biodiversa+
European Biodiversity Partnership

EUROPEAN PARTNERSHIP

Literature survey on biodiversity monitoring protocols used across countries

Document Information

Grant Agreement number:	101052342
Project acronym	Biodiversa+
Project full name	The European Biodiversity Partnership
Biodiversa+ duration:	7 years
Biodiversa+ start date	Start date: 1st October 2021
More information about Biodiversa+	Website: www.biodiversa.eu Email: contact@biodiversa.eu Twitter: @BiodiversaPlus LinkedIn: Biodiversa+

Title:	MS55 Literature survey on biodiversity monitoring protocols used across countries
Authors:	Michelle Silva del Pozo (OFB) and Guillaume Body (OFB).
Contributors	Mathieu Basille (OFB), Tom Breeze (University of Reading), Lluis Brotons (CREAF), Cécile Mandon (FBB), Gaby Rerig (DFG), Joana Santana (CIBIO-InBIO), Petteri Vihervaara (MoE_FI).
Work package:	WP2 Promote and support transnational biodiversity monitoring
Task or sub-task title:	Subtask 2.2.1: Harmonise operationalised protocols and inventory methods across regions and countries
Picture credits:	© Pixabay (cover picture)
Release date:	December 2022

What is Biodiversa+

Biodiversa+ is the new European co-funded biodiversity partnership supporting excellent research on biodiversity with an impact for policy and society. It was jointly developed by BiodivERsA and the European Commission (DG Research & Innovation and DG Environment) and was officially launched on 1 October 2021.

Biodiversa+ is part of the European Biodiversity Strategy for 2030 that aims to put Europe's biodiversity on a path to recovery by 2030.

The Partnership aims to connect science, policy and practise for transformative change. It currently gathers 74 research programmers and funders and environmental policy actors from 36 European and associated countries to work on 5 main objectives:

1. Plan and support research and innovation on biodiversity through a shared strategy, annual joint calls for research projects and capacity building activities
2. Set up a network of harmonised schemes to improve monitoring of biodiversity and ecosystem services across Europe
3. Contribute to high-end knowledge for deploying Nature-based Solutions and valuation of biodiversity in the private sector
4. Ensure efficient science-based support for policy-making and implementation in Europe
5. Strengthen the relevance and impact of pan-European research on biodiversity in a global context

More information at: https://www.biodiversa.eu/

Table of contents

Acronyms

ABLE	Assessing Butterflies in Europe
BMS	Butterfly Monitoring Scheme
BON	Biodiversity Observation Network
eBMS	European Butterfly Monitoring Scheme
EBV	Essential Biodiversity Variables
EEA	European Environment Agency
EMBAL	European Monitoring of Biodiversity in Agricultural Landscapes
ENVASSO	Environmental Assessment of Soil for Monitoring
GLORIA	Global Observation Research Initiative in Alpine Environments
IWC	International Waterbird Census
JRC	Joint Research Centre
LCIE	Large Carnivore Initiative for Europe
LUCAS	Land Use/Cover Area frame Survey
PECBMS	Pan-European Common Bird Monitoring Scheme
SCALP	Status and Conservation of the Alpine Lynx Population
SCANS	Small Cetaceans in European Atlantic waters and the North Sea
SPRING	Strengthening Pollinator Recovery through Indicators and Monitoring
WFD	Water Framework Directive

Executive Summary

Biodiversa+ WP2, Task 2.2 aims to harmonise biodiversity monitoring schemes across Europe. This report is the first phase that analyses different possible strategies for an optimal harmonisation of protocols for transnational monitoring, mainly focusing on biodiversity monitoring information workflows and governance. A particular interest is taken in determining the different geographical levels at which the biodiversity information is collected (e.g. local, national, European, global), and in what form it is transferred to other levels for decision-making (e.g. as raw data, Essential Biodiversity Variables (EBVs), indicators). This literature survey on existing pan-European biodiversity monitoring programmes highlights the different approaches used by those projects and the reasons behind the choices made. This analysis was carried out building on the outcome of a EuropaBON project, consultations with stakeholders involved in a few of the monitoring programmes taken as examples for this report, and knowledge contributions of internal Biodiversa+ members.

Fourteen monitoring programmes were taken as case studies. We showed that each programme has adopted a particular strategy, noticeably regarding the type of protocol and how the data is managed in the information chain. Various combinations of strategies are possible to deliver general trends and indices at the trans national level, with three main ones that seem to prevail among the studied cases: (1) applying one common strict protocol in all countries involved and aggregating raw data for joint analysis; (2) different protocols are applied across the different countries, each protocol gathering data which are treated locally to produce defined EBVs or indicators, which are then aggregated at the global (or trans national) level; (3) applying a protocol allowing some flexibility for an adapted implementation to each country, and treating data both locally and at a trans national level. We also highlighted that these combinations depend on the possible international cooperation and on the countries' means, in terms of budget as well as the existence of expert and volunteer networks.

This report will provide a starting point for discussions on the strategies to consider for the development of a European biodiversity monitoring coordination. An expert workshop will be organised by Biodiversa+ to encourage the exchange of ideas on the strategies between different stakeholders. The results of this workshop, in addition to the study carried out with this literature survey, will feed a final report (deliverable D2.6 by September 2023).

Introduction

The European Biodiversity Partnership, Biodiversa+[1], aims to harmonise operationalised protocols and inventory methods across regions and countries for biodiversity monitoring. In this context, Biodiversa+, in collaboration with EuropaBON[2] and other large-scale initiatives, is studying the possible strategies for an optimal harmonisation of protocols and methods for biodiversity monitoring.

Monitoring is the systematic observation and recording of an object in order to determine possible changes. Biodiversity monitoring aims to highlight changes in the various forms of biodiversity (genes, taxa, ecosystems, etc.) (Gruijter *et al.*, 2006; Juergens, 2006); it is a useful tool for keeping track of the results of management practices, in order to comply with regulations and public policies. Implementing standardised biodiversity monitoring programmes at the continent level is challenging, with Europe being diverse both in terms of ecological landscapes and historical monitoring practices.

For this study, a monitoring programme is understood in a broad way, being a project or a legal framework that provides periodic evaluations of biodiversity monitoring results. According to GEO BON[3] (Schmeller et al., 2015), a large-scale monitoring programme should take into account the different levels of the information chain, these being:

- target setting for the programme,
- survey design for data collection (sampling methods, field protocols, techniques, sites selection procedure, number of sites and replicates, sampling frequency),
- data storage and management,
- and production of results for policy reporting.

This integrated approach was identified by GEO BON as being essential since it was noticed that previous attempts to coordinate biodiversity monitoring schemes at the European level have failed due to a lack of alignment between data and policy needs, data interoperability, and inadequate survey design and plans for data storage and assessment (Schmeller *et al.*, 2015). In order to set a harmonised biodiversity monitoring scheme throughout the continent, efforts of cooperation between the countries involved should be taken for the entirety of this integrated approach.

Harmonisation can take place at different levels of this information chain. Firstly, the monitoring targets could be harmonised, which would imply working on setting common priorities. Part of the Biodiversa+ work focuses on defining shared priorities, adequate coverage, and indicators for biodiversity monitoring to better fit research, society, and policy needs.

Another possibility when coordinating a large-scale monitoring programme is to harmonise the protocols and uses of new technologies. GEO BON identified and analysed implementing common monitoring protocols, and integrating emerging technologies for monitoring as possible steps toward global biodiversity monitoring programmes (Schmeller *et al.*, 2015). EuropaBON also proposes to

[1] Biodiversa+. Available at: https://www.biodiversa.eu/
[2] EuropaBON. Available at: https://europabon.org/
[3] GEO BON. Available at: https://geobon.org/

provide support in improving modelling techniques and implementing new technologies, as some Member States expressed interest in these strategies for biodiversity monitoring (Moersberger *et al.*, 2022).

Schmidt & Van der Sluis (2021) reviewed different possible sampling strategies, means to collect data, and data analysis methods according to the monitoring target (e.g. species population, species trends, habitat distribution, etc.). Most schemes collect data through a field survey (field observations and measurements), but also automated techniques (such as eDNA, remote sensing, machine learning, etc.) can be used (Schmidt & Van der Sluis, 2021). Many current large-scale monitoring initiatives rely on citizen science, the data being collected in the field by volunteers. Citizen science has proven both that it can provide excellent data (Schmeller *et al.*, 2009, SPRING, 2022) and that it benefits society through the uptake of socially relevant questions and public empowerment, under the condition that citizen science projects follow a structured monitoring programme (Kamp *et al.*, 2016; Pocock *et al.*, 2018). The development and promotion of new and emerging methods, technologies, and approaches, including better involvement of citizens in biodiversity monitoring, are being tackled by Biodiversa+.

Data management can also be harmonised, for example by using a common data format for interoperability, and coordinated management of the infrastructure that stores data. Initiatives such as the Global Biodiversity Information Facility (GBIF[4]), the Ocean Biodiversity Information System (OBIS[5]) and GenBank[6] provide access to massive collections of biological data, with a certain standardisation of the data and metadata format, benefitting from initiatives discussing data standards such as the Biodiversity Information Standards (TDWG[7]). The International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT[8]) highlights the importance of ensuring the long-term preservation of and access to data, collecting and storing data using formats that preserve the data beyond the duration of the original research project, and applying commonly accepted standards to the metadata (Barry, 2018). A strong interest in a common platform for Europe, such as a coordination centre, has also been noted recently by EuropaBON (Moersberger et al., 2022) and even before by the European biodiversity observation network (EBONE[9]) (De Blust *et al.*, 2012). The harmonisation of databases and data interoperability is another aspect being assessed within Biodiversa+.

Finally, harmonisation can take place in the ways data are analysed and results are presented. The use of biodiversity monitoring data by research and innovation (to better understand the relationships between the state of biodiversity and drivers/pressures) is being supported by Biodiversa+. In addition, Biodiversa+ tackles the use of biodiversity data in public and private decision-making, and their usefulness to monitor the effectiveness of policies and the extent to which targets are met.

[4] GBIF. Available at: https://www.gbif.org/
[5] OBIS. Available at: https://obis.org/
[6] National Library of Medicine. (2021). GeneBank Overview. Available at: https://www.ncbi.nlm.nih.gov/genbank/
[7] TDWG. Available at: https://www.tdwg.org/
[8] INTERACT. (2017). Welcome to INTERACT. Available at: https://eu-interact.org/
[9] WUR. European Biodiversity Observation Network. Available at: https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Projects/EBONE.htm

The different levels of the information chain involve various domains: The target setting is mostly a matter of governance, the survey design and data analysis fall in the realm of the scientific domain, data management and storage are a matter of infrastructure, and the production and dissemination of results is making use of scientific communication. Biodiversa+ will mainly focus on biodiversity monitoring data workflows and governance by the different types of organisations handling monitoring data collection. Specifically, interest will be taken in determining the different geographical levels at which the biodiversity information is collected (e.g. local, national, European, global) and in what form it is transferred to other levels for decision-making (e.g. as raw data, Essential Biodiversity Variables, indicators). Here, Biodiversa+ aims to assess the possible strategies related to harmonising the identified processes.

EuropaBON is currently working on an extensive inventory of ongoing monitoring program workflows and their characteristics at the EU and transnational levels. Therefore, the focus of Biodiversa+ here is not to conduct an exhaustive literature review on transnational monitoring initiatives in Europe, but rather to gather the different approaches used for those initiatives and practical information to support actionable measures. Examples of monitoring programmes with defined protocols are targeted for this review. Other initiatives gathering non-structured opportunistic biological records are not part of the scope of this study, as they do not have a clear protocol or method description and, in consequence, the data cannot be easily harmonised or used to calculate biodiversity indicators.

