ES_str_habi_FW, Eco_ES_str_plan_TE
Satellite remote sensing	Using existing Earth Observation data to generate EBVs (this is also a proxy for data generated with radar). Unlike the other sampling networks, the costs for the modelling and workflows are entirely allocated to a central organisation like a European Biodiversity Observation Coordination Centre (EBOCC), but could be hosted in any EU member state at a suitable institution.	Satellite remote sensing plus phenocams, flux towers and imaging flow cytometry for validation. Other forms of validation would build on data from other sampling networks.	These networks take advantage of different existing datasets that span Europe. However, they should be validated with ground truth data. For this purpose, we estimate costs based on validation in a network of 1 site per 50 km^2 or 500 km^2. Flux towers and imaging flow cytometry are only present at 10% of the cells	Spp_ST_phe_plan_TE, Eco_CC_bio_bird_TE, Eco_CC_bio_mamm_TE, Eco_CC_bio_inse_TE, Eco_ES_con_habi_TE, Eco_EF_phe_ppla_FW, Eco_EF_pro_habi_FW[10], Eco_EF_phe_habi_MA, Eco_EF_phe_ppla_MA, Eco_EF_pro_habi_MA, Eco_EF_pro_unsp_TE, Eco_EF_dtb_fire_TE, Eco_EF_dtb_huma_TE, Eco_EF_phe_plan_TE

[8] In this sampling network, each population is only sampled once per 10 years.

[9] In this sampling network, workflows and models are implemented every 5 years from publicly available data

[10] This EBV is also included in the lake sampling network as, ideally, both methods would be required for effective monitoring

TABLE 3 Examples of large-scale or pan-European monitoring networks or integration nodes in Europe. The list is not exhaustive but exemplifies some of the major monitoring data integration efforts for land cover and biodiversity in the EU.

Monitoring network	Abbreviation	Description	Source or weblink
Terrestrial			
Pan-European Common Bird Monitoring Scheme	PECBMS	Joint initiative of the European Bird Census Council (EBCC) and BirdLife International with a large European network of collaborators to provide information on bird numbers, distribution, and their changes in Europe	https://pecbms.info/
European Butterfly Monitoring Scheme	eBMS	Collects data from national and sub-national butterfly monitoring schemes to analyse and produce the population trends of European butterfly species	https://butterfly-monitoring.net/
Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research	eLTER	A pan-European, in-situ research infrastructure with central facilities and distributed well-instrumented sites to study integrated human-nature systems (includes also freshwater and transitional water ecosystems)	https://elter-ri.eu/
European Vegetation Archive	EVA	An initiative of the European Vegetation Survey Working Group aimed at establishing and maintenance of a single data repository of vegetation-plot observations from Europe	https://euroveg.org/eva-database/
EU Pollinator Monitoring Scheme	EU PoMS	Development of a field-based monitoring scheme for assessing the status and trends of pollinator populations in EU countries	https://wikis.ec.europa.eu/pages/viewpage.action?pageId=23462107
Land Use / Cover Area frame Survey	LUCAS	An in-situ survey to provide detailed information on harmonised and comparable land use and land cover information for the EU	https://ec.europa.eu/eurostat/web/lucas
European Monitoring of Biodiversity in Agricultural Landscapes	EMBAL	Development of a monitoring scheme to collect information on the state of biodiversity in agricultural landscapes in EU member states	https://wikis.ec.europa.eu/pages/viewpage.action?pageId=25560696
Freshwater			
Freshwater Information System for Europe	WISE FRESHWATER	Integration node that collects biological data from national monitoring programs for rivers, lakes, transitional and coastal waters in the context of the Water Framework Directive	https://water.europa.eu/freshwater

Marine			
Marine Information System for Europe	WISE MARINE	Integration node that collects biological data from marine monitoring programs Europe’s seas in the context of the Marine Strategy Framework Directive	https://water.europa.eu/marine
European Marine Observation and Data Network	EMODnet	Network of organisations supported by the EU to provide access to European marine data (including distribution, abundance and biomass data from several taxa)	https://emodnet.ec.europa.eu/en
European Mammal Assessment for cetaceans and pinnipeds	-	Various monitoring schemes in the Arctic Sea, Baltic Sea, Mediterranean, Greater North Sea and Celtic Seas for both cetaceans (whales, dolphins, and porpoises) and seals	https://water.europa.eu/marine/state-of-europe-seas/state-of-biodiversity/marine-mammals

TABLE 4 Examples of current and future expected developments for the use of Earth Observation (EO) for biodiversity monitoring in the context of Essential Biodiversity Variables (EBVs) workflows. The overview was obtained during the EuropaBON workshop on EBV workflows (online, February 2023) through involvement of experts in the domain of EO and biodiversity monitoring.

Topic	Current	Future
EO input signals	Satellite multi-spectral Airborne LiDAR (local) Satellite LiDAR (continental)	Satellite hyperspectral Satellite or airborne very-high resolution (<1 m) Continental LiDAR (regular collection) Night-time
Data collection and sampling	Vegetation plots Chlorophyll a (Chl-a)	Harmonized vegetation plots, including standardized taxonomic information and better geospatial accuracy Landscape features (e.g. hedgerows, stonewalls, etc.) Biophysical properties (e.g. leaf chemistry, eDNA) Harmonized data collection with UAV flights
Data integration	Samples in space and time	Automated workflows Long consistent time-series Change detection and attribution
Modelling	Band indices Statistical models Machine learning (e.g. Random Forest)	Deep learning Ensemble models Spatio-temporal modelling Handling of uncertainties
Infrastructure & interoperability	Cloud optimized data	FAIR principles Semantic technologies Public cloud with free credits Central code repository
Knowledge	Few examples	Online tutorials, e-learnings Capacity building, COST actions Sustained funds Support, helpdesk

TABLE 5 Costs with *low* site numbers for EU-wide biodiversity monitoring using eighteen sampling networks (see Table 2 for details of each sampling network). Costs are given in million Euro. Costs for initial establishment and annual maintenance are separately provided across EU member states and for a European Biodiversity Observation Coordination Centre (EBOCC). Details on cost estimation are provided in Appendix S2.

Sampling network		**Member states**		**EBOCC**		Total
	EBVs	**Establishment**	**Maintenance**	**Establishment**	**Maintenance**	
River monitoring	9	€ 44.9	€ 28.3	€ 4.5	€ 5.2	€ 381
Lake monitoring	8	€ 16.2	€ 16.4	€ 2.2	€ 1.8	€ 200
Marine fish monitoring	3	€ 97.6	€ 5.7	€ 2.6	€ 2.1	€ 177
Other marine vertebrate monitoring	6	€ 19.4	€ 18.6	€ 5.7	€ 4.7	€ 256
Marine habitat monitoring	5	€ 23.9	€ 8.2	€ 5.6	€ 4.2	€ 152
Marine invertebrate & plankton monitoring	3	€ 19.3	€ 8.7	€ 3.4	€ 2.5	€ 134
Terrestrial invertebrate monitoring	3	€ 25.8	€ 145.8	€ 3.4	€ 4.2	€ 1,511
Vegetation monitoring	3	€ 16.9	€ 8.0	€ 2.5	€ 2.5	€ 119
Soil monitoring	2	€ 11.3	€ 10.8	€ 1.2	€ 0.9	€ 129
Mainland bird monitoring	5	€ 13.4	€ 27.5	€ 2.7	€ 3.2	€ 321
Mainland mammal monitoring	3	€ 28.1	€ 90.4	€ 2.0	€ 2.2	€ 955
Herpetology monitoring	3	€ 19.2	€ 9.0	€ 3.3	€ 2.5	€ 137
Priority insect monitoring	6	€ 30.5	€ 22.5	€ 4.0	€ 3.9	€ 302
Mainland habitat monitoring	2	€ 11.0	€ 7.6	€ 1.6	€ 1.6	€ 104
Genetic sequencing	3	€ 16.6	€ 10.9	€ 3.5	€ 1.4	€ 142
Citizen science apps	6	€ 18.4	€ 7.7	€ 6.6	€ 5.5	€ 150
LiDAR	2	€ 10.8	€ 16.0	€ 2.0	€ 1.1	€ 184
Satellite remote sensing	14	€ 83.3	€ 18.0	€ 11.5	€ 8.4	€ 368
Total		**€ 506.5**	**€ 460.0**	**€ 68.0**	**€ 56.3**	**€ 5,738**

TABLE 6 Costs with *high* site numbers for EU-wide biodiversity monitoring using eighteen sampling networks (see Table 2 for details of each sampling network). Costs are given in million Euro. Costs for initial establishment and annual maintenance are separately provided across EU member states and for a European Biodiversity Observation Coordination Centre (EBOCC). Details on cost estimation are provided in Appendix S2.

Sampling network		**Member states**		**EBOCC**		**Total**
	EBVs	**Establishment**	**Maintenance**	**Establishment**	**Maintenance**	
River monitoring	8	€ 206.6	€ 178.6	€ 4.5	€ 5.2	**€ 2,046**
Lake monitoring	8	€ 52.4	€ 66.4	€ 2.2	€ 1.8	**€ 736**
Marine fish monitoring	3	€ 871.2	€ 27.3	€ 2.6	€ 2.1	**€ 1,167**
Other marine vertebrate monitoring	6	€ 34.1	€ 124.4	€ 5.7	€ 4.7	**€ 1,329**
Marine habitat monitoring	5	€ 58.7	€ 27.1	€ 5.6	€ 4.2	**€ 376**
Marine invertebrate & plankton monitoring	3	€ 66.8	€ 56.3	€ 3.4	€ 2.5	**€ 658**
Terrestrial invertebrate monitoring	3	€ 125.2	€ 1,423.1	€ 3.4	€ 4.2	**€ 14,383**
Vegetation monitoring	3	€ 43.4	€ 45.2	€ 2.5	€ 2.5	**€ 517**
Soil monitoring	2	€ 56.6	€ 79.0	€ 1.2	€ 0.9	**€ 856**
Mainland bird monitoring	5	€ 50.7	€ 210.2	€ 2.7	€ 3.2	**€ 2,185**
Mainland mammal monitoring	3	€ 193.1	€ 869.2	€ 2.0	€ 2.2	**€ 8,908**
Herpetology monitoring	3	€ 70.5	€ 55.4	€ 3.3	€ 2.5	**€ 652**
Priority insect monitoring	6	€ 155.1	€ 154.1	€ 4.0	€ 3.9	**€ 1,681**
Mainland habitat monitoring	2	€ 33.7	€ 47.1	€ 1.6	€ 1.6	**€ 521**
Genetic sequencing	3	€ 32.1	€ 69.9	€ 3.5	€ 1.4	**€ 748**
Citizen science apps	6	€ 33.0	€ 20.1	€ 6.6	€ 5.5	**€ 288**
LiDAR	2	€ 10.8	€ 16.0	€ 2.0	€ 1.1	**€ 184**
Satellite remote sensing	13	€ 771.3	€ 153.8	€ 11.5	€ 8.4	**€ 2,413**
Total		**€ 2,865.4**	**€ 3,623.2**	**€ 68.0**	**€ 56.3**	**€ 39,729**

Figure captions

FIGURE 1 Summary of the current biodiversity monitoring situation in the European Union (EU). (a) Policy context showing the temporal evolution of EU legislation driving biodiversity and ecosystem monitoring and assessment (see Table 1 for details). (b) Current challenges for biodiversity monitoring in Europe as identified by EuropaBON (Morán-Ordóñez et al. 2023a, Santana et al. 2023, Moersberger et al. 2024). (c) Major needs to improve biodiversity monitoring and policy impact in Europe (Moersberger et al. 2024).

FIGURE 2 Framework for co-designing the European Biodiversity Observation Network. (a) Underlying the co-design is a comprehensive stakeholder network with nearly 1500 members from different occupational sectors, a wide policy interest in various European Union (EU) legislations, and with broad geographic representation within and outside the EU. (b) The concept of Essential Biodiversity Variables (EBVs) serves as a framework for identifying complementary variables for measuring biodiversity change at different levels (EBV classes, realms), with EBVs being modelled at different spatial and temporal resolutions and covering a broad range of taxa and ecosystems. (c) Design criteria include aspects of sampling networks, monitoring methods, and data integration. (d) Cost estimation is based on detailed materials and staff costs for data collection, workflows, and coordination. Costs for different sampling networks (illustrated with different colours) are estimated for different sampling networks that group various EBVs and use a low and high scenario for the number of sites included (compare Table 2). Abbreviations: NGO = non-governmental organization, EU-MS = member states of the EU.

FIGURE 3 Characteristics of Essential Biodiversity Variables (EBVs, n = 84) for a European Biodiversity Observation Network. (a) Proposed spatial and temporal resolution of modelled EBV products. (b) EBV representation within EBV classes and variable types for each realm (TE = terrestrial, MA = marine, FW = freshwater). (c) EBV coverage of taxonomic groups and other entities (habitats = ecosystem-focused EBVs without a specific taxonomic focus). Left: species-focused EBVs, n = 43; Right: ecosystem-focused EBVs, n = 41. See EBV details on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki). Abbreviations: TE = terrestrial, MA = marine, FW = freshwater.

FIGURE 4 Importance of monitoring techniques for Essential Biodiversity Variables (EBVs) in Europe. (a) Primary monitoring technique for each EBV classified into in-situ observations and remote sensing, with EBV examples for each technique (boxes). (b) Supplementary monitoring techniques and their importance for complementing primary monitoring techniques for each EBV as shown in (a), separated for species-focused vs. ecosystem-focused EBVs. Abbreviations: TE = terrestrial, MA = marine, FW = freshwater.

FIGURE 5 Key components of EBV workflows with examples from different realms and EBV classes. (a) Generic EBV workflow with details on raw observations, data integration and modelling. (b) Three examples of EBV workflows in Europe illustrating different realms (terrestrial, marine, freshwater) and EBV classes (species populations, ecosystem structure, community composition). Abbreviations: RGB = red, green, and blue imagery, NIR = near infrared spectroscopy, LiDAR = light detection and ranging, API = application programming interface, GAM = generalized additive model, GLM = generalized linear model, CNN = convolutional neural network, EQR = ecological quality ratio.

FIGURE 6 Direct and indirect links between Essential Biodiversity Variables (EBVs) and the main EU legislation on biodiversity (yellow), ecosystem service policies (green), and other EU policies, regulations and strategies (blue) (see Table 1 for abbreviations and short descriptions of these policies). Dark (yellow, blue and green) colours indicate EBVs that can be directly used to respond to a reporting requirement whereas light (yellow, blue and green) colours indicate that EBVs can provide underlying, complementary or voluntary information for such reporting requirements. Species-focused EBVs (top) and ecosystem-focused EBVs (bottom) are ordered separately for each EBV class and the freshwater, marine and terrestrial realm, respectively. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki). Details on the specific links are provided in the supplement (Appendix S1).

FIGURE 7 Example of a spatial sampling design for a European Biodiversity Observation Network that combines (a) an EU-wide stratified random selection of sites (e.g. grid cells) across Europe with (b) local sampling designs that consider randomisation, replication and stratification and various field survey methods.

FIGURE 8 Examples of sites, transects, photos, landscape elements, polygons, or water bodies (incl. lakes, river segments, transitional and coastal water bodies) from EU-wide monitoring schemes. Abbreviations: EVA = European Vegetation Archive, PECBMS = Pan-European Common Bird Monitoring Scheme, EMBAL = European Monitoring of Biodiversity in Agricultural Landscapes, LUCAS = Land Use / Cover Area frame Survey, eBMS = European Butterfly Monitoring Scheme, EU PoMS = EU Pollinator Monitoring Scheme, eLTER = Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research, WFD = Water Framework Directive.

FIGURE 9 Examples of the number of different water bodies (river segments, lakes, coastal and transitional waters) that are sampled for various biological quality elements in the context of the Water Framework Directive (WFD). Source: https://tableau-public.discomap.eea.europa.eu/views/WISE_SOW_SWB_QualityElement_qeMonitoringResults/SWB_QualityElement_qeMonitoringResults?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

FIGURE 10 Examples of spatial gaps in terrestrial, freshwater and marine biodiversity monitoring in Europe. (a) Spatial coverage of terrestrial butterfly monitoring. (b) Percentage of rivers with regulatory benthic invertebrate monitoring. (c) Percentage of lakes (>25 ha) with regulatory phytoplankton monitoring. (d) Number of marine monitoring programmes in European regional seas. Data in (a) illustrate the number of fixed transect routes of the European Butterfly Monitoring Scheme (eBMS) in which butterflies are recorded every year. Data in (b) and (c) are those reported in the 2nd River Basin Management Plans (RBMP) of the Water Information System for Europe (WISE) WFD Reference Spatial Datasets (covering EU member states plus Norway and the UK). Data in (d) represent marine monitoring programmes for which country-level spatial data from exclusive economic zones (EEZs) around Europe are available (Jessop et al. 2022). Colours are shown using a quantile classification.

FIGURE 11 The potential contribution of DNA-based methods for monitoring Essential Biodiversity Variables (EBVs) across Europe. Relative importance of different methods (including AFLP/microsatellite, SNPs, DNA metabarcoding) was obtained from an online survey during the EuropaBON workshop on EBV workflows (Lumbierres and Kissling

2023). Workshop participants were asked to assess whether this monitoring technique is of central importance for each EBV at a European scale. Relative importance is indicated with % answers (yes, partially, and no).

FIGURE 12 The potential contribution of digital sensors for monitoring Essential Biodiversity Variables (EBVs) across Europe. Relative importance of genetic methods (including AFLP/microsatellite, SNPs, DNA metabarcoding) was obtained from an online survey during the EuropaBON workshop on EBV workflows (Lumbierres and Kissling 2023). Workshop participants were asked to assess whether this monitoring technique is of central importance for each EBV at a European scale. Relative importance is indicated with % answers (yes, partially, and no).

FIGURE 13 Relative importance of satellite remote sensing for monitoring Essential Biodiversity Variables (EBVs) across Europe. The potential contribution of satellite remote sensing was obtained from an online survey during the EuropaBON workshop on EBV workflows (Lumbierres and Kissling 2023). Workshop participants were asked to assess whether this monitoring technique is of central importance for each EBV at a European scale. Relative importance is indicated with % answers (yes, partially and no).

FIGURE 14 Relative importance of citizen science for monitoring Essential Biodiversity Variables (EBVs) across Europe. The potential contribution of citizen science was obtained from an online survey during the EuropaBON workshop on EBV workflows (Lumbierres and Kissling 2023). Workshop participants were asked to assess whether this monitoring technique is of central importance for each EBV at a European scale. Relative importance is indicated with % answers (yes, partially and no).

FIGURE 15 Expert-suggested needs for developing workflows of Essential Biodiversity Variables (EBVs) in the context of a European Biodiversity Observation Network. Needs are separately shown for (a) data integration and (b) modelling. Needs were specified for each EBV by experts during the EuropaBON workshop on EBV workflows (Lumbierres and Kissling 2023) and subsequently grouped into different categories as shown on the x-axis. Abbreviations: TE = terrestrial, MA = marine, FW = freshwater.

FIGURE 16 Simplified design of an architecture for a digital infrastructure supporting the European Biodiversity Observation Network. Various research infrastructures (blue) are connected to the technology services, data management tools, and user platforms of the digital infrastructure (red) which leverage knowledge, data harvesting, workflows and automated assessments for biodiversity data in Europe (green).

Figure 1

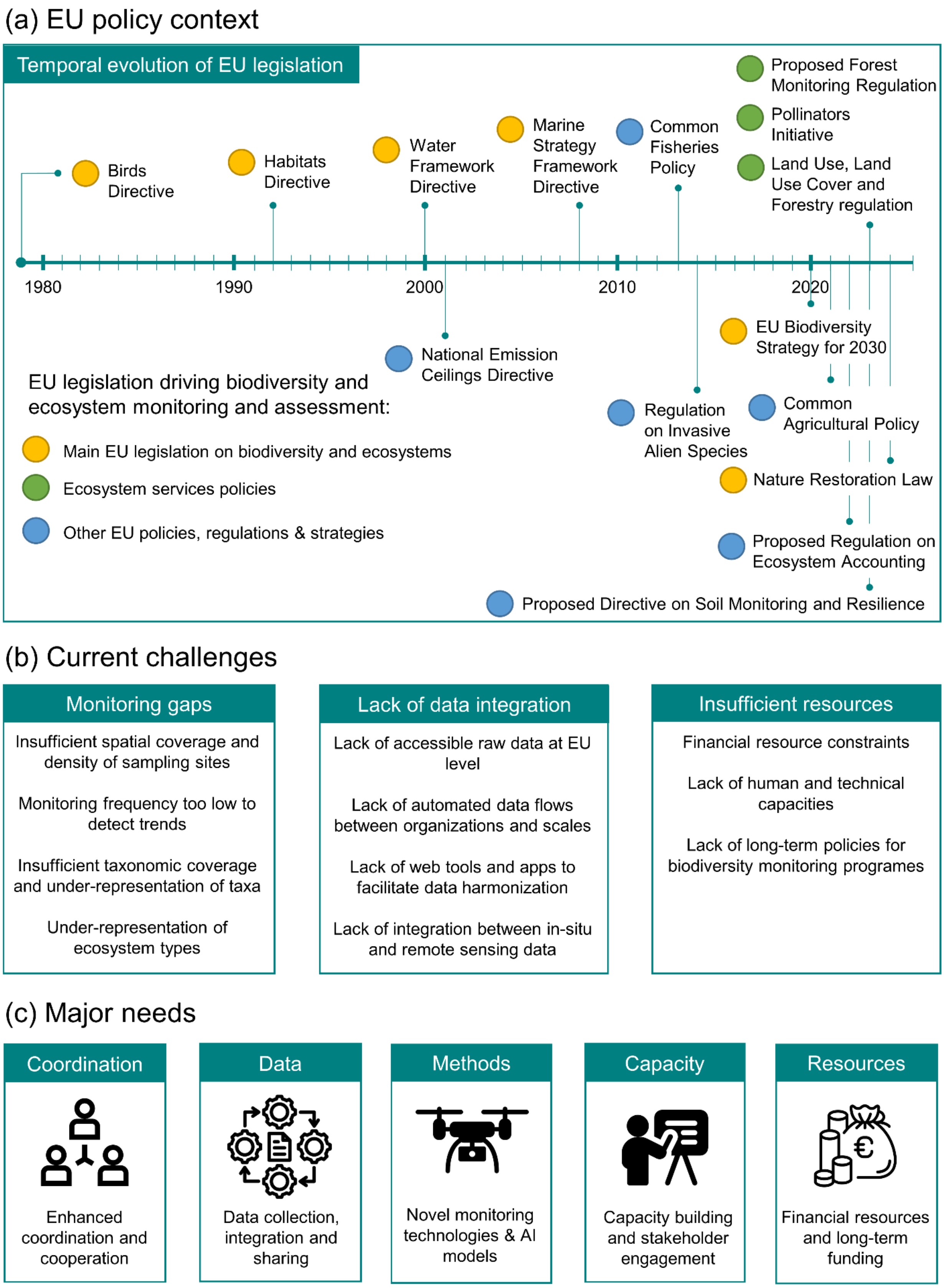
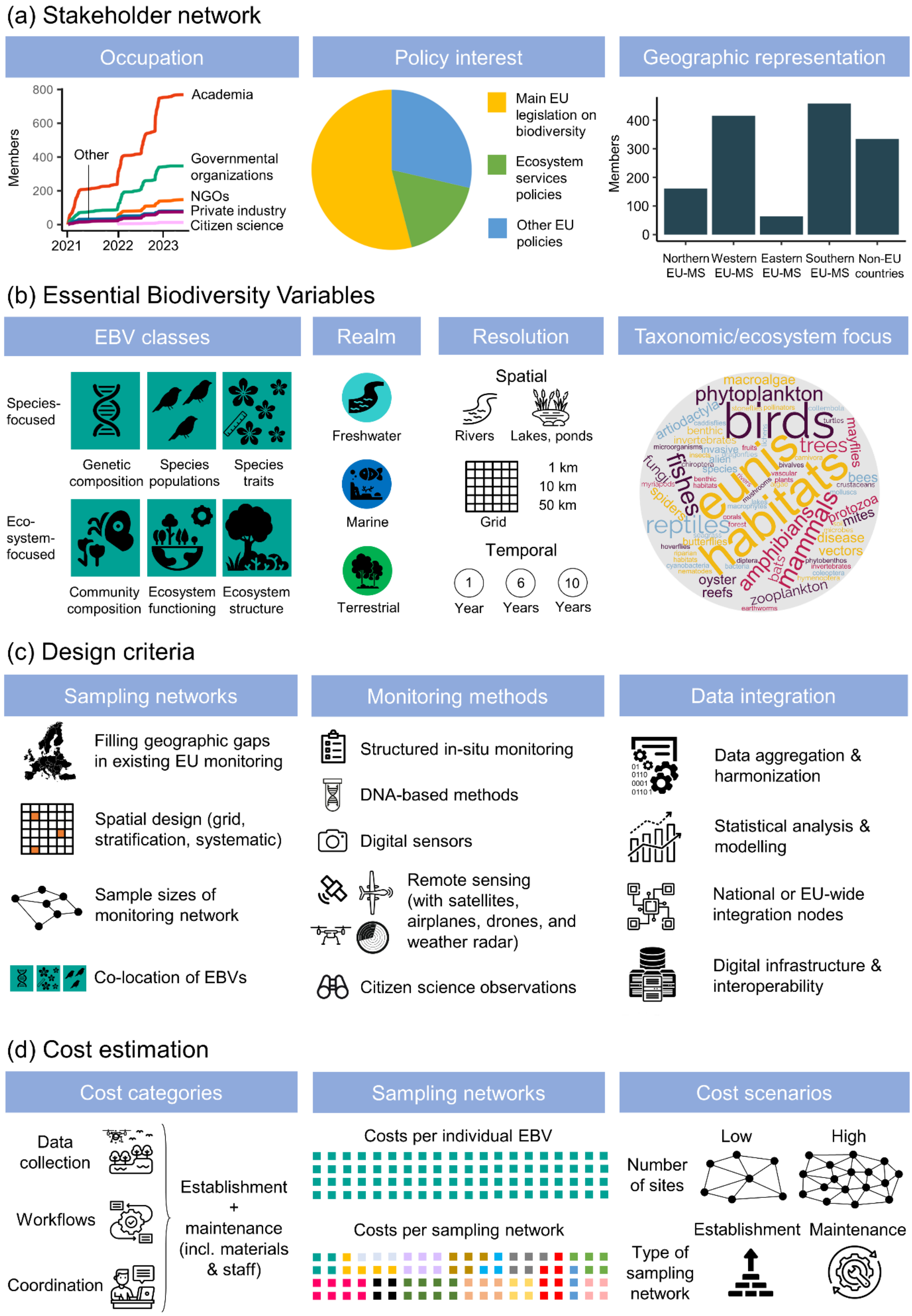
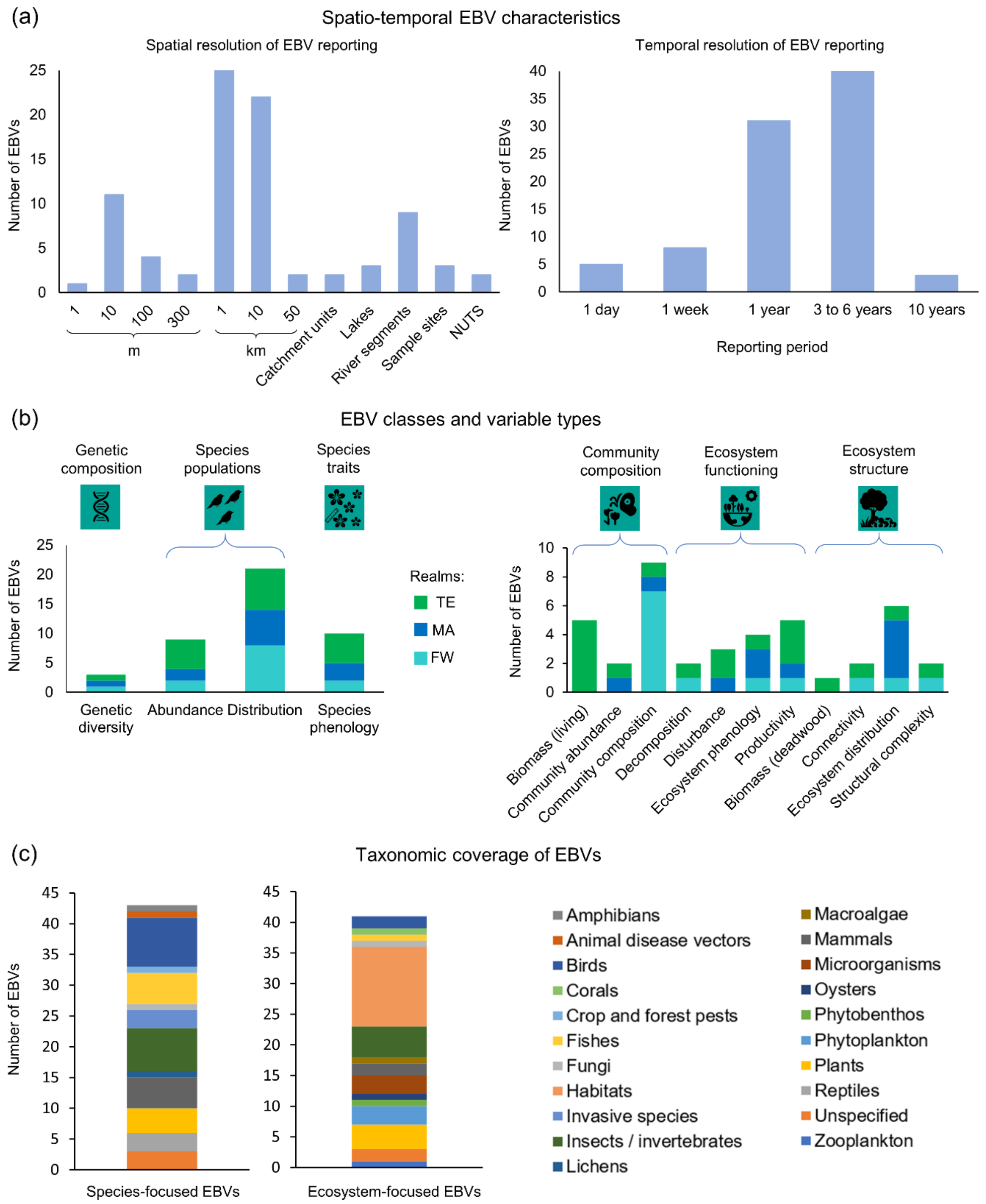

(a) EU policy context
Temporal evolution of EU legislation
Birds Directive
Habitats Directive
Water Framework Directive
Marine Strategy Framework Directive
Common Fisheries Policy
Proposed Forest Monitoring Regulation
Pollinators Initiative
Land Use, Land Use Cover and Forestry regulation
1980
1990
2000
2010
2020
National Emission Ceilings Directive
EU Biodiversity Strategy for 2030
Regulation on Invasive Alien Species
Common Agricultural Policy
Nature Restoration Law
Proposed Regulation on Ecosystem Accounting
Proposed Directive on Soil Monitoring and Resilience
EU legislation driving biodiversity and ecosystem monitoring and assessment:
Main EU legislation on biodiversity and ecosystems
Ecosystem services policies
Other EU policies, regulations & strategies
(b) Current challenges
Monitoring gaps
Insufficient spatial coverage and density of sampling sites
Monitoring frequency too low to detect trends
Insufficient taxonomic coverage and under-representation of taxa
Under-representation of ecosystem types
Lack of data integration
Lack of accessible raw data at EU level
Lack of automated data flows between organizations and scales
Lack of web tools and apps to facilitate data harmonization
Lack of integration between in-situ and remote sensing data
Insufficient resources
Financial resource constraints
Lack of human and technical capacities
Lack of long-term policies for biodiversity monitoring programes
(c) Major needs
Coordination
Enhanced coordination and cooperation
Data
Data collection, integration and sharing
Methods
Novel monitoring technologies & AI models
Capacity
Capacity building and stakeholder engagement
Resources
Financial resources and long-term funding

Figure 2


(a) Stakeholder network
Occupation
Policy interest
Geographic representation
Members
800
600
400
200
0
2021
2022
2023
Academia
Other
Governmental organizations
NGOs
Private industry
Citizen science
Main EU legislation on biodiversity
Ecosystem services policies
Other EU policies
Members
400
300
200
100
0
Northern EU-MS
Western EU-MS
Eastern EU-MS
Southern EU-MS
Non-EU countries
(b) Essential Biodiversity Variables
EBV classes
Realm
Resolution
Taxonomic/ecosystem focus
Species-focused
Genetic composition
Species populations
Species traits
Eco-system-focused
Community composition
Ecosystem functioning
Ecosystem structure
Freshwater
Marine
Terrestrial
Spatial
Rivers
Lakes, ponds
Grid
1 km
10 km
50 km
Temporal
1 Year
6 Years
10 Years
macroalgae
phytoplankton
birds
eunis
habitats
fishes
reptiles
amphibians
mammals
trees
mayflies
bees
protozoa
mites
disease vectors
oyster reefs
zooplankton
fungi
spiders
butterflies
bats
artiodactyla
(c) Design criteria
Sampling networks
Monitoring methods
Data integration
Filling geographic gaps in existing EU monitoring
Spatial design (grid, stratification, systematic)
Sample sizes of monitoring network
Co-location of EBVs
Structured in-situ monitoring
DNA-based methods
Digital sensors
Remote sensing (with satellites, airplanes, drones, and weather radar)
Citizen science observations
Data aggregation & harmonization
Statistical analysis & modelling
National or EU-wide integration nodes
Digital infrastructure & interoperability
(d) Cost estimation
Cost categories
Sampling networks
Cost scenarios
Data collection
Workflows
Coordination
Establishment + maintenance (incl. materials & staff)
Costs per individual EBV
Costs per sampling network
Low
High
Number of sites
Establishment
Maintenance
Type of sampling network