Biodiversa+ will build strategic considerations on the way to harmonise monitoring protocols. This report compiles lessons learned from the literature and diverse examples taken from projects that have tackled this issue, mostly at the European level.

Concept note: Essential Biodiversity Variables

Numerous levels can be used to express changes in biodiversity, as different components of biodiversity can be measured in different ways and across multiple scales (Hardisty *et al*. 2018). For the purpose of this literature survey and analysis of biodiversity information workflows in the information chain, biodiversity information can take the form of:

- Raw data
- Essential Biodiversity Variables (EBV)
- Indicators

Biodiversity data are sets of values collected through observations and describing variables about the targeted object. Raw data, often addressed as primary observations, may be obtained by different means, for example from field survey observations, camera traps, satellite remote sensing, and DNA sequencing, among others. At the other end of the spectrum, indicators are composite metrics combining relevant data from available sources, which are useful for decision-making and for assessing the progress toward biodiversity targets (Parliamentary Office of Science and Technology, 2021).

For informed decision-making purposes, information is needed on different spatial scales, from local to global, yet designing an optimal multi-scale and multi-purpose monitoring system is challenging as different monitoring objectives require different sampling designs (Schmeller *et al.*, 2015). To this end, GEO BON has developed the concept of EBVs[10]: a minimal set of variables capturing basic information on biodiversity, needed to support multi-purpose biodiversity information systems at various spatial and temporal scales. EBVs are grouped in 6 classes: 1) Genetic composition; 2) Species populations; 3) Species traits; 4) Community composition; 5) Ecosystem functioning; and 6) Ecosystem structure.

EBVs provide a layer between primary observations from which relevant indicators may be derived (Fig.1). Through EBVs, data coming from different sources and methods can be integrated into biodiversity indicators relevant for assessments and policy reporting while keeping current practices on the ground (i.e. field protocols). EBVs offer a promising approach to harmonise biodiversity monitoring methods of different Member States (Navarro *et al.*, 2017; Hardisty *et al.*, 2019), which has been identified as a necessary step to improve monitoring at the European level (e.g. Schmidt and Van der Sluis, 2021, on their guidance for a better implementation of the European Union regulations and directives, such as the Birds and Habitat Directives).

[10] GEO BON. What are EBVs? Available at: https://geobon.org/ebvs/what-are-ebvs/

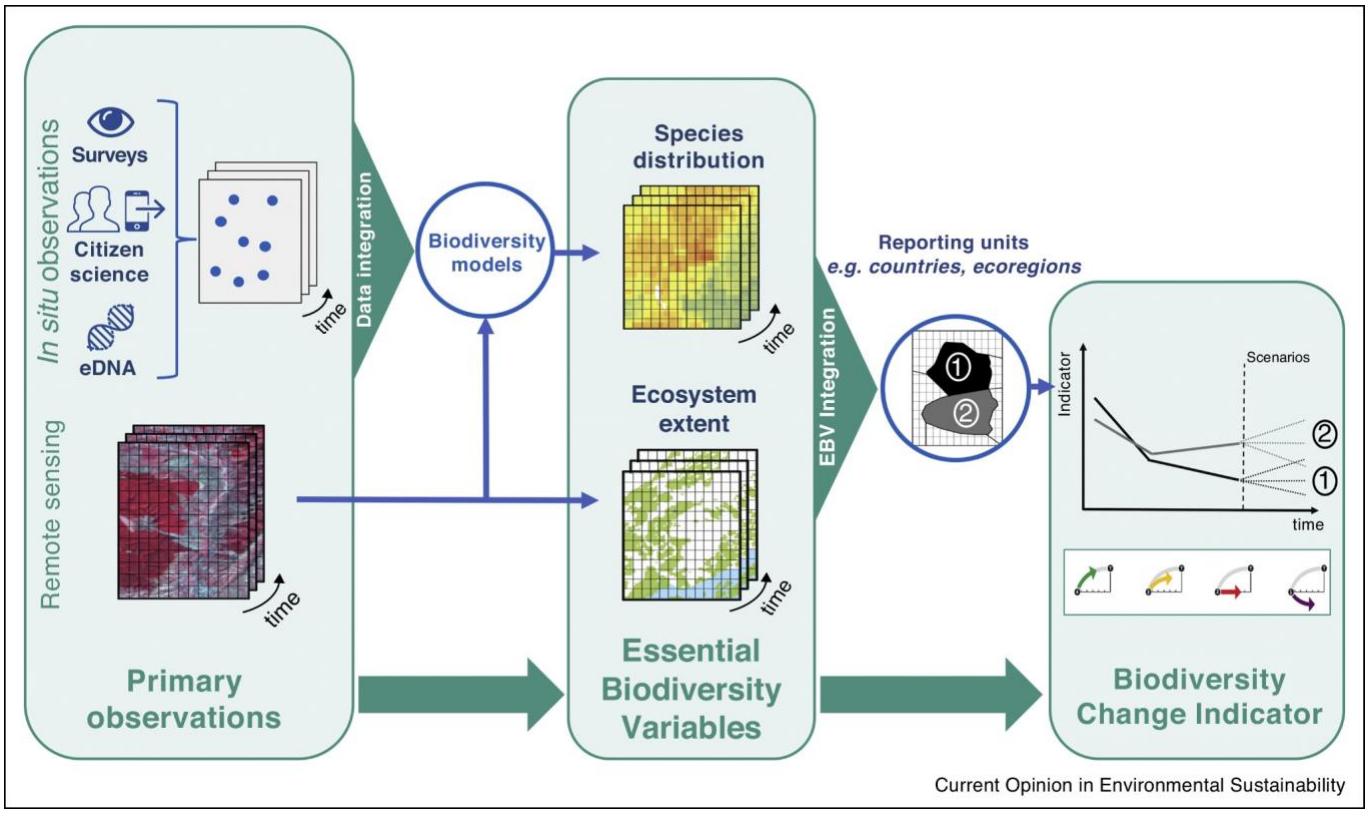

Figure 1. Figure from Navarro et al. *(2017)*[11]*: "From observations to the production of EBVs and indicators". Example in which data from different primary sources of observations are combined to produce layers of spatial and temporal variation in ecosystem extent and species distribution EBVs. This information is then integrated and summarised within reporting units to calculate an indicator of biodiversity change. No changes were made in this figure: https://creativecommons.org/licenses/by/4.0/.*

[11] Navarro, L. M., Fernández, N., Guerra, C., Guralnick, R., Kissling, W. D., Londoño, M. C., ... & Pereira, H. M. (2017). Monitoring biodiversity change through effective global coordination. *Current opinion in environmental sustainability*, *29*, 158-169. Available at: https://www.sciencedirect.com/science/article/pii/S1877343517301665#fig0010

Methods

A review of existing protocols and methods used for surveying biodiversity at a European level has been carried out between July and September 2022, consulting the EuropaBON monitoring database[12] and complementing it through web research and Biodiversa+ member knowledge. Thematic reviews of existing monitoring schemes have proven to be a useful tool for the assessment. Existing guidelines and best practices were also taken into account for this literature analysis. Finally, consultation with stakeholders involved in a few of the monitoring programmes taken as examples for this report provided us with additional insight into the functioning and reasoning behind the different approaches used.

Fourteen monitoring programmes revealed in the literature review are analysed in this document (the ones marked with a star are integrated in the EuropaBON database):

- IWC – International Waterbird Census
- EUROBATS Agreement*
- SCANS – Small Cetaceans in European Atlantic waters and the North Sea
- LCIE – Large Carnivore Initiative for Europe*
- WFD – Common Implementation Strategy for the Water Framework Directive (2000/60/EC)*
- GLORIA – Global Observation Research Initiative in Alpine Environments
- PECBMS – Pan-European Common Bird Monitoring Scheme*
- BioSoil project
- ENVASSO – Environmental assessment of soil for monitoring
- LUCAS soil – Land Use/Cover Area frame Survey*
- eBMS – European Butterfly Monitoring Scheme*
- SPRING – Strengthening Pollinator Recovery through Indicators and Monitoring
- EMBAL – European Monitoring of Biodiversity in Agricultural Landscapes
- LIFEPLAN – A Planetary Inventory of Life

For each of the identified programmes, information on its general functioning was compiled, including the programme's objectives, lifespan, and how it is organised in terms of coordination and funding. Then, the type of protocol used for monitoring is presented, mostly covering information on who gathers the data, how sampling sites are chosen, whether the protocol is strictly defined or not, and if a guidance document is available. Finally, information is provided about who treats and analyses the data, and what the final products are. Additional information that was considered relevant to the understanding of the choices made for the monitoring programme is also included, when available, noticeably in terms of future perspectives.

[12] EuropaBON biodiversity monitoring database: https://monitoring.europabon.org/monitoring/

Key issues and European initiatives

Probably the most crucial decision to be made for a large-scale monitoring initiative is the level and the metric at which the programme will be harmonised within and between the different countries involved. This is the central issue for this workstream of activity. This literature survey on the different existing pan-European biodiversity monitoring programmes shows which approaches have been taken by those projects and helps us understand the reasons behind the choices made.

Many ongoing monitoring programmes are established throughout Europe, monitoring different biodiversity traits, primarily on birds, mammals, and plants, whereas habitats are monitored to a much lesser extent. Several thematic reviews give an overview of existing monitoring programmes and practices, noticeably concerning birds (Schmeller *et al.*, 2012; Klvaňová, A., & Voříšek, P., 2007), and biodiversity in agricultural landscapes (Oppermann *et al.*, 2018; Guy *et al.*, 2021).The full range of essential biodiversity variable classes (genetic composition, species traits, species populations, community composition, ecosystem functioning and ecosystem structure) are generally not covered within each country by monitoring programmes, and data are collected through different protocols and methods.

Several initiatives at the pan-European level have worked towards international cooperation to harmonise and inter-calibrate existing monitoring methodologies. The European Commission and the European Environment Agency (EEA) have funded some projects[13] in this scope, such as the EUMON project (2004-2008) identifying EU-wide systems of surveillance for species and habitats of Community interest, the European biodiversity observation network (EBONE, 2008-2012) (De Blust *et al.*, 2012), the pan-European Marine Biodiversity Observatory System (EMBOS[14], 2010-2015, and EMBOS+ from 2015-on), the EU BON: building the European Biodiversity Observatory Network[15] (2012-2017), and the ongoing EuropaBON (2020-2023) and Biodiversa+ (2021-2028) projects. These projects aimed to design and test a biodiversity observation system over large scales of time and space, and have discussed the feasibility of developing such a monitoring network at a pan-European level; they have mostly highlighted the difficulties of such an approach. They provide a positive perspective for achieving a European-wide biodiversity monitoring scheme, but they also conclude that a considerable effort of harmonisation remains.

EuropaBON has taken a particular interest in the use of EBVs to achieve the design of an EU-wide monitoring framework for biodiversity. In their User and Policy Needs Assessment (2022), the results of EBV ranking by stakeholders for their relevance to policy needs are presented. Among the highest-ranked EBVs are species abundances, species distributions, and ecosystem and habitat distribution. The majority of these highly ranked EBVs were nevertheless said to be insufficiently monitored throughout Europe, although most are at least partially monitored in each country. A harmonisation effort still has to be done but there are bases to build onto.