2457 Figure 3



2458

Figure 4

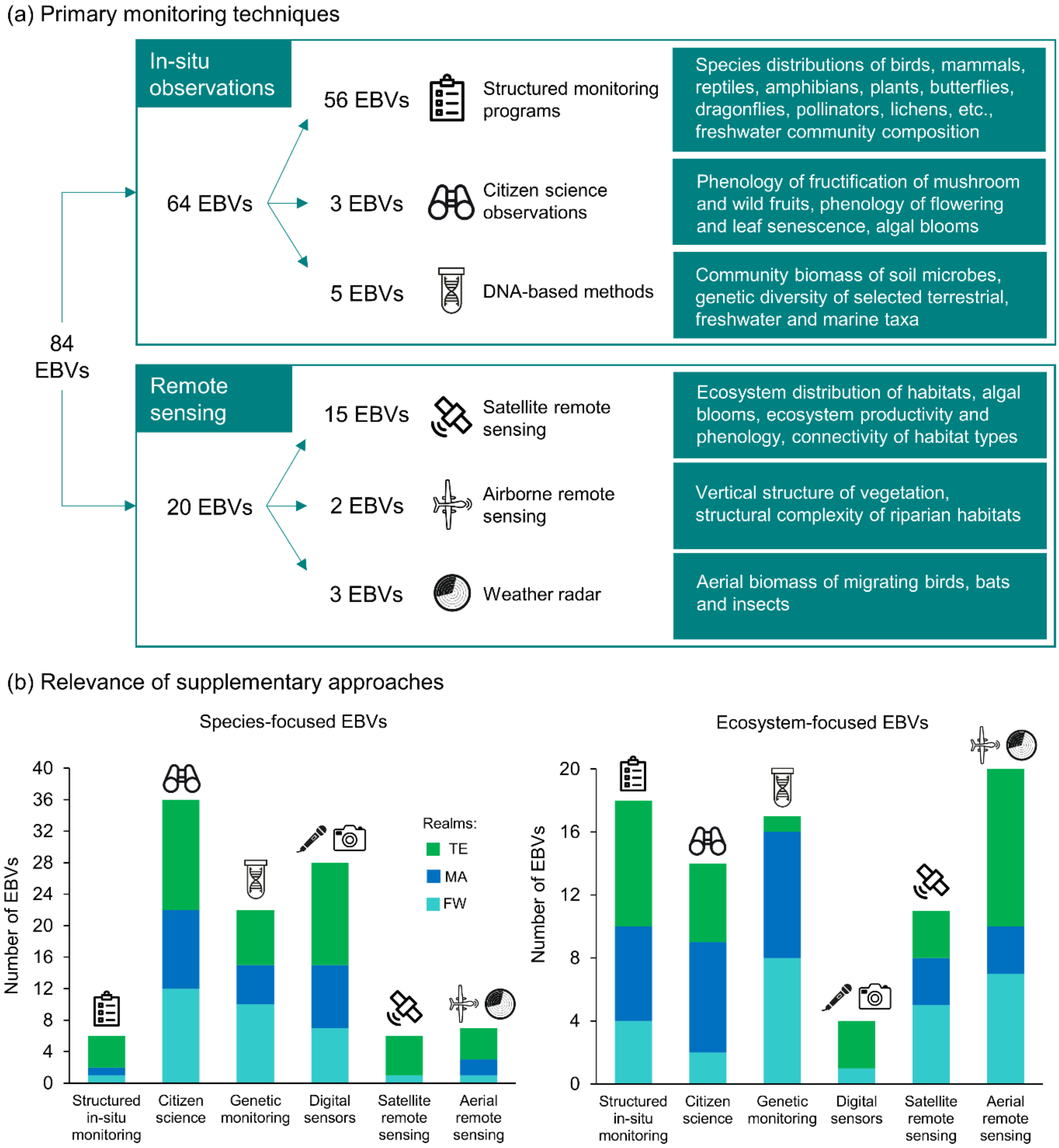

(a) Primary monitoring techniques
In-situ observations
Remote sensing
84 EBVs
64 EBVs
20 EBVs
56 EBVs
Structured monitoring programs
Species distributions of birds, mammals, reptiles, amphibians, plants, butterflies, dragonflies, pollinators, lichens, etc., freshwater community composition
3 EBVs
Citizen science observations
Phenology of fructification of mushroom and wild fruits, phenology of flowering and leaf senescence, algal blooms
5 EBVs
DNA-based methods
Community biomass of soil microbes, genetic diversity of selected terrestrial, freshwater and marine taxa
15 EBVs
Satellite remote sensing
Ecosystem distribution of habitats, algal blooms, ecosystem productivity and phenology, connectivity of habitat types
2 EBVs
Airborne remote sensing
Vertical structure of vegetation, structural complexity of riparian habitats
3 EBVs
Weather radar
Aerial biomass of migrating birds, bats and insects
(b) Relevance of supplementary approaches
Species-focused EBVs
Ecosystem-focused EBVs
Number of EBVs
40
36
32
28
24
20
16
12
8
4
0
Realms:
TE
MA
FW
Structured in-situ monitoring
Citizen science
Genetic monitoring
Digital sensors
Satellite remote sensing
Aerial remote sensing

Figure 5

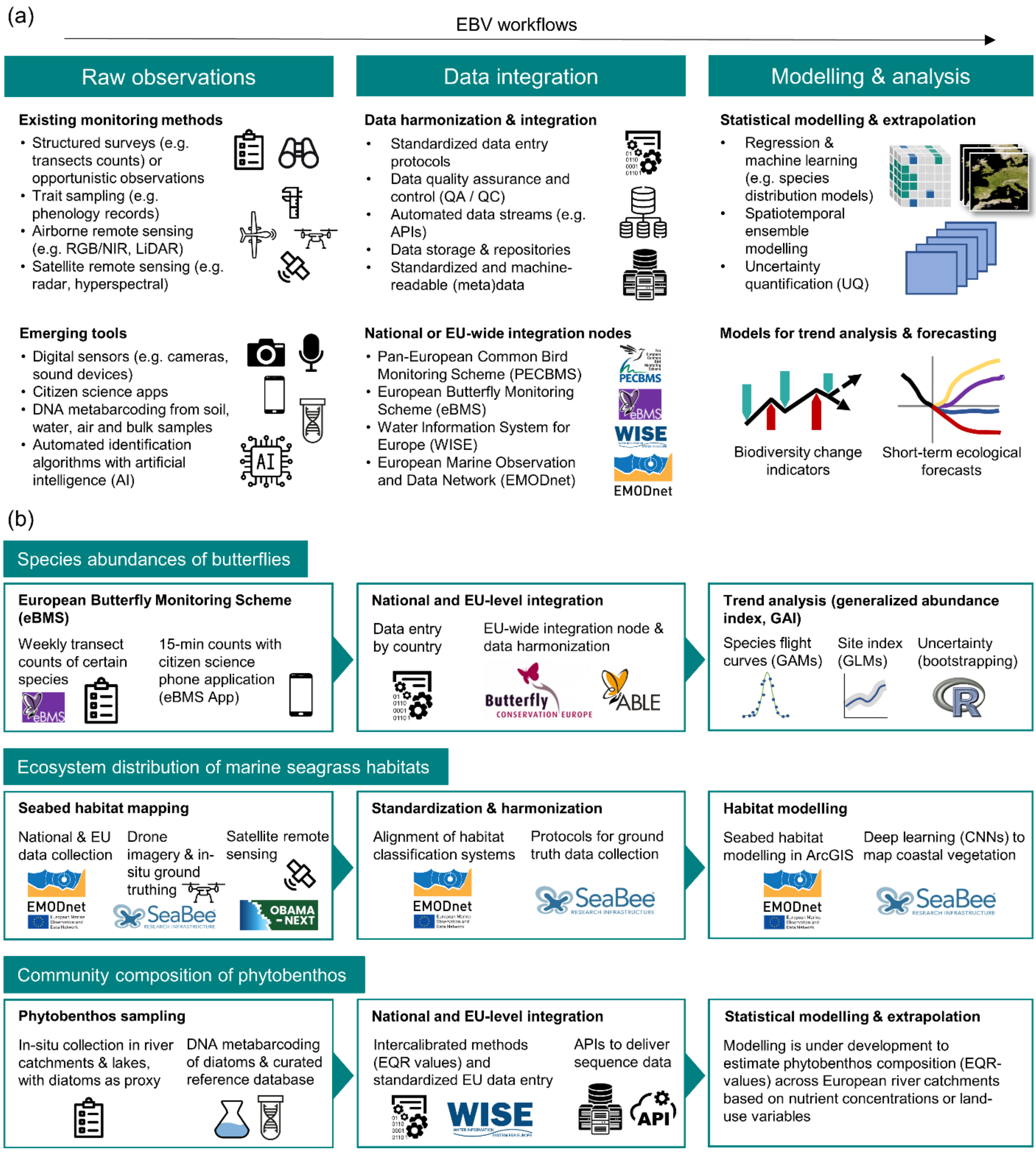
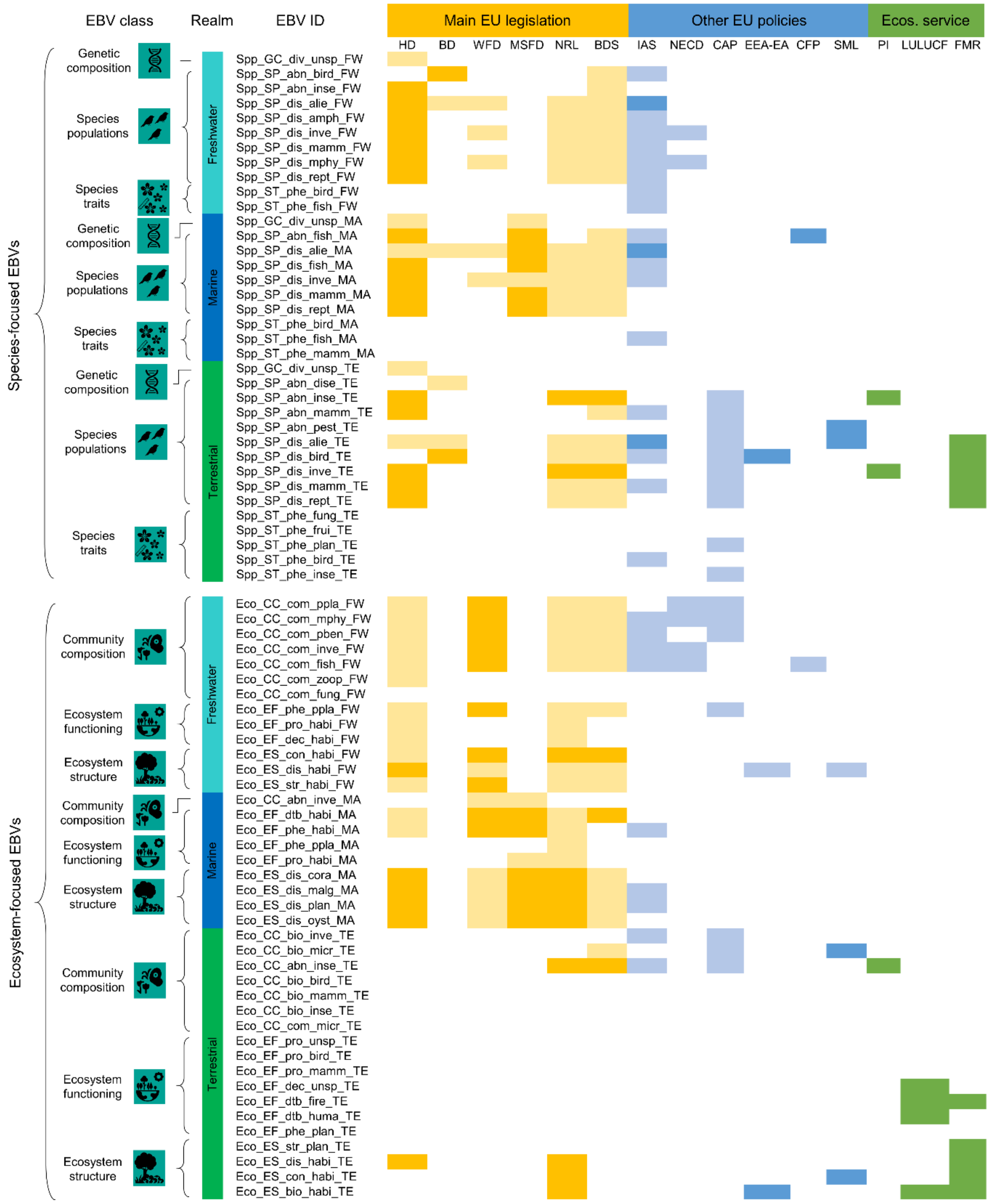
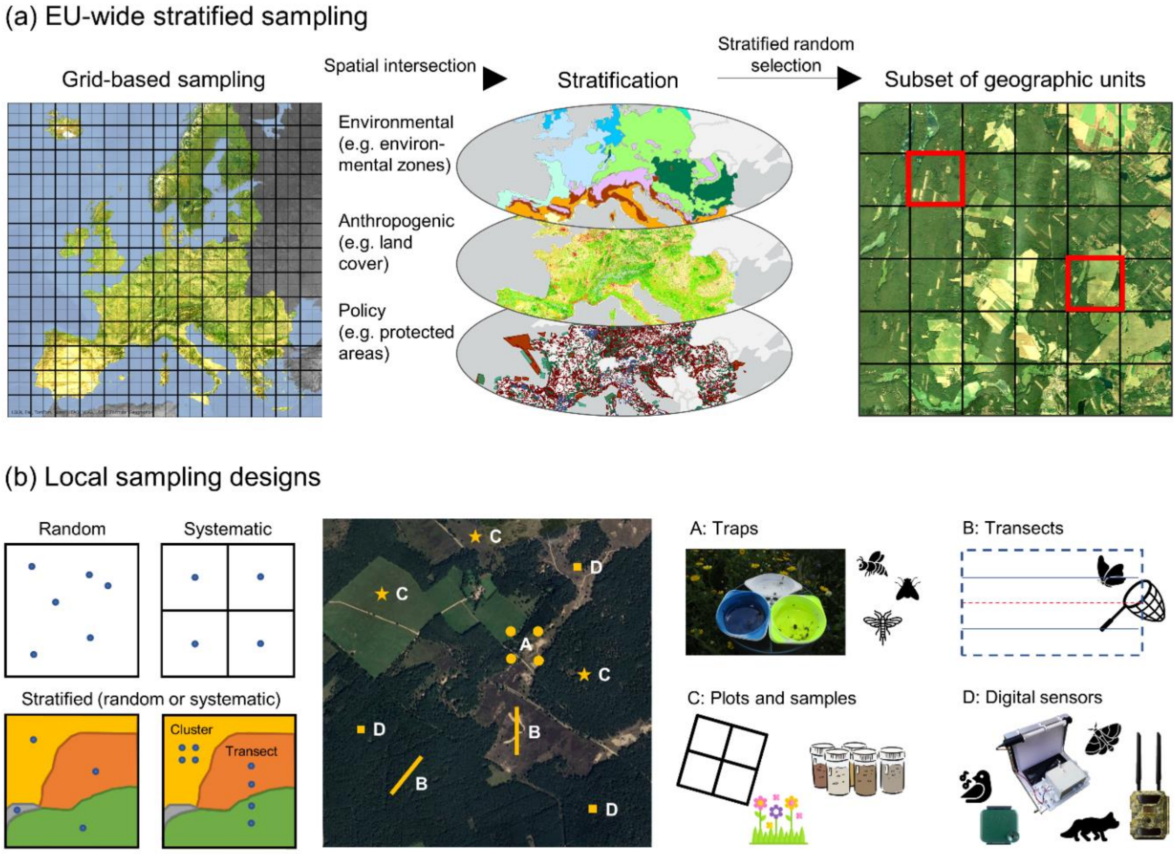

(a)
EBV workflows
Raw observations
Data integration
Modelling & analysis
Existing monitoring methods
• Structured surveys (e.g. transects counts) or opportunistic observations
• Trait sampling (e.g. phenology records)
• Airborne remote sensing (e.g. RGB/NIR, LiDAR)
• Satellite remote sensing (e.g. radar, hyperspectral)
Data harmonization & integration
• Standardized data entry protocols
• Data quality assurance and control (QA / QC)
• Automated data streams (e.g. APIs)
• Data storage & repositories
• Standardized and machine-readable (meta)data
Statistical modelling & extrapolation
• Regression & machine learning (e.g. species distribution models)
• Spatiotemporal ensemble modelling
• Uncertainty quantification (UQ)
Emerging tools
• Digital sensors (e.g. cameras, sound devices)
• Citizen science apps
• DNA metabarcoding from soil, water, air and bulk samples
• Automated identification algorithms with artificial intelligence (AI)
AI
National or EU-wide integration nodes
• Pan-European Common Bird Monitoring Scheme (PECBMS)
• European Butterfly Monitoring Scheme (eBMS)
• Water Information System for Europe (WISE)
• European Marine Observation and Data Network (EMODnet)
PECBMS
eBMS
WISE
EMODnet
Models for trend analysis & forecasting
Biodiversity change indicators
Short-term ecological forecasts
(b)
Species abundances of butterflies
European Butterfly Monitoring Scheme (eBMS)
Weekly transect counts of certain species
15-min counts with citizen science phone application (eBMS App)
eBMS
National and EU-level integration
Data entry by country
EU-wide integration node & data harmonization
Butterfly CONSERVATION EUROPE
ABLE
Trend analysis (generalized abundance index, GAI)
Species flight curves (GAMs)
Site index (GLMs)
Uncertainty (bootstrapping)
R
Ecosystem distribution of marine seagrass habitats
Seabed habitat mapping
National & EU data collection
Drone imagery & in-situ ground truthing
Satellite remote sensing
EMODnet
SeaBee
OBAMA - NEXT
Standardization & harmonization
Alignment of habitat classification systems
Protocols for ground truth data collection
EMODnet
SeaBee
Habitat modelling
Seabed habitat modelling in ArcGIS
Deep learning (CNNs) to map coastal vegetation
EMODnet
SeaBee
Community composition of phytobenthos
Phytobenthos sampling
In-situ collection in river catchments & lakes, with diatoms as proxy
DNA metabarcoding of diatoms & curated reference database
National and EU-level integration
Intercalibrated methods (EQR values) and standardized EU data entry
APIs to deliver sequence data
WISE
API
Statistical modelling & extrapolation
Modelling is under development to estimate phytobenthos composition (EQR-values) across European river catchments based on nutrient concentrations or land-use variables

Figure 6

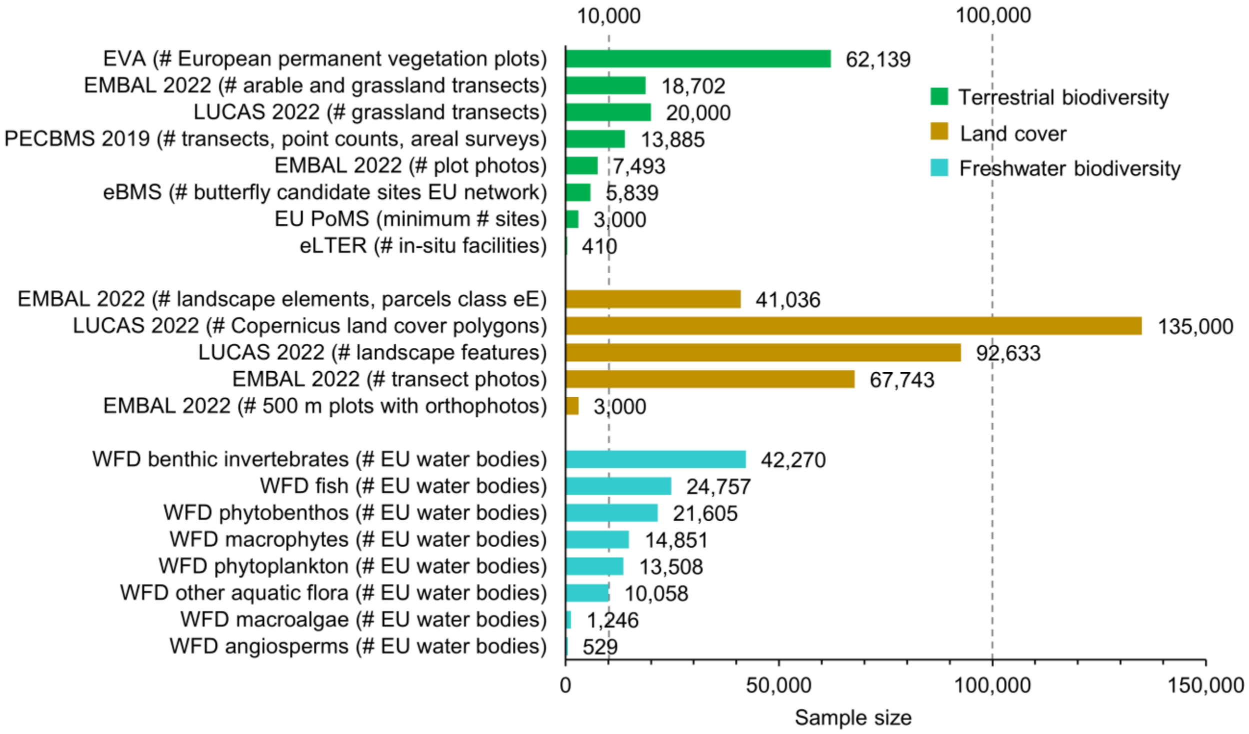

EBV class
Realm
EBV ID
Main EU legislation
Other EU policies
Ecos. service
HD BD WFD MSFD NRL BDS IAS NECD CAP EEA-EA CFP SML PI LULUCF FMR
Species-focused EBVs
Genetic composition
Species populations
Species traits
Freshwater
Marine
Terrestrial
Spp_GC_div_unsp_FW
Spp_SP_abn_bird_FW
Spp_SP_abn_inse_FW
Spp_SP_dis_alie_FW
Spp_SP_dis_amph_FW
Spp_SP_dis_inve_FW
Spp_SP_dis_mamm_FW
Spp_SP_dis_mphy_FW
Spp_SP_dis_rept_FW
Spp_ST_phe_bird_FW
Spp_ST_phe_fish_FW
Spp_GC_div_unsp_MA
Spp_SP_abn_fish_MA
Spp_SP_dis_alie_MA
Spp_SP_dis_fish_MA
Spp_SP_dis_inve_MA
Spp_SP_dis_mamm_MA
Spp_SP_dis_rept_MA
Spp_ST_phe_bird_MA
Spp_ST_phe_fish_MA
Spp_ST_phe_mamm_MA
Spp_GC_div_unsp_TE
Spp_SP_abn_dise_TE
Spp_SP_abn_inse_TE
Spp_SP_abn_mamm_TE
Spp_SP_abn_pest_TE
Spp_SP_dis_alie_TE
Spp_SP_dis_bird_TE
Spp_SP_dis_inve_TE
Spp_SP_dis_mamm_TE
Spp_SP_dis_rept_TE
Spp_ST_phe_fung_TE
Spp_ST_phe_frui_TE
Spp_ST_phe_plan_TE
Spp_ST_phe_bird_TE
Spp_ST_phe_inse_TE
Ecosystem-focused EBVs
Community composition
Ecosystem functioning
Ecosystem structure
Eco_CC_com_ppla_FW
Eco_CC_com_mphy_FW
Eco_CC_com_pben_FW
Eco_CC_com_inve_FW
Eco_CC_com_fish_FW
Eco_CC_com_zoop_FW
Eco_CC_com_fung_FW
Eco_EF_phe_ppla_FW
Eco_EF_pro_habi_FW
Eco_EF_dec_habi_FW
Eco_ES_con_habi_FW
Eco_ES_dis_habi_FW
Eco_ES_str_habi_FW
Eco_CC_abn_inve_MA
Eco_EF_dtb_habi_MA
Eco_EF_phe_habi_MA
Eco_EF_phe_ppla_MA
Eco_EF_pro_habi_MA
Eco_ES_dis_cora_MA
Eco_ES_dis_malg_MA
Eco_ES_dis_plan_MA
Eco_ES_dis_oyst_MA
Eco_CC_bio_inve_TE
Eco_CC_bio_micr_TE
Eco_CC_abn_inse_TE
Eco_CC_bio_bird_TE
Eco_CC_bio_mamm_TE
Eco_CC_bio_inse_TE
Eco_CC_com_micr_TE
Eco_EF_pro_unsp_TE
Eco_EF_pro_bird_TE
Eco_EF_pro_mamm_TE
Eco_EF_dec_unsp_TE
Eco_EF_dtb_fire_TE
Eco_EF_dtb_huma_TE
Eco_EF_phe_plan_TE
Eco_ES_str_plan_TE
Eco_ES_dis_habi_TE
Eco_ES_con_habi_TE
Eco_ES_bio_habi_TE

2465 Figure 7



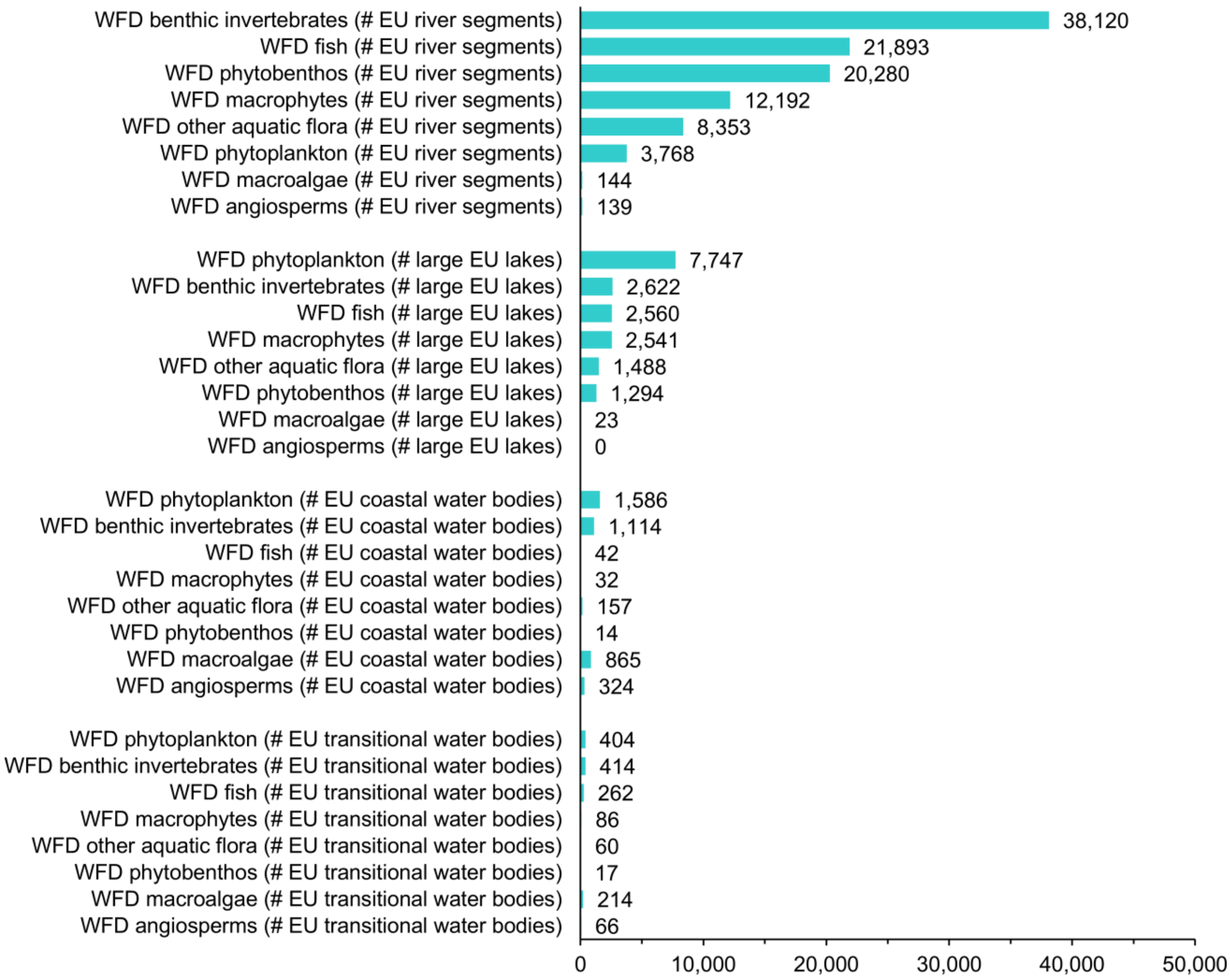
2466

Figure 8



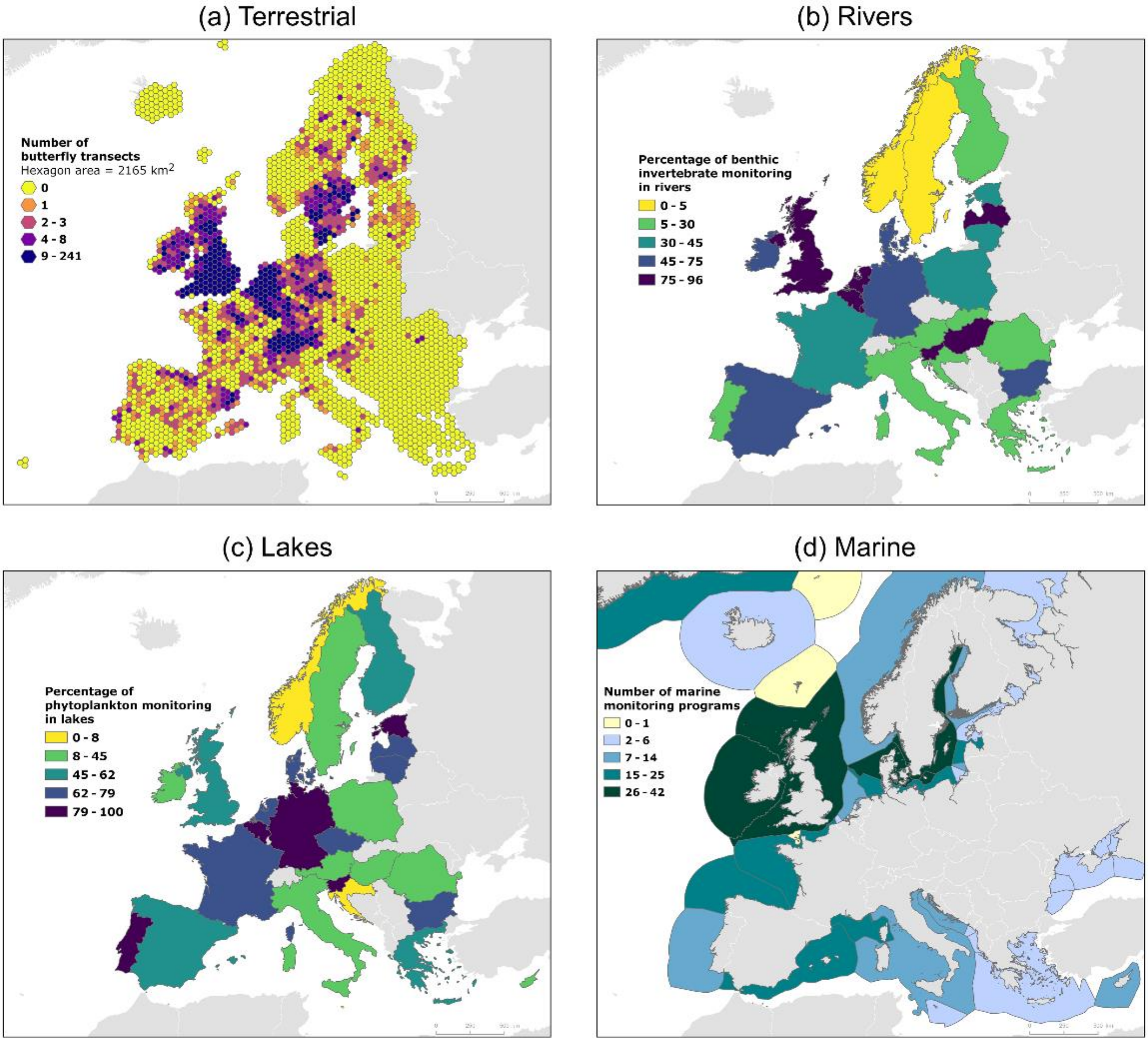
10,000
100,000
EVA (# European permanent vegetation plots)
62,139
EMBAL 2022 (# arable and grassland transects)
18,702
LUCAS 2022 (# grassland transects)
20,000
PECBMS 2019 (# transects, point counts, areal surveys)
13,885
EMBAL 2022 (# plot photos)
7,493
eBMS (# butterfly candidate sites EU network)
5,839
EU PoMS (minimum # sites)
3,000
eLTER (# in-situ facilities)
410
EMBAL 2022 (# landscape elements, parcels class eE)
41,036
LUCAS 2022 (# Copernicus land cover polygons)
135,000
LUCAS 2022 (# landscape features)
92,633
EMBAL 2022 (# transect photos)
67,743
EMBAL 2022 (# 500 m plots with orthophotos)
3,000
WFD benthic invertebrates (# EU water bodies)
42,270
WFD fish (# EU water bodies)
24,757
WFD phytobenthos (# EU water bodies)
21,605
WFD macrophytes (# EU water bodies)
14,851
WFD phytoplankton (# EU water bodies)
13,508
WFD other aquatic flora (# EU water bodies)
10,058
WFD macroalgae (# EU water bodies)
1,246
WFD angiosperms (# EU water bodies)
529
Terrestrial biodiversity
Land cover
Freshwater biodiversity
0
50,000
100,000
150,000
Sample size