[13] European Environment Agency. (2011) List of EU research projects about biodiversity and ecosystems. Available at: https://www.eea.europa.eu/data-and-maps/data/eu-research-projects-on-biodiversity/projects/research/view
[14] EMBOS. Available at: https://embos.info/
[15] EU BON. Available at: http://www.eubon.eu/

Case studies

International Waterbird Census (IWC) (1967–ongoing)

Objectives and organisation

The International Waterbird Census (IWC) is a monitoring scheme assessing waterbird populations abundance, and considered to be one of the most widespread and longest running biodiversity monitoring programmes, having kept the same monitoring scheme throughout the years, now with a modernised database for online submission, manipulation and storage of data. It is coordinated by Wetlands International, whose head office is based in the Netherlands and has a network of offices, often independent entities, around the world. The IWC is organised in separate regional schemes representing the major flyways: Africa-Eurasia (AEWC), Asia-Pacific (AWC), Caribbean (CWC), Neotropics (CNAA), and Central America (CCAA).

The monitoring programme operates in a total of 143 countries.

Protocol type

The IWC represents one of the largest citizen science programmes, with the vast majority of contributors being volunteer birdwatchers. The monitoring protocol is based on site-based counting. A single count at each same site is carried out yearly. A manual (Wetlands International, 2010) presenting the common standards and field protocol for the waterbird counting is available on the Wetlands International website [16], as well as a guidelines document (Delany, 2005) for the participants in the IWC. As various waterbird populations, here understood as different groups of a species, require different monitoring schemes, the manual provides general recommendations, no strict protocol is defined. These recommendations concern for example different possible counting techniques and specialised methods for roost counts and colonially nesting species counts.

Data analysis

The census is coordinated at a national level, coordinators manage their countries' counts and counters. National coordination entities gather the counts and send them to Wetlands International, which integrates the raw data into the global database and produces a synthesis at each regional flyway scale.

An online site[17] was developed for IWC national coordinators to submit and manage the counts, and define the count sites in their countries. Other users can request access to the national count information from national coordinators via the website.

In general, local entities analyse the Wetlands data to produce national annual trends as well.

The data gathered by Wetlands International are made accessible through the Conservation Status Reports, the Waterbird Population Estimates, and the Critical Site Network Tool[18]. The Waterbird

[16] Wetlands international. IWC Guidance: Field protocol for waterbird counting. Available at: https://www.wetlands.org/publications/iwc-guidance-field-protocol-for-waterbird-counting/

[17] Wetlands international. International Waterbirds Census. Available at: https://iwc.wetlands.org

[18] Critical sites network. Available at: http://criticalsites.wetlands.org/en

Populations Portal (WPP) online database[19] provides current and historic estimates and trends.

More information: https://www.wetlands.org/knowledge-base/international-waterbird-census/

Agreement on the Conservation of Populations of European Bats (EUROBATS) (1994–ongoing)

Objectives and organisation

The Agreement on the Conservation of Populations of European Bats (UNEP / EUROBATS) (1994) aims to set the implementation of conservation measures and international cooperation for all European bat species. The EUROBATS Secretariat undertakes initiatives for implementing the Agreement. The Secretariat assists in establishing a Pan-European monitoring scheme, bringing together existing surveillance programmes and starting up one in countries that have none, in order to detect changes in distribution, range, and abundance and provide long-term population trends at the continent scale.

To date, 38 States are Parties to the Agreement.

Protocol type

Involved State Parties provide the Secretariat of the Agreement with the results of monitoring work carried out in their territory to produce European-wide assessments (EUROBATS Meeting of the Parties, 2022).

A set of guidelines for the monitoring of European bats was published (Battersby, 2010), recommending best practices in monitoring methods. It was recognized that consistent methods need to be developed within and between countries to allow comparison of results obtained and eventually the production of European trends for bat populations. This document however stays quite general, acknowledging that there is no single methodology that would be applicable for all bat species at the continent level and that species-specific methods will need to be defined.

EUROBATS encourages all Parties and their governmental institutions as well as Non-Governmental Organisations involved in bat monitoring to adopt the proposed guidelines.

Data analysis

EUROBATS envisioned the development of a data sharing structure where raw data would be a census, with statistical tools to calculate pan-European and regional trends, managed by Batlife Europe. Nevertheless, the Working Group concluded that such a database was currently not possible to establish due to the significant variation in the kind of data currently available for incorporation (UNEP/EUROBATS, 2022).

[19] Wetlands international. Waterbird Population Portal. Available at: http://wpp.wetlands.org/

Prospects and further development

The development of a prototype bat population indicator is planned, in which national trends would be combined by a central statistical team to create pan-European trends. A workshop is to be hosted to agree on a strategy to better incorporate data provided by bat monitoring schemes. EUROBATS is aiming to follow an approach based on the production of national EBVs as a strategy to combine data at a wider scale (UNEP/EUROBATS, 2022).

More information: https://www.eurobats.org/

Small Cetaceans in European Atlantic waters and the North Sea (SCANS) (1994–ongoing)

Objectives and organisation

The SCANS project aims to estimate and assess the trends and abundance of the regularly occurring cetacean species in European Atlantic waters, providing information for the Member States to report under the Marine Strategy Framework Directive, the Habitats Directive, and for OSPAR/HELCOM assessments. SCANS is based on survey methods covering all Atlantic shelf waters under European jurisdiction. The group of researchers that proposed the first SCANS survey envisioned that surveys taking place every 5-10 years were adequate to provide information to meet the conservation objectives (Hague *et al.*, 2020).

The original SCANS (1994) and SCANS-II (2005-2007) projects were supported by the European LIFE Nature programme. Despite being rejected by the European Commission, the SCANS-III project (2016) was nevertheless carried out, funded by the committed Member States to a joint cetacean monitoring programme (Denmark, France, Germany, the Netherlands, Norway, Portugal, Spain, Sweden, and the UK) (Hammond *et al.*, 2017).

The SCANS-IV project (2022–2023) is also being supported by the Member States and is coordinated by the Institute for Terrestrial and Aquatic Wildlife Research (ITAW) of the University of Veterinary Medicine Hannover (TiHo) Foundation, in Germany, in partnership with institutes from other supporting countries.

Protocol type

A common protocol is carried out, the methodology consisting of both airborne and shipboard surveys, using regional existing survey teams, for visual counting and identification. In addition, a remote sensing system on board taking high-definition pictures is used.

Although having followed the same general methodologies, each SCAN project has been developed from scratch by a mixed team of scientists from different countries. The two main reasons for this

were first to further develop the previous SCAN framework to survey more species and to incorporate consideration of anthropogenic effects on the populations. On the other hand, the methodologies had to be revised considering the limiting funding, reducing the collection of data from one of the protocols, i.e. the shipboard surveys (Hammond *et al.*, 2017).

Data analysis

The surveys are carried out by experienced observers and researchers from the involved Member States, mostly coming from structures (NGOs, universities, research institutes) already participating in cetacean research and monitoring. At the beginning of the SCANS project, workshops are organised to train observers and data analysts (ASCOBANS, 2013).

The data are jointly processed and analysed by the scientific team, and the results are compared with those from previous projects.

More information: https://www.tiho-hannover.de/itaw/scans-iv-survey

Large Carnivore Initiative for Europe (LCIE) (1999–ongoing)

Objectives and organisation

LCIE, a Working Group within the Species Survival Commission (SSC) of the IUCN, coordinates and provides networking between conservation and research projects. A common report is produced every 6-7 years about the status of large carnivores across Europe with the information provided by each country to LCIE.

Protocol type

This coordinated framework sets basic principles and general guidelines for the management and monitoring of large carnivore populations, without defining a universal approach for each country to follow. Based on the understanding that Europe is diverse both in its bio-geographic and cultural contexts, LCIE takes a ‘freedom within frames' approach. Each country carries out a monitoring scheme tailored to its local social (e.g. the extent to which hunters collaborate with providing data) and ecological (e.g. the presence or absence of snow) conditions to study the status of large carnivore (bears, wolves, Eurasian lynx and wolverines) populations in its territory.

For example, some countries follow the populations by DNA collection (from scats or hairs): Scandinavia, Italy, Austria, Spain, France, Greece, and Slovenia. Other countries obtain data mainly by other methods (such as counts at feeding sites, snow tracking, and telemetry): Croatia, Poland, Slovakia (Linnell *et al.*, 2008).

Data analysis

LCIE gathers the EBVs provided by the Country Species Reports (noticeably the EBV population abundance and the EBV population distribution per species) and aggregates them to estimate population trends and produce distribution maps. Distribution ranges are calculated at the national level and aggregated at the European level.

More information: https://www.lcie.org/

Status and Conservation of the Alpine Lynx Population (SCALP) (2012-ongoing)

The Status and Conservation of the Alpine Lynx Population (SCALP) project is an example of a monitoring programme developed by the Large Carnivore Initiative for Europe (LCIE).

Nine countries participate in this monitoring programme, which is coordinated by the KORA - Carnivore Ecology and Wildlife Management foundation in Switzerland[20].

SCALP produces yearly lynx distribution maps based on data collected by different means. The standardisation process takes place at the data interpretation level. Each record is evaluated on whether the correct species identification was (or can be) verified, and classified according to three categories: verified observations, confirmed and controlled observations, and unconfirmed but plausible observations.

More information: https://www.kora.ch/en/kora/scalp/

Monitoring programmes for the Water Framework Directive (WFD, 2000/60/EC) (2000–ongoing)

Objectives and organisation

This Directive defines a European Union framework for community action to improve and protect the quality of all water bodies at the river-basin level across Europe (Off. J. Eur. Comm. L327 (2000)). Article 8 of the WFD calls for the implementation of a monitoring programme on water bodies to "establish a coherent and comprehensive overview of water status within each river basin district". The 27 EU Member States answer to this Directive.

The WFD has been cited by EuropaBON as being a good example of harmonisation at a European level. It is, nonetheless, complex in its structure and involves various levels of organisation for its setup.

[20] KORA. Carnivore Ecology and Wildlife Management. Available at: https://www.kora.ch/en/

Among the assessments to be carried out by each Member State, there is compliance with biota environmental quality standards (EQRs). The different EBVs to be assessed for each surface water category are taxonomic diversity, community abundance, and ecosystem disturbances. Other parameters taken into account are: age structure, disturbance of sensitive taxa and taxa indicative of pollution. The indices or metrics to be used for the assessment are not imposed by the WFD, this decision is up to each Member State, as long as they produce and deliver the asked EQRs for each biological element (Hering *et al.* 2010).

Protocol type

To assist stakeholders in implementing the WFD, guidance documents[21] and technical reports[22] have been drafted under the Common Implementation Strategy, providing an overall methodological approach. Nevertheless, the methods need to be adapted and tailored to the specific biogeographic circumstances and the ongoing national methods and monitoring traditions.

Data analysis

In order to ensure comparable results produced by different monitoring systems, an inter-calibration exercise was carried out under the coordination of the Joint Research Centre (JRC) and led by the Ecological Status Working Group (ECOSTAT) (Poikane *et al.*, 2014; Willby *et al.*, 2014). This inter-calibration takes effect on the classification results and on the commonly agreed standards and indicators, it does not impact the monitoring systems or biological methods themselves (De Blust *et al.*, 2012). Each country follows a nationally standardised method to produce the EBVs. Harmonisation at the European level is not done at the data or EBV level but at the qualitative result level.

EQRs are uploaded to the Water Information System for Europe - Biology data (WISE-2[23]) on the European Environment Information and Observation Network portal (Eionet[24]), established by the European Environment Agency (EEA).

More information: https://www.eea.europa.eu/policy-documents/directive-2000-60-ec-of

[21] European Commission. Water Framework Directive - Guidance Documents. Available at: https://ec.europa.eu/environment/water/water-framework/facts_figures/guidance_docs_en.htm
[22] CIRCABC. Available at: https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/a3c92123-1013-47ff-b832-16e1caaafc9a
[23] Eionet Central Data Repository. WISE SoE - Biology data (WISE-2). Available at: https://cdr.eionet.europa.eu/help/WISE_SoE/wise2
[24] Eionet Portal. Available at: https://www.eionet.europa.eu/

Global Observation Research Initiative in Alpine Environments (GLORIA) (2001–ongoing)

Objectives and organisation

The Global Observation Research Initiative in Alpine Environments (GLORIA) is a worldwide observation network to assess the impacts of climate change in alpine ecosystems, by establishing a long-term monitoring scheme on permanent plot sites. The GLORIA protocols provide standardised, quantitative data on species richness, plant species composition and abundance, and habitat characteristics to produce global trends.

It started as a European Union and Swiss MAVA foundation project. Funds are now provided by different national and private sources. The necessary funding has to be taken into account to assure the continued operation of long-term projects such as this one. For this reason, GLORIA opted for a monitoring scheme of low maintenance costs, keeping permanent plots, which are surveyed at a low frequency (every 5 to 10 years) via simple field methods.

Having a large-scale network of permanent plots to sample is also an attractive strategy for research purposes, as data can be used as a baseline for detailed monitoring.

GLORIA is coordinated at a joint office of the Austrian Academy of Sciences (ÖAW) and the University of Natural Resources and Life Sciences Vienna (BOKU), Austria. Regional GLORIA networks facilitate the implementation process, but all sites share a common protocol on a global scale. 138 sites are established, across 43 countries around the globe.

Protocol type

GLORIA surveys follow a strict protocol, detailed in the Guidelines for standardised use of the GLORIA monitoring methods manual[25]. The methods were refined at the GLORIA Conference (2010, Perth, Scotland) 10 years after the beginning of the initiative, incorporating field experience and feedback from around 100 members.

The implementation of a new target region for the GLORIA monitoring scheme comes from the volunteer initiative of an individual or institution interested in joining the network. Site managers are responsible for the maintenance of their site, ensuring sufficient funding and Human capacity for the programme, especially considering that specific expertise and experience are required to carry out the surveys. Most GLORIA participants are researchers or are based at universities, assuring a long-term monitoring effort through their institutions.

Data analysis

The collected data are uploaded to the GLORIA website, where it is checked by the programme's coordination group before being entered into the central GLORIA database (CGDB). The data provider retains nonetheless the exclusive ownership of the data and has to provide permission for their data to be used to calculate global trends. The collected data is used as well locally by

[25] GLORIA. The GLORIA field manual. Available at: https://gloria.ac.at/methods/manual

researchers for specific region-related studies regarding the effects of climate change.

More information: https://gloria.ac.at/home

Pan-European Common Bird Monitoring Scheme (PECBMS) (2002–ongoing)

Objectives and organisation

The Pan-European Common Bird Monitoring Scheme uses long-term monitoring data on common birds to produce policy-relevant indicators of the state of bird populations abundance at the European-level, by combining population trends from annual national breeding bird surveys.

Its central coordination unit overseeing the project is based at the Czech Society for Ornithology, and the project is co-founded by BirdLife International and the EU. Each Member State is in charge of its national monitoring schemes, via various institutions (governmental agencies, NGOs, research institutes, etc). In most cases, field surveys are done by volunteers, and managed by national coordinators.

This programme involves 29 countries, and 31 monitoring schemes (Belgium being covered by three regional schemes: Brussels, Wallonia and Flanders), with a total of 25,666 locations (PECBMS, 2022).

Protocol type

Member States carry out independent monitoring schemes, having their own methods for their national bird monitoring programmes. Annually, the national coordinators send the EBVs resulting from the monitoring schemes to the PECBMS central coordination. National EBVs are delivered according to agreed standards and formats.

The national EBVs delivered are:

- yearly abundance indices per species,
- yearly all-sites total counts per species.

The field methods to produce these national EBVs are free to each Member State to define, being of minor concern as long as this method is standardised and consistent through the years to provide reliable national trends (De Blust *et al.*, 2012*;* Schmidt & Van der Sluis, 2021). There is also a PECBMS Best Practice Guide (Voříšek *et al.*, 2008) available containing information on methods, with the aim of helping to improve the scientific standard of bird monitoring.

Data analysis

Supranational yearly trends are produced by the PECBMS coordination unit via TRIM (Trends and Indices for Monitoring Data; Pannekoek & Van Strien, 2001), a standard software tool to analyse

time series of count data obtained from different monitoring schemes. The calculations take into account the differences in field methods and the number of sites and years covered by country. European trends are published on the PECBMS website.

National farmland bird indicators are produced from the European biogeographical species-habitat classification used by PECBMS and not by the existing national classification system. They are accessible *via* the Organisation for Economic Co-operation and Development (OECD) website[26] and the EUROSTAT website[27].

Example of different schemes applied for the PECBMS in different countries

Bulgaria: Common Bird Monitoring Scheme (MOWP), coordinated by the Bulgarian Society for the Protection of Birds[28].

- 63 monitored bird species,
- 120 volunteers,
- line-transect method,
- stratified random selection of plots,
- carried out twice per year,
- observations are recorded and stored on a website specifically designed for the scheme[29]

Estonia: Point count project, coordinated by the Estonian Ornithological Society (EOS) in partnership with BirdLife Estonia[30].

- 90 monitored bird species,
- 60 volunteers,
- point count methods,
- free selection of points,
- Carried out once per year,
- data sent by email to the national coordinator.

Comparison of PECBMS and IWC

Both PECBMS and IWC are long-running programmes monitoring birds. A short comparison was carried out to determine whether there are overlaps, e.g. in the monitored species and whether these programmes come to the same results.

The final PECBMS list of species for 2021 (which can be downloaded on their website[31]), and the

[26] OECD.stat. Available at: https://stats.oecd.org/

[27] Eurostat. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_bio2&lang=en

[28] BSPD. (2012). Available at: http://www.bspb.org/monitoring/ (in Bulgarian)

[29] SmartBirds. Available at: https://smartbirds.org/

[30] BirdLife International. Available at: https://eoy.ee/ET/13/14/punktloendus/ (in Estonian)

[31] PECBMS and EBCC. Species selection and classification. Available at: https://pecbms.info/methods/pecbms-methods/3-multispecies-indicators/species-selection-and-classification/

IWC species count list[32] for the African-Eurasian region for the period 2017 - 2021 were compared: 24 out of the 170 species monitored in the PECBMS are also part of the IWC list (680 species).

Both programmes deliver trends for those species. It should be kept in mind nonetheless that IWC surveys take place in winter, whereas the ones for PECBMS are carried out during spring, so it is not the same populations that are monitored. Multispecies Trends for the European Union are also delivered by both programmes. Nevertheless, these are not suitable for comparison, as PECBMS takes into account all common birds, whereas IWC focuses on combined trends for either waterbird species protected under Annex 1 of the European Birds Directive, or on those under Annex 2, or on non-breeding EU waterbird species not listed under the Directive.

An information report on the overview of monitoring work of waterbird populations in the Wadden Sea and the East Atlantic Flyway (van Roomen *et al*., 2011) mentioned that the PECBMS and the IWC complement each other for some information on the species in common that are monitored. It was mentioned for example, that for a few isolated populations that are not well covered by the IWC, the data from the PECBMS are used to complete the dataset.

More information: https://pecbms.info/

Environmental Assessment for Soil Monitoring (ENVASSO) (2006–2008)

Objectives and organisation

ENVASSO was a project funded by the European Commission as Scientific Support to Policy (SSP). Its main objective was to harmonise existing national soil monitoring networks to establish a European-wide system in support of a Soil Framework Directive proposal. Nevertheless, this proposal was not accepted, there currently is no Soil Directive in place.

ENVASSO's approach was to review existing soil monitoring programmes, indicators, and criteria that could serve as a base for a soil monitoring system for Europe. Indicators were agreed on by experts and corresponding protocols were evaluated in pilot sites across Member States (Arrouays *et al*., 2008; Micheli *et al*., 2008).

The ENVASSO Consortium comprised 37 partners from 25 EU Member States and was tested in 28 pilot sites.

Protocol type

One of the difficulties encountered in the harmonisation of data from existing national Soil Monitoring Networks was the wide variety of well-established methods among countries. Implementing a new

[32] Wetlands international. International Waterbird Census. Available at: https://iwc.wetlands.org/index.php/nattotals

common protocol would impede the comparison with previous data and a parallel analysis using national and new reference methods would be needed. ENVASSO's recommendation was to adopt a cross-method validation programme so that the existing monitoring systems would be exploited efficiently to produce new common indicators, without having the past investment in those systems lost. As for the sample site location, it was recommended to establish a systematic grid across Europe.

Data analysis

Another cited difficulty was the variation in performance of different laboratories, even when applying the same methods. To improve harmonisation at the EU level, ENVASSO recommended the use of a central laboratory to carry out analysis on a subset of samples to compare the results of various methods used by different countries.

Conclusions and further development

The main conclusions of this project were that the harmonisation of field sampling and testing procedures requires the development of a calibration method, the production of guiding manuals and supporting advice, central archiving and reporting, a well-maintained database, and specific training for all agents involved. ENVASSO considered that the establishment of a European Center could facilitate the process, by providing the needed infrastructure and by acting as a reference laboratory for soil testing. BioSoil (detailed next) was identified by ENVASSO as being the monitoring scheme which comes the closest to the requirements proposed for large-scale soil monitoring in Europe (Kibblewhite *et al.*, 2008).

More information: https://esdac.jrc.ec.europa.eu/projects/envasso

BioSoil project (2006–2009)

Objectives and organisation

The BioSoil project was a test for the development of a harmonised and operational soil monitoring system at a European level, providing standardised soil and biodiversity data for research and forest-related policies. This demonstration project, under the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), was carried out as part of an administrative arrangement between the European Commission Joint Research Centre (JRC) and the Directorate General Environment (DG ENV). The survey was managed through National Focal Centres following standard procedures, with a total of 32 countries having submitted data.

The implementation of the BioSoil biodiversity project was successful, demonstrating that a European-level harmonised inventory of biodiversity indicators for forests is feasible. It also showed that it can be relatively rapidly implemented when building upon existing structures and procedures

to shorten the development phase (Hiederer *et al.*, 2011). The manual with the corresponding methods which have been tested and validated in the field is available (Neville & Bastrup-Birk, 2006)

The biodiversity survey of BioSoil aims to collect soil data from forest plots, which were classified according to age, origin, and composition of the stand and any known previous land-use and stand management:

- the structural forest diversity:
  - Diameter at breast height and species composition of all woody plants (DBH)
  - Forest deadwood assessment: coarse woody debris
  - Canopy closure and tree layering
- and the compositional forest diversity:
  - Ground vegetation (vascular plant species list)

Protocol type

BioSoil indicators were selected from existing recognized sampling variables. The assessments were fully harmonised, meaning that for every sampling point the same variables were assessed and followed the same methods.

Soil sampling plots are selected from a transnational grid network of sites, which was already defined for the forest environment monitoring under Forest Focus / ICP Forests.

There is nevertheless certain flexibility for the site selection and the sampling configuration. Countries may operate at a sample point level; its area being not necessarily known and/or fixed. Countries could also choose to use random sampling units instead of the recommended BioSoil subplots if wanted. The biodiversity survey was carried out by local surveyors.