Figure 9



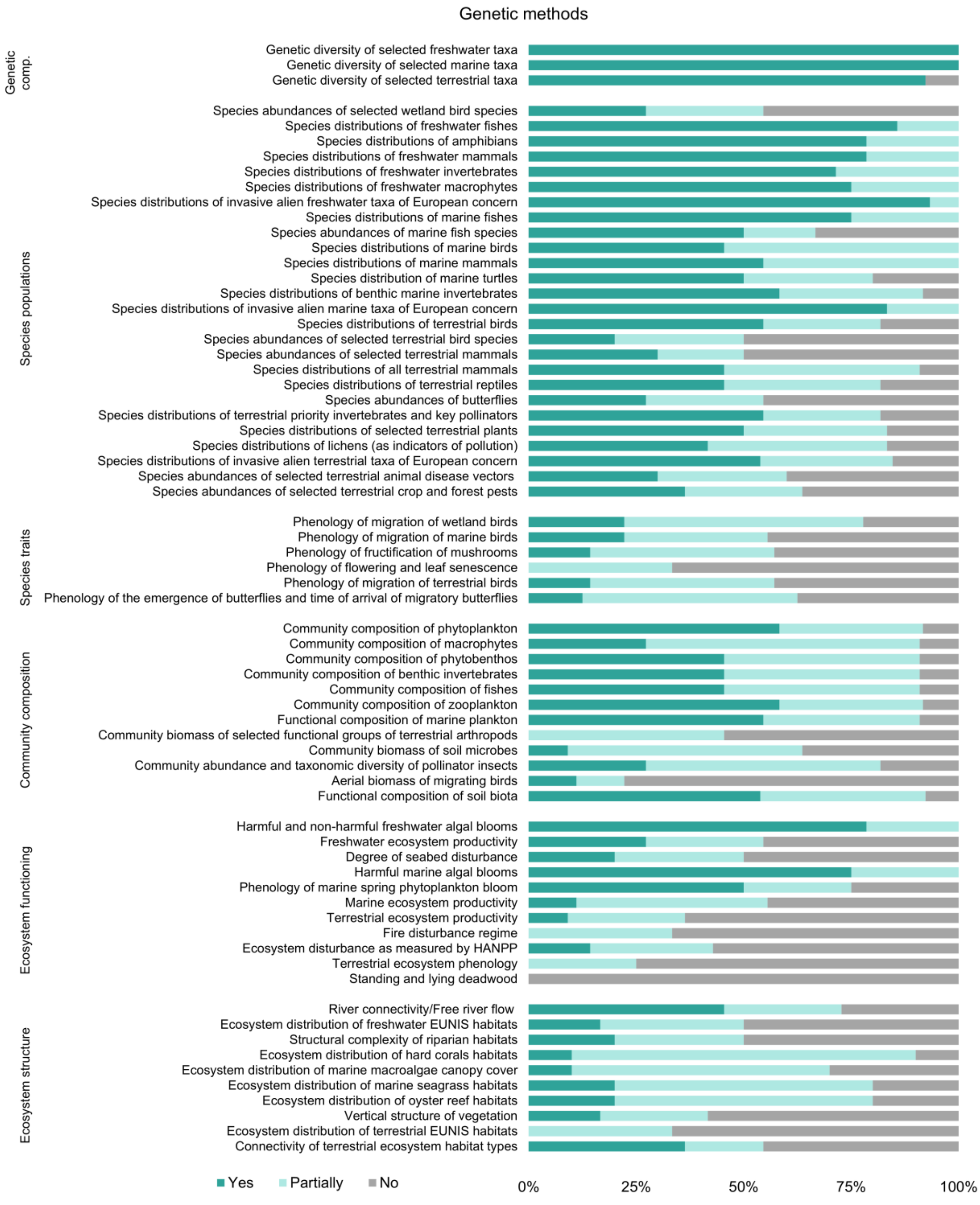
WFD benthic invertebrates (# EU river segments) 38,120
WFD fish (# EU river segments) 21,893
WFD phytobenthos (# EU river segments) 20,280
WFD macrophytes (# EU river segments) 12,192
WFD other aquatic flora (# EU river segments) 8,353
WFD phytoplankton (# EU river segments) 3,768
WFD macroalgae (# EU river segments) 144
WFD angiosperms (# EU river segments) 139
WFD phytoplankton (# large EU lakes) 7,747
WFD benthic invertebrates (# large EU lakes) 2,622
WFD fish (# large EU lakes) 2,560
WFD macrophytes (# large EU lakes) 2,541
WFD other aquatic flora (# large EU lakes) 1,488
WFD phytobenthos (# large EU lakes) 1,294
WFD macroalgae (# large EU lakes) 23
WFD angiosperms (# large EU lakes) 0
WFD phytoplankton (# EU coastal water bodies) 1,586
WFD benthic invertebrates (# EU coastal water bodies) 1,114
WFD fish (# EU coastal water bodies) 42
WFD macrophytes (# EU coastal water bodies) 32
WFD other aquatic flora (# EU coastal water bodies) 157
WFD phytobenthos (# EU coastal water bodies) 14
WFD macroalgae (# EU coastal water bodies) 865
WFD angiosperms (# EU coastal water bodies) 324
WFD phytoplankton (# EU transitional water bodies) 404
WFD benthic invertebrates (# EU transitional water bodies) 414
WFD fish (# EU transitional water bodies) 262
WFD macrophytes (# EU transitional water bodies) 86
WFD other aquatic flora (# EU transitional water bodies) 60
WFD phytobenthos (# EU transitional water bodies) 17
WFD macroalgae (# EU transitional water bodies) 214
WFD angiosperms (# EU transitional water bodies) 66
0
10,000
20,000
30,000
40,000
50,000

2471 Figure 10



2472

2473 Figure 11



2474

Figure 12

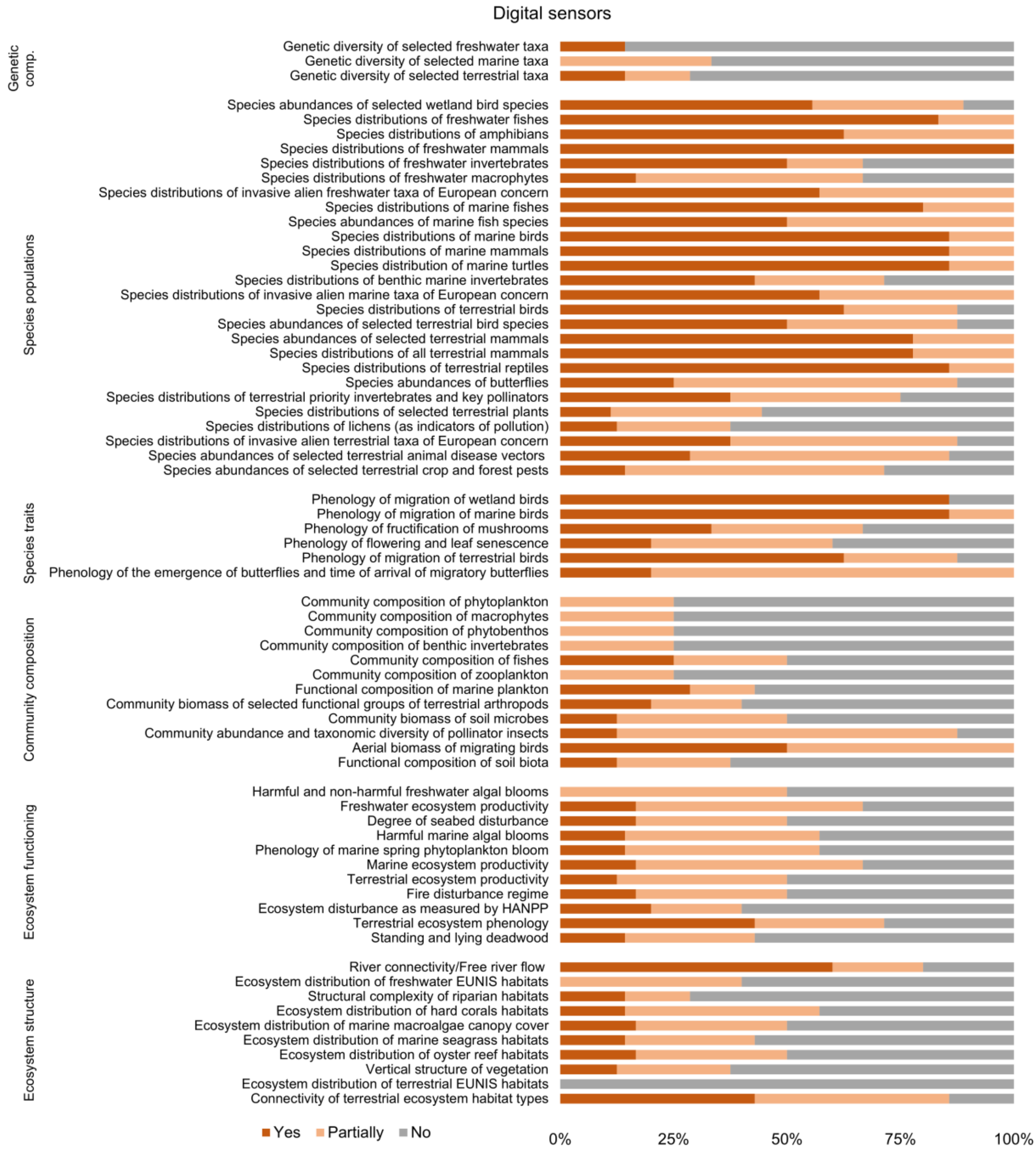
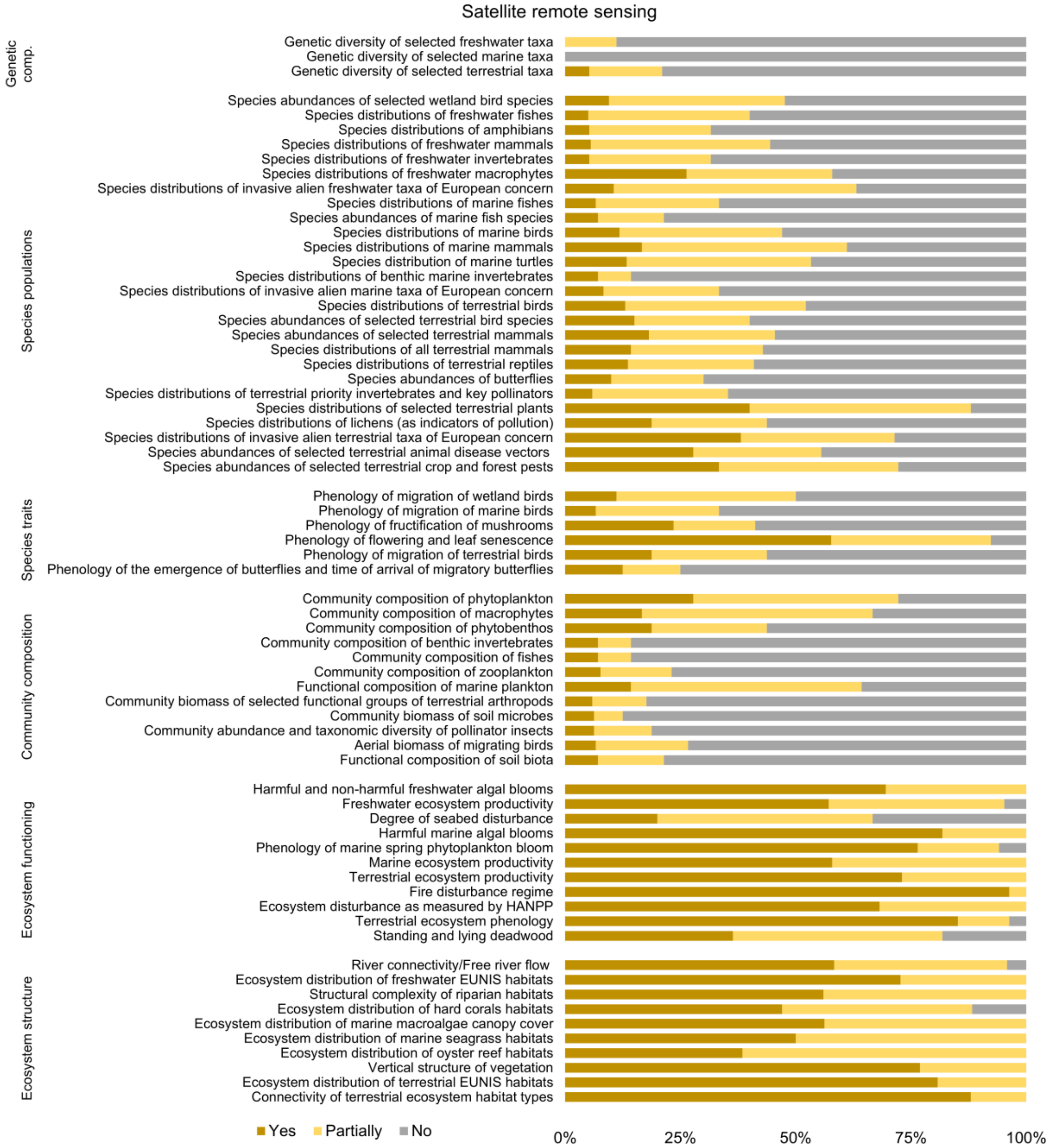
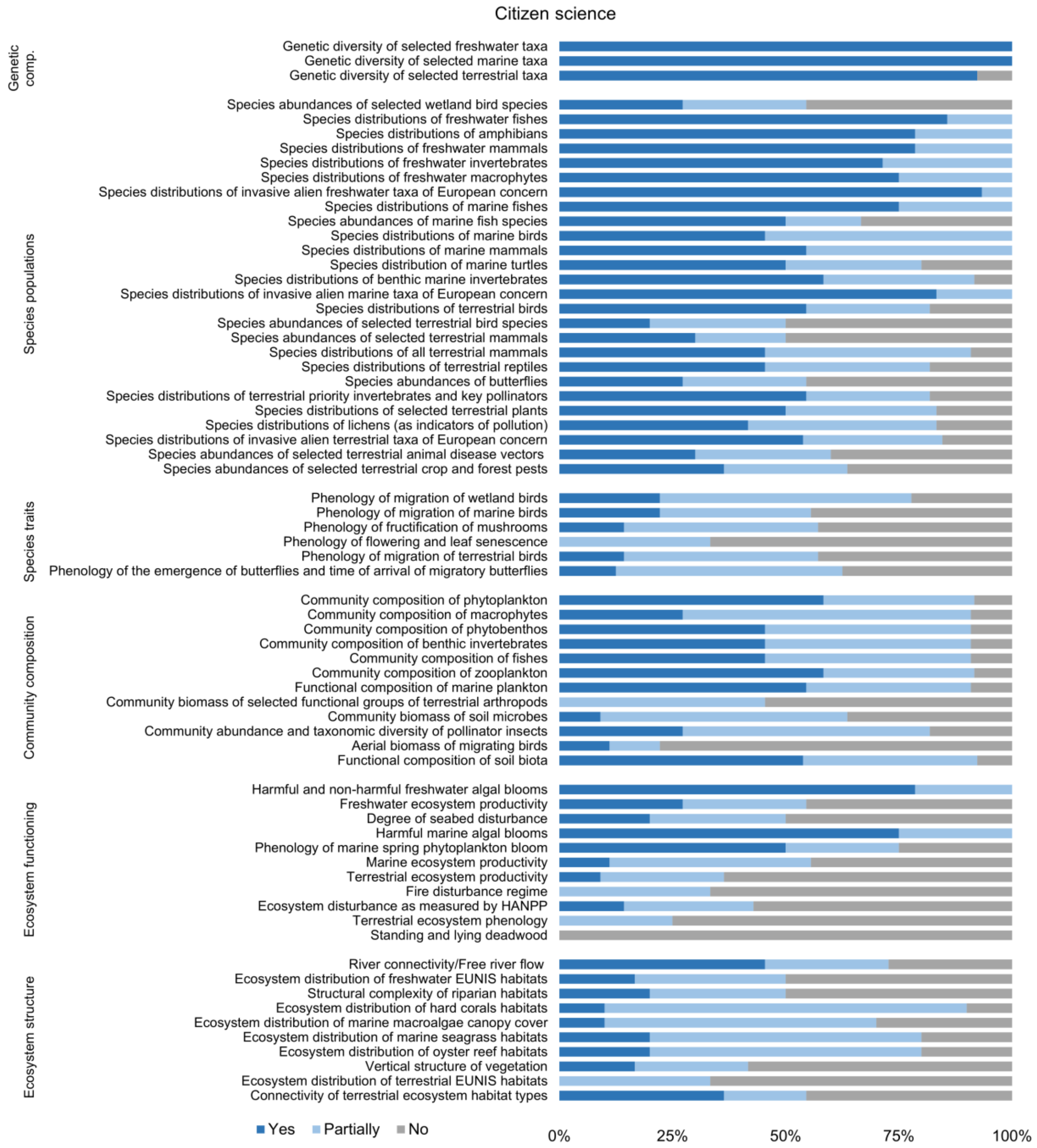

Digital sensors
Genetic comp.
Genetic diversity of selected freshwater taxa
Genetic diversity of selected marine taxa
Genetic diversity of selected terrestrial taxa
Species populations
Species abundances of selected wetland bird species
Species distributions of freshwater fishes
Species distributions of amphibians
Species distributions of freshwater mammals
Species distributions of freshwater invertebrates
Species distributions of freshwater macrophytes
Species distributions of invasive alien freshwater taxa of European concern
Species distributions of marine fishes
Species abundances of marine fish species
Species distributions of marine birds
Species distributions of marine mammals
Species distribution of marine turtles
Species distributions of benthic marine invertebrates
Species distributions of invasive alien marine taxa of European concern
Species distributions of terrestrial birds
Species abundances of selected terrestrial bird species
Species abundances of selected terrestrial mammals
Species distributions of all terrestrial mammals
Species distributions of terrestrial reptiles
Species abundances of butterflies
Species distributions of terrestrial priority invertebrates and key pollinators
Species distributions of selected terrestrial plants
Species distributions of lichens (as indicators of pollution)
Species distributions of invasive alien terrestrial taxa of European concern
Species abundances of selected terrestrial animal disease vectors
Species abundances of selected terrestrial crop and forest pests
Species traits
Phenology of migration of wetland birds
Phenology of migration of marine birds
Phenology of fructification of mushrooms
Phenology of flowering and leaf senescence
Phenology of migration of terrestrial birds
Phenology of the emergence of butterflies and time of arrival of migratory butterflies
Community composition
Community composition of phytoplankton
Community composition of macrophytes
Community composition of phytobenthos
Community composition of benthic invertebrates
Community composition of fishes
Community composition of zooplankton
Functional composition of marine plankton
Community biomass of selected functional groups of terrestrial arthropods
Community biomass of soil microbes
Community abundance and taxonomic diversity of pollinator insects
Aerial biomass of migrating birds
Functional composition of soil biota
Ecosystem functioning
Harmful and non-harmful freshwater algal blooms
Freshwater ecosystem productivity
Degree of seabed disturbance
Harmful marine algal blooms
Phenology of marine spring phytoplankton bloom
Marine ecosystem productivity
Terrestrial ecosystem productivity
Fire disturbance regime
Ecosystem disturbance as measured by HANPP
Terrestrial ecosystem phenology
Standing and lying deadwood
Ecosystem structure
River connectivity/Free river flow
Ecosystem distribution of freshwater EUNIS habitats
Structural complexity of riparian habitats
Ecosystem distribution of hard corals habitats
Ecosystem distribution of marine macroalgae canopy cover
Ecosystem distribution of marine seagrass habitats
Ecosystem distribution of oyster reef habitats
Vertical structure of vegetation
Ecosystem distribution of terrestrial EUNIS habitats
Connectivity of terrestrial ecosystem habitat types
Yes
Partially
No
0%
25%
50%
75%
100%

Figure 13



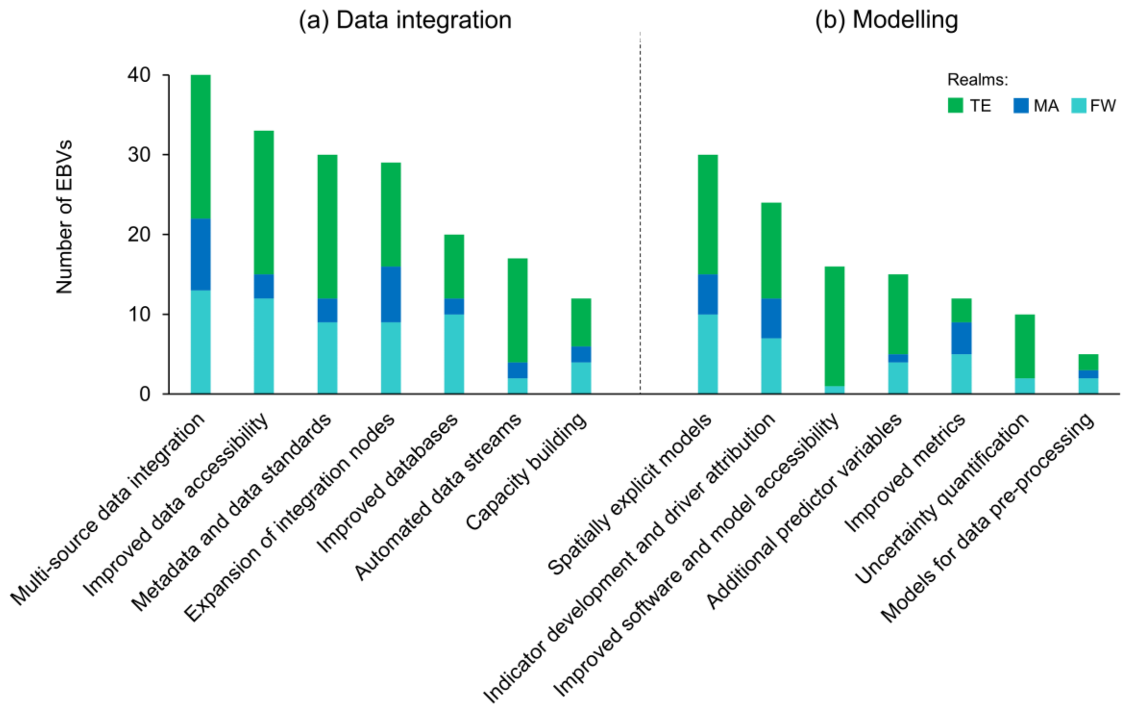
Satellite remote sensing
Genetic comp.
Genetic diversity of selected freshwater taxa
Genetic diversity of selected marine taxa
Genetic diversity of selected terrestrial taxa
Species populations
Species abundances of selected wetland bird species
Species distributions of freshwater fishes
Species distributions of amphibians
Species distributions of freshwater mammals
Species distributions of freshwater invertebrates
Species distributions of freshwater macrophytes
Species distributions of invasive alien freshwater taxa of European concern
Species distributions of marine fishes
Species abundances of marine fish species
Species distributions of marine birds
Species distributions of marine mammals
Species distribution of marine turtles
Species distributions of benthic marine invertebrates
Species distributions of invasive alien marine taxa of European concern
Species distributions of terrestrial birds
Species abundances of selected terrestrial bird species
Species abundances of selected terrestrial mammals
Species distributions of all terrestrial mammals
Species distributions of terrestrial reptiles
Species abundances of butterflies
Species distributions of terrestrial priority invertebrates and key pollinators
Species distributions of selected terrestrial plants
Species distributions of lichens (as indicators of pollution)
Species distributions of invasive alien terrestrial taxa of European concern
Species abundances of selected terrestrial animal disease vectors
Species abundances of selected terrestrial crop and forest pests
Species traits
Phenology of migration of wetland birds
Phenology of migration of marine birds
Phenology of fructification of mushrooms
Phenology of flowering and leaf senescence
Phenology of migration of terrestrial birds
Phenology of the emergence of butterflies and time of arrival of migratory butterflies
Community composition
Community composition of phytoplankton
Community composition of macrophytes
Community composition of phytobenthos
Community composition of benthic invertebrates
Community composition of fishes
Community composition of zooplankton
Functional composition of marine plankton
Community biomass of selected functional groups of terrestrial arthropods
Community biomass of soil microbes
Community abundance and taxonomic diversity of pollinator insects
Aerial biomass of migrating birds
Functional composition of soil biota
Ecosystem functioning
Harmful and non-harmful freshwater algal blooms
Freshwater ecosystem productivity
Degree of seabed disturbance
Harmful marine algal blooms
Phenology of marine spring phytoplankton bloom
Marine ecosystem productivity
Terrestrial ecosystem productivity
Fire disturbance regime
Ecosystem disturbance as measured by HANPP
Terrestrial ecosystem phenology
Standing and lying deadwood
Ecosystem structure
River connectivity/Free river flow
Ecosystem distribution of freshwater EUNIS habitats
Structural complexity of riparian habitats
Ecosystem distribution of hard corals habitats
Ecosystem distribution of marine macroalgae canopy cover
Ecosystem distribution of marine seagrass habitats
Ecosystem distribution of oyster reef habitats
Vertical structure of vegetation
Ecosystem distribution of terrestrial EUNIS habitats
Connectivity of terrestrial ecosystem habitat types
Yes
Partially
No
0%
25%
50%
75%
100%

Figure 14



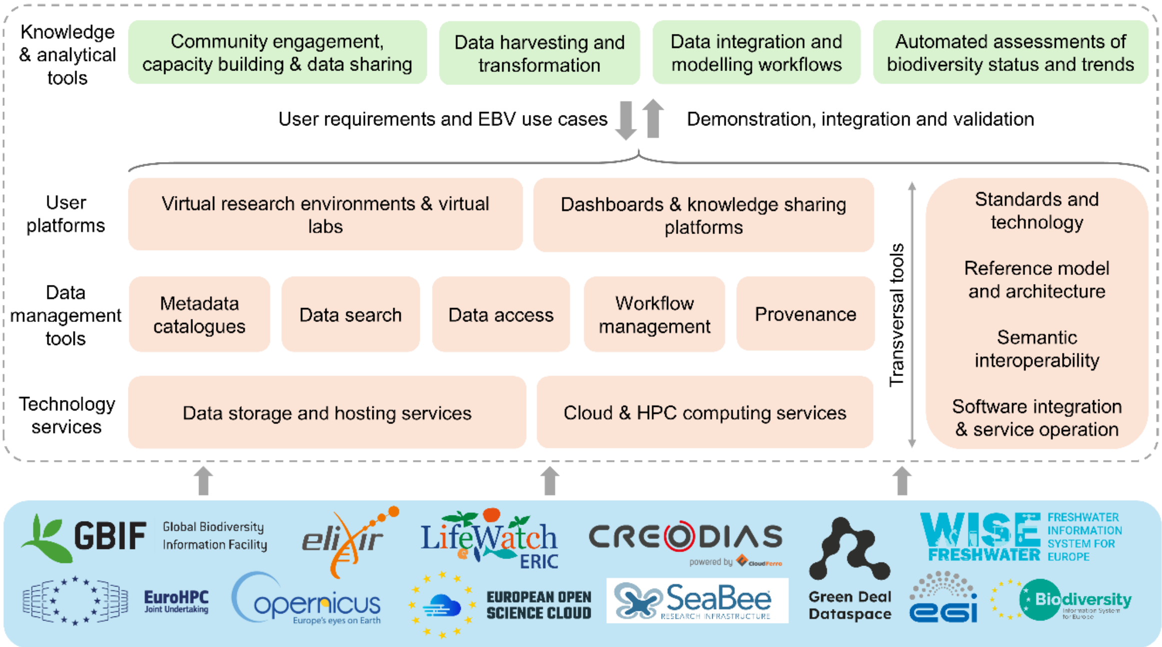
Citizen science
Genetic comp.
Genetic diversity of selected freshwater taxa
Genetic diversity of selected marine taxa
Genetic diversity of selected terrestrial taxa
Species populations
Species abundances of selected wetland bird species
Species distributions of freshwater fishes
Species distributions of amphibians
Species distributions of freshwater mammals
Species distributions of freshwater invertebrates
Species distributions of freshwater macrophytes
Species distributions of invasive alien freshwater taxa of European concern
Species distributions of marine fishes
Species abundances of marine fish species
Species distributions of marine birds
Species distributions of marine mammals
Species distribution of marine turtles
Species distributions of benthic marine invertebrates
Species distributions of invasive alien marine taxa of European concern
Species distributions of terrestrial birds
Species abundances of selected terrestrial bird species
Species abundances of selected terrestrial mammals
Species distributions of all terrestrial mammals
Species distributions of terrestrial reptiles
Species abundances of butterflies
Species distributions of terrestrial priority invertebrates and key pollinators
Species distributions of selected terrestrial plants
Species distributions of lichens (as indicators of pollution)
Species distributions of invasive alien terrestrial taxa of European concern
Species abundances of selected terrestrial animal disease vectors
Species abundances of selected terrestrial crop and forest pests
Species traits
Phenology of migration of wetland birds
Phenology of migration of marine birds
Phenology of fructification of mushrooms
Phenology of flowering and leaf senescence
Phenology of migration of terrestrial birds
Phenology of the emergence of butterflies and time of arrival of migratory butterflies
Community composition
Community composition of phytoplankton
Community composition of macrophytes
Community composition of phytobenthos
Community composition of benthic invertebrates
Community composition of fishes
Community composition of zooplankton
Functional composition of marine plankton
Community biomass of selected functional groups of terrestrial arthropods
Community biomass of soil microbes
Community abundance and taxonomic diversity of pollinator insects
Aerial biomass of migrating birds
Functional composition of soil biota
Ecosystem functioning
Harmful and non-harmful freshwater algal blooms
Freshwater ecosystem productivity
Degree of seabed disturbance
Harmful marine algal blooms
Phenology of marine spring phytoplankton bloom
Marine ecosystem productivity
Terrestrial ecosystem productivity
Fire disturbance regime
Ecosystem disturbance as measured by HANPP
Terrestrial ecosystem phenology
Standing and lying deadwood
Ecosystem structure
River connectivity/Free river flow
Ecosystem distribution of freshwater EUNIS habitats
Structural complexity of riparian habitats
Ecosystem distribution of hard corals habitats
Ecosystem distribution of marine macroalgae canopy cover
Ecosystem distribution of marine seagrass habitats
Ecosystem distribution of oyster reef habitats
Vertical structure of vegetation
Ecosystem distribution of terrestrial EUNIS habitats
Connectivity of terrestrial ecosystem habitat types
Yes
Partially
No
0%
25%
50%
75%
100%

2481 Figure 15



2482

Figure 16


Knowledge & analytical tools
Community engagement, capacity building & data sharing
Data harvesting and transformation
Data integration and modelling workflows
Automated assessments of biodiversity status and trends
User requirements and EBV use cases
Demonstration, integration and validation
Digital infrastructure of a European Biodiversity Observation Network
User platforms
Virtual research environments & virtual labs
Dashboards & knowledge sharing platforms
Data management tools
Metadata catalogues
Data search
Data access
Workflow management
Provenance
Technology services
Data storage and hosting services
Cloud & HPC computing services
Transversal tools
Standards and technology
Reference model and architecture
Semantic interoperability
Software integration & service operation
Research infrastructures & services
GBIF Global Biodiversity Information Facility
elixir
LifeWatch ERIC
CREODIAS
EuroHPC Joint Undertaking
opernicus Europe's eyes on Earth
EUROPEAN OPEN SCIENCE CLOUD
SeaBee RESEARCH INFRASTRUCTURE
Green Deal Dataspace
WISE FRESHWATER
FRESHWATER INFORMATION SYSTEM FOR EUROPE
egi
Biodiversity

APPENDIX S1: LINKS BETWEEN EBVS AND POLICIES

Towards a modern and efficient European biodiversity observation network fit for multiple policies

W. Daniel Kissling | Tom D. Breeze | Camino Liquete | Anne Lyche Solheim | Ian McCallum | Joachim Maes | Tim Hirsch | Maria Lumbierres | Roy H. A. van Grunsven | Pedro Beja | Bruno Smets | César Capinha | Ana Ceia-Hasse | Néstor Fernández | Francisco Moreira | Jessica Junker | Florian Leese | Eleanor Hammond | Lluís Brotons | Alejandra Morán Ordóñez | Simon G. Potts | Joana Santana | Jose Valdez | Ingolf Kühn | Marija Milanović | Astrid Schmidt-Kloiber | Dimitrios Bormpoudakis | Dani Villero | Peter Haase | Kristian Meissner | Helge Bruelheide | Marcel Buchhorn | Irene Calderon-Sanou | Miguel Fernandez | Anna Gamero | Anne Gobin | Irene Guerrero | Ute Jandt | Alena Klvaňová | Martina Marei Viti | S. Jannicke Moe | Aletta Bonn | Henrique Miguel Pereira

Journal name: *Ecological Monographs*

Link definitions and policy references

The link between a specific EBV and a specific EU policy was specified as a direct or indirect link, and as a partial or complete link. If there was no link at all, a 'No' was entered. The specific definitions of the links are given in Table S1.

TABLE S1 Definitions used to describe the link between EBVs and EU policies.

Link description	Definition
Direct	The information provided by the EBV can be directly used to respond to reporting requirements.
Indirect	The EBV could provide underlying, complementary, or voluntary information for reporting requirements.
Complete	The EBV is completely filling one specific reporting requirement, for example an indicator, or the whole taxonomic scope (e.g. all species) for a reporting requirement
Partial	The EBV covers part of specific reporting requirement, e.g. part of an indicator, but is still missing some conceptual, taxonomic, geographical or temporal aspect
No	No link. Specifies all relationships that have no clear operational application for the implementation (i.e. monitoring and reporting) of the policy. This does NOT imply that the EBV cannot provide useful information about EU biodiversity and ecosystems and their exploitation, but simply that the official reporting requirements do not request this information.

The links between EBVs and EU policies were derived from policy documents. The references and weblinks for the policy documents are provided in Table S2.

TABLE S2 EU policy documents that were used to specify the link with an EBV.