Data analysis

The collected data were sent to a central laboratory, the European Commission's Institute for Environment and Sustainability (IES) (Ispra, Italy), for a joint analysis of all Member States' data. This was the first project in which a central laboratory acted as a reference for European soil analysis, improving harmonisation for a proper comparison of results.

For the biodiversity module, only raw data were sent to the IES central laboratory for analysis. The soil module, however, adopted a different approach in which analyses were performed both at national laboratories and at a central reference laboratory (INRA Arras laboratory). Soil samples analysis was first done at a national level by national laboratories following all the same procedures and the same inter-calibration tests. Then, 10% of the samples were sent to the central laboratory managed by the French National Institute for Agricultural Research (INRA) to be re-analyzed. The results from the central laboratory were compared with those coming from different national laboratories using different methods for analysing the data. This exercise was done as a data quality check. It showed that there was in general a good agreement between the results, but that there were procedural inconsistencies in sample labelling and results reporting (Hiederer *et al.*, 2011).

Land Use/Cover Area frame statistical Survey (LUCAS Soil) (2009–ongoing)

Objectives and organisation

LUCAS soil is a regular, harmonised field survey covering all 27 European Union Member States to derive policy-relevant statistics on the effect of land use on soil characteristics. It has allowed the creation in 2013 of the first consistent open-access dataset of topsoil properties for the European Union, with only a negligible phenomenon of missing data (Orgiazzi *et al.*, 2017). The surveys have been carried out and the results of sampling campaigns are made available on the database every 3 years (2009 /2012 - 2015 - 2018 - 2021/2022).

This programme is managed by the Statistical Office of the EU (Eurostat) with the technical support of the Joint Research Centre (JRC). All choices related to the survey are taken at the JRC, from defining and selecting the different targets, and sampling protocol management (e.g. selecting the sampling points), to analysing the data and producing the final statistics.

To carry out the survey with different levels of quality control, a hierarchical structure has been set up, including local surveyors, an internal JRC supervisor for a second quality check, Eurostat Central Office, and external Quality Control performed by private companies. The various actors involved in each step have received specific training from Eurostat in Luxembourg.

Protocol type

A strict protocol for data collection is followed and carried out in a single sampling period for all Member States. The initial field sampling protocol was built based on the 2006 BioSoil sampling manual (see below) and from the standard FAO Guideline for Soil Profile Description. Feedback from surveyors brought the protocol to be slightly adapted, the corresponding amendments were made to the guidelines for sample collection.

The site selection for data collection follows a multi-stage stratified random sampling approach. The LUCAS soil points are selected from the LUCAS 2009 regular grid based on land use and terrain information. Surveyors are given a list of three alternative sampling points within the surveyed area from the LUCAS grid that have common characteristics in case the extraction in the first given site is not possible.

In the 2009-2012-2015 surveys, physico-chemical parameters were studied. From 2018 on, LUCAS soil includes soil biodiversity in the EU as one of the 10 data sets developed. An EU assessment of soil biodiversity based on DNA metabarcoding is being included as part of the survey, aiming to determine the biological diversity of soil, and estimate its spatial distribution and its relations with environmental features. Biodiversity indicators are still to be defined; the sampling and analysis follow an exploratory approach for the moment (Maréchal *et al.*, 2022).

Data analysis

All soil samples of the LUCAS Surveys have been analysed by a single accredited laboratory since the beginning of the programme, the SGS Hungária Kft in Hungary, using standard analytical

methods to provide coherent and comparable data (Jones *et al.*, 2020). This choice was made to reduce unknown systematic errors and inter-laboratory bias between countries. These same reasons were cited by the German Agricultural Soil Inventory when using a similar approach for data analysis (Bach *et al.*, 2011 cited in Jones *et al.*, 2022). Furthermore, experience with data collected under the BioSoil Forest Focus (see below) showed that inter-laboratory bias between countries resulted in inconsistencies between the Member States for the final results (Jones *et al.*, 2022).

The analytical data are then made available to the public through the European Soil Data Centre[33].

Prospects and further development

A study carried out by IPC Forest, comparing LUCAS soil samples in forest areas, revealed that the LUCAS points' representativeness could be improved (Ziche *et al.*, 2022; Maréchal *et al.*, 2022).

The number of sites to assess is being reevaluated to have a representative EU soil monitoring system, as part of the LANDMARK H2020 Project. Given recent budgetary considerations, the funding will probably not be made available to sample the scale proposed by the LANDMARK study (and earlier, by the ENVASSO project 2008) (Jones *et al.*, 2022; European Commission, Joint Research Centre, 2020).

Other options are being explored to see how LUCAS soil can be integrated into or aligned with national monitoring schemes. This could be possible by keeping good quality management of the sampling process and by recording any deviations from the original LUCAS grid. Allowing higher flexibility in the choice of sampling sites is being thought of as improving the quality and significance of the data set. The EU Soil Observatory (EUSO), launched in December 2020 under the umbrella of the European Green Deal, is looking into this, as part of its mission to support the development of an operational EU-wide Soil harmonised Monitoring System (Technical Working Group on Soil Monitoring, workshop on soil monitoring at the EUSO Stakeholder Forum, 19-21 October 2021). Discussions between EUSO and some Member States lead to including a number of sampling points specifically requested by the Member States for LUCAS 2022 (Maréchal *et al.*, 2022).

LUCAS grassland survey

In 2018 a pilot grassland module was carried out within the LUCAS survey, being the first standardised methodology to collect ecological data on grasslands at the European level. Among the information collected, there was for example the presence of indicator species, or the number of flowering species. The parameters were recorded by trained surveyors on transects placed over a subset of LUCAS points randomly selected. In addition, to check the accuracy of the recording, botanists from the different countries were recruited to carry out full vegetation inventories on a subsample of the transects (Sutcliffe *et al.*, 2019).

The results of the pilot show an overall successful survey, and the continuation of the LUCAS grassland survey was encouraged (LUCAS, 2018).

More information: https://esdac.jrc.ec.europa.eu/projects/lucas

[33] Joint Research Centre. European Soil Data Centre. Available at: https://esdac.jrc.ec.europa.eu/

European Butterfly Monitoring Scheme (eBMS) (2016–ongoing)

Objectives and organisation

Butterfly Monitoring Schemes (BMS) are organised throughout Europe recording butterflies yearly to identify population trends and assess the status of butterfly species. eBMS is a joint initiative formed by Butterfly Conservation Europe and the Center for Ecology and Hydrology (UK) and is managed by the Natural Environment Research Council (UK). Currently, 22 countries have their respective BMS.

The first BMS was carried out in the United Kingdom in 1976, following the standardised survey method of "Pollard Walks" (designed by the Monks Wood Experimental Station in the UK by Pollard and Yates, 1983). Since the 90s, other European countries have adopted the same methodology, slightly adapting it to their territory in terms of survey frequency and transect site selection. This monitoring methodology was formally organised as eBMS in 2016 by Butterfly Conservation Europe[34], bringing together the data resulting from the different countries' BMS into a common database.

Protocol type

Data are collected following the same standardised survey method with some flexibility, noticeably in regards to transect location and number of counts, allowing a better adaptation to each country's ecological context and means. The method is based on line transect sampling under standardised conditions. As an alternative, when there might be difficulties in applying transects in some areas, the methodology of 15-min Counts can be used (Van Swaay *et al.*, 2015), allowing even further flexibility.

Data collection is generally done by trained volunteers.

Data analysis

The collected data goes through a quality control check by national coordinators, who then submit the data to the eBMS database. A standardised assessment of changes in butterfly abundance at the EU scale over time is achieved through the implementation of statistical modelling techniques taking into account uneven sampling.

Furthermore, the data uploaded to the eBMS database is available, on request, for targeted analyses (e.g. for specific regional studies).

More information: https://butterfly-monitoring.net/

[34] Butterfly Conservation Europe. Available at: https://www.vlinderstichting.nl/butterfly-conservation-europe/

Assessing Butterflies in Europe (ABLE) (2019–2020)

ABLE was a project under the direction of eBMS which aimed to develop capacity building and improve butterfly monitoring data collection. This project had successful results in promoting and improving butterfly monitoring as well as in producing high-quality butterfly indicators and tools for volunteers and coordinators across Europe (Roy *et al*, 2020).

One of ABLE's results was the establishment of new Citizen Science Butterfly Monitoring Schemes in 10 additional countries. The project's approach was to apply the methods from existing BMSs combined with knowledge and experience of differences in cultural identity and habits between countries. A considerable effort was made to promote citizen science in countries where the general public volunteering in environmental projects isn't part of the culture (such as in eastern countries, compared to the UK and the Netherlands). This was achieved through workshops, training events, outreach activities, and social media promotion.

National coordinators train volunteers, define the transect routes and organise the field surveys.

A Butterfly Transect Manual (Sevilleja *et al.*, 2019) was produced, along with other support materials and tools (such as the ButterflyCount App).

It was noted that, although the Butterfly Monitoring Schemes are standardised between countries, the flexibility given for the choices of the location for the transect and the number of counts may lead to biases in the calculation of the eBMS trends, especially as there tends to be an oversampling in species-rich sites (Sevilleja *et al*., 2020). It has also been noted that there are gaps between regions and within the Member States regarding the implementation of eBMS, some regions being more covered than others (SPRING, 2022).

An investment in developing tools to integrate data from various sources was recommended, noticeably with the implementation of the planned implementation of the Strengthening pollinator recovery through indicators and monitoring (SPRING) project (Sevilleja *et al*., 2020).

More information: https://butterfly-monitoring.net/able-results

Strengthening Pollinator Recovery through Indicators and Monitoring (SPRING) (2021–2023)

Objectives and organisation

SPRING is an eBMS pilot project for monitoring pollinators at the European level, building on the work of the ABLE project. The SPRING project aims to complete the coverage of the eBMS to all 27 EU Member States, and to expand the monitoring effort to other pollinator groups beyond butterflies. Another of the project's aims is to develop training courses and tools for the volunteer participants.

The results and experience from this project will be used to make recommendations for establishing a sustainable EU Pollinator Monitoring Scheme (EU-PoMS[35]).

This pilot project is under a Parliamentary Preparatory Action contract, coordinated by DG Environment, involving 19 partners, and led by the Helmholtz Centre for Environmental Research (UFZ, Germany). A regional coordination approach was taken, where 7 regions were designed and 1 country per region is in charge of the implementation of the pilot study.

Protocol type

This project focuses on a core scheme defining the minimum viable schemes (MVS) to set up. The MVS methods will be piloted at 1-24 sites per country, according to the geographic area of each country, in at least 209 sites across the EU. Those sites will include sites that are already part of other Schemes, such as within the eBMS partnership.

It is not yet defined whether these sites will be the definitive ones for long-run monitoring. This question will be further studied to see if it would be beneficial to set them in the same sites as LUCAS on soil or EMBAL in agricultural landscapes.

The SPRING monitoring schemes are based on eBMS protocols, and integrate a new monitoring approach: the Flower-Insect Timed (FIT) counts, which have been adapted to each country's species and habitats.

The protocols for this monitoring programme have some flexibility, with each country implementing the same general methodology in a best-adapted way for their territory.

Data analysis

For this pilot study, the data collected from the two different methods are combined to produce trends at the EU scale. A specific website supports the data entry for the SPRING project[36]. Modelling tools are used to harmonise the data, considering that Member States implement the protocols with different frequencies and that different recorders are involved (e.g. for some pilot sites there are no volunteer observers, only trained professionals).