EU policy	Reference	URL 1	URL 2
Main EU legislation			
Birds Directive	Reference portal for reporting under Article 12 of the Birds Directive.	https://cdr.eionet.europa.eu/help/birds_art12	
Habitats Directive	Reporting Format, Explanatory Notes, and Guidelines for reporting under Art. 17 of the Habitats Directive.	https://cdr.eionet.europa.eu/help/habitats_art17	
Water Framework Directive	WFD (Directive 2000/60/EC). Technical specifications described in Annex II (reference conditions and typology) and Annex V Surface water status: including normative definitions for biological and supporting quality elements to be used for assessing ecological status. WFD-CIS guidance no. 13 on Classification of ecological status; WFD-CIS guidance no. 21 for reporting under the WFD. Commission decision on Intercalibration of high/good and good/moderate EQR-values.	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018D0229	
Marine Strategy Framework Directive	MSFD (Directive 2008/56/EC). Technical speficications described in Part II of COMMISSION DECISION (EU) 2017/848 and in MSFD Guidance Document 19.	https://eur-lex.europa.eu/eli/dir/2008/56/oj	https://eur-lex.europa.eu/eli/dec/2017/848/oj
Nature Restoration Law	Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance).	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1728024382866	
EU Biodiversity Strategy for 2030	Annex to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - EU Biodiversity Strategy for 2030 — Bringing nature back into our lives (COM(2020) 380 final, 20.5.2020).	https://eur-lex.europa.eu/legal-content/EN/AUTO/?uri=celex:52020DC0380	
Ecosystem service policies			
Pollinators Initiative	Proposal for an EU Pollinator Monitoring Scheme (EUPOMS).	https://wikis.ec.europa.eu/pages/viewpage.action?pageId=23462107	

Land Use, Land Use Change and Forestry regulation	Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. Methodologies for greenhouse gas inventories given in Volume 4 of IPCC 2006	https://eur-lex.europa.eu/eli/reg/2023/839/oj	https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/
Proposed Forest Monitoring Regulation	Proposal for a Regulation of the European Parliament and of the Council on a monitoring framework for resilient European forests (Submitted on 22 November 2023).	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A728%3AFIN	
Other EU policies, regulations and strategies			
Regulation on Invasive Alien Species	Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (updated version on 14/12/2019).	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02014R1143-20191214	
National Emission Ceilings Directive	Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG	
Common Agricultural Policy	Article 128 and Annex I of Regulation (EU) 2021/2115 provides that a performance framework is to be established to allow reporting, monitoring and evaluation of the CAP Strategic Plans. Implementing regulation (EU) 2022/1475 addresses CAP monitoring and evaluation.	https://eur-lex.europa.eu/eli/reg/2021/2115/oj	https://eur-lex.europa.eu/eli/reg_impl/2022/1475
Proposed regulation on ecosystem accounting	Regulation of the European Parliament and of the Council amending Regulation (EU) No 691/2011 as regards introducing new environmental economic accounts modules.	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022PC0329	
Common Fisheries Policy	CFP (Regulation (EU) No 1380/2013). Fisheries data collection framework (Regulation (EU) 2017/1004 with subsequent implementing and delegated acts.	https://eur-lex.europa.eu/eli/reg/2013/1380/oj	https://eur-lex.europa.eu/eli/reg/2017/1004/oj

Proposed Directive on Soil Monitoring and Resilience	COM (2023) 416 final: Proposal for a Directive on Soil Monitoring and Resilience (Soil Monitoring Law); reporting under Art.18 every 5 years and permanent online access to data; descriptors, criteria and methodologies in Annex I & II	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0416

Links between EBVs and main EU legislation

TABLE S3 Specific links between EBVs and the main EU legislation for biodiversity, namely the Birds Directive, Habitats Directive, Water Framework Directive, Marine Strategy Framework Directive, the Proposed Nature Restoration Law and the EU Biodiversity Strategy for 2030. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

EBV ID	Realm	EBV name	Birds Directive	Habitats Directive	Water Framework Directive	Marine Strategy Framework Directive	Nature Restoration Law	EU Biodiversity Strategy for 2030
Eco_CC_com_fish_FW	Freshwater	Community composition of fishes	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting for all habitats matching the WFD types	Complete / Direct. Directly linked, as needed to calculate the EQR-ratios for assessing ecological status for fish, which is obligatory to report, see Article 4, referring to Annex V, section 1.2.1-1.2.4 , subsection on biological quality elements and Annex II, section 1.3 for establishment of reference conditions, which is the basis for	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

					calculating the EQR-ratios for single water bodies			
Eco_CC_com_fung_FW	Freshwater	Community composition of aquatic fungi	No.	No. Not linked, although it is related to the "bacterial tufts and coats", which is included in Annex V as a part of phytobenthos in rivers. If a river is full of fungi or large colonial bacteria (*Sphaerotilus natans*), such heterotrophic organisms indicate massive organic pollution.	No. Not linked, although it is related to the "bacterial tufts and coats", which is included in Annex V as a part of phytobenthos in rivers. If a river is full of fungi or large colonial bacteria (*Sphaerotilus natans*), such heterotrophic organisms indicate massive organic pollution.	No.	No.	No.
Eco_CC_com_inve_FW	Freshwater	Community composition of benthic invertebrates	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under	Complete / Direct. Directly linked, as needed to calculate the EQR-ratios for assessing ecological status for benthic invertebrates,	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in

				Art. 17 reporting for all habitats matching the WFD types	which is obligatory to report, see Article 4, referring to Annex V, section 1.2.1-1.2.4, subsection on biological quality elements and Annex II, section 1.3 for establishment of reference conditions, which is the basis for calculating the EQR-ratios for single water bodies			conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"
Eco_CC_com_mphy_FW	Freshwater	Community composition of macrophytes	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting for all habitats matching the WFD types	Complete / Direct. Directly linked, as needed to calculate the EQR-ratios for assessing ecological status for macrophytes, which is obligatory to report, see Article 4, referring to Annex V,	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and

					section 1.2.1-1.2.4, subsection on biological quality elements and Annex II, section 1.3 for establishment of reference conditions, which is the basis for calculating the EQR-ratios for single water bodies			carbon-rich ecosystems are restored"
Eco_CC_com_pben_FW	Freshwater	Community composition of phytobenthos	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting for all habitats matching the WFD types	Complete / Direct. Directly linked, as needed to calculate the EQR-ratios for assessing ecological status for phytobenthos, which is obligatory to report, see Article 4, referring to Annex V, section 1.2.1-1.2.4, subsection on biological quality elements	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_CC_com_ppla_FW	Freshwater	Freshwater Community composition of phytoplankton	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting	Complete / Direct. Directly linked, as needed to calculate the EQR-ratios for assessing ecological status for phytoplankton, which is obligatory to report, see Article 4, referring to Annex V, section 1.2.1-1.2.4, subsection on biological quality elements, and Annex II, section 1.3 for establishment of reference conditions, which is the basis for calculating the EQR-ratios for single water bodies	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_CC_com_zoop_FW	Freshwater	[Community composition of zooplankton]()	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting for all habitats matching the WFD types	No. Not linked (zooplankton is not included in Annex V as a separate biological quality element), although it could be helpful to interpret the ecological status of phytoplankton and fish, as they graze on phytoplankton and is food for pelagic fish species.	No.	No.	No.
Eco_EF_dec_habi_FW	Freshwater	[Rate of decomposition]()	No.	Partial / Indirect. Can help to determine the 'Pressures and threats' for freshwater species and habitats under the Habitats Directive Article 17 reporting	No. Not linked, although it can be useful for interpreting ecological status for biological quality elements and oxygenation conditions, which are part of the physico-chemical quality elements required in Annex V	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	No.

Eco_EF_phe_ppla_FW	Freshwater	Harmful and non-harmful freshwater algal blooms	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status, as well as the 'Pressures and threats' for freshwater species and habitats under the Habitats Directive Article 17 reporting	Partial / Direct. Directly linked as blooms are an integral part of the phytoplankton assessment system for lakes required in Annex V, see also WFD Intercalibration reports for Lakes	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"
Eco_EF_pro_habi_FW	Freshwater	Freshwater ecosystem productivity	No.	Partial / Indirect. Can help to determine the 'Pressures and threats' for freshwater species and habitats under the Habitats Directive Article 17 reporting	No. Not linked, although it can be useful for interpreting ecological status for biological quality elements and nutrients, which are part of the physico-chemical quality elements required in Annex V	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	No.

Eco_ES_con_habi_FW	Freshwater	River Connectivity - Free river flow	No.	Partial / Indirect. Can help to determine the pressures and threats for river species and protected habitats in Art. 17 reporting.	Partial / Direct. Directly linked, as needed to assess ecological status for river continuity, which is obligatory to report, see Annex V, section 1.2.1-1.2.4 subsection on hydromorphological quality elements,	No.	Complete / Direct. Monitors the natural connectivity of rivers for Art.7	Complete / Direct. Useful to assess progress to Target 11 (At least 25,000 km of free-flowing rivers are restored)
Eco_ES_dis_habi_FW	Freshwater	Ecosystem distribution of freshwater EUNIS Habitats	No.	Complete / Direct. Can be used for producing distribution maps and for assessing the range and the area covered by habitats for determining the conservation status under Art. 17 reporting, but only for those habitat types that match the HD Annex 1.	Partial / Indirect. Indirectly relevant for assessing the type for each water body according to Art. 5 and Annex II.	No.	Partial / Indirect. Can help monitoring the area and condition of the areas covered by the habitat types listed in Annex I that match the revised EUNIS types	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_ES_str_habi_FW	Freshwater	Structural complexity of riparian habitats	No.	Partial / Indirect. Can help to determine the structure and function parameter of habitats for determining the conservation status under Art. 17 reporting	Partial / Direct. Directly linked, as needed to assess ecological status for morphological conditions, which is obligatory to report, see Annex V, section 1.2.1-1.2.4 subsection on hydromorphological quality elements,	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"
Spp_SP_abn_bird_FW	Freshwater	Species abundances of selected wetland bird species	Partial / Direct. Relevant for art 12 reporting; Member states required to report estimates of population sizes (breeding pairs or number of individuals)	No.	No. Not linked, as birds are not included in the WFD	No.	No.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_SP_abn_inse_FW	Freshwater	Species abundances of dragonflies	No.	Complete / Direct. Can be used to calculate population size under Art.17 reporting	No.	No.	No.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_alie_FW	Freshwater	Species distributions of invasive alien freshwater taxa of European concern	Partial / Indirect. Can be used to determine the pressures and threats for bird species as main drivers related to status and trends, and further help to identify actions required for restoration (see Art 12 guidelines).	Partial / Direct. Can help identifying the distribution of alien invasive species for reporting on pressures and threats for Annex I habitats	Partial / Indirect. Indirectly relevant for assessing pressures and decide if such pressure may be significant or not. Invasive alien species must be reported as a significant pressure if such species cause a water body to be in less than good ecological status for one or more of the obligatory	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, it can help measure part of Target 12 (reduction in the number of Red List species threatened by invasive alien species)

					biological quality elements.			
Spp_SP_dis_amph_FW	Freshwater	[Species distributions of amphibians]()	No.	Complete / Direct. Allows calculating distribution range and trends required for Art. 17 conservation status assessments and for setting favourable reference values.	No. Not linked, as amphibians are not included in the WFD	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_inve_FW	Freshwater	[Species distributions of freshwater invertebrates]()	No.	Complete / Direct. Allows calculating distribution range and trends required for Art. 17 conservation status assessments and for setting favourable reference values.	Partial / Indirect. Indirectly relevant for assessing ecological status for benthic invertebrates in rivers and lakes (underlying data for calculating the community composition EBV, which is directly linked).	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_SP_dis_mamm_FW	Freshwater	Species distributions of freshwater mammals	No.	Complete / Direct. Allows calculating distribution range and trends required for Art. 17 conservation status assessments and for setting favourable reference values.	No. Not linked, as mammals are not included in the WFD	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_mphy_FW	Freshwater	Species distributions of freshwater macrophytes	No.	Complete / Direct. Allows calculating distribution range and trends required for Art. 17 conservation status assessments and for setting favourable reference values.	Partial / Indirect. Indirectly relevant for assessing ecological status for macrophytes in rivers and lakes (underlying data for calculating the community composition EBV, which is directly linked).	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_SP_dis_rept_FW	Freshwater	Species distributions of freshwater reptiles	No.	Complete / Direct. Can be used to map and to calculate the distribution range, trends, and favourable reference range of protected species under Art. 17 reporting.	No. Not relevant, as reptiles is not part of the WFD	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_GC_div_unsp_FW	Freshwater	Genetic diversity of selected freshwater taxa	No.	Partial / Indirect. Although reporting is not required, genetic variation is mentioned in the reporting guidelines a recommended criteria for setting favourable reference values and for assessing the status of species populations.	No.	No.	No.	No.

Spp_ST_phe_bird_FW	Freshwater	Phenology of migration of wetland birds	No.	No.	No. Not linked, as birds are not included in the WFD	No.	No.	No.
Spp_ST_phe_fish_FW	Freshwater	Phenology of migration of freshwater fishes	No.	No.	No. Not linked, although it could be helpful to assess the ecological status of fish	No.	No.	No.
Eco_CC_abn_inve_MA	Marine	Community abundance of functional groups of soft-bottom benthic macroinvertebrate communities	No.	No.	Partial / Indirect. Could be relevant for countries that are using functional groups in their assessment method for ecological status for soft-bottom benthic invertebrates, according to Annex V for coastal and transitional waters	Partial / Indirect. Partially covers D6C5 (pressures over and condition of broad benthic habitat types, including alteration to its functions), no abundance required or differentiation of macroinvertebrates. D6C5 equals to 'specific structures and functions' of HD.	No.	No.

Eco_EF_dtb_habi_MA	Marine	Degree of seabed disturbance	No.	Partial / Indirect. Can be used to determine the pressures and threats for species and habitats for Article 17 reporting	Partial / Direct. Directly linked, as needed to assess ecological status for morphological conditions, which is obligatory to report, see Annex V, section 1.2.1-1.2.4 subsection on hydromorphological quality elements	Complete / Direct. D6C2 (Physical disturbance to the seabed). Primary.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	Complete / Direct. Useful to assess progress to Target 15 (The negative impacts on sensitive species and habitats, including on the seabed [...] are substantially reduced)
Eco_EF_phe_habi_MA	Marine	Harmful marine algal blooms	No.	Partial / Indirect. Can be used to determine the pressures and threats for species and habitats for Article 17 reporting	Partial / Direct. Directly linked as blooms are related to chlorophyll a, which is used for assessing ecological status for phytoplankton, as required in Annex V, see also WFD Intercalibration reports for transitional and coastal waters	Complete / Direct. D5C3 (number, spatial extent and duration of harmful algal bloom events). Voluntary criterion.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	No.

Eco_EF_phe_ppla_MA	Marine	Phenology of marine spring phytoplankton bloom	No.	No.	No. Not linked, although it could be helpful to assess the ecological status of phytoplankton in transitional and coastal waters	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	No.
Eco_EF_pro_habi_MA	Marine	Marine ecosystem productivity	No.	No.	No. Not linked, although it can be useful for interpreting ecological status for biological quality elements and nutrients, which are part of the physico-chemical quality elements required in Annex V for transitional and coastal waters	Partial / Indirect. D5C2 asks for the Chlorophyll a concentrations in the water column. D4C4 (voluntary, where necessary): Productivity of the trophic guild is not adversely affected due to anthropogenic pressures.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	No.

Eco_ES_dis_cora_MA	Marine	Ecosystem distribution of hard corals habitats	No.	Complete / Direct. Important to calculate range and area for habitats under Art. 17 reporting	Partial / Indirect. Could be relevant for countries that are using corals in their assessment method for ecological status for hard-bottom benthic invertebrates, according to Annex V for coastal and transitional waters	Partial / Direct. It could be used (aggregated with other info) to estimate: D6C1 (extent and distribution of physical loss), D6C3 (broad habitat types adversely affected), D6C4 (Benthic habitat extent taking into account extent of habitat loss), D6C5 (Benthic habitat condition taking into account extent of adverse effects). All of them are compulsory criteria.	Partial / Direct. Can help monitoring the area covered by the habitat types listed in Annex II	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_ES_dis_malg_MA	Marine	Ecosystem distribution of marine macroalgae canopy cover	No.	Complete / Direct. Important to calculate range and area for habitats under Art. 17 reporting	Partial / Indirect. Could be relevant for countries that are using macroalgae canopy cover in their assessment method for ecological status for macroalgae, according to Annex V for coastal and transitional waters	Partial / Direct. It could be used (aggregated with other info) to estimate: D6C1 (extent and distribution of physical loss), D6C3 (broad habitat types adversely affected), D6C4 (Benthic habitat extent taking into account extent of habitat loss), D6C5 (Benthic habitat condition taking into account extent of adverse effects).	Partial / Direct. Can help monitoring the area covered by the habitat types listed in Annex II	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_ES_dis_oyst_MA	Marine	Ecosystem distribution of oyster reef habitats	No.	Complete / Direct. Important to calculate range and area for habitats under Art. 17 reporting	Partial / Indirect. Could be relevant for countries that are using oysters as part of their assessment method for ecological status for hard-bottom benthic invertebrates, according to Annex V for coastal and transitional waters	Partial / Direct. It could be used (aggregated with other info) to estimate: D6C1 (extent and distribution of physical loss), D6C3 (broad habitat types adversely affected), D6C4 (Benthic habitat extent taking into account extent of habitat loss), D6C5 (Benthic habitat condition taking into account extent of adverse effects).	Partial / Direct. Can help monitoring the area covered by the habitat types listed in Annex II	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Eco_ES_dis_plan_MA	Marine	Ecosystem distribution of marine seagrass habitats	No.	Complete / Direct. Important to calculate range and area for habitats under Art. 17 reporting	Partial / Indirect. Could be relevant for assessment of ecological status for angiosperms (seagrasses), according to Annex V for coastal and transitional waters	Partial / Direct. It could be used (aggregated with other info) to estimate: D6C1 (extent and distribution of physical loss), D6C3 (broad habitat types adversely affected), D6C4 (Benthic habitat extent taking into account extent of habitat loss), D6C5 (Benthic habitat condition taking into account extent of adverse effects).	Partial / Direct. Can help monitoring the area covered by the habitat types listed in Annex II	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"

Spp_SP_abn_fish_MA	Marine	Species abundances of marine commercial fish species and long-distance migratory fishes	No.	Complete / Direct. Can be used to calculate population size under Art.17 reporting	No. Not linked, as there is no requirement for assessing fish in coastal waters in the WFD Annex V.	Complete / Direct. D3C2 (The Spawning Stock Biomass of populations of commercially-exploited species are above biomass levels capable of producing maximum sustainable yield), primary. "Long-distance migratory fish" is not differentiated.	No.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_alie_MA	Marine	Species distributions of invasive alien marine taxa of European concern	Partial / Indirect. Can be used to determine the pressures and threats for bird species as main drivers related to status and trends, and further help to identify actions required for restoration (see Art 12 guidelines).	Partial / Indirect. Can help identifying the distribution of alien invasive species for reporting on pressures for Annex I habitats	Partial / Indirect. Indirectly relevant for assessing pressures in coastal and transitional waters, as invasive alien species are considered as a pressure on the other biological quality elements	Partial / Direct. Partially covers D2C2 (Abundance and spatial distribution of established non-indigenous species, particularly of invasive species), voluntary criterion. However, the taxa listed as IAS of European concern can be	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	Partial / Indirect. Highly aggregated, it can help measure part of Target 12 (reduction in the number of Red List species threatened by invasive alien species)

						insufficient for the marine environment.		
Spp_SP_dis_fish_MA	Marine	Species distributions of marine fishes	No.	Complete / Direct. Important to calculate distribution ranges surface area, trends, and favourable reference range of species listed under the Habitats Directive for reporting under Art. 17.	No. Not linked, as there is no requirement for assessing fish in coastal waters in the WFD Annex V.	Complete / Direct. This is criterion D1C4 (species distributional range) - Fish reported under Art.8.1a every 6 years. Compulsory for the few coastal or anadromous fishes listed in Annexes II, IV and V of the HD; Voluntary for the rest. Fish species should be grouped in Coastal fish, Pelagic shelf fish, Demersal shelf fish, Deep-sea fish.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 5.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_SP_dis_inve_MA	Marine	Species distributions of benthic marine invertebrates	No.	Complete / Direct. Important to calculate distribution ranges surface area, trends, and favourable reference range of species listed under the Habitats Directive for reporting under Art. 17.	Partial / Indirect. Indirectly relevant for assessing ecological status for benthic invertebrates in coastal and transitional waters	Partial / Indirect. Relevant for D6C4 (extent of loss vs natural extent of broad benthic habitats types), but no single species distribution are required. D6C4 equates to the ‘range/area covered by habitat type within range’ of the HD.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 5	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_mamm_MA	Marine	Species distributions of marine mammals	No.	Complete / Direct. Important to calculate distribution ranges surface area, trends, and favourable reference range of species listed under the Habitats Directive for reporting under Art. 17.	No. Not linked, as there is no requirement for assessing mammals in coastal waters in the WFD Annex V.	Complete / Direct. Criterion D1C4 (species distributional range) - mammals reported under Art.8.1a, compulsory. Mammal species should be grouped in Small toothed cetaceans, Deep-diving toothed cetaceans, Baleen whales and Seals.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 5.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

		Populations should be assessed separately.	

Spp_SP_dis_rept_MA	Marine	Species distribution of marine turtles	No.	Complete / Direct. Important to calculate distribution ranges surface area, trends, and favourable reference range of species listed under the Habitats Directive for reporting under Art. 17.	No. Not linked, as there is no requirement for assessing turtles in coastal waters in the WFD Annex V.	Partial / Direct. Partially covers criterion D1C4 (species distributional range) - reptiles (primary) because this EBV is defined as limited to EU's coastline. Relevant EBV for the Action Plan for the Conservation of Marine Turtles in the Mediterranean (https://www.rac-spa.org/sites/default/files/action_plans/marine_turtles_ap_fr_en.pdf)	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 5.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_GC_div_unsp_MA	Marine	Genetic diversity of selected marine taxa	No.	Partial / Indirect. Although reporting is not required, genetic variation is mentioned in the reporting guidelines a recommended criteria for setting favourable reference values and for assessing the status of species populations.	No.	Partial / Indirect. Criteria D3C3 includes among the parameters of a healthy population of commercially-exploited species 'limited adverse effects of exploitation on genetic diversity'.	No.	No.
Spp_ST_phe_bird_MA	Marine	Phenology of migration of marine birds	No.	No.	No. Not relevant, as birds are not included	No.	No.	No.
Spp_ST_phe_fish_MA	Marine	Phenology of migration of highly migratory marine fish	No.	No.	No. Not linked, although it could be relevant for eel, sturgeon and wild salmon, which may be included in assessment systems for ecological status for fish in rivers, lakes and/or	No.	No.	No.

					transitional waters			
Spp_ST_phe_mamm_MA	Marine	Phenology of migration of highly migratory marine mammals	No.	No.	No. Not relevant, as mammals are not included	No.	No.	No.
Eco_CC_abn_inse_TE	Terrestrial	Community abundance and taxonomic diversity of pollinator insects	No.	No.	No.	No.	Partial / Direct. Can be used to monitor the pollinator diversity referred in Art. 8	Partial / Direct. Useful to assess progress to Target 5 (The decline of pollinators is reversed)
Eco_CC_bio_bird_TE	Terrestrial	Aerial biomass of migrating birds	No.	No.	No.	No.	No.	No.
Eco_CC_bio_inse_TE	Terrestrial	Aerial biomass of migrating insects	No.	No.	No.	No.	No.	No.
Eco_CC_bio_inve_TE	Terrestrial	Community biomass of selected functional groups of terrestrial arthropods (e.g. predator, decomposer)	No.	No.	No.	No.	No.	No.
Eco_CC_bio_mamm_TE	Terrestrial	Aerial biomass of migrating bats	No.	No.	No.	No.	No.	No.

Eco_CC_bio_micr_TE	Terrestrial	Community biomass of soil microbes	No.	No.	No.	No.	No.	Partial / Indirect. Highly aggregated, it can help monitor Target 10 in selected sites (Significant progress in the remediation of contaminated soil sites)
Eco_CC_com_micr_TE	Terrestrial	Functional composition of soil biota	No.	No.	No.	No.	No.	Partial / Indirect. Highly aggregated, it can help monitor Target 10 in selected sites (Significant progress in the remediation of contaminated soil sites)
Eco_EF_dec_unsp_TE	Terrestrial	Rate of decomposition	No.	No.	No.	No.	No.	No.
Eco_EF_dtb_fire_TE	Terrestrial	Fire disturbance regime	No.	Partial / Indirect. Helps determining the structure and function parameters for assessing the condition of habitats under Article 17 reporting.	No.	No.	Partial / Indirect. Can be used to monitor trends in the condition of habitats referred in Art. 4	No.

Eco_EF_dtb_huma_TE	Terrestrial	Ecosystem disturbance as measured by HANPP	No.	Partial / Indirect. Indirect link to determining the structure and function parameter of habitats protected under the Habitats directive that member states have to report under Article 17. The structure and function parameter assesses the condition of habitats. It is one of the 4 parameters to determine habitat conservation status	No.	No.	Partial / Indirect. Can be used to monitor trends in the condition of habitats referred in Art. 4	No.
Eco_EF_phe_plan_TE	Terrestrial	Terrestrial ecosystem phenology	No.	No.	No.	No.	Partial / Indirect. Can be used to monitor trends in the condition of habitats referred in Art. 4	No.
Eco_EF_pro_bird_TE	Terrestrial	Total bird herbivory	No.	No.	No.	No.	No.	No.

Eco_EF_pro_mamm_TE	Terrestrial	Total mammal herbivory	No.	No.	No.	No.	No.	No.
Eco_EF_pro_unsp_TE	Terrestrial	Terrestrial ecosystem productivity	No.	No.	No.	No.	Partial / Indirect. Can be used to monitor trends in the condition of habitats referred in Art. 4	No.
Eco_ES_bio_habi_TE	Terrestrial	Standing and lying deadwood	No.	Partial / Indirect. Helps determining the structure and function parameters for assessing the condition of habitats under Article 17 reporting.	No.	No.	Complete / Direct. Can be used to monitor the standing deadwood and lying deadwood indices referred in Art. 10	No.
Eco_ES_con_habi_TE	Terrestrial	Connectivity of terrestrial ecosystem habitat types	No.	Partial / Indirect. Can be used to determine the structure and function parameter of habitats protected under the Habitats directive that member states have to report under Article 17. The structure and function	No.	No.	Partial / Direct. Can be used to monitor the forest connectivity index referred in Art. 10. Can be used to monitor the condition of Annex I habitats of the HD	Partial / Indirect. Highly aggregated, it would contribute to the part of Target 1 dealing with "integrate ecological corridors"

				parameter assesses the condition of habitats. It is one of the 4 parameters to determine habitat conservation status				
Eco_ES_dis_habi_TE	Terrestrial	Ecosystem distribution of terrestrial EUNIS Habitats	No.	Complete / Direct. Can be used for producing distribution maps and for assessing the range and the area covered by habitats for determining the conservation status under Art. 17 reporting	No.	No.	Partial / Direct. Can help monitoring the area and condition of the areas covered by the habitat types listed in Annexes I and II	Partial / Indirect. Highly aggregated, all information about habitats would feed the parts of target 4 dealing with "no deterioration in conservation trends and status" and "areas of degraded and carbon-rich ecosystems are restored"
Eco_ES_str_plan_TE	Terrestrial	Vertical structure of vegetation	No.	Partial / Indirect. Helps determining the structure and function parameters for assessing the condition of habitats under	No.	No.	Partial / Indirect. Can be used as complementary information to monitor the share of forests with uneven-aged structure	No.

				Article 17 reporting.			referred in Art. 10	
Spp_SP_abn_dise_TE	Terrestrial	Species abundances of selected terrestrial animal disease vectors	Partial / Indirect. Can be used to determine the pressures and threats for bird species as main drivers related to status and trends (e.g. bird flu), and further help to identify actions required for restoration (see Art 12 guidelines).	No.	No.	No.	No.	No.
Spp_SP_abn_inse_TE	Terrestrial	Species abundances of butterflies	No.	Complete / Direct. Can be used to calculate population size under Art.17 reporting	No.	No.	Partial / Direct. Can be used to monitor the Grassland Butterfly Index referred in Art. 9	Partial / Direct. Useful to assess progress to Target 5 (The decline of pollinators is reversed)
Spp_SP_abn_mamm_TE	Terrestrial	Species abundances of selected terrestrial mammals	No.	Complete / Direct. Can be used to calculate population size under Art.17 reporting	No.	No.	No.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4

								dealing with "no deterioration in conservation trends and status"
Spp_SP_abn_pest_TE	Terrestrial	Species abundances of selected terrestrial crop and forest pests	No.	No.	No.	No.	No.	No.
Spp_SP_dis_alie_TE	Terrestrial	Species distributions of invasive alien terrestrial taxa of European concern	Partial / Indirect. Can be used to determine the pressures and threats for bird species as main drivers related to status and trends, and further help to identify actions required for restoration (see Art 12 guidelines).	Partial / Indirect. Can help identifying the distribution of alien invasive species for reporting on pressures for Annex I habitats	No.	No.	Partial / Indirect. Can help monitoring the condition and trends in condition of habitats referred in Art. 4	Partial / Indirect. Highly aggregated, it can help measure part of Target 12 (reduction in the number of Red List species threatened by invasive alien species)
Spp_SP_dis_bird_TE	Terrestrial	Species distributions of terrestrial birds	Complete / Direct. relevant for art 12 reporting; Member states required to report on total surface area of the breeding	No.	No.	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of

			distribution in km2, as well as provide a map.				referred in Art. 4.	target 4 dealing with "no deterioration in conservation trends and status"
Spp_SP_dis_inve_TE	Terrestrial	Species distributions of terrestrial priority invertebrates and key pollinators	No.	Complete / Direct. Can be used to map and to calculate the distribution range, trends, and favourable reference range of protected species under Art. 17 reporting.	No.	No.	Partial / Direct. Can be used to monitor the pollinator diversity referred in Art. 8	Partial / Direct. Useful to assess progress to Target 5 (The decline of pollinators is reversed)
Spp_SP_dis_mamm_TE	Terrestrial	Species distributions of all terrestrial mammals	No.	Complete / Direct. Can be used to map and to calculate the distribution range, trends, and favourable reference range of protected species under Art. 17 reporting.	No.	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"

Spp_SP_dis_rept_TE	Terrestrial	Species distributions of terrestrial reptiles	No.	Complete / Direct. Can be used to map and to calculate the distribution range, trends, and favourable reference range of protected species under Art. 17 reporting.	No.	No.	Partial / Indirect. Can help monitoring the habitat quality and trends in habitat quality of species referred in Art. 4.	Partial / Indirect. Highly aggregated, all information about species abundance or range would feed the part of target 4 dealing with "no deterioration in conservation trends and status"
Spp_ST_phe_bird_TE	Terrestrial	Phenology of migration of terrestrial birds	No.	No.	No.	No.	No.	No.
Spp_ST_phe_frui_TE	Terrestrial	Phenology of fructification of wild fruits	No.	No.	No.	No.	No.	No.
Spp_ST_phe_fung_TE	Terrestrial	Phenology of fructification of mushrooms	No.	No.	No.	No.	No.	No.
Spp_ST_phe_inse_TE	Terrestrial	Phenology of the emergence of butterflies and time of arrival of migratory butterflies	No.	No.	No.	No.	No.	No.
Spp_ST_phe_plan_TE	Terrestrial	Phenology of flowering and leaf senescence	No.	No.	No.	No.	No.	No.

Links between EBVs and ecosystem service policies

TABLE S4 Specific links between EBVs and ecosystem service policies of the EU, namely the Pollinators Initiative, the Land Use, Land Use Cover and Forestry Regulation, and the Proposed Forest Monitoring Regulation. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

EBV ID	Realm	EBV name	Pollinators Initiative	Land Use Land Use Change and Forestry regulation	Proposed forest monitoring regulation
Eco_CC_com_fish_FW	Freshwater	Community composition of fishes	No.	No.	No.
Eco_CC_com_fung_FW	Freshwater	Community composition of aquatic fungi	No.	No.	No.
Eco_CC_com_inve_FW	Freshwater	Community composition of benthic invertebrates	No.	No.	No.
Eco_CC_com_mphy_FW	Freshwater	Community composition of macrophytes	No.	No.	No.
Eco_CC_com_pben_FW	Freshwater	Community composition of phytobenthos	No.	No.	No.
Eco_CC_com_ppla_FW	Freshwater	Freshwater Community composition of phytoplankton	No.	No.	No.
Eco_CC_com_zoop_FW	Freshwater	Community composition of zooplankton	No.	No.	No.
Eco_EF_dec_habi_FW	Freshwater	Rate of decomposition	No.	No.	No.

Eco_EF_phe_ppla_FW	Freshwater	Harmful and non-harmful freshwater algal blooms	No.	No.	No.
Eco_EF_pro_habi_FW	Freshwater	Freshwater ecosystem productivity	No.	No.	No.
Eco_ES_con_habi_FW	Freshwater	River Connectivity - Free river flow	No.	No.	No.
Eco_ES_dis_habi_FW	Freshwater	Ecosystem distribution of freshwater EUNIS Habitats	No.	No.	No.
Eco_ES_str_habi_FW	Freshwater	Structural complexity of riparian habitats	No.	No.	No.
Spp_SP_abn_bird_FW	Freshwater	Species abundances of selected wetland bird species	No.	No.	No.
Spp_SP_abn_inse_FW	Freshwater	Species abundances of dragonflies	No.	No.	No.
Spp_SP_dis_alie_FW	Freshwater	Species distributions of invasive alien freshwater taxa of European concern	No.	No.	No.
Spp_SP_dis_amph_FW	Freshwater	Species distributions of amphibians	No.	No.	No.
Spp_SP_dis_inve_FW	Freshwater	Species distributions of freshwater invertebrates	No.	No.	No.

Spp_SP_dis_mamm_FW	Freshwater	Species distributions of freshwater mammals	No.	No.	No.
Spp_SP_dis_mphy_FW	Freshwater	Species distributions of freshwater macrophytes	No.	No.	No.
Spp_SP_dis_rept_FW	Freshwater	Species distributions of freshwater reptiles	No.	No.	No.
Spp_GC_div_unsp_FW	Freshwater	Genetic diversity of selected freshwater taxa	No.	No.	No.
Spp_ST_phe_bird_FW	Freshwater	Phenology of migration of wetland birds	No.	No.	No.
Spp_ST_phe_fish_FW	Freshwater	Phenology of migration of freshwater fishes	No.	No.	No.
Eco_CC_abn_inve_MA	Marine	Community abundance of functional groups of soft-bottom benthic macroinvertebrate communities	No.	No.	No.
Eco_EF_dtb_habi_MA	Marine	Degree of seabed disturbance	No.	No.	No.
Eco_EF_phe_habi_MA	Marine	Harmful marine algal blooms	No.	No.	No.
Eco_EF_phe_ppla_MA	Marine	Phenology of marine spring phytoplankton bloom	No.	No.	No.

Eco_EF_pro_habi_MA	Marine	Marine ecosystem productivity	No.	No.	No.
Eco_ES_dis_cora_MA	Marine	Ecosystem distribution of hard corals habitats	No.	No.	No.
Eco_ES_dis_malg_MA	Marine	Ecosystem distribution of marine macroalgae canopy cover	No.	No.	No.
Eco_ES_dis_oyst_MA	Marine	Ecosystem distribution of oyster reef habitats	No.	No.	No.
Eco_ES_dis_plan_MA	Marine	Ecosystem distribution of marine seagrass habitats	No.	No.	No.
Spp_SP_abn_fish_MA	Marine	Species abundances of marine commercial fish species and long-distance migratory fishes	No.	No.	No.
Spp_SP_dis_alie_MA	Marine	Species distributions of invasive alien marine taxa of European concern	No.	No.	No.
Spp_SP_dis_fish_MA	Marine	Species distributions of marine fishes	No.	No.	No.
Spp_SP_dis_inve_MA	Marine	Species distributions of benthic marine invertebrates	No.	No.	No.

Spp_SP_dis_mamm_MA	Marine	Species distributions of marine mammals	No.	No.	No.
Spp_SP_dis_rept_MA	Marine	Species distribution of marine turtles	No.	No.	No.
Spp_GC_div_unsp_MA	Marine	Genetic diversity of selected marine taxa	No.	No.	No.
Spp_ST_phe_bird_MA	Marine	Phenology of migration of marine birds	No.	No.	No.
Spp_ST_phe_fish_MA	Marine	Phenology of migration of highly migratory marine fish	No.	No.	No.
Spp_ST_phe_mamm_MA	Marine	Phenology of migration of highly migratory marine mammals	No.	No.	No.
Eco_CC_abn_inse_TE	Terrestrial	Community abundance and taxonomic diversity of pollinator insects	Partial / Direct. Potts et al. (2021) presents a series of options (pp. 164) of suitable indicators - it is recommended that a combination of average trends in species occupancy/diversity (Option 1), Trends in abundance of pollinator groups (option 2) and modelled trends in average species abundance (option 3A) are used (pp. 168) - Options 2 and 3A correspond to this EBV	No.	No.
Eco_CC_bio_bird_TE	Terrestrial	Aerial biomass of migrating birds	No.	No.	No.

Eco_CC_bio_inse_TE	Terrestrial	Aerial biomass of migrating insects	No.	No.	No.
Eco_CC_bio_inve_TE	Terrestrial	Community biomass of selected functional groups of terrestrial arthropods (e.g. predator, decomposer)	No.	No.	No.
Eco_CC_bio_mamm_TE	Terrestrial	Aerial biomass of migrating bats	No.	No.	No.
Eco_CC_bio_micr_TE	Terrestrial	Community biomass of soil microbes	No.	No.	No.
Eco_CC_com_micr_TE	Terrestrial	Functional composition of soil biota	No.	No.	No.
Eco_EF_dec_unsp_TE	Terrestrial	Rate of decomposition	No.	Partial / Direct. Article 5 and Annex 1 of LULUCF: Member states must report on change in annual carbon stocks in pools including mineral soils and dead organic matter. This EBV could be used as a parameter for estimating carbon stock in mineral soils and dead organic matter, if member states use tier 2 or 3 IPCC methodology - e.g. if using "model-based approaches... [such as] mechanistic simulation models that capture the underlying processes driving carbon gains and losses... [due to e.g.] microbial	No.

				decomposition" (IPCC 2006 Volume 4, Chapter 2)	
Eco_EF_dtb_fire_TE	Terrestrial	[Fire disturbance regime]()	No.	Partial / Direct. Article 10 and Annex VI: Member states may exclude greenhouse gas emissions, for afforested and managed forest land, resulting from natural disturbances (including fire) above background level. This EBV may be relevant for member states calculating and reporting emissions from fires. To report background levels of disturbance, MS must demonstrate time series consistency in parameters including minimum area of disturbance, which is similar	Partial / Direct. The average disturbance size metric of this EBV is relevant to the member states reporting obligation of burnt forest areas (at least once a week) under Article 5 of this Regulation. The average disturbance severity metric of this EBV is relevant to the member states reporting obligation of fire severity (every two weeks) under Article 5 of this Regulation. However, the definition of the severity metrics are different in EBV vs. Regulation:

				to the average disturbance size metric of this EBV.	- Definition of indicator fire severity in the Regulation: "short-term degree of damage caused by a wildfire to the vegetation and expressed in categories: unburned, scorched, light, moderate and heavy... difference between pre-fire vegetation conditions to post-fire vegetation state" - Definition of average disturbance severity in this EBV: "probability of a disturbance being stand replacing". This EBV is also relevant to the MS reporting obligation of fire events (at least once a week) under Article 5 of this Regulation. In the Regulation, fire events are "characterized by date of fire occurrence, duration of the fire and fire size" and so the average disturbance size metric of this EBV is relevant to reporting on fire size.
Eco_EF_dtb_huma_TE	Terrestrial	Ecosystem disturbance as measured by HANPP	No.	Partial / Direct. HANPP = HANPPluc + HANPPharv. Article 5 and Annex I of LULUCF: Member states must report on the change in the carbon stock of living biomass. The equation for IPCC tier 2 and 3 methods for calculating annual change carbon stock in living	No. No, because the indicator removals in this Regulation is defined as "volume of all trees that are harvested and removed from forests...", whereas HANPPharv concerns the quantity of carbon in biomass harvested or

				biomass for converted land includes the parameter annual increase in carbon stocks in biomass due to growth on land converted to another land-use category (ΔCG). This parameter is very similar to HANNluc (HANNluc goes one step further by comparing the NPP of the converted land type to the NPP that would have occured for native vegetation). This IPCC equation also contains parameters for initial and annual change in carbon stocks in biomass on converted land, these are very similar to HANPPharv (quantity of carbon in biomass harvested or otherwise consumed including crops, timber, harvested crop residues, forest slash, etc.) HANPP also relevant to other carbon pools, such as mineral soil: change in NPP relative to native vegetation (i.e. HANPPluc) determines which stock exchange factor should be used for that particular piece of land	otherwise consumed by people.
Eco_EF_phe_plan_TE	Terrestrial	Terrestrial ecosystem phenology	No.	No.	No.

Eco_EF_pro_bird_TE	Terrestrial	Total bird herbivory	No.	No.	No.
Eco_EF_pro_mamm_TE	Terrestrial	Total mammal herbivory	No.	No.	No.
Eco_EF_pro_unsp_TE	Terrestrial	Terrestrial ecosystem productivity	No.	No.	No.
Eco_ES_bio_habi_TE	Terrestrial	Standing and lying deadwood	No.	Partial / Direct. Article 5 and Annex 1 of LULUCF: Member states must report on change in annual carbon stocks in deadwood. This EBV refers to the volume of deadwood, rather than carbon stock. However, when using the stock-difference method for estimating change in carbon stock in deadwood, the parameter dead wood stock (at two different time points) in tonnes d.m. ha-1 is needed. (IPCC Volume 4, Chapter 2), meaning this EBV is relevant to the calculation of deadwood carbon stock for this Regulation	Complete / Direct. Directly relevant to the indicator 'deadwood [volume]' that MS have to report on every 5 years under Article 5. Note that in the Regulation, it explicitly states that the deadwood indicator "The volume of dead standing and lying wood includes stumps and roots", whereas the EBV does not specify whether stumps and roots are included in the deadwood definition.
Eco_ES_con_habi_TE	Terrestrial	Connectivity of terrestrial ecosystem habitat types	No.	No.	Partial / Direct. Related to the forest connectivity indicator that must be reported under Article 5, but this EBV is probably not useful because the forest monitoring regulation has a very specific definition of the forest connectivity indicator ('degree of compactness of forest areas'),

					for which specific methodology has been defined.
Eco_ES_dis_habi_TE	Terrestrial	[Ecosystem distribution of terrestrial EUNIS Habitats]	No.	No.	Complete / Direct. Could contribute to the reporting of forest area (member states must report annually under Article 5)
Eco_ES_str_plan_TE	Terrestrial	[Vertical structure of vegetation]	No.	No.	Partial / Direct. Somewhat relevant to the reporting of tree cover density (annual reporting under Article 5): one of the metrics of this EBV is vegetation cover, canopy gaps and penetration ratios, which relates to tree cover density. Also somewhat relevant to aboveground biomass (Article 8): one of the metrics of this EBV is total plant biomass per vegetation strata
Spp_SP_abn_dise_TE	Terrestrial	[Species abundances of selected terrestrial animal disease vectors]	No.	No.	No.

Spp_SP_abn_inse_TE	Terrestrial	Species abundances of butterflies	Partial / Direct. Potts et al. (2021) presents a series of options (pp. 164) of suitable indicators - it is recommended that a combination of average trends in species occupancy/diversity (Option 1), Trends in abundance of pollinator groups (option 2) and modelled trends in average species abundance (option 3A) are used (pp. 168) - Option 1 corresponds to this EBV	No.	No.
Spp_SP_abn_mamm_TE	Terrestrial	Species abundances of selected terrestrial mammals	No.	No.	No.
Spp_SP_abn_pest_TE	Terrestrial	Species abundances of selected terrestrial crop and forest pests	No.	No.	No.
Spp_SP_dis_alie_TE	Terrestrial	Species distributions of invasive alien terrestrial taxa of European concern	No.	No.	Complete / Direct. Could be used for reporting on the indicator 'presence of invasive species' (defined as 'maps of invasive alien plant and tree species in a forest area, as defined in the list of invasive alien species of Union concern') that MS

					are required to report on (Article 8).
Spp_SP_dis_bird_TE	Terrestrial	Species distributions of terrestrial birds	No.	No.	Partial / Direct. Could be used for reporting on the indicator 'threatened species' that member states are required to report on (Article 8). The 'threatened species' indicator is defined as 'maps of the presence of threatened species in forest ecosystems classified according to IUCN Red List categories', and so since this EBV is defined as 'presence/absence or probability of occurrence of each European terrestrial bird species', it could be used to assess presence/absence of particular terrestrial bird species that are threatened within forest ecosystems.

Spp_SP_dis_inve_TE	Terrestrial	Species distributions of terrestrial priority invertebrates and key pollinators	Partial / Direct. Potts et al. (2021) presents a series of options (pp. 164) of suitable indicators - it is recommended that a combination of average trends in species occupancy/diversity (Option 1), Trends in abundance of pollinator groups (option 2) and modelled trends in average species abundance (option 3A) are used (pp. 168) - Option 1 corresponds to this EBV	No.	Partial / Direct. Could be used for reporting on the indicator 'threatened species' that member states are required to report on (Article 8). The 'threatened species' indicator is defined as 'maps of the presence of threatened species in forest ecosystems classified according to IUCN Red List categories', and so it could be used to assess presence/absence of priority invertebrates and key pollinators species that are threatened within forest ecosystems.
Spp_SP_dis_mamm_TE	Terrestrial	Species distributions of all terrestrial mammals	No.	No.	Partial / Direct. Could be used for reporting on the indicator 'threatened species' that member states are required to report on (Article 8). The 'threatened species' indicator is defined as 'maps of the presence of threatened species in forest ecosystems classified according to IUCN Red List categories', and so it could be used to assess presence/absence of particular terrestrial mammal species that are threatened within forest ecosystems.

Spp_SP_dis_rept_TE	Terrestrial	Species distributions of terrestrial reptiles	No.	No.	Partial / Direct. Could be used for reporting on the indicator 'threatened species' that member states are required to report on (Article 8). The 'threatened species' indicator is defined as 'maps of the presence of threatened species in forest ecosystems classified according to IUCN Red List categories', and so it could be used to assess presence/absence of particular terrestrial reptile species that are threatened within forest ecosystems.
Spp_ST_phe_bird_TE	Terrestrial	Phenology of migration of terrestrial birds	No.	No.	No.
Spp_ST_phe_frui_TE	Terrestrial	Phenology of fructification of wild fruits	No.	No.	No.
Spp_ST_phe_fung_TE	Terrestrial	Phenology of fructification of mushrooms	No.	No.	No.
Spp_ST_phe_inse_TE	Terrestrial	Phenology of the emergence of butterflies and time of arrival of migratory butterflies	No.	No.	No.
Spp_ST_phe_plan_TE	Terrestrial	Phenology of flowering and leaf senescence	No.	No.	No.

Links between EBVs and other EU policies, regulations, and strategies

TABLE S5 Specific links between EBVs and other EU policies, regulations and strategies, namely the Regulation on Invasive Alien Species, National Emission Ceilings Directive, Common Agricultural Policy, Proposed Regulation on Ecosystem Accounting, Common Fisheries Policy, and the Proposed Directive on Soil Monitoring and Resilience. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

EBV ID	Realm	EBV name	Regulation on Invasive Alien Species	National Emission Ceilings Directive	Common Agricultural Policy	Proposed regulation on ecosystem accounting	Common Fisheries Policy (CFP)	Proposed Directive on Soil Monitoring and Resilience
Eco_CC_com_fish_FW	Freshwater	Community composition of fishes	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring	No.	No.	Partial / Indirect. There is no obligation to monitor this EBV, although the Data Collection Framework (DCF) asks for biological data on eels and salmon in inland waters. Some data on anadromous fish can be collected by the International Council for the Exploration	No.

				of loss of fish stocks is suggested in Annex V as an optional indicator for this purpose.			of the Sea (ICES).	
Eco_CC_com_fung_FW	Freshwater	Community composition of aquatic fungi	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Eco_CC_com_inve_FW	Freshwater	Community composition of benthic invertebrates	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in	No.	No.	No.	No.

			in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of loss of freshwater invertebrates is suggested in Annex V as an optional indicator for this purpose.				
Eco_CC_com_mphy_FW	Freshwater	[Community composition of macrophytes]()	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting	Partial / Indirect. Can help to determine the I.15 and C.39 indicators for water quality; gross nutrient balance for Nitrogen and phosphorus.	No.	No.	No.

			this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of macrophytes is suggested in Annex V as an optional indicator for this purpose.				
Eco_CC_com_pben_FW	Freshwater	[Community composition of phytobenthos]()	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity,	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance	Partial / Indirect. Can help to determine the I.15 and C.39 indicators for water quality; gross nutrient balance for Nitrogen and phosphorus.	No.	No.	No.

			reproduction, abundance or distribution may be applicable.	with Article 9				
Eco_CC_com_ppla_FW	Freshwater	[Freshwater Community composition of phytoplankton]	No.	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of microphytes and diatoms is suggested in Annex V	Partial / Indirect. Can help to determine the I.15 and C.39 indicators for water quality; gross nutrient balance for Nitrogen and phosphorus.	No.	No.	No.

				as an optional indicator for this purpose.				
Eco_CC_com_zoop_FW	Freshwater	Community composition of zooplankton	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Eco_EF_dec_habi_FW	Freshwater	Rate of decomposition	No.	No.	No.	No.	No.	No.
Eco_EF_phe_ppla_FW	Freshwater	Harmful and non-harmful freshwater algal blooms	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for	Partial / Indirect. Can help to determine the I.15 and C.39 indicators for water quality; gross nutrient balance for	No.	No.	No.

				monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Nitrogen and phosphorus.			
Eco_EF_pro_habi_FW	Freshwater	[Freshwater ecosystem productivity]()	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Eco_ES_con_habi_FW	Freshwater	[River Connectivity - Free river flow]()	No.	No.	No.	No.	No.	No.

Eco_ES_dis_habi_FW	Freshwater	Ecosystem distribution of freshwater EUNIS Habitats	No.	No.	No.	Partial / Indirect. The EBV will deliver necessary information but in a different format (see Annex IX - Section 3, Paragraph 1). Useful to map the extent of ecosystem types. The classifications given only approximately match the top level EUNIS habitats (inland waters are split into lakes & reservoirs, rivers & canals and inland waters). EUNIS inland water habitats are under revision to better match	No.	Partial / Indirect. Can contribute to "land take indicators" from Annex I (e.g. land taken, artificial land - compulsory -, fragmentation -voluntary-)

						the WFD broad types.		
Eco_ES_str_habi_FW	Freshwater	Structural complexity of riparian habitats	No.	No.	No.	No.	No.	No.
Spp_SP_abn_bird_FW	Freshwater	Species abundances of selected wetland bird species	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Spp_SP_abn_inse_FW	Freshwater	Species abundances of dragonflies	No.	No. Not explicitly mentioned as an	No.	No.	No.	No.

				example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9				
Spp_SP_dis_alie_FW	Freshwater	[Species distributions of invasive alien freshwater taxa of European concern]()	Partial / Direct. Directly linked, because in Regulation No1143/2014, Article 5, a risk assessment will be carried out concerning to current and potential range of invasive alien species. Thus, information on invasive species identity and distribution	No.	No.	No.	No.	No.

			(provided by this EBV) is applicable.					
Spp_SP_dis_amph_FW	Freshwater	Species distributions of amphibians	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Spp_SP_dis_inve_FW	Freshwater	Species distributions of freshwater invertebrates	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems,	No.	No.	No.	No.

			(the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	in accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of loss of freshwater invertebrates is suggested in Annex V as an optional indicator for this purpose.				
Spp_SP_dis_mamm_FW	Freshwater	[Species distributions of freshwater mammals]()	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014)	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of	No.	No.	No.	No.

			. Thus, within this EBV, information on the taxa’s identity, reproduction, abundance or distribution may be applicable.	air pollution upon ecosystems in accordance with Article 9				
Spp_SP_dis_mphy_FW	Freshwater	[Species distributions of freshwater macrophytes]()	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa’s identity, reproduction, abundance or distribution may be applicable.	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of macrophytes is	No.	No.	No.	No.

				suggested in Annex V as an optional indicator for this purpose.				
Spp_SP_dis_rept_FW	Freshwater	Species distributions of freshwater reptiles	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	No.	No.	No.	No.
Spp_GC_div_unsp_FW	Freshwater	Genetic diversity of selected freshwater taxa	No.	No.	No.	No.	No.	No.

Spp_ST_phe_bird_FW	Freshwater	Phenology of migration of wetland birds	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No.	No.	No.
Spp_ST_phe_fish_FW	Freshwater	Phenology of migration of freshwater fishes	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's	No.	No.	No.	No.	No.

			identity, reproduction, abundance or distribution may be applicable.					
Eco_CC_abn_inve_MA	Marine	Community abundance of functional groups of soft-bottom benthic macroinvertebrate communities	No.	No.	No.	No.	No.	No.
Eco_EF_dtb_habi_MA	Marine	Degree of seabed disturbance	No.	No.	No.	No.	No. No direct link, although the DCF asks for data to assess the impact of EU fisheries on marine habitats.	No.
Eco_EF_phe_habi_MA	Marine	Harmful marine algal blooms	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within	No.	No.	No.	No.	No.

			this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.					
Eco_EF_phe_ppla_MA	Marine	Phenology of marine spring phytoplankton bloom	No.	No.	No.	No.	No.	No.
Eco_EF_pro_habi_MA	Marine	Marine ecosystem productivity	No.	No.	No.	No.	No.	No.
Eco_ES_dis_cora_MA	Marine	Ecosystem distribution of hard corals habitats	No.	No.	No.	No. Not suitable - the requirements of the framework are for all marine habitats together while this EBV is much more specific. The regulation requires the accounting for three main marine habitat categories that are much broader than this EBV (Annex XI -	No.	No.

						Section 3, Paragraph 1).		
Eco_ES_dis_malg_MA	Marine	Ecosystem distribution of marine macroalgae canopy cover	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No. Not suitable - the requirements of the framework are for all marine habitats together while this EBV is much more specific. The regulation requires the accounting for three main marine habitat categories that are much broader than this EBV (Annex XI - Section 3, Paragraph 1).	No.	No.
Eco_ES_dis_oyst_MA	Marine	Ecosystem distribution of oyster reef habitats	No.	No.	No.	No. Not suitable - the requirements of the framework are for all marine habitats together while this EBV is much more	No.	No.

						specific. The regulation requires the accounting for three main marine habitat categories that are much broader than this EBV (Annex XI - Section 3, Paragraph 1).		
Eco_ES_dis_plan_MA	Marine	[Ecosystem distribution of marine seagrass habitats]()	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No. Not suitable - the requirements of the framework are for all marine habitats together while this EBV is much more specific. The regulation requires the accounting for three main marine habitat categories that are much broader than this EBV (Annex XI - Section 3, Paragraph 1).	No.	No.

Spp_SP_abn_fish_MA	Marine	Species abundances of marine commercial fish species and long-distance migratory fishes	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No.	Complete / Direct. Biomass of commercial fish species is collected and assessed by international organisations (ICES, ICCAT, RFMOs, STECF) and used for CFP.	No.
Spp_SP_dis_alie_MA	Marine	Species distributions of invasive alien marine taxa of European concern	Partial / Direct. Directly linked because in Regulation No1143/2014, Article 5, a risk assessment will be carried out concerning to current and potential range of invasive alien species.	No.	No.	No.	No.	No.

			Thus, information on invasive species identity and distribution (provided by this EBV) is applicable.					
Spp_SP_dis_fish_MA	Marine	Species distributions of marine fishes	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No.	No. The CFP and related regulations do not require 'distribution'.	No.
Spp_SP_dis_inve_MA	Marine	Species distributions of benthic marine invertebrates	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien	No.	No.	No.	No. The CFP and related regulations do not require 'distribution'. Some data	No.

			species of Union concern (the Union list in Regulation No1143/2014) . Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.				about commercial invertebrates species or bycatch (e.g. shrimps) is collected for the DCF.	
Spp_SP_dis_mamm_MA	Marine	Species distributions of marine mammals	No.	No.	No.	No.	No. The CFP and related regulations do not require 'distribution' . If any, the data on marine mammals would be collected for DCF as data on incidental bycatch of sensitive species	No.
Spp_SP_dis_rept_MA	Marine	Species distribution of marine turtles	No.	No.	No.	No.	No. The CFP and related regulations do not require	No.

							'distribution'. If any, the data on marine turtles would be collected for DCF as data on incidental bycatch of sensitive species	
Spp_GC_div_unsp_MA	Marine	Genetic diversity of selected marine taxa	No.	No. No (marine ecosystems not explicitly mentioned as a required ecosystem type for monitoring of negative impacts of air pollution upon ecosystems in Article 9)	No.	No.	No.	No.
Spp_ST_phe_bird_MA	Marine	Phenology of migration of marine birds	No.	No.	No.	No.	No.	No.
Spp_ST_phe_fish_MA	Marine	Phenology of migration of highly migratory marine fish	Partial / Indirect. At least one taxa within this EBV is present on the list of	No.	No.	No.	No.	No.

			invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.					
Spp_ST_phe_mamm_MA	Marine	Phenology of migration of highly migratory marine mammals	No.	No.	No.	No.	No.	No.
Eco_CC_abn_inse_TE	Terrestrial	Community abundance and taxonomic diversity of pollinator insects	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute as additional information for evaluation. Additionally, and if harmonised, the information can be of use to the Farmland Pollinator Indicator under development.	No.	No.	No.

			distribution may be applicable.					
Eco_CC_bio_bird_TE	Terrestrial	Aerial biomass of migrating birds	No.	No.	No.	No.	No.	No.
Eco_CC_bio_inse_TE	Terrestrial	Aerial biomass of migrating insects	No.	No.	No.	No.	No.	No.
Eco_CC_bio_inve_TE	Terrestrial	Community biomass of selected functional groups of terrestrial arthropods (e.g. predator, decomposer)	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014) . Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute as additional information for evaluation	No.	No.	No.
Eco_CC_bio_mamm_TE	Terrestrial	Aerial biomass of migrating bats	No.	No.	No.	No.	No.	No.

Eco_CC_bio_micr_TE	Terrestrial	Community biomass of soil microbes	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute as additional information for evaluation	No. Not suitable - the EBV will deliver necessary information but in a different format (see Annex XI - Section 3, Paragraph 3b/c). It concerns the overall quantity of soil carbon, not specifically microbial carbon.	No.	Partial / Direct. The only compulsory descriptor for the loss of soil biodiversity is "Soil basal respiration in dry soil" (no match). Member States may also select other optional soil descriptors for biodiversity such as microbial biomass.
Eco_CC_com_micr_TE	Terrestrial	Functional composition of soil biota	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in	Partial / Indirect. Can contribute as additional information for evaluation	No.	No.	Partial / Indirect. The only compulsory descriptor for the loss of soil biodiversity is "Soil basal respiration in dry soil" (no match). Member States may also select other optional soil

			identity, reproduction, abundance or distribution may be applicable.	accordance with Article 9				descriptors for biodiversity such as: - metabarcoding of bacteria, fungi, protists and animals; - abundance and diversity of nematodes; - microbial biomass; - abundance and diversity of earthworms (in cropland); - invasive alien species and plant pests.
Eco_EF_dec_unsp_TE	Terrestrial	Rate of decomposition	No.	No.	No.	No.	No.	No.
Eco_EF_dtb_fire_TE	Terrestrial	Fire disturbance regime	No.	No.	No.	No.	No.	No.
Eco_EF_dtb_huma_TE	Terrestrial	Ecosystem disturbance as measured by HANPP	No.	No.	Partial / Indirect. Can contribute as additional information for evaluation	Partial / Indirect. The EBV will deliver necessary information but in a different format (see Annex IX - Section 3, Paragraph 2). This EBV	No.	No.

						can help determining land conversion between ecosystem types, but HANPP is not specifically necessary.		
Eco_EF_phe_plan_TE	Terrestrial	Terrestrial ecosystem phenology	No.	No.	Partial / Indirect. Can contribute as additional information for evaluation	No.	No.	No.
Eco_EF_pro_bird_TE	Terrestrial	Total bird herbivory	No.	No.	No.	No.	No.	No.
Eco_EF_pro_mamm_TE	Terrestrial	Total mammal herbivory	No.	No.	No.	No.	No.	No.
Eco_EF_pro_unsp_TE	Terrestrial	Terrestrial ecosystem productivity	No.	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting required every 4 years). The indicators to use for	Partial / Indirect. Can contribute as additional information for evaluation	Partial / Indirect. Annex IX Section 4 - (b) regulating services : Global climate regulation. This EBV can be used to derive carbon sequestration	No.	No.

				monitoring impacts of pollution are to be decided by the MS, but the monitoring of loss of vegetation growth and foliar damage is suggested in Annex V as an optional indicator for this purpose - for which several metrics within this EBV are relevant.				
Eco_ES_bio_habi_TE	Terrestrial	Standing and lying deadwood	No.	No.	No.	Complete / Direct. Annex IX - Section 3, Paragraph 3d: dead wood shall be reported in m3/ha, as a national average for the reporting period;	No.	No.
Eco_ES_con_habi_TE	Terrestrial	Connectivity of terrestrial	No.	No.	Partial / Indirect. Can contribute to	No.	No.	Partial / Direct. Can contribute to

		ecosystem habitat types			I20 (Enhancing biodiversity protection: Percentage of species and habitats of Community interest related to agriculture with stable or increasing trends) from Annex I of Regulation (EU) 2021/2115.			"land take indicators" from Annex I (e.g. land taken, artificial land - compulsory -, fragmentation -voluntary-)
Eco_ES_dis_habi_TE	Terrestrial	Ecosystem distribution of terrestrial EUNIS Habitats	No.	No.	Partial / Indirect. Can contribute to I20 (Enhancing biodiversity protection: Percentage of species and habitats of Community interest related to agriculture with stable or increasing trends) from Annex I of Regulation (EU) 2021/2115.	Partial / Indirect. The EBV will deliver necessary information but in a different format (see Annex IX - Section 3, Paragraph 1). The EBV can be used to calculate the extent of ecosystem types (not distribution in particular) and doesn't align with the highest level	No.	Partial / Indirect. Can contribute to "land take indicators" from Annex I (e.g. land taken, artificial land - compulsory -, fragmentation -voluntary-)

						of EUNIS classification.		
Eco_ES_str_plan_TE	Terrestrial	Vertical structure of vegetation	No.	Partial / Indirect. Could be used for the monitoring of negative impacts of air pollution upon ecosystems, in accordance with Article 9 (reporting required every 4 years). The indicators to use for monitoring impacts of pollution are to be decided by the MS, but the monitoring of loss of vegetation growth and foliar damage is suggested in Annex V as	Partial / Indirect. Can contribute as additional information for evaluation related with landscape structure	No.	No.	No.

				an optional indicator for this purpose - for which this EBV could be relevant.				
Spp_SP_abn_dise_TE	Terrestrial	Species abundances of selected terrestrial animal disease vectors	No.	No.	No.	No.	No.	No.
Spp_SP_abn_inse_TE	Terrestrial	Species abundances of butterflies	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute to calculation of the population of selected species included on the I.20 PMEF indicator.	No.	No.	No.

Spp_SP_abn_mamm_TE	Terrestrial	Species abundances of selected terrestrial mammals	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Following reporting on Habitats Directive, a selection of habitats and species strongly linked to agriculture are included on the I.20 PMEF indicator: Share of species and habitats of Community interest related to agriculture with stable or increasing trends. So this variable can contribute to the calculation of population size of selected species.	No.	No.	No.
Spp_SP_abn_pest_TE	Terrestrial	Species abundances of selected terrestrial crop and forest pests	No.	No.	Partial / Indirect. Can contribute as additional information for evaluation	No.	No.	Partial / Direct. Optional soil descriptors for invasive alien species and plant pests (Annex I)

Spp_SP_dis_alie_TE	Terrestrial	Species distributions of invasive alien terrestrial taxa of European concern	Partial / Direct. Directly linked because in Regulation No1143/2014, Article 5, a risk assessment will be carried out concerning to current and potential range of invasive alien species. Thus, information on invasive species identity and distribution (provided by this EBV) is applicable.	No.	Partial / Indirect. Can contribute as additional information for evaluation	No.	No.	Partial / Direct. Optional soil descriptors for invasive alien species and plant pests (Annex I)

Spp_SP_dis_bird_TE	Terrestrial	Species distributions of terrestrial birds	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute as additional information for the evaluation of responses to agricultural policy interventions, as suggested in Implementing regulation (EU) 2022/1475 on CAP monitoring and evaluation: "In addition, Member States may use in their evaluations specific indicators other than those set out in Annex I to Regulation (EU) 2021/2115 or any other relevant quantitative and qualitative information to drawing relevant	Partial / Direct. Annex IX - Section 3 for cropland and grassland: common farmland bird index shall be reported as a national aggregate index for the reporting period.	No.	No.

					conclusions on the impact of the CAP Strategic Plans." Therefore, EBVs with potential response to the implementation of agricultural policy interventions can be linked. This EBV cannot contribute directly to the I.19 indicator: Farmland Bird Index as no information on species abundance is provided.			
Spp_SP_dis_inve_TE	Terrestrial	Species distributions of terrestrial priority invertebrates and key pollinators	No.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution	Partial / Indirect. Can contribute to calculation of the range of selected species included on the I.20 PMEF indicator.	No.	No.	No.

				upon ecosystems in accordance with Article 9				
Spp_SP_dis_mamm_TE	Terrestrial	[Species distributions of all terrestrial mammals]	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No. Not explicitly mentioned as an example optional indicator in Annex V, but could be used for monitoring of negative impacts of air pollution upon ecosystems in accordance with Article 9	Partial / Indirect. Can contribute to calculation of the range of selected species included on the I.20 PMEF indicator.	No.	No.	No.
Spp_SP_dis_rept_TE	Terrestrial	[Species distributions of terrestrial reptiles]	No.	No.	Partial / Indirect. Can contribute to calculation of the range of selected species included on the I.20 PMEF indicator.	No.	No.	No.

Spp_ST_phe_bird_TE	Terrestrial	Phenology of migration of terrestrial birds	Partial / Indirect. At least one taxa within this EBV is present on the list of invasive alien species of Union concern (the Union list in Regulation No1143/2014). Thus, within this EBV, information on the taxa's identity, reproduction, abundance or distribution may be applicable.	No.	No.	No.	No.	No.
Spp_ST_phe_frui_TE	Terrestrial	Phenology of fructification of wild fruits	No.	No.	No.	No.	No.	No.
Spp_ST_phe_fung_TE	Terrestrial	Phenology of fructification of mushrooms	No.	No.	No.	No.	No.	No.
Spp_ST_phe_inse_TE	Terrestrial	Phenology of the emergence of butterflies and time of arrival of migratory butterflies	No.	No.	Partial / Indirect. Can contribute to additional information for evaluation	No.	No.	No.
Spp_ST_phe_plan_TE	Terrestrial	Phenology of flowering and leaf senescence	No.	No.	Partial / Indirect. Can contribute as additional	No.	No.	No.

information
for evaluation

APPENDIX S2: COST ESTIMATION

Towards a modern and efficient European biodiversity observation network fit for multiple policies

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Journal name: *Ecological Monographs*

Disclaimer

Obtaining precise cost estimates can be challenging and take considerable time to account properly. All cost estimates were based on the best available data, but due to the large number of EBVs involved, it is not possible to give precise estimates of every possible methodology involved. Furthermore, all countries will have to make specific adaptations to suit their national and local needs. As such, all cost estimates should be taken as *indicative only*, and further be improved through dedicated collaborations with local experts and researchers. The number of sites used in the sampling networks is a generalised figure that may over- or under-estimate the sampling effort required to detect all species that comprise the EBV. This especially applies for rare or threatened species which may not be well sampled with a stratified random selection of sites.

Key terms

Throughout Appendix S2, several terms are used for simplicity in the following way:

- **Site:** a grid cell of 2 × 2 km (terrestrial and cross-realm) or 10 × 10 km (marine) size, or a lake or river segment (freshwater)
- **Round:** one visit to a site in which data is collected. The same site may be visited multiple times (i.e. multiple rounds)
- **Sample:** an individual sample taken during a sampling round (e.g. a single insect, the contents of a single malaise trap, a single faecal sample etc.)
- **Collector:** individuals who collect data. A single collector is not necessarily a single individual, as for some data, multiple people may be required (e.g. marine mammal surveys by plane or ship). This affects the amount of data collection materials, as e.g. two people may not need to have two copies of the same equipment.

General cost estimation

To estimate the costs of a European Biodiversity Observation Network, we generally estimated the costs for both developing and maintaining the monitoring of each individual Essential Biodiversity Variable (EBV). Costs included data collection methods that are used in biodiversity monitoring and the workflows needed to process the collected data into EBV data products. To estimate the costs, we used both empirical data (e.g. staff salaries, material costs, time required to perform a task) and several assumptions (e.g. level of coordination, number of sites, amount of training, average travel distance, data handling and workflow tasks). Empirical data included material costs to cover the equipment, consumables and services and staff costs to cover the labour required in data collection, workflows, and administration.

Cost estimates were generally divided into three cost components (Table S1): (1) data collection, (2) workflows for data integration and modelling, and (3) coordination. For each component, the costs were further divided into establishment costs (one-off expenses needed to set up activities) and maintenance costs (recurring expenses that occur in maintaining the work, Table S1). Establishment costs included materials that could be re-used between years (e.g. large lab equipment, insect nets, servers) and staff time for setting up sampling sites, calibrating equipment etc. Maintenance costs included materials that could not be re-used (e.g. fuel, reagents), digital materials that need to be paid annually (e.g. Virtual Machines, Storage etc,) and staff time for activities that need to be repeated regularly. Costs were generally estimated over a 10 years timespan and, where possible, for each EU member state separately to account for relative costs (e.g. wages). Each cost estimation was done separately for material costs (i.e. costs associated with physical materials such as traps, fuel, and servers) and staff costs (i.e. the wages of staff involved in the work) (Table S1).

TABLE S1 Overview and general description of costs categories.

Component	Phase	Type	Category	Description
Data collection	Establishment	Materials	Field materials	Materials required to establish field sites (e.g. traps)
			Lab materials	Materials required for lab analysis of data (e.g. PCA machines)
		Staff	Field set-up	Staff time to set-up field sites
			Lab set-up	Staff time to set-up lab equipment
			Training	Training for staff in the field
	Maintenance	Materials	Field materials	Annual consumables for field data collection (e.g. fuel, ethanol, vehicle hire)
			Lab materials	Annual consumables for lab analysis data collection (e.g. postage, reagents)
		Staff	Field collection	Staff time to conduct the field protocol
			Lab analysis	Staff time to analyse the data
			Maintenance	Staff time to maintain field and lab equipment
Workflows	Establishment	Materials	Hardware	Hardware purchased (e.g. computers, servers)
			Software	Software purchased (e.g. commercial modelling software)
		Staff	Projects	Costs of projects to develop models and integration tools (e.g. standards)
			Integration systems	Staff time to create digital integration systems (e.g. web portals, databases)

	Maintenance	Materials	Data pipelines	Staff time to establish and test data pipelines
			Hardware	Annual costs of server hire, data storage etc.
			Software	Annual costs of licenses, virtual machines etc.
		Staff	Managing workflow	Staff time to maintain the workflow, including uploading data to repositories
			Modelling	Staff time to conduct the modelling of the data
Coordination	Establishment	Materials	IT costs	Data storage, servers, APIs, platform services and other IT costs for both EU and member state actors
		Staff	National	Staff time for data management and harmonisation, power analysis, national assessments and workshops
			EU scale	Staff time for coordination, data analysis and modelling activities of a European Biodiversity Observation Coordination Centre (EBOCC)
	Maintenance	Materials	IT costs	Data storage, cloud computing, portal services, system maintenance for EU and member states
		Staff	National	Staff time to manage core activities, manage volunteers and produce reports
			EU scale	Staff time in a European Biodiversity Observation Coordination Centre (EBOCC) to co-ordinate and engage with EU member states and to perform modelling and maintain data pipelines

Data collection

Materials

Material costs for data collection were derived from the commercial prices of materials identified in monitoring protocols, using appropriate commercial suppliers with English language website (e.g. thermofischer, Amazon EU and Cole-Palmer for field materials, and Google, Microsoft and Amazon for cloud computing) or directly supplied by experts or published literature. Value Added Tax (VAT) was applied on all materials at the standard rate of each member state. The number of materials required was based on our assumptions about the number of sites each professional collector would visit (between 1–100, see assumptions below) as this reduces the need to purchase multiple items of some materials (e.g. insect sampling nets). We also included fuel costs for all data collection, assuming an average of 180 km^2 round trip, travelled at 60 km/hr travel to a site for each sampling visit (i.e. 3 hours travel time per site), plus and extra 5 km for travel within sites. Once all costs per site were estimated, they were multiplied by the number of sites and sampling rounds needed per year per member state to generate an annual cost. We do not include the costs of significant data collection materials such as microscopes, gene sequencers and refrigerators. These items are already funded by EU agencies or member states for other purposes.