At the end of this pilot phase, a standardised tested approach will be available, and it would be up to each Member State to implement it, or not, to report to the EU on the state of pollinators in their territory.

The data are therefore treated at a national level by each Member State, and at a European level for the test phase of the methods.

It hasn't been decided yet where data and trends will be stored. For the moment, a few countries already have their own system, so probably it will be developed independently in each country and there will be no need to develop a central data storage infrastructure.

More information: https://www.ufz.de/spring-pollination/

[35] European Commission. Pollinator Species Monitoring (EUPoMS). Available at: https://wikis.ec.europa.eu/pages/viewpage.action?pageId=23462107
[36] SPRING. Available at: https://pollinator-monitoring.net/

European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL) (2017–ongoing)

Objectives and organisation

The EMBAL project aims to provide a harmonised pan-European monitoring system to assess biodiversity in agricultural landscapes. This initiative was launched by the European Commission as part of the EU biodiversity strategy and the EU common agricultural policy implementation. The Institute of Agro-ecology and Biodiversity (Ifab) is running the EMBAL project in partnership with EFTAS-Geoinformation and IT services. EFTAS hired freelance surveyors for the EU 27 countries, specifically for the EMBAL project (Offer: Surveyors for Europe-wide EMBAL field surveys 2022)

EMBAL builds on the Landscape, Infrastructures and Sustainable Agriculture (LISA) study (Oppermann *et al.*, 2021), which was proposed and tested in 2014–2017, a methodology for the data collection on farmland biodiversity. A pilot project was launched to test the monitoring system developed by EMBAL, and experts and stakeholders' workshops were organised for further discussion on the methodology. EMBAL is currently in its implementation phase in all 27 EU Member States for 2022-2023.

Protocol type

For the development of the methodology, a thorough analysis of existing monitoring approaches at the national and European scales had been conducted, with the aim of harmonising as much as possible the new approach with existing schemes. The field survey methodology combines parameters from the most relevant established surveys that were identified, noticeably the LUCAS surveys and the HNV farmland monitoring. These two approaches were selected for their relevance with respect to their spatial and temporal coverage, cost-effectiveness, and ability to assign recorded change to policy measures.

The biodiversity parameters that are monitored through the transect survey are species diversity and composition, coverage of wild plants, and the types and distribution of EUNIS habitats. The species lists are harmonised with the LUCAS grassland survey and the HNV farmland monitoring lists from Germany (Oppermann *et al.*, 2018).

EMBAL follows a strict survey protocol on sampling plots randomly selected from the LUCAS grid, with the number of survey points left to each member state to decide based on political and/or budgetary considerations. A field survey manual was published in 2017.

Data analysis

Data is collected by trained surveyors and uploaded to an open-source software Open Data Kit (ODK) Central server. An automatic data upload to the central database is now possible through the smartphone application for surveyors, since inconsistent data entries were producing errors for the calculations in previous years' surveys (Lindemann *et al.*, 2021, EMBAL survey protocol). The raw datasets uploaded to ODK Central are then treated per plot by EFTAS' central office in Münster, Germany.

More information: https://wikis.ec.europa.eu/pages/viewpage.action?pageId=25560696

A Planetary Inventory of Life (LIFEPLAN) (2020–2025)

Objectives and organisation

The LIFEPLAN project, “a planetary inventory of life”, aims to characterise the state of biodiversity across the globe, by establishing a worldwide sampling programme for a range of species groups. Global joint species distribution models will be developed, to improve the knowledge about species richness and community structures and how they face global change.

This project is funded by the European Commission through a European Research Council (ERC) grant, and coordinated by the University of Helsinki.

Protocol type

The sampling design is composed of permanent monitoring plots in 100 sites across the globe. A call for teams interested in joining the project was open, and a selection according to the contribution of the proposed sampling location to the coverage of the network was made. Self-sponsored applications were also opened. Two study plots are selected per site, “natural” habitat and “urban” habitat, to be sampled alternating yearly. The protocol is to be carried out for 6 years. The monitoring schemes have started in different sites (ICTS Doñana Biological Reserve, 2022).

The project established common semi-automated methods to generate standardised global data, the sampling can be ensured by any team regardless of their level of expertise. The procedures were defined jointly with the teams participating in the sampling, in order to ensure that everyone will be able to carry them out. Detailed instructions (manuals and a set of videos) on the sampling protocol are available on the LIFEPLAN website[37].

The project has 5 protocols for different variables to be measured:

- Soil sampling,
- Permanent sampling of camera traps using machine learning techniques for identifications
- Permanent sampling of audio recorders
- Spore (and pollen) sampling by establishing a cyclone sampler
- Insect sampling with malaise traps

Data analysis

The samples are shipped, at least twice per year, to a central laboratory at the Biodiversity Institute of Ontario, Canada. All the sample and data processing and analysis (DNA extraction, sequencing, image, and sound analysis) is done at the laboratory by the LIFEPLAN team. The results will be published in scientific journals. The sampling teams providing the data will be cited as co-authors for the publications, and are encouraged to bring comments and edits to the manuscripts.

More information: https://www2.helsinki.fi/en/projects/lifeplan

[37] University of Helsinki. LIFEPLAN. Available at: https://www.helsinki.fi/en/projects/lifeplan/instructions

Summary table

Table 1. Summary of the main information for each programme detailed in this review.

Programme	Lifespan	Focus	Geographical scale	Protocol type	Level of aggregation
International Waterbird Census (IWC)	1967 - ongoing	Bird species/ populations	Global. 143 countries	open	Raw data aggregated at the continent level + National aggregation
Agreement on the Conservation of Populations of European Bats (EUROBATS)	1994 - ongoing	Bat species	Pan-European. 38 countries	open	Raw data aggregated at the pan-European level + National aggregation
Small Cetaceans in European Atlantic waters and the North Sea (SCANS)	1994 - ongoing	Cetacean species	European Atlantic waters	strict	Raw data aggregated at the European level
Large Carnivore Initiative for Europe (LCIE)	1999 - ongoing	Large Carnivore species and populations	Europe	open	National distributions aggregated at the European level
Water Framework Directive (WFD)	2000 - ongoing	Water biota communities/ Ecosystem	European Union. 27 countries	open	National quality status aggregated at the European level
Global Observation Research Initiative in Alpine Environments (GLORIA)	2001 - ongoing	Vegetation communities/ species	Global. 43 countries	strict	Raw data aggregated at the global level
Pan-European Common Bird Monitoring Scheme (PECBMS)	2002 - ongoing	Bird species/ populations	Pan-European. 29 countries	open	National aggregation, National indices aggregated at the pan-European level
Environmental Assessment for Soil Monitoring (ENVASSO)	2006 - 2008	Soil biodiversity community	European Union. 25 countries	strict	Raw data aggregated at the European level

Programme	Lifespan	Focus	Geographical scale	Protocol type	Level of aggregation
BioSoil project	2006 - 2009	Soil biodiversity community	Pan-European. 32 countries	flexible	Raw data aggregated at the European level + National aggregation
Land Use/Cover Area frame statistical Survey (LUCAS Soil)	2009 - ongoing	Soil biodiversity community	European Union. 27 countries	strict	Raw data aggregated at the European level
European Butterfly Monitoring Schemes (eBMS)	2016 - ongoing	Butterfly species	Europe. 22 countries	flexible	Raw data aggregated at the European level
European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL)	2017 - ongoing	Vegetation communities/ species. Habitats	European Union. 27 countries	strict	Raw data aggregated at the European level
Strengthening Pollinator Recovery through Indicators and Monitoring (SPRING)	2021 - 2023	Butterfly species	European Union. 27 countries	flexible	Raw data aggregated at the European level + National aggregation
A Planetary Inventory of Life (LIFEPLAN)	2025 - 2025	Species/ communities	Global. 100 countries	strict	Raw data aggregated at the global level

For the protocol type, “open” refers to programmes for which each country is free to define its own protocol to gather the data; “strict” when one common standardised protocol is applied in all countries involved; and “flexible” when one same general protocol is used but its implementation in each country can differ in the survey frequency or choice of sampling locations for example.

Harmonising monitoring at a pan-European level: lessons learned

As seen with the case studies, each programme has adopted a particular strategy to set a monitoring protocol, treat and validate the data, and produce results at the European (or transnational) level, informing on the specific biodiversity focus (soil, birds, pollinators, butterflies, bats, large carnivores, large marine mammals, agricultural land, alpine ecosystems, freshwater ecosystems). Decisions have been made on the protocol type and how to build it, and on how to manage the data in the information chain, in particular the level at which the biodiversity information is aggregated.

Combination of possible strategies: summary

The monitoring programmes studied in this literature survey can be sorted according to the possible combinations of identified strategies (Table 2), which are discussed later on. Three main combinations of strategies seem to prevail among the case studies:

- Applying one common strict protocol in all countries involved and aggregating raw data for joint analysis, to deliver general trends and indices (Table 2: First row, last column).
- Different protocols are applied across different countries, each protocol gathering data which are treated locally (or nationally) to produce defined EBVs or indicators, which are then aggregated at the global (or transnational) level, to deliver general trends and indices (Table 2: Second row, first column).
- Applying a protocol allowing some flexibility for an adapted implementation to each country, and treating data both locally and at the transnational level (Table 2: Third row, second column).

In Table 2 below, biodiversity monitoring strategies identified in this literature survey are compared taking into account whether the monitoring is done via one common strict protocol, a common protocol in a flexible way, or different protocols; and the levels at which the biodiversity information is aggregated. ENVASSO was not included in this table, as it was considered to be a research study providing recommendations to support a future European soil monitoring initiative, and not a monitoring programme that is implemented in itself.

Table 2. Different combinations of transnational biodiversity monitoring strategies

Monitoring *via*: / Level of data aggregation:	**1 strict protocol** *(applied everywhere in the same way)*	**1 flexible protocol** *(adapted to the bio-geographical context and means of each country)*	**Different (open) protocols** *(countries may use different protocols to monitor the same biodiversity entity)*
Local *(produced data are treated locally into EBVs, which are then transmitted to a trans-national level)*			PECBMS WFD LCIE / SCALP
Both *(produced raw data are transmitted to a trans-national level and treated locally in parallel for national use)*	GLORIA	SPRING BioSoil IWC	EUROBATS
Global *(produced raw data are gathered and treated at a transnational level)*	LUCAS soil SCANS EMBAL LIFEPLAN	eBMS / ABLE	

On protocols design for trans-national biodiversity monitoring

A gradient of strategies to design global biodiversity monitoring

When designing a new monitoring programme, different scenarios are possible considering the choices taken around the protocols that will be used to carry out the surveys, noticeably regarding whether it is only one or various protocols that are applied. A gradient has been revealed with the reviewed monitoring programmes, going from one strict standardised protocol applied equally in the entirety of the territory covered by the monitoring programme (e.g. LIFEPLAN) to independent protocols applied in the different regions or countries (e.g. PECBMS). In between, there are cases where one general protocol is applied, tolerating some flexibility on certain choices of protocol implementation, such as defining the collection sites, the frequency at which the methods are carried out, etc. (e.g. IWC).

This gradient seems to appear due to a trade-off between the scientific robustness of the biodiversity monitoring programmes and their applicability in the given territory. On one hand, applying one strict

protocol ensures that the data is collected following the same methodologies and techniques, and therefore more easily comparable across the monitoring sites. On the other hand, it should be kept in mind that cultural, historical and socioeconomic differences between involved parties, as well as biological differences among territories, influence the applicability of a given protocol (Kühl *et al.*, 2020). Flexibility in the protocols' implementation allows a better adaptation of the programme to the particular context of each country, and thus its successful implementation.