Staff

To estimate the staff costs for data collection, we used the pro-rata costs of employing staff to undertake different aspects of monitoring. We generally estimated the time that staff would be required to (1) collect data in each sampling round, (2) analyse (if appropriate) samples from each sampling round, and (3) maintain equipment. Where possible, time requirements were drawn directly from monitoring protocols, published literature or reports. In addition, for some EBVs we used information provided by experts in workshop discussions and from a series of 20 interviews with experts from different realms. Costs for workflow activities and coordination are rarely reported and can vary significantly between member states even for the same EBV. As such, we made a series of assumptions to represent these costs.

Time requirements were converted into costs by multiplying the hours taken by the average hourly wage of staff in each member state, using data from interviews and surveys of research organizations for four groups of staff: (1) administrators: experienced administrators who would be expected to handle non-scientific and reporting tasks; (2) field staff: research technician and junior ecologists; (3) consultants: experienced and specialist technicians, postdoctoral researchers and consultants; and (4) senior researchers: senior researchers who would be expected to lead scientific coordination and advanced modelling tasks. These costs included organizational overheads. Where a range of salaries was provided for a given role, we used the median value.

For estimating the costs for field data collection, we assumed that field technicians would be employed where sampling protocols indicated that the field work could be undertaken by citizen scientists or persons that do not require specialist training. Otherwise we assumed that more experienced professionals would be required (e.g. for marine data collection). For data collection in the laboratory, such as analysis of soil samples or identification of insects, we assumed that highly skilled professionals would be required and used consultant or postdoctoral researcher salaries.

We also included staff time for site selection, assuming 0.5 hrs of senior researcher time per site, and professional staff training, based on the assumption of 0–40 staff being trained by a senior researcher once every 5 years (see assumptions section, Tables S4 & S5).

Workflows

Materials

For costing the workflows (data integration and modelling), the material costs captured costs of data storage, server hire, and cluster or cloud computing for modelling and data processing. Data storage costs were assumed for most methods to be very small, with expert opinion and past literature used for genetic, photographic, audio, LiDAR and satellite remote sensing data. We did not include the costs of major data infrastructure that is already in use such as research vessels, physical servers, or the deployment of satellites and LiDAR drones. These items are already funded by EU agencies or member states for other purposes. Cost details on materials for workflows were collected for each individual EBV (Appendix S3).

Staff

The staff costs for workflows were estimated based on the number of person days required to set-up the workflow (e.g. establishing APIs) and to maintain these workflows (e.g. running the models). Where possible, this information was obtained from expert interviews with various organisations and from costing reports of other initiatives such as INSPIRE (see GitHub 'INSPIRE-in-your-Country'). The time required to set up and manage workflows is seldom recorded and few experts were available to provide suggestions. Based on these discussions, we developed a number of assumptions about the workflow effort involved in setting up and maintaining workflows and data harmonization, and on modelling. These are detailed in the assumptions section below (Tables S4 & S5).

Coordination

Staff
In addition to staff costs for data collection and workflows, there will be also a need for staff at the national scale to supervise the administration and coordination of the network. The number of staff required per member state to manage and coordinate the data collection and workflow activities was assumed to be between 1–3 full time administrators and 0.5–1.5 FTE of senior researcher staff, based on discussions with monitoring organizations on the number of staff employed as coordinators. We also included additional time for a senior researcher to support data workflow set-ups.

In addition to the national costs for member states, we also estimated the EU scale costs incurred by a European Biodiversity Observation Coordination Centre (EBOCC) in supporting the development of workflows and data products. We also include the costs of hosting and running satellite remote sensing products, but they are for illustrative purposes only. These products would be hosted by Copernicus, ESA, EEA or other existing actors. For each individual EBV, we used the EuropaBON analysis of bottlenecks in current monitoring workflows (Morán-Ordóñez et al. 2023) and the outputs of the workflows workshop to identify different categories of EBOCC operations that are required. We then used the material and staff costs from the proposal for the terms of reference of an EBOCC (Liquete et al. 2024) for estimating the staff costs for coordination at both national (Table S6) and EU scale (Tables S7–S9), and the interoperability requirements of member states with EBOCC (details in Table S10).

Sampling networks and monitoring methods

Besides estimating the costs for each EBV individually (details in Appendix S3), we also estimated the costs combined for sampling networks that simultaneously record data for multiple EBVs. The following sampling networks with their monitoring methods were distinguished:

River monitoring
This sampling network covers methods for monitoring river biodiversity in the context of the Water Framework Directive. It is sampled once per 3 years. Information on data collection time was provided by NIVA (Anne Lyche Solheim, pers. comm. 2023). This included the following monitoring methods:

- Electrofishing to sample freshwater fish at two points per site twice per year, following the standard EN 14011:2003 (Water quality - sampling of fish with electricity) from the European Committee for Standardization
- Benthic invertebrate sampling using kick sampling for water dwelling invertebrates twice per year and pump/core sampling for sediment dwelling invertebrates once per year, following the standard EN 16772:2016 (Water quality - guidance on methods for sampling invertebrates in the hyporheic zone of rivers) from the European Committee for Standardization
- Diatom sampling to sample phytobenthos twice per year (Kelly et al. 2016), following the standards EN 13946:2014 (Water quality - guidance for the routine sampling and preparation of benthic diatoms from rivers and lakes) and EN 14407:2014 (Water quality

- Guidance for the identification and enumeration of benthic diatom samples from rivers and lakes)
- Macrophyte transects twice per year (Kanninen et al. 2013)
- Bivalve transects twice per year (Young et al. 2003, Sime 2015)

Lake monitoring
This sampling network covers methods for monitoring lake biodiversity in the context of the Water Framework Directive. Sampling is done once every 3 years for phytoplankton (monthly samples in the growing season) and fish, and every 6 years for macrophytes.

- Gillnetting to sample fish eight times per year, following the standard EN 14757:2015 (Water quality - sampling of fish with multi-mesh gillnets) from the European Committee for Standardization
- Benthic invertebrate sampling using kick sampling as a proxy for water dwelling invertebrates twice per year and pump/core sampling for sediment dwelling invertebrates once per year, following the standard EN 16772:2016 (Water quality - guidance on methods for sampling invertebrates in the hyporheic zone of rivers) from the European Committee for Standardization
- Diatom sampling to sample phytobenthos twice per year (Kelly et al. 2016), following the standards EN 13946:2014 (Water quality - guidance for the routine sampling and preparation of benthic diatoms from rivers and lakes) and EN 14407:2014 (Water quality - Guidance for the identification and enumeration of benthic diatom samples from rivers and lakes)
- Dip sampling for phytoplankton, zooplankton and cyanobacteria six times per year, following the standards EN-15972:2015 (Water quality - Guidance on the estimation of phytoplankton biovolume) and EN 15110:2006 (CEN, 2006 Water quality - Guidance standard for the sampling of zooplankton from standing waters). As separate data is not available for the time required for cyanobacteria and zooplankton monitoring, we use phytoplankton data as a proxy but assume separate sampling
- Macrophyte transects twice per year (Kanninen et al. 2013)

Marine fish monitoring
This sampling networks spans methods for assessing the abundance of fish from commercial trawlers and acoustic tracking arrays.

- Trawling surveys using remote electronic trawling monitoring (Mack et al. 2020) attached to a number trawlers equal to the number of sites
- Marine acoustic sensor arrays, one per site of 35 receivers and tagging sixty fish per site (David Villegas-Rios, pers comm, 2023; Clarke et al., 2021)

Other marine vertebrate monitoring
This sampling network covers the sampling of marine birds, mammals, and turtles all of which can be sampled via plane and ship transects.

- Ship transects following the monitoring guidelines from HELCOM 2018, HELCOM 2021, ISPRA 2017, OSPAR 2018, and SCANS-III 2021, with fifteen transects per site per year

- Aerial transects following the monitoring guidelines from HELCOM 2021 and Evans and Thomas (2013), with five times per site per year

Marine habitat monitoring
This sampling network spans different methods for monitoring the distribution and condition of marine habitats. The methods used are a simplification as a wide range of different technologies and protocols are used. This network is sampled once over a six-year period.

- Marine video transects (EN 19493:2007 Water quality. Guidance on marine biological surveys of hard-substrate communities, OSPAR 2018), with one transect per site
- Sediment core sampling following guidelines and methodology from Le et al. (2022) and JNCC Report no 705, with three samples per site

Marine invertebrate and plankton monitoring
This sampling network considers a range of small marine organisms that are monitored under the Marine Strategy Framework Directive.

- Water column and plankton net sampling following guidelines and methodology from HELCOM 2021 and the EMO BON Handbook 2021, conducted six times per site
- Autonomous Reef Monitoring Structure (ARMS) and Artificial Substrate Unit (ASU) sampling following guidelines and methodology from (Mack et al. 2020), with genetic metabarcoding EMO BON Handbook 2023. Three units are placed per site and collected every second year
- Marine video transects (EN 19493:2007 Water quality. Guidance on marine biological surveys of hard-substrate communities, OSPAR 2018), with one transect per site.
- Sediment core sampling following guidelines and methodology from Le et al. (2022) and JNCC Report no 705, with three samples per site

Terrestrial invertebrate monitoring
This sampling network builds on multiple malaise trap networks and other lethal sampling methods for insects, particularly pests and disease vectors.

- Malaise traps following guidelines and methodology from LIFEPLAN 2022 and Buchner et al. (2024), with one trap per site sampled fifteen times per year
- Pitfall traps (Burrascano et al. 2021), with four traps per site sampled fifteen times per year
- Suction, sticky and light traps following guidelines and methodology from EFSA 2018 and Braks et al. (2022), with one of each per site (different sites will require different numbers). Data on the time requirements for these methods are limited, so we use information on the placement and collection of pan traps from EU PoMS (Potts et al. 2021). Sampling occurs once per month for six months
- Cloth drag sampling of ticks following guidelines and methodology from EFSA 2018 and (Salomon et al. 2020), with 40 drags on average per site (30 are normally required, with an additional 30 if <50 ticks are detected, which we conservatively assume will occur once per 3 sites). Sampling occurs once per month for six months

Vegetation monitoring

This sampling network amalgamates various vegetation sampling protocols which could be undertaken together to cover a wider variety of plants.

- Vegetation plots following Burrascano et al. (2021) and the Handbook Biodiversity Monitoring South Tyrol, assuming one plot per site visited twice per year.
- Lichen sampling following Burrascano et al. (2021) and the ICP Forests Manual 2020–2022, assuming one plot per site
- Dead wood transect sampling following the Dead Good Deadwood Survey Booklet 2019 and the National Forest Inventory 2nd Cycle Field Data Collection Manual 2016, assuming one plot per site

Soil monitoring

This sampling network covers the collection of soil sampling for microbes and invertebrates and broadly aligns with the sampling protocols from the Land Use / Cover Area frame Survey (LUCAS). Sites are sampled every 4 years, in line with the LUCAS sampling period.

- Soil sampling following the LUCAS 2018 Soil Module protocol, with DNA metabarcoding, assuming six samples per site taken once
- Soil invertebrate sampling following the SoilRecon project and standards EN 23611-4:2022 (Soil Quality, Sampling of Soil Invertebrates, Part 4: Sampling, extraction and identification of soil-inhabiting nematodes) and EN 23611-1:2018 (Soil Quality, Sampling of Soil Invertebrates, Part 1: Hand-sorting and extraction of earthworms), assuming six samples per site taken once

Mainland bird monitoring

This sampling network captures the most common sampling methods for terrestrial and freshwater birds. We assume that 50% of the sites are sampled by citizen scientists who each sample a single site.

- Point counts (Voříšek et al. 2008), twenty per site, sampled three times per year
- Bird transects (Voříšek et al. 2008), two per site, sampled three times per year (median of the 2-4 visits recommended by Voříšek et al. (2008)).
- Constant effort ringing at 10% of the sites following guidelines and methodology from BTO 2004 and Arizaga et al. (2023)

Mainland mammal monitoring

This sampling network includes various methods for monitoring mainland mammals but does not include full genetic sampling as this is included in the later genetic sequencing sampling network.

- Camera traps (ENETWILD-consortium et al. 2022, Kissling et al. 2024) which are maintained monthly (12 visits per year) whereby their batteries and memory cards are replaced. Camera traps are typically dispersed within a larger area or landscape forming a network cameras (Kays et al. 2020). As the sampling network used here is based on 2 × 2 km grid cells, we allocate a single camera trap per grid cell
- Passive acoustic sampling for bat monitoring following guidelines and methodology from the JNCC Report No. 688, using one bat detector sampling device per site which are maintained monthly
- Live trapping capture-recapture (Ferreira et al. 2018), conducted once per year

- Mammal transects following guidelines and methodology from JNCC 2004 and PTES 2018, conducted monthly over a five month period, with 20% including boat transects for freshwater mammals
- Faecal/spraint sampling following guidelines and methodology from ENETWILD-consortium et al. (2022), Ferreira et al. (2018) and Chanin (2003), conducted monthly for four months

Herpetology monitoring
This sampling network combines reptile and amphibian sampling.

- Transects and bottle samples for amphibians following the UK National Amphibian Survey protocol, collected six times per year.
- Transects for reptiles (including artificial refugia) following the UK National Reptile Survey protocol, sampled six times per year.

Priority insect monitoring
This sampling network considers the sampling of pollinating insects and dragonflies. It aligns with the European Butterfly Monitoring Scheme (eBMS) and the EU Pollinator Monitoring Scheme (EU PoMS). We assume 25% of the sites are sampled by citizen scientists.

- Transects following suggestions and guidelines from Potts et al. (2021), Thomaes et al. (2021), and the manual for butterfly monitoring, sampling ten times per year
- Pan traps (Potts et al. 2021), ten per site sampled eight times per year
- Light traps (Potts et al. 2021), five per site sampled eight times per year
- Floral visiting Insect Timed (FIT) counts, following the manual for butterfly monitoring and the UK PoMS Annual report 2022, with four counts per site sampled eight times per year

Mainland habitat monitoring
This sampling network represents the data collection for an in-depth higher-tier EUNIS habitat classification.

- Random/systemic large plot surveys following guidelines and methodology from the JNCC Report No. 440, with additional information from the Handbook Biodiversity Monitoring South Tyrol, and Burrascano et al. (2021)

Genetic sequencing
This sampling network represents the full genome sequencing of 10,000 to 100,000 populations (for cost calculation purposes this is assumed to be 1 per site) necessary to generate genetic diversity EBVs for selected freshwater, marine and terrestrial species.

- Whole genome sequencing following Theissinger et al. (2023), once every 10 years

Citizen science apps
This sampling network includes EBVs that are most effectively monitored through citizen science apps, ideally with photographs. We focus the costs on those EBVs where this monitoring method is the most viable means of monitoring, although they are also relevant for a large number of other EBVs. We assume that each member state maintains an app, but that a European coordination (e.g. EBOCC) handles the modelling and workflow maintenance, reflecting the feed

of data to organizations such as EASIN (invasive species) and Natureforecast (fruitification of wild fruits and fungi).

- Photographic data collection, based on information provided by the Adaptive Management of Barriers in European River (AMBER), Fruitwatch, Dutch Butterfly Conservation and Nature forecast.

LiDAR

This sampling network concerns the use of airborne Light Detection and Ranging (LiDAR) data, collected in EU member states as part of their national mapping efforts (Kakoulaki et al. 2021). It only includes the processing of the data, not the actual aerial surveys

- Deploying high-throughput workflows for generating geospatial data products of ecosystem structure from airborne laser scanning point clouds (Kissling et al. 2022, 2023), conducted once every five years

Satellite remote sensing

This sampling network concerns EBVs which are most effectively monitored through satellite remote sensing. We include EBVs that are monitored with weather radar here as we were not able to determine the specific costs for this method. We assume that the workflow costs are similar. This concerns 11 EBVs, although some of these EBVs will also need validation through field data collected through other sampling networks. Unlike other monitoring methods, member states are only assumed to conduct the validation, with the costs of implementing and maintaining each remote sensing product being attributed to a European coordination (e.g. EBOCC, ESA, EEA etc. but for simplicity we group these with EBOCC costs).

- Satellite remote sensing (based on data from the Copernicus monitoring; Bruno Smets pers. comm. 2023).
- Phenocams to validate ecosystem phenology EBVs, based on information from the PhenoCam Network
- Flux towers to validate ecosystem productivity EBVs, based on information from Fluxnet 2023 and the SEACRIFOG Deliverable 3.2
- Image flow cytometry to validate marine algal bloom EBVs, based on methods such as in Dashkova et al. (2017)

TABLE S2 Summary of costs per monitoring method involved in each sampling network. Unless otherwise noted, all staff time was costed using field staff wages.

Sampling network *Freshwater*	Monitoring method	Materials for data collection	Collection time	Materials workflow	Workflow time
River monitoring	Electrofishing	€6400/collector for electrofishing equipment (including protective equipment)	Sampling (0.3hrs/sample, 20 samples per round) in-field sorting and identification (1hr/round), site description (1hr/site)	Data storage/site (<€1/month)	7.5hrs/site data handling
	Kick sampling	€375/collector for waders, plastic nets, jars and specimen sorting tray and 0.3ml ethanol/sample at €1.4/l	0.67hrs/kick sample (3 per round, (standard EN 16772:2016; Anne Lyche Solheim, pers. comm 2023) with 1.9hrs/round for lab identification.	Data storage/site (<€1/month)	4hrs/site for data handling
	Pump/core sampling	€350/collector for vacuum pump	0.17hrs per vacuum pump sample (3 per round), 0.25hrs per year to install the vacuum pump (this can be left in place between rounds, standard EN 16772:2016) and 2.7hrs/sample for lab analysis, based on 10% the time to identify a marine core sample (Le et al. 2022).	Data storage/site (<€1/month)	1.75hrs/round for data handling
	Diatom sampling	€90/collector for rake, waders, underwater viewing aid/aquascope, storage box, bucket, glass vials, 10x magnification hand lens and toothbrush and 10ml ethanol/sample at €1.4/l. €116/collector for filtration/sieving kit and pipette, and	0.75hrs per round (Anne Lyche Solheim, pers. comm. 2023, based on kick sampling time). 2hrs per sample for identification to genus level, identified to genus level, based on costs of hired specialists in Bennett et al. (2014) and for monitoring the UK National Trust freshwaters	Data storage/site (<€1/month)	1.25hrs/round for data handling

		~€80/yr for consumables			
	Macrophyte transects	€115/collector for taxonomic keys	Nine transects per site at an average 0.6hrs/transect (Kanninen et al. 2013) per survey round. 2.2hrs per site for laboratory identification and cataloguing of specimens (Anne Lyche Solheim, pers. comm. 2023).	Data storage/site (<€1/month)	3.8hrs/round for data handling
	Bivalve transects	€69/collector for tape measure, 1m quadrat dial clippers and glass bottom bucket	2.4hrs per round (assuming that 20% of sites will require quadrat surveys, each replicated 5 times), including a river habitat survey (Young et al. 2003)	Data storage/site (<€1/month)	1.2hrs/round data handling
Lake monitoring	Gillnets	€785 for Pelagic gillnets and €385 for benthic gillnets	2hrs/round for set up and removal of nets. 10hrs/round for sorting, weighing and identification (Anne Lyche Solheim, pers. comm. 2023).	Data storage/site (<€1/month)	6hrs/round data handling
	Kick sampling	€375/collector for waders, plastic nets, jars and specimen sorting tray and 0.3ml ethanol/sample at €1.4/l	0.67hrs/kick sample (3 per round, (standard EN 16772:2016; Anne Lyche Solheim, pers. comm. 2023) with 1.9hrs/round for lab identification.	Data storage/site (<€1/month)	4hrs/site for data handling
	Pump/core sampling	€350/collector for vacuum pump	0.17hrs per vacuum pump sample (3 per round), 0.25hrs per year to install the vacuum pump (this can be left in place between rounds – standard EN 16772:2016) and 2.7hrs/sample for lab analysis, based on 10% the time to identify a marine core sample in Le et al. (2022).	Data storage/site (<€1/month)	1.75hrs/round for data handling
	Dip sampling (phytoplankton)	€1520/collector for tube sampler, small	0.7hrs/round for sampling (Anne	Data storage/site (<€1/month)	0.33hrs/round for data handling

		boat, glass bottles nixing jar, pipette and storage box. €850/collector for sedimentation chamber, €40/site/year for Lugol's solution.	Lyche Solheim, pers. comm. 2023) 0.87hrs/round in lab analysis time (consultant rate) (Anne Lyche Solheim, pers. comm. 2023).		
	Dip sampling (Zooplankton)	€690/collector for plankton nets, draining cups, funnel winch, sample bottles, weight, spray bottle and bucket €850/collector for sedimentation chamber, €40/site/year for Lugol's solution.	0.7hrs/round for sampling (Anne Lyche Solheim, pers. comm. 2023) 0.7hrs/round in lab analysis time (consultant rate) (Anne Lyche Solheim, pers. comm. 2023).	Data storage/site (<€1/month)	0.33hrs/round for data handling
	Macrophyte transects	€115/collector for taxonomic keys	Nine transects per site at an average 0.6hrs/transect (Kanninen et al. 2013) per survey round. An additional 0.6hrs/transect is added for the sampling macrophytes in deep lakes 2.2hrs per site for laboratory identification and cataloguing of specimens (Anne Lyche Solheim, pers. comm. 2023).	Data storage/site (<€1/month)	3.8hrs/round for data handling
Marine					
Marine fish monitoring	Trawl Surveys	Remote electronic trawling monitoring equipment (€13,000/ship) based on (Mack et al. 2020), €300 for acoustic	5 days to arrange and set up the remote electronic trawling monitoring. (consultant rate) 28hrs/yr for trawler maintenance (Mack et al., 2020)	€2,000 for remote electronic trawling maintenance (Mack et al., 2020)	7hrs/site for data handling

		tracking software (Clarke et al., 2021)		Data storage/site (~€5/month)	
	Marine acoustic sensors	Thirty five acoustic receivers (average price €1502 each) and twenty five moorings (average price €85 each – it is assumed that 10 are moored to other objects; Clarke et al., 2021; David Villegas-Rios, pers comm, 2023). €10,300 for two deck boxes and €580 for directional headphones (Clarke et al., 2021). Ship charter for site set up at €1250/day (Clarke et al., 2021). Tags at €260 each (based on the average from Clarke et al., 2021). We assume all tags and moorings are replaced every 5 years and that 10% of receivers are lost each year.	4 hours per array for permissions (12hrs/site). For each receiver, 0.7hrs to set up moorings, 0.38hrs to set up receiver, 0.75hrs to deploy. 0.75 hrs per individual to tag fish (David Villegas-Rios, pers comm, 2023). 4 days per year to maintain each array (including replacement of damaged and non-functional acoustic receivers; David Villegas-Rios, 2023). All time is costed at consultant grade.	€300 for acoustic tracking software (Clarke et al., 2021). Data storage/site (~€5/month)	2 days per array data handling
Other marine vertebrate monitoring	Ship transects	€3500 per site for materials for a team of six staff, including a laptop, waterproof hard drive, one set of image stabiliser binoculars and two power	45hrs per round (six observers together) (HELCOM 2021)	Data storage/site (<€1/month)	22.5hrs/round data handling

		banks (HELCOM, 2021). Ship charter at €1,250/day (commercial rates)			
	Aerial transects	€1010 per site for two people's materials (HELCOM, 2021), including dictaphone and GPS device as well as binoculars. Plane hire at €1,000/hr for 8hrs (commercial rates).	16hrs per round (two observers together) (SCANS-III)	Data storage/site (<€1/month)	8hrs/round data handling
Marine habitat monitoring	Marine video transects	€2500/collector for an underwater video camera. €56/round air refills. €1,250/round ship charter	36hrs/site video surveying time (team of three, assumed to take place in one day), 8hrs/year for permits (PNNL-32310 report by Fu et al. 2021). 24hrs/site to review video and collect data (PNNL-32310 report by Fu et al. 2021).	Data storage/site (~€10/month) plus €4350/year computing expenses.	17hrs/site data handling
	Sediment core sampling	€20,000 for sediment corers (Mack et al. 2020), €225 for sieves and other field equipment for core sampling (OSPAR 2018). €80/round for consumables €4,700 per collector for lab equipment (EMO BON Handbook 2023).	6hrs/round for core sampling and sieving (Mack et al. 2020), and 15hrs/round to run metabarcoding (PNNL-32310 report by Fu et al. 2021).	Data storage/site (~€25/month)	10.5hrs/round data handling
Marine invertebrate &	Water column and plankton net sampling	€1066/collector for Water Column field	7.5hrs to collect nine plankton	Data storage/site (~€25/month)	5.4hrs/site data handling

plankton monitoring		equipment (EMO BON Handbook 2021, commercial rates) €74/collector and €14/sample for sample processing materials €4,700 per collector for lab equipment (EMO BON Handbook 2023).	samples (Mack et al. 2020). 3.3hrs per round to process specimens (Mack et al. 2020), assumed to be the same for water column		
	Autonomous Reef Monitoring Structure (ARMS) and Artificial Substrate Unit (ASU) sampling with genetic metabarcoding	€585 for three ARMS and ASU units (Mack et al. 2020). €4,700 per collector for lab equipment (EMO BON Handbook 2023). €250/site for ARMS and ASU losses (assuming 5% and 20%, respectively). €47/collector and €8/sample for consumables for ARMS & ASU. €56/round air refills. €1,250/round ship charter	7hrs to place all three ARMS and ASU devices. 6.5hrs to collect all three ARMS and ASU Devices (Mack et al. 2020) 3.3hrs per round to process specimens (Mack et al. 2020), 0.25hrs per sample to extract DNA and run PRC (Matteo Montagna, pers. comm, 2023).	Data storage/site (~€25/month)	8.4hrs/site data handling
	Marine Video transects	€2500/collector for an underwater video camera. €56/round air refills. €1,250/round ship charter	36hrs/site video surveying time (team of three, assumed to take place in one day), 8hrs/year for permits (PNNL-32310 report by Fu et al. 2021). 24hrs/site to review video and collect data (PNNL-32310	Data storage/site (~€10/month) plus €4350/year computing expenses.	17hrs/site data handling

			report by Fu et al. 2021).		
	Sediment core sampling	€20,000 for sediment corers (Mack et al. 2020), €225 for sieves and other field equipment for core sampling (OSPAR 2018). €80/round for consumables €4,700 per collector for lab equipment (EMO BON Handbook 2023).	6hrs/round for core sampling and sieving (Mack et al. 2020), and 15hrs/round to run metabarcoding (Lu et al., 2021). (consultant rate)	Data storage/site (~€25/month)	10.5hrs/round data handling
Terrestrial					
Terrestrial invertebrate monitoring	Malaise traps	€250/collector for malaise traps (including pegs, nitex and bottles). €1.34/round for glycol for traps (€0.4l at €3.35/l) (Burrascano et al. 2021). Sample postage at local rates twice per year. €14/sample for consumables and €4000 for metabarcoding equipment maintenance and depreciation (Buchner et al. 2024).	0.8hrs/round for malaise trap sampling (Buchner et al. 2024) 0.25hrs/round for sample sorting, 0.3 hours/round for metabarcoding and 0.03hrs/round for bioinformatics analysis (Buchner et al. 2024) (consultant rate).	Data storage/site (~€25/month)	0.63hrs/round data handling
	Pitfall traps	€40/site for pitfall traps. €0.42/round for ethanol (0.3l at €1.4/l)	0.25hrs/year for pitfall trap set up and 0.25hrs/round for sample collection.	Data storage/site (~€25/month)	0.5hrs/round data handling

		(LIFEPLAN 2022). Sample postage at local rates twice per year. €14/round (all four traps) for consumables and €4000 for equipment maintenance and depreciation (Buchner et al. 2024).	0.25hrs/round for sample sorting, 0.3 hours/round for metabarcoding and 0.03hrs/round for bioinformatics analysis (Buchner et al. 2024) (consultant rate).		
	Suction traps, sticky traps and light traps (mosquitos)	€3250/collector for a full set of trap types (light, CO_2, sticky) and associated equipment (EFSA 2018). €14/collector for consumables such as ethanol.	0.49hrs/round for setting and collecting one trap/round 5.5hrs/yr for site mapping and equipment set up (based on Potts et al. (2021)). 0.24hrs/specimen for identification assuming ~19.1/round (SPRING project). (consultant rate)	Data storage/site (<€1/month)	1hr/round data handling (lower assumption due to limited taxa)
	Cloth drag sampling	€68/collector for cloth drag materials, including spare parts (Salomon et al. 2020). €16 for disposable personal protection equipment	2mins per tick drag (40/round – 1.33hrs/round; Lyons et al., 2021, assuming one on three drags will not detect the required 30 ticks and require a further 30 drags).	Data storage/site (<€1/month)	0.33hrs/round data handling (lower assumption due to limited taxa)
Vegetation monitoring	Vegetation plots	€268 per collector for field equipment (tablet, quadrat, 10m and 40m measures, folding ruler, clipboard, tent pegs, species guide and pencils, based on Handbook Biodiversity	1.5hrs per 30m2 plot to fully survey (field staff rate) (Burrascano et al. 2021).	Data storage/site (<€1/month)	0.75hrs/round data handling

		Monitoring South Tyrol).			
	Lichen samples	€104 per collector for 100m tape measure, guide book, hand lens and 5 × 10cm quadrats.	1.5hrs for a complete survey (Burrascano et al. 2021).	Data storage/site (<€1/month)	0.75hrs/round data handling
	Dead wood transect sampling	€76/collector for fieldwork materials (pencils, tray, hand lens, tape measure, trowel; The Dead Good Deadwood Survey).	2.13hrs per transect (Burrascano et al. 2021).	Data storage/site (<€1/month)	1.08hrs/round data handling
Soil monitoring	Soil sampling with DNA metabarcoding	€1500 per collector for field kit including soil sample rings trowel, weight balance and sample boxes (Sophia Costa., pers. comm. 2023). €8,000/lab/year for consumables. €5 per sample for soil field consumables (Sophia Costa., pers. comm. 2023). Postage of samples once per year at local rates.	~1.5hrs per site preparation and checking time, including tool disinfection. 1hr per sample to extract soil samples (6 per site) (Sophia Costa., pers. comm. 2023) 1 year of bioinformatician time to set up workflows, reference libraries etc. 2.25hrs per sample to conduct genetic analyses (these are done in batches of 8-10) (consultant rate; Sophia Costa., pers. comm. 2023)	Data storage/site (€25/month)	1.3hrs/site for data handling
	Soil invertebrate sampling	€604 per collector for sampling equipment, including replacements (spades, trowels, hori knives, ice packs, nylon gloves; Susana Mendes, pers. comm., 2023).	2.66hrs per round for invertebrate sample collection. 2.5hrs per sample (6 per site) to identify invertebrates (Susana Mendes, pers. comm., 2023).	Data storage/site (€25/month)	1.3hrs/site for data handling

		€610 for lab equipment (refrigerator, extraction tray, squirt bottle, tally counter; Susana Mendes, pers comm, 2023).			
Cross-realm					
Mainland bird monitoring	Point counts	€148 per collector for field equipment including binoculars, telescope and tally counter (Voříšek et al. 2008).	0.5hrs Preparation, 0.18hrs per point count (including setting in time, we assume an average of 20 counts per site) (Bird Survey Guidelines 2023).	Data storage/site (<€1/month)	1.8hrs/round data handling
	Bird transects	€60 per collector for binoculars, (Voříšek et al. 2008).	0.75hrs per transect (2 per round) (Bird Survey Guidelines 2023).	Data storage/site (<€1/month)	0.75hrs/round data handling
	Constant effort ringing	€1,012 per collector for mist netting and ringing equipment	6hrs/round for set up, collection, ringing and data logging (Arizaga et al. 2023).	Data storage/site (<€1/month)	3hrs/round for data handling
Mainland mammal monitoring	Camera traps	€700/site for a camera trap, including enclosure, memory cards and replacement at 5% of devices per year (Kissling et al. 2024). We only use one camera trap per site given the scale of sites used here.	1.05hrs/camera for set up and installation (Kissling et al. 2024). 1.16hrs/camera replacement and 0.48hrs/camera/month for maintenance	Data storage/camera (~€10/month) €690/collector for a multi-SD card reader (Kissling et al. 2024).	40 images per camera per day. 50% of which are removed automatically as empty by e.g. Agouti). ~2s per image for manual annotation and 5s for manual validation of 5% of images (Kissling et al. 2024).
	Passive acoustic sampling	€750/site for a group of a bat monitoring device enclosure, memory cards and replacement at 5% of devices per year.	0.3hrs/audio device for set up and installation (Williams et al. 2018). 0.95hrs/month audio monitoring maintenance (Williams et al. 2018).	€50 for external hard drives, €30 for portable SD card readers. Data storage/site (~€10/month)	0.6hrs per device per round to examine audio (Williams et al. 2018).

	Live trapping capture-recapture	€908/collector for live trap materials and €1,012 for lab materials (Ferreira et al. 2018).	21 days/site for live trapping field work and 37hrs for lab work (Ferreira et al. 2018).	Data storage/site (~€25/month)	19hrs/site data handling (based on lab work only)
	Mammal transects	€159/collector for binoculars, waders and reflective jacket. Plus €400 for an inflatable boat for freshwater transects (JNCC 2004 and PTES 2018).	0.25hrs/site for annual site survey, 0.75hrs/round to walk transect (plus 1hrs if the transect is a boat-based transect, which we assume occur at 10% of sites) (JNCC 2004 and PTES 2018).	Data storage/site (<€1/month)	0.37hrs/round data handling
	Faecal/spraint sampling	€23.4/site for artificial spraint sites and faecal handling materials. €77/sample for lab expenses (Ferreira et al. 2018).	2hrs/round for spraint site placement and faecal collection (Chanin 2003). 1hrs/sample for genetic analysis (Ferreira et al. 2018) (we assume 1 sample/round).	Data storage/site (~€25/month)	1.5hrs/round data handling
Herpetology monitoring	Transect and bottle samples for amphibians	€403/collector for torches, pond nets, digital thermometer and bottles (from UK National Amphibian Survey protocol).	1hr/round (UK National Amphibian Survey protocol)	Data storage/site (<€1/month)	0.5hrs/round data handling
	Reptile transects	€52 for ten artificial cover objects per site	2.5hrs per round for transects (median time stated for collecting, UK National Reptile Survey protocol).	Data storage/site (<€1/month)	1.25hrs/site data handling
Priority insect monitoring	Insect transects	€119/collector for tape measure, net and guide books. €8/round and replicate for sampling tubes, ethanol, muslin. €10/specimen for storage and	3.4 hrs for initial site description Transect description (0.25hrs/transect/round) and walking the transects (two 1 km transects per round at 1.3hrs – 2.6hrs/round), from manual for butterfly	Data storage/site (<€1/month)	2.02hrs/round for data handling

		lab consumables. Sample postage at local rates once per round.	monitoring and SPRING project. 0.24hrs/specimen for identification of bees assuming ~6 per transect (average across all countries - SPRING project). (consultant rate)		
	Pan traps	€200/collector for pan trap materials Sample tubes (10 per replicate at €0.47 each), ethanol (€4.21 per replicate), Muslin gauze (€0.77 per replicate). Sample postage at local rates once per round.	Painting an traps (0.1hrs/trap – SPRING project). Set up of traps (3.84hrs/site/year), trap placement (0.26hrs/round), sample sorting (0.26hrs/round). 0.24hrs/specimen for identification assuming ~192/round (SPRING project). (consultant rate)	Data storage/site (<€1/month)	23hrs/round data handling
	Light traps	€1500 per collector for light trap equipment.(SPRING project)	Light trap site set up (1hr/site) deployment and collection (1.67hrs/round). 0.34hrs/round to identify trapped moths (consultant rate) (SPRING project)	Data storage/site (<€1/month)	1hr/round data handling
	Floral visiting Insect Timed (FIT) counts	€12 for tally counter	0.25hrs per count, (1hr per round).	Data storage/site (<€1/month)	0.5hrs/round data handling
Mainland habitat monitoring	Large plot surveys	€268/collector for field equipment (tablet, quadrat, 10m and 40m measures, folding ruler, clipboard, tent pegs, species guide and pencils, based on Handbook Biodiversity Monitoring South Tyrol).	Conducting a large randomised plot survey requires 1.5hrs to locate plots within a site and 30mins per 10m^2 sub-plot (10 plots) to survey, for a total of 6.5hrs per site (JNCC Report No. 440). Larger subplots can require up to 2hrs to survey (Burrascano et al. 2021).	Data storage/site (<€1/month)	3.25hrs/site data handling

<table>
<tr><td>Genetic sequencing</td><td colspan="5">Detailed breakdowns of the data required were not available for these EBVs. As such. we used estimates from Posledovich et al., (2021), converted to Euros and then scaled by the Purchase Power Parity (PPP) conversion factor from the World Bank 2024 for each member state relative to Sweden (using data on the US$ to LCU rate of each member state in 2022).

We assume that initial genetic markers will be needed for 10% of the populations, doubling the costs for those populations.</td></tr>
<tr><td>Citizen science apps</td><td colspan="5">Monitoring apps should ideally be designed around an Application Programming Interface (API) that is compatible across Europe (see Table S8). For the purpose of this costing work we attribute these costs to EBOCC but in reality, different organizations may develop some of these apps separately. However, each EU member state is assumed to design and coordinate an app that can be used to promote national recording.

This will require a specialist to design the website and forms (20 days), develop a compatible database (5 days) and administrative tools (15 days, based on 20% of the time taken to develop these across Europe). A further 10 days should be spent translating the main EU portal and guidance into local languages (consultant rate).

Annually, Member State expenses would be ~€4,000 for servers, €2,000 for remote desktop (Chris Wyver., pers. comm., 2023, César Capinha, pers. comm. 2023), €0.2/month per 1000 records for data storage (assuming photographs are 5MB each at 0.04/GB storage), plus manual validation of images at an average of 11s per record and 2 days per month maintaining the website and interface (field staff rate, Bas Otteman pers. comm. 2023). We assume 10 images per site.</td></tr>
<tr><td>LiDAR</td><td colspan="5">Processing workflows for converting LiDAR raw data from country-wide laser scanning surveys into geospatial data products of ecosystem structure have been developed and applied to single countries (Kissling et al. 2022, 2023), but would require scaling, harmonization and adaptation at the EU-level. We did not include data collection costs as the national LiDAR surveys are already generated by member states for other purposes.

Based on the time taken for LiDAR processing in the Netherlands, member states would be expected to spend ~€14/1000km vCPU time for cloud computing (16hrs of 12 core vCPU time at €0.87/hr), ~€11,088/100km^2 for data storage (4200GB/100km^2 at €0.04 per GB).

Staff time would consist of 97.16hrs per 10,000km^2 for downloading, retiling, normalisation, feature extraction and rasterization (Yifang Shi 2023, pers. comm.). Consultant rate.</td></tr>
<tr><td rowspan="2">Satellite remote sensing</td><td colspan="5">Satellite remote sensing products and workflows are assumed to be developed entirely by a central organization (e.g. ESA, EBOCC), while Member States are entirely focused on validation and co-ordination. These costs are detailed in Table S8.</td></tr>
<tr><td>Phenocams</td><td>Phenocams: €1752 (€875 each, replaced every 5 years, with a 5% attrition rate (~€43.8/site), based on costs of recommended Phenocams (PhenoCam Network).</td><td>Phenocam set up (1.3 hrs per site, based on the time taken to set up autonomous camera traps in Kissling et al. (2024))

Time to replace ~5% of phenocams each year (~0.06hrs/site), plus 0.24hrs/site for maintenance and travel time. Field staff rate. 10% of a</td><td>€80/month for a virtual machine, €6.5 for FTP server ad €6/year for automated data transfer (based on the costs of autonomous camera traps in Kissling et al. (2024)).

Data storage/site (€10/month,</td><td>1 person month for establishing automated data streams (based on half the time for autonomous camera traps in Kissling et al. (2024)).

1.48hrs/year to maintain phenocams (twice the time to maintain one</td></tr>
</table>

			senior researcher and 25% of an administrator to support data national data collection.	assuming 24 images/day)	autonomous camera trap in Kissling et al. (2024), four times per year).
	Flux towers	€316,000 per site for a tower, instrumentation, solar panels and ancillary meteorological equipment and CO_2 Flux sensors (SEACRIFOG Deliverable 3.2). €10,000 for maintenance and replacement parts on flux towers (SEACRIFOG Deliverable 3.2).	1 year of consultant grade staff time to set up. One full time member of staff to maintain. (SEACRIFOG Deliverable 3.2)	€6,000 for data services, including storage and transmission (SEACRIFOG Deliverable 3.2)	NA – this is included in column 'Collection time'.
	Image flow cytometry	One Flowcam per site (€120,000), (Mack et al. 2020)	Set up of the Flowcam system (3 person months of consultant time, including establishing workflows). 5.5 days/site (10% of set up time) to maintain the Flowcam. 0.25hrs for image validation and checking (assuming 20 per day; (Dashkova et al. 2017)).	€20/yr for data storage (500GB), plus 1000hrs vCPU time (€8,700) for image processing.	0.125hrs/day for data handling.

Site numbers

The primary driver for the monitoring costs is the number of sites sampled as it strongly affects the amount of staff and materials required for monitoring. Estimating precise site numbers across the EU would usually require comprehensive power analyses, ideally for each EBV and/or taxonomic group to estimate which sampling effort is required to capture a percentage change in a certain aspect of biodiversity such as species abundance, distribution or species richness (Potts et al. 2021, Valdez et al. 2023). However, only few studies have employed such power analyses and many of them are based on local case studies. Here, we use a simplified approach by choosing a low site-number and a high site-number scenario for the sites sampled. In most cases (except large lakes), this corresponded to ~1% and ~10% of the total number of sample sites across Europe, with a site being defined as grid cell of 2 × 2 km (terrestrial and cross-realm) or 10 × 10 km (marine) size, or a lake or river segment (freshwater). Total site numbers were then proportionally divided among EU Member States (Table S3). High and low site numbers were chosen for the following five generic sampling networks:

River segments

We used 10,000 river segments (low site-number scenario) and 100,000 river segments (high site-number scenario) of all river types as defined in Lyche Solheim et al. (2019). This corresponds to ~0.7% and ~7% of the 1,348,163 river segments that are defined in the European catchments and rivers network system (Ecrins).

Lakes

We used 2,000 lakes (low site-number scenario) and 20,000 lakes (high site-number scenario) of all lake types as defined in Lyche Solheim et al. (2019). Note that Luxembourg and Slovakia have no lakes according to this definition. The numbers correspond roughly to 2.8% and 28% of the 70,847 lakes that are defined in the European catchments and rivers network system (Ecrins).

Marine sites

We summed the area of the polygons of each exclusive economic zone (EEZ) around Europe from Jessop et al. (2022), including EEZs from EU countries and those of from the overseas territories of the Canary Islands, Medira, and the Azores. This amounted to an area of ~5.5 Mio km^2 of EEZ. Dividing this area into $10km^2$ cells, we then used 1% (550 sites) and 10% (5,500 sites) of possible cells as the basis for the low site-number and high site-number scenario, respectively. The number of sites was then divided among Member States based on their proportion of the total EU EEZ.

Terrestrial and cross-realm sites

We assumed a grid with 2 × 2 km grid cells across Europe, similar to the master grid of the Land Use / Cover Area frame Survey (LUCAS) survey design in the EU, which has 1,033,759 grid cells. This is approximately 1 grid cell per $4km^2$ of EU land. We then used 10,000 sites (~1% of grid cells) and 100,000 sites (10% of grid cells), distributed by the proportion of the total EU land area in each Member State. For cross-realm networks (Table S2), it is assumed that these would be allocated appropriately to capture both freshwater and terrestrial data.

Validation sites

LiDAR and satellite remote sensing offer powerful tools to monitor biodiversity from data already collected by Member States and Copernicus, the Earth observation component of the European Union's Space programme. However, they should be accompanied with in-situ validation and ground truthing to support workflow and product development. We use a simple site network of 1 site per 500 km and 1 site per 50 km of each Member State to represent the low site-number and high site-number scenario, respectively. To avoid double counting costs, we did not include primary data collection for models that could be generated from other sampling networks. For example, vegetation survey protocols could be adapted to measure vegetation height for validating LiDAR.

TABLE S3 Distribution of sites among EU Member States using a low site-number and a high site-number scenario for each of five generic sampling networks (river segments, lakes, marine sites, terrestrial & cross-realm sites, and validation sites for LiDAR and satellite remote sensing). Note that site numbers are rounded and as such will slightly exceed the expected number.

EU Member State	River segments		Lakes		Marine sites		Terrestrial & cross-realm sites		Validation sites	
	10,000 Rivers	100,000 Rivers	2,000 lakes	20,000 Lakes	550 sites	5,500 Sites	10,000 sites	100,000 sites	1 per 500km	1 per 50km
AUT	927	9,261	7	68	0	0	200	2,000	4	34
BEL	61	606	2	20	1	4	70	700	2	13
BGR	101	1,003	5	41	4	36	270	2,700	5	45
CYP	20	200	1	9	11	101	20	200	1	4
CZE	120	1,199	9	85	0	0	190	1,900	4	32
DEU	1,034	10,333	80	798	6	59	870	8,700	15	144
DNK	893	8,930	94	936	11	108	100	1,000	2	18
ESP	505	5,041	36	357	104	1,033	1,210	12,100	20	200
EST	75	741	10	98	4	38	110	1,100	2	19
FIN	220	2,197	505	5,045	9	84	820	8,200	14	136
FRA	1,230	12,294	48	476	36	354	1,330	13,300	22	220
GRC	155	1,545	5	42	50	495	320	3,200	6	53
HRV	171	1,705	5	41	6	57	140	1,400	3	23
HUN	111	1,106	13	126	0	0	230	2,300	4	38
IRL	367	3,666	89	888	44	438	170	1,700	3	29
ITA	861	8,605	38	380	55	550	730	7,300	13	121
LTU	95	944	40	391	1	8	160	1,600	3	27
LUX	13	127	0	0	0	0	10	100	1	2
LVA	24	234	29	283	3	30	160	1,600	3	27
MLT	1	4	1	3	6	55	0	0	1	1
NLD	29	283	50	493	7	66	90	900	2	16
POL	527	5,266	115	1,141	4	31	760	7,600	13	126
PRT	219	2,181	3	26	178	1,772	220	2,200	4	36
ROU	332	3,320	15	143	4	31	580	5,800	10	96
SVK	174	1,734	0	0	1	1	120	1,200	2	20
SVN	16	158	2	14	0	0	50	500	1	9
SWE	1,733	17,330	811	8,110	16	160	1,090	10,900	18	180
Total	**10,014**	**10,013**	**2,013**	**20,014**	**561**	**5,511**	**10,020**	**100,200**	**178**	**1,669**

Assumptions

General cost assumptions

All cost estimates were based on the best available data, but not all aspects of biodiversity monitoring can be quantified using real-world data. Hence, several assumptions have to be made to account for aspects such as site selection, amount of training, travel distances, number of sites per collector, time for data management, workflow tasks and coordination. An overview of these general cost assumptions is provided in Table S4.

TABLE S4 Overview of general cost assumptions.

Assumption	Details
Site selection	Sites should ideally be selected by developing a spatial sampling design that considers basic principles such as randomisation, replication, and stratification, and taking logistics into account. As a simplification, we assumed that each Member State needs 0.5hrs of a Senior Researcher's time for selecting an individual site.
Training	Staff requires training for different monitoring methods, but this can vary between Member States due to national laws, variations in methods, different focal species etc. For each Member State, we assume that one senior researcher is required to train between 5 and 20 staff at a time for 2–5 days depending on the EBV. The senior researcher must also spend the same number of days preparing the training.
Travel distance	Travel distances between sites will affect staff and fuel costs. Since the actual sites are unknown, we assume a 180 km round trip per site, plus additional travel where terrestrial and freshwater sites have to cover large areas (e.g. marine mammals). This is especially applied to marine EBVs for covering travel to and from ports.
Sites per collector	The number of sites that a single collector can cover will affect the need to buy non-consumable materials. We assume that a single staff member can collect data from 1–70 sites depending on the data collection protocol of the specific EBV.
Data management	Data management includes data entry and validation which is often not considered in cost analyses. However, this can take considerable time that should be accounted for. This will vary between different data types and the precise details of a protocol. We assume that data management time is approximately 50% of the time taken to collect the data.
Workflow tasks	Managing and maintaining workflows from raw data to harmonization and modelling is often a time-consuming process that requires significant expertise. Modelling the EBVs should also be considered, as should the required data storage. For each Member State, we assume that ~0.5FTE of a consultant grade staff is required for managing the EBV workflows and EBV modelling within a sampling network. We further allocate a budget of 500–1,000 vCPU hours to each EBV
Coordination	Coordination is a vital component of biodiversity monitoring, with coordinators handling administrative and reporting duties, arranging site permissions and liaising with stakeholders. We assume that between 1–3 administrative staff and 0.5–1.5 FTE of senior research staff are required to coordinate a sampling network at the Member State level. This increases by 0.1 FTE administrators and 0.05 FTE senior researchers for every 10 data collectors in most sampling networks to reflect the larger coordination effort required to manage large sampling networks.

Cost assumptions at the member state level

At the level of the member states, we made several assumptions for the costs involved in data collection, workflows and coordination.

Data collection

Collectors: For each method, we indicate the number of sites that are assumed to be covered by one "collector". At the level of sampling networks, the sites per collector vary between 0–100 with an average of ~18 sites (Table S5). A collector can be a professional, a volunteer or a group working together. The number of sites per collector is important as this can affect the scale of many costs, such as equipment that is reusable between sites. For instance, methods where collectors can only cover 10 sites will incur twice as many costs as those where the individual covers 20 sites. As a guideline, we assume that each collector can spend approximately 80 days in the field, based on ten sites sampled eight times as assumed by the EU PoMS proposal where the protocols take 1 full day to complete a single round of pollinator surveys (Potts et al. 2021).

TABLE S5 Data collection and workflow assumptions for each sampling network (per member state).

Sampling network	**Sites per collector**	**Training**		**Number of EBVs generated by the network**	**vCPU hours**
		Collectors per instructor	**Training days**		
River monitoring	20	20	8	8	4000
Lake monitoring	20	20	12	12	4000
Marine fish monitoring	1	10	3	3	1500
Other marine vertebrate monitoring	5	10	6	6	3000
Marine habitat monitoring	5	10	5	5	2500
Marine invertebrate & plankton monitoring	5	10	3	3	1500
Terrestrial invertebrate monitoring	10	20	3	3	1500
Vegetation monitoring	30	40	3	3	1500
Soil monitoring	30	10	2	2	1000
Mainland bird monitoring	20	20	5	5	2500
Mainland mammal monitoring	15	20	3	3	1500
Herpetology monitoring	20	20	3	3	1500
Priority insect monitoring	10	20	6	6	3000
Mainland habitat monitoring	30	20	2	2	1000
Genetic sequencing	100	0	3	3	3000
Citizen science apps	1	0	6	6	3000
LiDAR	0	0	2	2	*
Satellite remote sensing	1	0	13	13	*

* The computing costs for these networks are based on real data and are included in Table S2. Four EBVs are included in both lake and river sampling networks, but they are only counted once for the purposes of modelling and workflow management.

Site travel distances: Travelling to and from sites, and to and from ports (for marine EBVs), can be a considerable part of the total time involved in data collection. This can vary tremendously depending on the sites selected relative to the collecting institution, ranging from almost no distance where the collecting institution is adjacent to a suitable site (e.g. a Natura2000 site) or a tremendous distance where the data must be collected over a wide area (e.g. terrestrial mammals) or in a difficult to access region (e.g. mountain areas, islands or national parks that are far from settlements). As such, we estimate an average travel distance of 180 km per site as a round trip (i.e., an average distance of 90km travelled), with many sites being closer than this but some being much further. This was then increased by 5km to represent the need to travel within sites for some of the sampling networks. We include this travel distance estimate for marine EBVs to represent travel to a port and the associated preparation time. Ship time is included at €1250/day.

Site selection: Selecting sites can be time consuming, requiring a balance of scientific rigor and practicality and often requiring time to agree access with landowners. We assume that, given a spatial sampling design in place, it requires 0.5hrs per site for site selection.
Training: We assume that a degree of training is required for all methods in each sampling network (Table S5). Based on the effort invested in training staff for the EU PoMS pilot and the ongoing pollinator academy, we assume this is undertaken across all staff every 5 years by a senior researcher who is assumed to spend 0–5 days, depending on the method or taxa, training 0–40 collectors. The senior staff time is then doubled to reflect the time needed to prepare for the training. Some staff may be trained at different times.

Workflows
Number of EBVs generated by the network: Each network will generate several EBVs, ranging from 2–13 EBVs per network (Table S5). This influences workflow costs because each EBV will require a separate workflow and modelling effort as well as data storage. In some cases, an EBV will be in multiple networks reflecting modelling of field and remote sensing data.
Data entry: A considerable amount of time can be spent on checking and validating data. This will vary with data complexity, but there are few estimates of the time taken. We assume that data management (i.e. entry, checking and validation of data) takes at least 50% of the time of data collection. The only exceptions are data collection via LiDAR and genetic analyses where most of the data handling is done in an automated workflow.
Workflow maintenance, data harmonization: For each EBV in the network, we assume that three person months per EBV of an experienced staff member (postdoc/consultant grade) is required to maintain the workflow and harmonize the data. These estimates are based on the time taken to maintain workflows for large-scale biodiversity models by the Joint Research Centre (JRC). We also assume that a single person year is spent for harmonizing data for sampling networks that build on existing networks: River surveys and Lake surveys, which build on the Water Framework Directive reporting, Vegetation surveys which build on European Vegetation Archive, and Habitat Surveys which build on LUCAS).
For all marine networks, an initial start up phase is required for each member state, consisting of one senior researcher and one bioinformatician at 0.5 FTE each for two years (total 1 FTE each) to support full workflow set-up and integration with the Ocean Biogeographic Information System (OBIS) (Ward Appeltans, pers. comm. 2023).
Modelling: We assume that each EU member state will undertake their own modelling. Based on experiences with national-scale modelling (e.g. Gardner et al., 2020), this is assumed to take two person months per EBV, even if the data was collected from the same sampling method as another EBV. This assumes the models are developed and only require data checking and slight recalibration. We use precise figures for remotely sensed data products (LiDAR and satellite remote sensing), which are indicated in Table A2.
Material costs: Most data collection methods do not have any material components to their workflows, but all will have data storage and computing time requirements. For most monitoring methods, the data generated is very small and can be stored in digital worksheets and databases. However, for genetic methods, digital sensors, drone and satellite data, this can be considerably higher, often in the hundreds of GB per year. Unless otherwise noted in Table A5, we assume that a method will generate ~0.1 GB of data per site per year. Besides data storage, we also included ~500 vCPU hours (at €0.87/hr, based on the average of Amazon, Google and Microsoft, assuming 1 year bulk rates) per EBV for modelling, which amounted to €8,700–€34,800 per sampling network (Table S5).

Coordination

Based on discussions with existing monitoring schemes as part of the EuropaBON workshops, we estimate that one full time administrator and 0.5 FTE of senior researcher time are required to form the core of a national monitoring network for a given taxa (equivalent to approximately three EBVs), resulting in 1–3 administrators and 0.5–1.5 FTE of senior researcher staff per network as a baseline (Table S6). This is then increased by 0.1 FTE administrator and 0.05 FTE of senior researcher for every 100 data collectors that are involved. We assume that only a single FTE of administrator and 0.5 FTE of senior researcher time are required for LiDAR and satellite remote sensing as these require liaison with other agencies and less field data collection. We also assume that an additional 1-person year of experienced staff time (consultant grade) is required to link the new or expanded network to existing infrastructure such as OBIS or the Global Biodiversity Information Facility (GBIF). These figures should be considered an absolute minimum and may require higher coordination efforts where volunteers are difficult to recruit, where regulation complicates data collection (for example, in member states where permits are required for the lethal trapping of insects). Where a member state is lacking this level of full-time support, it should aspire to address this gap immediately.

TABLE S6 Assumptions of EU member state level coordination for each sampling network.

Name of sampling network	Min admin staff	Min senior researchers	Collectors per extra admin	Collectors per extra senior researcher
River monitoring	3	1.5	100	200
Lake monitoring	3	1.5	100	200
Marine fish monitoring	1	0.5	100	200
Other marine vertebrate monitoring	2	1	100	200
Marine habitat monitoring	2	1	100	200
Marine invertebrate & plankton monitoring	1	0.5	100	200
Terrestrial invertebrate monitoring	1	0.5	100	200
Vegetation monitoring	1	0.5	100	200
Soil monitoring	1	0.5	100	200
Mainland bird monitoring	2	1	100	200
Mainland mammal monitoring	1	0.5	100	200
Herpetology monitoring	1	0.5	100	200
Priority insect monitoring	2	1	100	200
Mainland habitat monitoring	1	0.5	100	200
Genetic sequencing	1	0.5	100	200
Citizen science apps	2	1	1000	2000
LiDAR	1	0.5	100	200
Satellite remote sensing	1	0.5	100	200

Costs for a European Biodiversity Observation Coordination Centre (EBOCC)

EBOCC costs

In addition to the costs for member states, monitoring EBVs at an EU-scale will require investments into European coordination, e.g. through a European Biodiversity Observation Coordination Centre (EBOCC). Using the identified tasks and responsibilities of the EBOCC (EuropaBON deliverable 2.3 – Liquete et al., 2024), we estimated the European coordination costs of the EBOCC for each EBV (Table S7). Costs were based on information of EBV workflows, interoperability, modelling and coordination needs as identified in the EuropaBON deliverable 3.3 (Morán-Ordóñez et al. 2023) and in the EuropaBON workshop on EBV workflows (Kissling and Lumbierres 2023, Lumbierres and Kissling 2023, Lumbierres et al. 2024). These costs are incurred on a per EBV basis because separate EBOCC activities will be needed to develop models and power analyses for each EBV, although in reality it may be faster to undertake power analyses for multiple EBVs together. Where the EBV was not evaluated by EuropaBON deliverable 3.3, we made cost estimates based on information provided by experts invited to the EuropaBON workshop on showcases and co-design (April 2023 in Troia, Portugal). The costs for each EBV were then summarized for each activity in each sampling network, for workflow and interoperability activities (Table S8) and modelling (Table S9).

TABLE S7 Costs of activities per EBV incurred by a European Biodiversity Observation Coordination Centre (EBOCC). Maintenance costs are annual unless otherwise stated. The full details of these costs are included in the appendix of Liquete et al. (2024).

Activity	EBOCC establishment	EBOCC maintenance
Standardisation	-----	€18,750 for workshops and training
	156 days (expert) for training, project coordination, costing analysis, guidance materials, field guides, data management proposals, and novel method assessment	20 days (Expert) for training
Power analysis	€20,000 for power analysis	-----
	162 days (expert) for project coordination and power analysis	-----
Capacity building	€420,000 for field guides.	-----
	113 days (expert) for taxonomic assessment and project coordination	-----
Modelling (genetics)	0.29 years (consultant) and 0.08 years (Senior researcher) for data analysis	-----
Modelling (field)	€26,100 for processing	€8,700 for cloud computing
	2 years (consultant) for modelling set up, 128 days (expert) for indicator development and testing	625 days (Senior researcher) for data modelling
Modelling (LiDAR)	€191,937 for baseline data storage and processing setup	€76,911 for cloud storage
	3 years (consultant) for modelling setup	-----
Modelling (satellite remote sensing)	€133,000 for baseline data storage and processing setup	€44,918 for temporary storage, cloud storage and cloud computing
	2 years (consultant) for workflow setup	160 days and 0.1 years (consultant) for data dissemination and user support
Metadata	75 days (expert) for workflow standard development	50 days (expert) for training, 0.7 years (technician) for maintenance of meta data and database
Central repository	€220,000 for private server, additional IT costs, and FAIR setup	€25,984 for IT costs, FAIR, and portal services

	0.2 years (consultant) for function development, IT infrastructure, platform services, API development and FAIR	0.5 years (consultant) to update services, 18 days (expert) for FAIR, 0.7 years (technician) to maintain platform and infrastructure
Citizen science app	Developing a central API (30 days), portal (85 days), administrative tools (75 days), website (20 days), Progressive Web App (40 days) and database (5 days). 1.25 years (Consultant) for model development and data scraping	€8710 for annual maintenance and cloud storage 300 hours (tech) for user support, web maintenance, system and model updates
Automated pipeline (field / genetic data)	€20,000 for interoperability and harmonisation 2.5 years (consultant) for automated pipeline, interoperability and harmonisation; 75 days (expert) for workflow standards	€10,000 for updating interoperability and harmonisation 1 year (consultant) for updating interoperability and harmonisation; 0.65 years (technician) for quality control and maintenance
Automated pipeline (LiDAR)	----- 2 years (consultant) for workflow setup	€115,026 for cloud computing -----
Automated pipeline (satellite remote sensing)	€133,000 for baseline storage, processing, and temporary storage. 2 Years FTE for modelling set up	€44,918 for cloud computing and storage. 5 × this expense every 5 years for recompiling. 160 hours (consultant) for daily processing 160 days for burst processing. 2 months every 5 years for recompiling.
Open data	-----	----

TABLE S8 Workflow and interoperability activities of a European Biodiversity Observation Coordination Centre (EBOCC) summarized per sampling network.

Sampling networks	Standardisation	Power analysis	Capacity building	Metadata	Central repository	Citizen science app	User friendly software	Open codes	Open data
River monitoring	1	1	9	0	0	0	9	9	6
Lake monitoring	1	1	2	1	1	0	3	3	2
Marine fish monitoring	2	2	3	3	1	0	3	3	0
Other marine vertebrate monitoring	6	6	4	3	3	0	6	6	6
Marine habitat monitoring	5	5	5	5	5	0	5	5	5
Marine invertebrate & plankton monitoring	3	3	3	3	3	0	3	3	3
Terrestrial invertebrate monitoring	4	4	5	1	0	1	6	6	6
Vegetation monitoring	3	3	3	3	3	0	3	3	3
Soil monitoring	3	2	3	2	1	0	2	3	3
Mainland bird monitoring	1	0	0	1	0	0	2	2	0
Mainland mammal monitoring	2	0	0	0	0	0	5	5	5
Herpetology monitoring	3	3	2	0	0	0	3	3	3
Priority insect monitoring	3	3	2	3	3	0	3	3	3
Mainland habitat monitoring	2	1	1	1	1	0	1	2	2
Genetic sequencing	3	3	3	3	3	0	3	3	3
Citizen science apps	6	3	3	6	4	6	6	6	4
LiDAR	2	2	2	2	2	0	2	2	2
Satellite remote sensing	13	3	12	13	12	1	13	13	13

TABLE S9 Modelling activities of a European Biodiversity Observation Coordination Centre (EBOCC) summarized per sampling network. Note that .5 values indicate partial development.

Sampling networks	Modelling (genetics)	Modelling (field data)	Modelling (LiDAR)	Modelling (satellite remote sensing)	Automated pipeline (field data)	Automated pipeline (LiDAR)	Automated pipeline (satellite remote sensing)
River monitoring	0	9	0	0	9	0	0
Lake monitoring	0	2	0	1	3	0	1
Marine fish monitoring	0	3	0	0	3	0	0
Other marine vertebrate monitoring	0	6	0	0	6	0	0
Marine habitat monitoring	0	5	0	0	5	0	0
Marine invertebrate & plankton monitoring	0	3	0	0	3	0	0
Terrestrial invertebrate monitoring	0	6	0	0	5	0	0
Vegetation monitoring	0	3	0	0	3	0	0
Soil monitoring	0	2	0	0	3	0	0
Mainland bird monitoring	1	1	0	0	2	0	0
Mainland mammal monitoring	0	5	0	0	5	0	0
Herpetology monitoring	0	3	0	0	3	0	0
Priority insect monitoring	0	3	0	0	3	0	0
Mainland habitat monitoring	0	2	0	0	2	0	0
Genetic sequencing	3	0	0	0	3	0	0
Citizen science apps	0	5	0	1	3	0	1
LiDAR	0	0	2	0	0	2	0
Satellite remote sensing	0	2	0	12	3	0	10

Member state interoperability

In addition to the costs of setting up their own national workflows, member states will also incur costs for European integration, e.g. working with the EBOCC. We estimated the costs for these activities as part of member state costs, using the same data and assumptions as Liquete et al. (2024) (Table S10).

TABLE S10 Costs of interoperability activities with an European Biodiversity Observation Coordination Centre (EBOCC) per EBV (incurred by member state).

Activity	Establishment (initial workflow tasks)	Maintenance (annual activities)
Standardisation	275 days (consultant) for protocol revision and harmonisation	55 days (consultant) for harmonisation
Power analysis	90 days (consultant) for power analysis	
Capacity building	220 days (consultant) for national assessment experts	40 days (consultant * 10 staff) for training workshops
Modelling (genetics)	5 days (consultant * 10 staff) for attendance at workshops	-----
Modelling (field)	5 days (consultant * 10 staff) for attendance at workshops	-----
Modelling (LiDAR)	5 days (consultant * 10 staff) for attendance at workshops	-----
Modelling (satellite remote sensing)	5 days (consultant * 10 staff) for attendance at workshops	-----
Metadata	10 hours (consultant * 10 staff) for data management workshops	-----
Central repository	220 hours (consultant) for establishing repository	-----
Automated pipeline (field data)	110 days (consultant) for adapting to pipelines	20 days (consultant * 10 staff) for workshops
Automated pipeline (LiDAR)	55 days (consultant) for workshops	20 hours (consultant) for workshops
Automated pipeline (satellite remote sensing)	55 days (consultant) for workshops	20 hours (consultant) for workshops
Open data	110 days (consultant) for data upload and management	-----

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APPENDIX S3: COSTS PER EBV

Towards a modern and efficient European biodiversity observation network fit for multiple policies

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Journal name: *Ecological Monographs*

To estimate the cost-efficiency of the sampling networks (see Appendix S2), we estimated the costs for each EBV individually and compared the total costs for EBV monitoring to the total costs of the sampling networks. Cost estimations for individual EBVs were possible for 68 of the 84 EBVs. We used the same site numbers as in the sampling networks and calculated costs for a low and high site scenario, respectively. Cost calculations followed the same assumptions as in the sampling networks, with some variations, as described below.

Data collection methods

For each EBV, we used the same cost data as described for the respective methods in Appendix S2. For consistency, we assumed that the number of sites and the number of collectors would be the same as in the respective sampling networks. For EBVs with sampling in rivers and lakes, we used 10,000 and 100,000 sites (low and high site scenario) and assumed that 20% of these were lakes.

Administration

Unlike the sampling networks, which would combine existing and new monitoring methods, there are some existing infrastructures in place for specific EBVs. As such, we estimated the number of administrators required for each EBV separately. The following staff requirements for each member state were estimated on a per EBV basis.

- Where systematic monitoring is already in place, we assumed one full time administrator and 0.5 FTE of a senior researcher are required as a baseline. For every 10 collectors, the number of administrators increases by 0.1 FTE and the number of full-time staff by 0.05 FTE. This is especially important for EBVs where a significant proportion of data collection is to be made by volunteers. Although volunteers donate their time for monitoring, they cannot be regarded as a “free” resource and must be supported to encourage retention. Larger countries will also require considerable additional coordination efforts.

- Where data collection is currently in place via NGOs or research institutions but expansion is needed, we assumed that member states will require an additional 0.25 FTE of an administrator and 0.1 FTE of a senior researcher to represent an expansion of the role of existing staff. This will also increase for every 10 collectors, as defined above.
- Where the data collection is already in place via government agencies (e.g. Water Framework Directive), we estimated that 0.1 FTE of additional administration and 0.05 FTE of senior researcher time is required to support the expansion as the administrative infrastructure is well established.
- Where only satellite remote sensing data is required, we assumed that only an additional 0.05 FTE of a senior researcher per member state is required.

Summary of cost assumptions for individual EBVs

An overview of the cost assumptions for each EBV regarding monitoring methods, relation to a sampling network, monitoring frequency, and assumptions for the number of sites per collector, the amount of data collected, and the minimum number of administrative and senior research staff is provided in Table S1.