For instance, BioSoil would have ideally applied one strict protocol, but some flexibility was allowed for the site selection out of convenience. This was also the case with the butterfly monitoring programmes, which have evolved from having a strict protocol (the original Butterfly Monitoring Scheme from the UK), to a more flexible implementation of the protocol (eBMS and ABLE). ABLE was especially confronted with differences in monitoring traditions when implementing a volunteer-based butterfly monitoring programme across Europe. Initially built for the UK, where there is an active engagement in volunteering, this protocol was set up in countries where this practice was not so prevalent. Motivating citizens proved to be a hard goal to achieve, although finally successful. Socioeconomic conditions and political histories have indeed been shown to prevent the development of a volunteerism culture in the country, where noticeably fewer skilled amateurs are participating in monitoring activities in countries for which state agencies have low budgets (Vandzinskaite *et al.*, 2010; Danielsen *et al*., 2009, as cited by Schmidt & Van der Sluis, 2021).

Dealing with the existent

Three main non-mutually exclusive strategies for designing a monitoring protocol have been identified by Schmidt & Van der Sluis (2021) and de Boois (2019):

- Starting a monitoring programme from scratch, with its own protocol, based on the best practices and research results;
- Redesigning existing monitoring programmes by adapting the protocols to the new territories and for them to answer to the new objectives;
- Using an existing monitoring programme to collect the new data, without changing the programme's design.

The development of a completely new monitoring programme is recommended when there are no existing programmes in place that can meet the specific biodiversity objective. When there are a number of existing monitoring systems already in use, the strategy of adapting them to answer to new monitoring needs seems preferable, avoiding this way duplication of effort. With this approach, the continuation of existing time series can be taken into account after standardisation exercises with previous datasets, and therefore data produced in previous years would not be lost. Other advantages of this strategy are that the current monitoring systems have learned from years of experience and have undergone the necessary changes for optimised applicability in the territory. The human and material means to set up the protocols are already available, as well as the respective funding.

These approaches can develop in parallel at a larger scale, as countries with already established monitoring systems could continue their programmes as is, while other countries could start newly developed ones. The challenge would then be to translate the produced data time series into each other for a general overview (de Boois, 2019).

"Community deals" as a solution?

Different biodiversity monitoring communities (e.g for birds, soil, freshwater ecosystems, etc.) have different starting points in terms of existing monitoring schemes and traditions, and different data collection and analysis techniques that might be more or less adapted to implementation in different bio-geographical conditions. Some of the difficulties to harmonise are sometimes very technical or only emerge on the path of harmonisation, as the SPRING project discovered. Therefore, there cannot be a unique and uniform solution for all. Decisions on the monitoring programme's protocol design call for deals or agreements to be reached by experts in their monitoring community.

However, a common framework should be built to be able to integrate the results of these different communities together for a general view. A particular attention should be given to transversal components, to ensure that results from the different communities are interoperable and of good quality. For instance, a strong attention should be given to sampling design procedures, to ensure all of these are representative of the same geographical elements, and to give programmes' managers advice on how to deal with flexibility in selecting sampling sites.

On the information chain for a multi-level monitoring system

At which level is the biodiversity information integrated?

The first strategy encountered in the studied monitoring programmes consists in processing raw data at a transnational level (Kissling *et al*. 2018). In this strategy, raw data are directly submitted to a common centralised structure for a joint analysis for all countries involved to produce trends and indicators. The data are usually treated with modelling techniques to take into account the possible variabilities. The reasons why a few monitoring programmes, such as LUCAS Soil or EMBAL, are using this strategy are mainly related to the quality and reliability of the gathered data. The use of raw data allows the interested structure to gather the information that is specifically needed. Reliable estimates can be produced at a finer geographical level.

Another strategy is to aggregate and process nationally Essential Biodiversity Variables (EBVs) at a national or at local level. Each country is in charge of collecting and treating the data, then providing this standardised outcome to a higher structure that combines the EBVs produced in different countries in order to have a continental overview. This strategy is used for instance by the monitoring programmes under the WFD or by PECBMS, and ends up with commonly used indices at the European level (e.g. farmland bird index). This approach largely matches the reporting procedure of nations to European nature directives.

Some of the main reasons stated for the projects using this approach, for example under the WFD, are that the alignment of different efforts and existing independent programmes into a network of stakeholders, data, and schemes have positive results by fostering a sense of ownership, and preventing possible conflicts among stakeholders. Furthermore, it avoids duplication of effort and

funds regarding ongoing local activities, which would continue regardless. To ensure the production of EBVs in every country, guidance is generally provided to design new monitoring schemes where there are none yet, or for integrating additional elements in existing programmes. Programmes opting for this strategy often rely on regular workshops where all national coordinators share their experiences and discuss the project's future development.

The last strategy revealed by this study is actually a combination of both strategies previously described, the collected data being sent for a joint analysis to a central structure, and in parallel being treated locally to produce national indices and trends. With this mixed approach, the higher level (e.g. the EU) analyses the received biodiversity information and can provide guidance through general methodologies and best practices documents.

For instance, the GLORIA monitoring programme allows different types of research to be carried out with the same data that are collected. This programme was designed to produce global indices with the collected data, but various research activities and articles are published on specific sites and/or species using raw data that are available on the GLORIA website. In the case of EUROBATS, global trends are produced from a vast array of existing protocols, and each country produces its own trends as well. However, it was noticed that EUROBATS is leaning towards a new strategy, as they are shifting to a local analysis of data to produce national EBVs and using those for a global analysis.

Data curation & validation

Regardless of the strategy adopted to collect and aggregate the biodiversity information, validation and data curation are key steps in the transfer of data from the field to end users of large-scale indicators. This concerns the process of organising, checking, maintaining and submitting the records of the collected data.

Inconsistencies in how data are curated are particularly noticeable in programmes relying on citizen science where, for example, a misidentification of species can occur, e.g. due to a lack of technical skills, leading to data inaccuracy (Musvuugwa et al., 2021). As seen with transnational biodiversity monitoring programmes involving volunteers (e.g. PECBMS), national coordination is set in place, where national coordinators (or site managers in some cases) are in charge of checking the collected data. Even for the programmes following stricter protocols by trained professionals, a data quality check is usually carried out along the information chain. The SCALP program has even set up an harmonisation process across countries on the data quality evaluation itself, to ensure a coherent interpretation of what is a valid proof of lynx presence. There are also programmes using a central laboratory specifically to assure this quality control, such as BioSoil where the results obtained with a local laboratory analysis of data were compared to those with a global analysis through a central laboratory, as an exercise of data quality check.

The process of data curation and standardisation plays an essential role in transnational programmes, as the submitted records (in the form of raw data, EBVs, or indicators) to the higher-level structure are expected to be of quality and meet the interoperability requirements (Hackett *et al.*, 2019). It should be noted that this process can be time-consuming and should be considered when developing a monitoring scheme. It is crucial to take validation and data curation into account

for a harmonisation process at the governance level since it relates to who bears the responsibility of data quality along the monitoring workflow.

A "double" approach as a solution?

The review of literature and monitoring programmes shows that transferring data to the upper (European) level could be either operated through raw data or EBVs. Both approaches are currently used, and seem operational. The best way to analyse data at a European level can vary according to the specificities of each community. When protocols have important variation across Europe, either due to historical reasons or high level of specificities, a local analysis will most often be more precise than a global analysis. In such a case, merging local EBVs could be easier and more performant than analysing raw data aggregated at the higher level. When protocols are rather similar, the increased dataset size of raw data may improve the ability of analysis to estimate European values through modelling and could sometimes improve national values. It must be noted that the process of merging EBVs could be more stable than modelling raw data in case of unstable context such as protocol or sampling effort variation through time in different countries. In this case, models should indeed be rebuilt according to dataset particularities.

Transferring both raw data and national EBVs to the European level could be a good common strategy in every community of practice. It would then be up to each community European node to use raw or EBV values for their analysis. This proposition also has the potential to answer the various needs around the access to monitoring data and information, and help to design common tools to manage this information.

Governance in transnational monitoring programmes

Multiscale ownership

Governance of biodiversity data collection and curation is handled by a vast array of large or small organisations, NGOs, universities or research institutes, and legal entities at the national and/or European level, which in many cases have been collecting data independently. Issues of ownership and distribution of responsibilities need to be taken into consideration for the integration of the different stakeholders into a biodiversity monitoring system (Kühl *et al.*, 2020). Many countries have for instance mentioned a struggle to fulfil the monitoring obligations under European Directives, as well as drafting the requested reports with often poor-quality or incomplete data sets (Moersberger et al., 2022).

Harmonising biodiversity monitoring at a transnational scale is challenging in the sense that effort, time and funding are already allocated to the existing organisations' biodiversity observation systems (Scholes et al., 2012). These observation systems produce relevant biodiversity records to answer local management needs, on top of providing data for large-scale policy (Honrado *et al.*, 2016). On the other hand, protocols applied uniformly at European scale may not have sufficient statistical

power on their own to provide lower scale information. For instance, within the SPRING project, the required sampling effort to reach statistical power to produce European trends is estimated to be 2,000 sites across Europe, but this effort will not be enough to provide information at national level on which European directives applied.

Another recurrent challenge relates to budgetary constraints to carrying out long-term monitoring programmes (Moersberger *et al.*, 2022).When the budget is limited, national financial effort will likely be directed toward the system providing information at the national level rather than European level only. Even for European protocols, budgetary constraints exist. For example, LUCAS Soil and ENVASSO projects, aiming to produce a harmonised monitoring system across Europe, were not able to collect and analyse samples at the full scale that was envisioned or even had to stop altogether (Jones *et al.*, 2022; Kibblewhite *et al.*, 2008). Meanwhile, in France, LUCAS Soil exists alongside the RMQS (national network of soil quality monitoring) which benefits from important national funding. The risk of budgetary constraint could be assessed and avoided with multilevel governance including national nodes.

Ensuring international cooperation

Obstacles to establishing a transnational monitoring programme include the lack of political will to cooperate, the difference in the legislation of neighbour countries and differences in language, culture and traditions, as identified during the seminar on transboundary management of Large Carnivore Populations (Bath, 2005). International administrative procedures have also been a source of issues in the implementation of some programmes, such as the International Bottom Trawl Survey, where Germany was denied a UK permit to carry out the surveys (ICES, 2020).

Coordination within and among each country to avoid administrative fragmentation can be encouraged by hosting workshops regularly, creating networks involving various levels of governance, or funding exercises in cross-cultural exchanges (Bath, 2005). For example, these techniques were successful for the ABLE project in the creation of a common monitoring scheme for the island of Cyprus, which is a culturally- and historically-sensitive region regarding Greek Cypriot and Turkish Cypriot communities (Sevilleja *et al.*, 2020).

One of the key lessons learned from transnational projects is that communication with all parties involved is essential throughout the entire development and harmonisation process (Livoreil *et al*, 2016; de Boois, 2019). The likelihood of finding a consensus for a coordinated effort is greater when there is a strong partnership between science, society, policy, and individuals within and across countries (Kühl *et al*., 2020).