TABLE S1 Cost assumptions for individual EBVs. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

Code	Methods	Sampling network	Frequency	Sites/ Collector	Data (GB/site)	Min Admin	Min Snr. Res
SPP_SP_dis_fish_FW	Electrofishing, gillnetting	River monitoring	3 years	20	0.2	0.1	0.05
SPP_SP_dis_inve_FW	Kick sampling, pump/core sampling, transects (bivalves)	River monitoring	3 years	50	0.3	0.1	0.05
Eco_CC_com_mphy_FW	Transects (macrophytes)	River monitoring	3 years	20	0.1	0.1	0.05
Eco_CC_com_pben_FW	Diatom sampling	River monitoring	3 years	20	0.1	0.1	0.05
Eco_CC_com_inve_FW	Kick sampling, pump/core sampling, transects (bivalves)	River monitoring	3 years	50	0.3	0.1	0.05
Eco_CC_com_fish_FW	Electrofishing, gillnetting	River monitoring	3 years	20	0.2	0.1	0.05
SPP_SP_dis_mphy_FW	Transects (macrophytes)	River monitoring	3 years	20	0.1	0.1	0.05
Eco_CC_com_ppla_FW	Dip sampling (phytoplankton)	Lake monitoring	3 years	20	0.1	0.1	0.05
Eco_CC_com_zoop_FW	Dip sampling (zooplankton)	Lake monitoring	3 years	20	0.1	1	0.5
SPP_SP_dis_fish_MA	Acoustic sensors (fish), trawling	Marine fish monitoring	Annual	1	5	1	0.5
SPP_SP_abn_fish_MA	Trawling	Marine fish monitoring	Annual	1	1	1	0.5
SPP_SP_dis_bird_MA	Ship transects, aerial transects	Other marine vertebrate monitoring	Annual	1	0.2	0.5	0.25
SPP_SP_dis_mamm_MA	Ship transects, aerial transects	Other marine vertebrate monitoring	Annual	1	0.1	1	0.5
SPP_SP_dis_rept_MA	Ship transects, aerial transects	Other marine vertebrate monitoring	Annual	1	0.1	1	0.5
Spp_ST_phe_bird_MA	Point counts (birds)	Other marine vertebrate monitoring	Annual	5	0.1	0.25	0.1
Eco_ES_dis_cora_MA	Marine video transects	Marine habitat monitoring	5 years	5	20	1	0.5

Eco_ES_dis_malg_MA	Marine video transects	Marine habitat monitoring	5 years	5	20	1	0.5
Eco_ES_dis_plan_MA	Marine video transects	Marine habitat monitoring	5 years	5	20	1	0.5
Eco_ES_dis_oyst_MA	Marine video transects	Marine habitat monitoring	5 years	5	20	1	0.5
Eco_EF_dtb_habi_MA	Core sampling	Marine habitat monitoring	5 years	1	0.1	1	0.5
SPP_SP_dis_inve_MA	Marine video transects, autonomous reef monitoring structure, core sampling	Marine invertebrate & plankton monitoring	Annual	5	1820	1	0.5
Eco_CC_com_micr_MA	Plankton trawl, autonomous reef monitoring structure	Marine invertebrate & plankton monitoring	5 years	5	700	1	0.5
SPP_SP_abn_dise_TE	Flying disease vector traps, tick cloth drags	Terrestrial invertebrate monitoring	Annual	10	0.2	0.5	0.25
SPP_SP_abn_pest_TE	Flying disease vector traps	Terrestrial invertebrate monitoring	Annual	10	0.1	1	0.5
Eco_CC_bio_inve_TE	Malaise traps, pitfall traps	Terrestrial invertebrate monitoring	Annual	10	200	1	0.5
SPP_SP_dis_plan_TE	Vegetation plots	Vegetation monitoring	Annual	10	0.1	0.5	0.25
SPP_SP_dis_lich_TE	Lichen sampling	Vegetation monitoring	Annual	40	0.1	1	0.5
Eco_ES_bio_habi_TE	Transects (dead wood)	Vegetation monitoring	Annual	40	0.1	1	0.5
Eco_CC_bio_micr_TE	Soil sampling with DNA metabarcoding	Soil monitoring	4 years	50	100	1	0.5
Eco_CC_com_micr_TE	Soil sampling with DNA metabarcoding, soil macroinvertebrate sampling	Soil monitoring	4 years	30	100.1	1	0.5
Spp_SP_abn_bird_FW	Point counts (birds), transects (birds)	Mainland bird monitoring	Annual	20	0.2	1	0.5
Spp_SP_dis_bird_TE	Transects (birds), point counts (birds)	Mainland bird monitoring	Annual	20	0.2	0.5	0.25
Spp_SP_abn_bird_TE	Transects (birds), point counts (birds)	Mainland bird monitoring	Annual	20	0.2	0.5	0.25
Spp_ST_phe_bird_TE	Constant effort ringing[1], point counts (birds)	Mainland bird monitoring	Annual	10	0.2	0.5	0.25
Spp_ST_phe_bird_FW	Constant effort ringing, point counts (birds)	Mainland bird monitoring	Annual	10	0.2	0.5	0.25

[1] We assume that this is only undertaken at 20% of sites

Spp_SP_dis_mamm_FW	Transects (freshwater mammals), faecal sampling	Mainland mammal monitoring	Annual	20	1000.1	1	0.5
Spp_SP_abn_mamm_TE	Live capture, camera traps, passive acoustic sampling	Mainland mammal monitoring	Annual	15	223.65	1	0.5
Spp_SP_dis_mamm_TE	Camera traps, passive acoustic sampling	Mainland mammal monitoring	Annual	15	223.65	1	0.5
Spp_SP_dis_amph_FW	Transects (amphibians)	Herpetology monitoring	Annual	20	0.1	1	0.5
Spp_SP_dis_rept_TE	Transects (reptiles)	Herpetology monitoring	Annual	20	0.1	1	0.5
Spp_SP_abn_inse_TE	Transects (insects), Flower-Insect Timed (FIT) counts, light traps	Priority insect monitoring	Annual	10	0.3	1	0.5
Spp_SP_dis_inve_TE	Transects (Insects), Flower-Insect Timed (FIT) counts, light traps	Priority insect monitoring	Annual	10	0.3	1	0.5
Spp_ST_phe_inse_TE	Citizen science observations	Priority insect monitoring	Annual	10	0.5	0.25	0.1
Eco_CC_abn_inse_TE	Transects (Insects), Flower-Insect Timed (FIT) counts, light traps	Priority insect monitoring	Annual	10	0.3	1	0.5
Eco_ES_dis_habi_FW	Large habitat plots	Mainland habitat monitoring	Annual	30	0.1	1	0.5
Eco_ES_dis_habi_TE	Large habitat plots	Mainland habitat monitoring	Annual	30	0.1	1	0.5
Spp_GC_div_unsp_TE	Genetic sequencing	Genetic sequencing	10 years	10	100	1	0.5
Spp_GC_div_unsp_FW	Genetic sequencing	Genetic sequencing	10 years	10	100	1	0.5
Spp_GC_div_unsp_MA	Genetic sequencing	Genetic sequencing	10 years	10	100	1	0.5
Spp_SP_dis_alie_FW	Citizen science observations	Citizen science apps	Annual	30	0.5	0.5	0.25
Eco_ES_con_habi_FW	Satellite remote sensing, citizen science observation, barrier mapping[2]	Citizen science apps	Annual	20	1.5	0.15[3]	0
Spp_SP_dis_alie_MA	Citizen science observations, autonomous reef monitoring structure (ARMS)[4]	Citizen science apps	Annual	1	0.5	0.5	0.25

[2] These are transect surveys with no physical data collection
[3] This represents an estimate of the required administrative burden of expanding the Adaptive Management of Barriers in European Rivers (AMBER)
[4] These are collected and deployed every year, more frequently than in the methods described in Appendix S2

Spp_SP_dis_alie_TE	Citizen science observations, transects (insects)	Citizen science apps	Annual	30	0.5	0.5	0.25
Spp_ST_phe_fung_TE	Citizen science observations	Citizen science apps	Annual	1	0.5	0.5	0.25
Eco_ES_str_habi_FW	LiDAR	LiDAR	5 years	10	4200	1	0.5
Eco_ES_str_plan_TE	LiDAR	LiDAR	5 years	10	4200	1	0.5
Eco_EF_pro_habi_FW	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_phe_habi_MA	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_phe_ppla_MA	Satellite remote sensing, imaging flow cytometry	Satellite remote sensing	Annual	10	200	0.25	0.1
Eco_EF_pro_habi_MA	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Spp_ST_phe_plan_TE	Satellite remote sensing, phenocams	Satellite remote sensing	Annual	10	43.8	0.25	0.1
Eco_CC_bio_bird_TE	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_phe_ppla_FW	Satellite remote sensing, dip sampling (phytoplankton)	Satellite remote sensing	Annual	10	10	0.25	0.1
Eco_ES_con_habi_TE	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_pro_unsp_TE	Satellite remote sensing, flux towers	Satellite remote sensing	Annual	10	10	0.25	0.1
Eco_EF_dtb_fire_TE	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_dtb_huma_TE	Satellite remote sensing	Satellite remote sensing	Annual	10	0	0	0.05
Eco_EF_phe_plan_TE	Satellite remote sensing, phenocams	Satellite remote sensing	Annual	10	43.8	0.25	0.1

European integration tasks per EBV

For each EBV, we identified the tasks that are needed for an integration at the EU-level with the European Biodiversity Observation Coordination Centre (EBOEco_CC). This was based on the assessment of current EU monitoring workflows and bottlenecks (Morán-Ordóñez et al. 2023) and additional information that was collected per EBV during the EuropaBON workshop on EBV workflows (Lumbierres et al. 2024). For EBVs that were not considered in these assessments, we assumed that their closest associated EBV was reflective. We also added the requirements for power analyses in all EBVs that are not currently covered by existing monitoring efforts, although power analyses are very strongly recommended for all EBVs. An overview of the identified integration tasks per EBV is provided in Table S2.

TABLE S2 Overview of integration needs per EBV. A "Yes" means that the full costs are included. A 'Yes*' means that only 50% of the investment is included. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

EBV	Taxa for capacity building	Standardisation	Power analysis	Novel methods	Capacity building	Modelling (genetics)	Modelling (field)	Modelling (LiDAR)	Modelling (satellite RS)	Metadata	Central repository	Citizen science observation app	User friendly software	Open codes	Automated pipeline (field data)	Automated pipeline (LiDAR)	Automated pipeline (satellite RS)	Open data
Spp_SP_dis_fish_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Spp_SP_dis_inve_FW	0	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Spp_SP_dis_mphy_FW	0	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Eco_CC_com_mphy_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	No
Eco_CC_com_pben_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	No
Eco_CC_com_inve_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	No
Eco_CC_com_fish_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Eco_CC_com_fung_FW	0	Yes	Yes	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Spp_ST_phe_fish_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes

Eco_CC_com_ppla_FW	0	No	No	No	Yes*	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	No
Eco_CC_com_zoop_FW	0	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_EF_phe_ppla_FW	0	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes*	No	Yes*	Yes*
Spp_SP_dis_fish_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes*	No	No	Yes	Yes	Yes*	No	No	No
Spp_SP_abn_fish_MA	0	No	No	Yes*	Yes	No	Yes	No	No	Yes*	Yes*	No	Yes	Yes	Yes*	No	No	No
Spp_ST_phe_fish_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes*	No	No	Yes	Yes	Yes*	No	No	No
Spp_SP_dis_bird_MA	0	Yes	Yes	Yes*	No	No	Yes*	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Spp_SP_abn_bird_MA	0	Yes	Yes	Yes*	No	No	Yes*	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes
Spp_SP_dis_mamm_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_rept_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_ST_phe_bird_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Spp_ST_phe_mamm_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_dis_cora_MA	0	Yes	Yes	Yes*	Yes	No	Yes*	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_dis_malg_MA	0	Yes	Yes	Yes*	Yes	No	Yes*	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_dis_plan_MA	0	Yes	Yes	Yes*	Yes	No	Yes*	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_dis_oyst_MA	0	Yes	Yes	Yes*	Yes	No	Yes*	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_EF_dtb_habi_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_inve_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_CC_com_micr_MA	0	Yes*	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_CC_abn_inve_MA	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_abn_inse_FW	1	Yes	Yes	Yes*	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_inse_FW	1	Yes	Yes	Yes*	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_abn_inse_TE	0	No	Yes	No	No	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_SP_dis_inve_TE	2	Yes	No	Yes*	Yes	No	Yes*	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_ST_phe_inse_TE	0	Yes	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	No	No	No	Yes*
Eco_CC_abn_inse_TE	2	No	No	No	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_abn_dise_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_abn_pest_TE	1	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_CC_bio_inve_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes*	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_plan_TE	0	Yes	No	Yes*	Yes	No	No	No	No	No	No	No	No	Yes	Yes*	No	No	Yes*
Spp_SP_dis_lich_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_bio_habi_TE	0	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	No	No	Yes

Eco_CC_bio_micr_TE	0	No	No	No	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes*	No	No	No
Eco_CC_com_micr_TE	2	Yes	No	Yes*	No	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes*	No	No	No
Spp_SP_abn_bird_FW	0	No	No	No	No	No	Yes*	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_bird_TE	0	No	No	No	No	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_SP_abn_bird_TE	0	No	No	No	No	No	Yes*	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_ST_phe_bird_TE	0	Yes	No	Yes*	No	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_ST_phe_bird_FW	0	Yes	No	Yes*	No	No	Yes	No	No	No	No	No	Yes	Yes	Yes*	No	No	Yes*
Spp_SP_dis_mamm_FW	0	Yes	Yes	Yes*	No	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes*
Spp_SP_abn_mamm_TE	0	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes*
Spp_SP_dis_mamm_TE	0	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	Yes*
Spp_SP_dis_amph_FW	0	Yes	Yes	Yes*	No	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes*
Spp_SP_dis_rept_FW	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes*
Spp_SP_dis_rept_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes*
Eco_ES_dis_habi_FW	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Eco_ES_dis_habi_TE	0	Yes	No	No	No	No	Yes	No	No	No	No	No	No	Yes	Yes	No	No	Yes*
Spp_GC_div_unsp_TE	0	Yes	Yes	Yes*	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_GC_div_unsp_FW	0	Yes	Yes	Yes*	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_GC_div_unsp_MA	0	Yes	Yes	Yes*	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Spp_SP_dis_alie_FW	0	Yes	No	Yes*	No	No	Yes	No	No	Yes*	Yes*	Yes	Yes	Yes	Yes*	No	No	Yes*
Eco_ES_con_habi_FW	0	Yes	Yes	Yes*	Yes	No	No	No	Yes*	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes*	Yes
Spp_SP_dis_alie_MA	0	Yes	No	Yes*	No	No	Yes	No	No	Yes*	No	Yes	Yes	Yes	No	No	No	No
Spp_SP_dis_alie_TE	0	Yes	No	Yes*	No	No	Yes*	No	No	Yes*	No	Yes	Yes	Yes	Yes*	No	No	No
Spp_ST_phe_fung_TE	0	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Spp_ST_phe_fung_TE	0	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Eco_ES_str_habi_FW	0	Yes	Yes	No	Yes	No	No	Yes*	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes
Eco_ES_str_plan_TE	0	Yes	Yes	No	Yes	No	No	Yes*	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes
Eco_EF_pro_habi_FW	0	Yes	Yes	Yes*	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_phe_habi_MA	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_phe_ppla_MA	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_pro_habi_MA	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Spp_ST_phe_plan_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Eco_CC_bio_bird_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes

Eco_CC_bio_mamm_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_CC_bio_inse_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_ES_con_habi_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_pro_unsp_TE	0	Yes	No	No	No	No	No	No	Yes*	Yes	No	No	Yes	Yes	Yes	No	No	Yes
Eco_EF_dtb_fire_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_dtb_huma_TE	0	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Eco_EF_phe_plan_TE	0	Yes	Yes	Yes*	Yes	No	Yes	No	Yes*	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes

Low site number costs per EBV

The total costs per EBV for a low site-number scenario are summarised below in Table S3.

TABLE S3 Low site-number scenario with costs per EBV. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

		Member states (Mio €)		EBOEco_CC (Mio €)		Total (Mio €)
EBV	**Sites**	**Establishment**	**Maintenance**	**Establishment**	**Maintenance**	
Spp_SP_dis_fish_FW	10,000 rivers & lakes	€ 14.80	€ 4.74	€ 0.27	€ 0.58	€ 94.42
Spp_SP_dis_inve_FW	10,000 rivers & lakes	€ 10.18	€ 3.31	€ 0.35	€ 0.58	€ 73.74
Eco_CC_com_mphy_FW	10,000 rivers & lakes	€ 5.75	€ 1.57	€ 0.29	€ 0.51	€ 28.66
Eco_CC_com_pben_FW	10,000 rivers & lakes	€ 11.44	€ 2.93	€ 0.28	€ 0.51	€ 74.35
Eco_CC_com_inve_FW	10,000 rivers & lakes	€ 11.09	€ 4.83	€ 0.29	€ 0.51	€ 96.77
Eco_CC_com_fish_FW	10,000 rivers & lakes	€ 13.18	€ 8.16	€ 0.28	€ 0.58	€ 155.57
Spp_SP_dis_mphy_FW	10,000 rivers & lakes	€ 6.36	€ 1.57	€ 0.34	€ 0.58	€ 29.59
Eco_CC_com_ppla_FW	2,000 lakes	€ 5.57	€ 1.69	€ 0.44	€ 0.51	€ 36.31
Eco_CC_com_zoop_FW	2,000 lakes	€ 8.23	€ 3.38	€ 1.17	€ 0.85	€ 57.89
Spp_SP_dis_fish_MA	550 sites	€ 92.59	€ 12.33	€ 0.49	€ 0.67	€ 223.08
Spp_SP_abn_fish_MA	550 sites	€ 92.59	€ 12.33	€ 0.49	€ 0.67	€ 223.08
Spp_SP_dis_bird_MA	550 sites	€ 12.14	€ 46.30	€ 0.32	€ 0.74	€ 482.85
Spp_SP_dis_mamm_MA	550 sites	€ 14.32	€ 47.15	€ 0.99	€ 0.85	€ 495.26
Spp_SP_dis_rept_MA	550 sites	€ 14.32	€ 47.15	€ 0.98	€ 0.85	€ 495.25
Spp_ST_phe_bird_MA	550 sites	€ 6.17	€ 1.33	€ 0.67	€ 0.74	€ 30.70
Eco_ES_dis_cora_MA	550 sites	€ 1.77	€ 3.32	€ 0.87	€ 0.85	€ 39.62
Eco_ES_dis_malg_MA	550 sites	€ 1.77	€ 3.32	€ 0.87	€ 0.85	€ 39.62
Eco_ES_dis_plan_MA	550 sites	€ 1.77	€ 3.32	€ 0.87	€ 0.85	€ 39.62
Eco_ES_dis_oyst_MA	550 sites	€ 1.77	€ 3.32	€ 0.87	€ 0.85	€ 39.62
Eco_EF_dtb_habi_MA	550 sites	€ 22.17	€ 3.49	€ 0.99	€ 0.85	€ 61.62
Spp_SP_dis_inve_MA	550 sites	€ 11.96	€ 11.09	€ 0.99	€ 0.85	€ 132.32
Eco_CC_com_micr_MA	550 sites	€ 8.85	€ 4.74	€ 0.92	€ 0.71	€ 65.86
Spp_SP_dis_inse_FW	10,000 rivers & lakes	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00

Spp_SP_abn_inse_TE	10,000 sites	€ 12.38	€ 37.69	€ 0.37	€ 0.58	€ 395.46
Spp_SP_dis_inve_TE	10,000 sites	€ 14.82	€ 37.71	€ 1.14	€ 0.74	€ 400.40
Spp_ST_phe_inse_TE	10,000 sites	€ 12.92	€ 13.53	€ 0.73	€ 0.79	€ 156.88
Eco_CC_abn_inse_TE	10,000 sites	€ 19.97	€ 88.35	€ 1.40	€ 0.66	€ 911.45
Spp_SP_abn_dise_TE	10,000 sites	€ 12.34	€ 33.82	€ 0.99	€ 0.85	€ 360.03
Spp_SP_abn_pest_TE	10,000 sites	€ 12.25	€ 24.86	€ 1.41	€ 0.85	€ 270.73
Eco_CC_bio_inve_TE	10,000 sites	€ 17.42	€ 67.45	€ 0.96	€ 0.77	€ 700.57
Spp_SP_dis_plan_TE	10,000 sites	€ 11.68	€ 7.50	€ 0.14	€ 0.37	€ 90.58
Spp_SP_dis_lich_TE	10,000 sites	€ 12.90	€ 8.09	€ 0.99	€ 0.85	€ 103.29
Eco_ES_bio_habi_TE	10,000 sites	€ 6.70	€ 5.43	€ 0.84	€ 0.81	€ 69.95
Eco_CC_bio_micr_TE	10,000 sites	€ 12.82	€ 7.07	€ 0.28	€ 0.15	€ 93.70
Eco_CC_com_micr_TE	10,000 sites	€ 14.03	€ 9.07	€ 0.36	€ 0.74	€ 136.96
Spp_SP_abn_bird_FW	10,000 sites	€ 10.43	€ 24.25	€ 0.35	€ 0.58	€ 259.08
Spp_SP_dis_bird_TE	10,000 sites	€ 9.64	€ 21.40	€ 0.30	€ 0.58	€ 229.73
Spp_SP_abn_bird_TE	10,000 sites	€ 9.58	€ 15.03	€ 0.18	€ 0.58	€ 165.86
Spp_ST_phe_bird_TE	10,000 sites	€ 43.14	€ 102.49	€ 0.37	€ 0.74	€ 1,075.78
Spp_ST_phe_bird_FW	10,000 sites	€ 9.11	€ 27.93	€ 0.37	€ 0.74	€ 296.11
Spp_SP_dis_mamm_FW	10,000 sites	€ 12.82	€ 50.54	€ 0.61	€ 0.74	€ 526.21
Spp_SP_abn_mamm_TE	10,000 sites	€ 26.47	€ 171.69	€ 0.67	€ 0.74	€ 1,751.37
Spp_SP_dis_mamm_TE	10,000 sites	€ 26.47	€ 171.69	€ 0.67	€ 0.74	€ 1,751.37
Spp_SP_dis_amph_FW	10,000 sites	€ 14.19	€ 15.27	€ 0.92	€ 0.85	€ 176.28
Spp_SP_dis_rept_TE	10,000 sites	€ 14.07	€ 18.46	€ 0.99	€ 0.85	€ 208.11
Eco_ES_dis_habi_FW	10,000 sites	€ 13.82	€ 7.67	€ 0.99	€ 0.85	€ 100.02
Eco_ES_dis_habi_TE	10,000 sites	€ 6.86	€ 7.22	€ 0.55	€ 0.74	€ 86.98
Spp_GC_div_unsp_TE	10,000 populations	€ 6.54	€ 14.96	€ 0.98	€ 0.48	€ 118.36
Spp_GC_div_unsp_FW	10,000 populations	€ 6.54	€ 14.96	€ 0.98	€ 0.48	€ 118.36
Spp_GC_div_unsp_MA	550 populations	€ 0.33	€ 3.55	€ 0.98	€ 0.48	€ 32.37
Spp_SP_dis_alie_FW	10,000 sites	€ 11.58	€ 4.38	€ 0.62	€ 0.97	€ 65.67
Eco_ES_con_habi_FW	10,000 rivers & lakes	€ 3.31	€ 18.33	€ 1.05	€ 0.93	€ 196.95
Spp_SP_dis_alie_MA	550 sites	€ 4.70	€ 2.84	€ 0.61	€ 0.72	€ 54.58
Spp_SP_dis_alie_TE	10,000 sites	€ 13.74	€ 8.06	€ 0.52	€ 0.87	€ 103.54
Spp_ST_phe_fung_TE	10,000 sites	€ 11.85	€ 3.55	€ 1.06	€ 0.90	€ 57.45

Eco_ES_str_habi_FW	NA – LiDAR	€ 5.80	€ 10.75	€ 0.68	€ 0.53	€ 115.11
Eco_ES_str_plan_TE	NA – LiDAR	€ 5.80	€ 11.13	€ 0.68	€ 0.53	€ 118.88
Eco_EF_phe_ppla_FW	per 500 km^2	€ 1.78	€ 1.58	€ 0.17	€ 0.47	€ 22.42
Eco_EF_pro_habi_FW	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.88	€ 0.58	€ 7.56
Eco_EF_phe_habi_MA	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.40
Eco_EF_phe_ppla_MA	per 500 km^2	€ 4.89	€ 1.57	€ 0.81	€ 0.58	€ 27.60
Eco_EF_pro_habi_MA	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.40
Spp_ST_phe_plan_TE	per 500 km^2	€ 9.60	€ 0.71	€ 1.21	€ 1.05	€ 28.36
Eco_CC_bio_bird_TE	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.47
Eco_ES_con_habi_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_pro_unsp_TE	per 500 km^2	€ 71.40	€ 2.21	€ 0.38	€ 0.59	€ 138.85
Eco_EF_dtb_fire_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_dtb_huma_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_phe_plan_TE	per 500 km^2	€ 6.41	€ 0.50	€ 1.02	€ 0.99	€ 22.35
Total		**€ 890**	**€ 1,305**	**€ 48**	**€ 47**	**€ 14,606**

High site number costs per EBV

The total costs per EBV for a high site-number scenario are summarised below in Table S4.

TABLE S4 High site-number scenario with costs per EBV. The IDs for each EBV follow a coding system available on GitHub (https://github.com/EuropaBON/EBV-Descriptions/wiki).

		Member states (M €)		EBOEco_CC (M €)		Total
EBV	**Sites**	**Establishment**	**Maintenance**	**Establishment**	**Maintenance**	
Spp_SP_dis_fish_FW	100,000 rivers & lakes	€ 108.86	€ 37.49	€ 0.27	€ 0.58	€ 781.71
Spp_SP_dis_inve_FW	100,000 rivers & lakes	€ 77.94	€ 23.18	€ 0.35	€ 0.58	€ 589.61
Eco_CC_com_mphy_FW	100,000 rivers & lakes	€ 29.68	€ 5.97	€ 0.29	€ 0.51	€ 140.19
Eco_CC_com_pben_FW	100,000 rivers & lakes	€ 84.45	€ 19.48	€ 0.28	€ 0.51	€ 594.12
Eco_CC_com_inve_FW	100,000 rivers & lakes	€ 81.04	€ 38.36	€ 0.29	€ 0.51	€ 817.43
Eco_CC_com_fish_FW	100,000 rivers & lakes	€ 107.24	€ 71.91	€ 0.28	€ 0.58	€ 1,409.88
Spp_SP_dis_mphy_FW	100,000 rivers & lakes	€ 30.28	€ 5.97	€ 0.34	€ 0.58	€ 141.13
Eco_CC_com_ppla_FW	20,000 lakes	€ 27.39	€ 7.21	€ 0.44	€ 0.51	€ 214.46
Eco_CC_com_zoop_FW	20,000 lakes	€ 30.13	€ 8.83	€ 1.17	€ 0.85	€ 235.24
Spp_SP_dis_fish_MA	5,500 sites	€ 865.37	€ 99.95	€ 0.49	€ 0.67	€ 1,872.02
Spp_SP_abn_fish_MA	5,500 sites	€ 865.37	€ 99.95	€ 0.49	€ 0.67	€ 1,872.02
Spp_SP_dis_bird_MA	5,500 sites	€ 79.85	€ 441.70	€ 0.32	€ 0.74	€ 4,504.53
Spp_SP_dis_mamm_MA	5,500 sites	€ 83.09	€ 442.54	€ 0.99	€ 0.85	€ 4,517.99
Spp_SP_dis_rept_MA	5,500 sites	€ 83.09	€ 442.54	€ 0.98	€ 0.85	€ 4,517.98
Spp_ST_phe_bird_MA	5,500 sites	€ 11.64	€ 3.24	€ 0.67	€ 0.74	€ 83.29
Eco_ES_dis_cora_MA	5,500 sites	€ 10.77	€ 11.27	€ 0.87	€ 0.85	€ 146.39
Eco_ES_dis_malg_MA	5,500 sites	€ 10.77	€ 11.27	€ 0.87	€ 0.85	€ 146.39
Eco_ES_dis_plan_MA	5,500 sites	€ 10.77	€ 11.27	€ 0.87	€ 0.85	€ 146.39
Eco_ES_dis_oyst_MA	5,500 sites	€ 10.77	€ 11.27	€ 0.87	€ 0.85	€ 146.39
Eco_EF_dtb_habi_MA	5,500 sites	€ 160.18	€ 13.37	€ 0.99	€ 0.85	€ 315.13
Spp_SP_dis_inve_MA	5,500 sites	€ 56.21	€ 87.59	€ 0.99	€ 0.85	€ 941.55
Eco_CC_com_micr_MA	5,500 sites	€ 27.60	€ 25.21	€ 0.92	€ 0.71	€ 353.23
Spp_SP_dis_inse_FW	100,000 rivers & lakes	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Spp_SP_abn_inse_TE	100,000 sites	€ 107.42	€ 351.41	€ 0.37	€ 0.58	€ 3,627.73
Spp_SP_dis_inve_TE	100,000 sites	€ 109.86	€ 351.43	€ 1.14	€ 0.74	€ 3,632.67

Spp_ST_phe_inse_TE	100,000 sites	€ 92.11	€ 118.72	€ 0.73	€ 0.79	€ 1,287.92
Eco_CC_abn_inse_TE	100,000 sites	€ 175.95	€ 858.03	€ 1.40	€ 0.66	€ 8,764.18
Spp_SP_abn_dise_TE	100,000 sites	€ 123.30	€ 321.97	€ 0.99	€ 0.85	€ 3,352.45
Spp_SP_abn_pest_TE	100,000 sites	€ 122.46	€ 223.27	€ 1.41	€ 0.85	€ 2,365.07
Eco_CC_bio_inve_TE	100,000 sites	€ 119.41	€ 648.99	€ 0.96	€ 0.77	€ 6,618.00
Spp_SP_dis_plan_TE	100,000 sites	€ 78.77	€ 58.59	€ 0.14	€ 0.37	€ 668.50
Spp_SP_dis_lich_TE	100,000 sites	€ 73.99	€ 54.94	€ 0.99	€ 0.85	€ 632.81
Eco_ES_bio_habi_TE	100,000 sites	€ 66.85	€ 29.44	€ 0.84	€ 0.81	€ 370.19
Eco_CC_bio_micr_TE	100,000 sites	€ 80.92	€ 45.97	€ 0.28	€ 0.15	€ 633.86
Eco_CC_com_micr_TE	100,000 sites	€ 95.28	€ 66.38	€ 0.36	€ 0.74	€ 1,056.16
Spp_SP_abn_bird_FW	100,000 sites	€ 92.15	€ 216.25	€ 0.35	€ 0.58	€ 2,260.85
Spp_SP_dis_bird_TE	100,000 sites	€ 84.72	€ 197.67	€ 0.30	€ 0.58	€ 2,067.53
Spp_SP_abn_bird_TE	100,000 sites	€ 84.13	€ 134.01	€ 0.18	€ 0.58	€ 1,430.24
Spp_ST_phe_bird_TE	100,000 sites	€ 86.26	€ 203.17	€ 0.37	€ 0.74	€ 2,125.72
Spp_ST_phe_bird_FW	100,000 sites	€ 90.89	€ 263.14	€ 0.37	€ 0.74	€ 2,730.03
Spp_SP_dis_mamm_FW	100,000 sites	€ 85.05	€ 478.81	€ 0.61	€ 0.74	€ 4,881.18
Spp_SP_abn_mamm_TE	100,000 sites	€ 222.68	€ 1,691.39	€ 0.67	€ 0.74	€ 17,144.59
Spp_SP_dis_mamm_TE	100,000 sites	€ 222.68	€ 1,691.39	€ 0.67	€ 0.74	€ 17,144.59
Spp_SP_dis_amph_FW	100,000 sites	€ 86.80	€ 125.87	€ 0.92	€ 0.85	€ 1,354.84
Spp_SP_dis_rept_TE	100,000 sites	€ 87.54	€ 159.08	€ 0.99	€ 0.85	€ 1,687.80
Eco_ES_dis_habi_FW	100,000 sites	€ 83.15	€ 50.32	€ 0.99	€ 0.85	€ 595.78
Eco_ES_dis_habi_TE	100,000 sites	€ 68.36	€ 46.72	€ 0.55	€ 0.74	€ 543.47
Spp_GC_div_unsp_TE	100,000 populations	€ 65.32	€ 56.40	€ 0.98	€ 0.48	€ 583.94
Spp_GC_div_unsp_FW	100,000 populations	€ 72.16	€ 58.07	€ 0.98	€ 0.48	€ 608.46
Spp_GC_div_unsp_MA	5,500 populations	€ 3.18	€ 5.59	€ 0.98	€ 0.48	€ 55.62
Spp_SP_dis_alie_FW	100,000 sites	€ 75.87	€ 17.02	€ 0.62	€ 0.97	€ 256.33
Eco_ES_con_habi_FW	100,000 rivers & lakes	€ 7.29	€ 172.01	€ 1.05	€ 0.93	€ 1,737.74
Spp_SP_dis_alie_MA	550 sites	€ 23.73	€ 6.28	€ 0.61	€ 0.72	€ 228.67
Spp_SP_dis_alie_TE	100,000 sites	€ 109.07	€ 55.04	€ 0.52	€ 0.87	€ 668.65
Spp_ST_phe_fung_TE	100,000 sites	€ 70.06	€ 14.62	€ 1.06	€ 0.90	€ 226.31
Eco_ES_str_habi_FW	NA – LiDAR	€ 5.80	€ 10.75	€ 0.68	€ 0.53	€ 115.11
Eco_ES_str_plan_TE	NA – LiDAR	€ 5.80	€ 11.13	€ 0.68	€ 0.53	€ 118.88

Eco_EF_phe_ppla_FW	per 50 km^2	€ 1.99	€ 2.70	€ 0.17	€ 0.47	€ 33.85
Eco_EF_pro_habi_FW	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.88	€ 0.58	€ 7.56
Eco_EF_phe_habi_MA	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.40
Eco_EF_phe_ppla_MA	per 50 km^2	€ 4.89	€ 1.57	€ 0.81	€ 0.58	€ 27.60
Eco_EF_pro_habi_MA	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.40
Spp_ST_phe_plan_TE	per 50 km^2	€ 9.60	€ 0.71	€ 1.21	€ 1.05	€ 28.36
Eco_CC_bio_bird_TE	NA – Satellite remote sensing	€ 0.00	€ 0.08	€ 0.81	€ 0.58	€ 7.47
Eco_ES_con_habi_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_pro_unsp_TE	per 50 km^2	€ 645.35	€ 16.79	€ 0.38	€ 0.59	€ 1,185.52
Eco_EF_dtb_fire_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_dtb_huma_TE	NA – Satellite remote sensing	€ 0.00	€ 0.09	€ 0.81	€ 0.58	€ 7.49
Eco_EF_phe_plan_TE	per 50 km^2	€ 9.60	€ 0.71	€ 1.02	€ 0.99	€ 27.63
Total Costs		€ 6,503	€ 10,736	€ 48	€ 47	€ 117,418

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