Conclusions

Strategic considerations on the way to establish a harmonised biodiversity monitoring programme have to be taken into account for its successful implementation. Essential decisions have to be made on the level and metric at which the programme will be harmonised within and between the different countries involved. Many decisions will have to be made and trade-offs assessed in order to implement a harmonised monitoring programme as a group. As seen with the examples from existing pan-European biodiversity monitoring programmes, choices regarding the protocol type and the data management in the information chain lead to different possible combinations and approaches to setting a biodiversity monitoring system at a transnational scale. It should be kept in mind that these possible combinations when developing a monitoring protocol depend on the possible international cooperation and on the different countries' means, in terms of budget and the existence or not of experts and volunteer networks. It is important to stress the need for coordination at the pan-European level and for an effective guidance provision, protocol development and data integration capacity with a common perspective, along the networking of strong national coordination centres ensuring national ownership. Successful monitoring initiatives are in fact characterised by a strong multilevel, governance structure. Finally, funding has been mentioned as a major driver of monitoring gaps across Europe. The creation of dedicated and sustained funding for biodiversity monitoring available to member states is thus critical to the implementation and success of any monitoring programme at the European level.

References

Arrouays, D, Morvan, X., Saby, N.P.A., Richer de Forges, A., Le Bas, C., Bellamy, P.H., Berényi Üveges, J., Freudenschuß, A., Jones, A.R., Jones, R.J.A., Kibblewhite, M.G., Simota, C., Verdoodt, A., Verheijen, F.G.A. (eds) (2008). Environmental Assessment of Soil for Monitoring: Volume IIa Inventory & Monitoring. EUR 23490 EN/2A, Office for the Official Publications of the European Communities, Luxembourg, 188pp. Available at: https://esdac.jrc.ec.europa.eu/Projects/Envasso/documents/ENV_Vol-IIb_Final2_web.pdf

ASCOBANS (2013). Small Cetaceans in European Atlantic waters and the North Sea (SCANS-III): Project Introduction. University of St. Andrews. Available at: https://www.ascobans.org/sites/default/files/document/AC20_4.1.a_SCANSIII.pdf

Barry, T. (2018). D7. 2- Data management plan for the RIF field station. Available at: https://eu-interact.org/app/uploads/2018/11/D7.2.pdf

Bath, A. (2005). Seminar on transboundary management of large carnivore populations. *Osilnica, Slovenia*, 15-17. Available at: http://www1.nina.no/lcie_new/pdf/634989782789145792_Bath%20COE%20Osilnica%20report.pdf

de Boois, I. J. (Ed). 2019. Moving towards integrated ecosystem monitoring. ICES Cooperative Research Report No. 347. 44 pp. Available at: https://archimer.ifremer.fr/doc/00585/69721/67611.pdf

Battersby, J. (comp.) (2010): Guidelines for Surveillance and Monitoring of European Bats. EUROBATS Publication Series No. 5. UNEP / EUROBATS Secretariat, Bonn, Germany, 95 pp. Available at: https://www.eurobats.org/sites/default/files/documents/publications/publication_series/EUROBATS_PublSer_No5_3rd_edition.pdf

De Blust, G., Laurijssens, G., Van Calster, H., Verschelde, P., Bauwens, D., De Vos, B., & Svensson, J. (2012). EBONE WP8 Design of a monitoring system and its cost-effectiveness. Available at: https://www.wur.nl/upload_mm/b/a/1/994e8c39-e549-4836-af10-39b9aa638b8c_EBONE_D81_31052012.pdf

European Commission, Joint Research Centre, Panagos, P., Jones, A., Van Liedekerke, M., et al. (2020), JRC support to the European Joint Programme for soil (EJP SOIL): datasets, technical advice and scientific guidance, *Publications Office*. Available at: https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/JRC122248_technical_report_ejp-jrc_final_register3.pdf

European Commission. (2022). *WFD Guidance documents*. Available at: https://ec.europa.eu/environment/water/water-framework/facts_figures/guidance_docs_en.htm

Hackett, R. A., Belitz, M. W., Gilbert, E. E., & Monfils, A. K. (2019). A data management workflow of biodiversity data from the field to data users. *Applications in Plant Sciences*, *7*(12), e11310. Available at: https://doi.org/10.1002/aps3.11310

Hague, E. L., Sinclair, R. R., & Sparling, C. E. (2020). Regional baselines for marine mammal knowledge across the North Sea and Atlantic areas of Scottish waters. *Scottish Marine and Freshwater Science*. Available at: https://doi.org/10.7489/12330-1

Hammond, P. S., Lacey, C., Gilles, A., Viquerat, S., Börjesson, P., Herr, H., ... & Øien, N. (2017). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. *Wageningen Marine Research*. Available at: https://edepot.wur.nl/414756

Hardisty, A. R., Michener, W. K., Agosti, D., García, E. A., Bastin, L., Belbin, L., ... & Kissling, W. D. (2019). The Bari Manifesto: An interoperability framework for essential biodiversity variables. *Ecological informatics*, *49*, 22-31. Available at: https://doi.org/10.1016/j.ecoinf.2018.11.003

Heink, U., & Kowarik, I. (2010). What are indicators? On the definition of indicators in ecology and environmental planning. *Ecological indicators*, *10*(3), 584-593. Available at: https://doi.org/10.1016/j.ecolind.2009.09.009

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C. K., ... & van de Bund, W. (2010). The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. *Science of the total Environment*, *408*(19), 4007-4019. Available at: https://doi.org/10.1016/j.scitotenv.2010.05.031

Hiederer, R., E. Michéli and T. Durrant (2011) Evaluation of BioSoil Demonstration Project - Soil Data Analysis. EUR 24729 EN. Publications Office of the European Union. 155pp. Available at: https://data.europa.eu/doi/10.2788/56105

Honrado, J. P., Pereira, H. M., & Guisan, A. (2016). Fostering integration between biodiversity monitoring and modelling. *Journal of Applied Ecology*, *53*(5), 1299-1304. Available at: http://www.jstor.org/stable/44133883

ICES. (2020). International Bottom Trawl Survey Working Group (IBTSWG). ICES Scientific Reports. 2:92. 197pp. Available at: http://doi.org/10.17895/ices.pub.7531

Jones, A, Fernandez-Ugalde, O., Scarpa, S. (2020). LUCAS 2015 Topsoil Survey. Presentation of dataset and results, EUR 30332 EN, Publications Office of the European Union: Luxembourg. ISBN 978-92-76-21080-1, doi:10.2760/616084, JRC121325. Available at: https://data.europa.eu/doi/10.2760/616084

Jones, A, Fernandes-Ugalde, O., Scarpa, S., & Eiselt, B. (2021). LUCAS 2022, EUR 30331 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-76-21079-5, doi:10.2760/74624, JRC121253. Available at: https://data.europa.eu/doi/10.2760/74624

Kaczensky, P., Chapron, G., von Arx, M., Huber, D., Andrén, H., and Linnell, J. 2013. Status, management and distribution of large carnivores - bear, lynx, wolf & wolverine - in Europe. Part 1 - Europe summaries. Report: 1-72. A Large Carnivore Initiative for Europe Report prepared for the European Commission. Available at: https://www.europarc.org/wp-content/uploads/2017/02/Kaczensky_et_al_2013_Status_management_and_distribution_of_large_carnivores_in_Europe_1.pdf

Kamp, J., Oppel, S., Heldbjerg, H., Nyegaard, T., & Donald, P. F. (2016). Unstructured citizen science data fail to detect long-term population declines of common birds in Denmark. *Diversity and Distributions*, *22*(10), 1024-1035. Available at: https://doi.org/10.1111/ddi.12463

Kibblewhite, M.G., Jones, R.J.A., Montanarella, L., Baritz, R., Huber, S., Arrouays, D., Micheli, E. and Stephens, M. (eds) (2008). Environmental Assessment of Soil for Monitoring Volume VI: Soil Monitoring System for Europe. EUR 23490 EN/6, Office for the Official Publications of the European Communities Luxembourg, 72pp. Available at: https://esdac.jrc.ec.europa.eu/Projects/Envasso/documents/ENV_Vol-VI_Final2_web.pdf

Klvaňová, A., & Voříšek, P. (2007). Review on large-scale generic population monitoring schemes in Europe 2007. *Bird Census News*, *20*(2), 50-56. Available at: https://www.ebcc.info/wp-content/uploads/2020/06/bcn-20-2.pdf

Kühl, H. S., Bowler, D. E., Bösch, L., Bruelheide, H., Dauber, J., Eichenberg, D., ... & Bonn, A. (2020). Effective biodiversity monitoring needs a culture of integration. *One Earth*, *3*(4), 462-474. Available at: https://doi.org/10.1016/j.oneear.2020.09.010

Lindemann, D., Kobs, M., Oppermann, R., Sutcliffe, L. (2021). EMBAL Survey Protocol. *European Commission, DG ENV.* Available at: *https://wikis.ec.europa.eu/download/attachments/25560696/EMBAL%202021%20Survey%20Protocol.pdf?version=1&modificationDate=1634068697799&api=v2*

Linnell, J., Salvatori, V., & Boitani, L. (2008). Guidelines for population level management plans for large carnivores in Europe. *A Large Carnivore Initiative for Europe report prepared for the European Commission (contract 070501/2005/424162/MAR/B2)*, *83*. Available at: https://ec.europa.eu/environment/nature/conservation/species/carnivores/pdf/guidelines_for_population_level_management.pdf

Livoreil, B., Geijzendorffer, I., Pullin, A. S., Schindler, S., Vandewalle, M., & Nesshöver, C. (2016). Biodiversity knowledge synthesis at the European scale: actors and steps. *Biodiversity and Conservation*, *25*(7), 1269-1284. Available at: https://doi.org/10.1007/s10531-016-1143-5

Lomba, A., Guerra, C., Alonso, J., Honrado, J. P., Jongman, R., & McCracken, D. (2014). Mapping and monitoring high nature value farmlands: challenges in European landscapes. Journal of Environmental Management, 143, 140-150. Available at: https://doi.org/10.1016/j.jenvman.2014.04.029

LUCAS grassland module (2018) - Description and validation. *Grassland test module report for LUCAS-website.* Available at: https://ec.europa.eu/eurostat/documents/205002/9722562/Grassland-Modelling-Report.pdf

Maes, J., Teller, A., Erhard, M., Grizzetti, B., Barredo, J., Paracchini, M. L., ... & Werner, B. (2018). Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. *Publications office of the European Union, Luxembourg*, 1-75. doi:10.2779/055584. Available at: https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/5th%20MAES%20report.pdf

Maréchal, A; Jones, A.; Panagos, P. Belitrandi, D.; De Medici, D.; De Rosa, D.; Jiminez, J.M.; Koeninger, J.; Labouyrie, M., Liakos, L.; Lugato, E.; Matthews, F.; Montanarella, L.; Muntwyler, A.; Orgiazzi, A.; Scarpa , S.; Schillaci, C.; Wojda, P.; Van Liedekerke, M.; Vieira , D. (2022). EU Soil Observatory 2021. EUR 31152 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-55031-0, doi:10.2760/582573, JRC129999. Available at: https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/EUR31152.pdf

Micheli, E., Bialousz, S., Bispo, A., Boixadera, J., Jones, A.R., Kibblewhite, M.G., Kolev, N., Kosmas, C., Lilja, H., Malucelli, F., Rubio, J.L., Stephens, M. (eds) (2008). Environmental Assessment of Soil for Monitoring: Volume IVa Prototype Evaluation EUR 23490 EN/4A, Office for the Official Publications of the European Communities, Luxembourg, 96pp. Available at: https://esdac.jrc.ec.europa.eu/Projects/Envasso/documents/ENV_Vol-IVa_Final2_web.pdf

Moersberger, H., Martin, J. G., Junker, J., Georgieva, I., Bauer, S., Beja, P., ... & Bonn, A. (2022). Europa Biodiversity Observation Network: User and Policy Needs Assessment. Available at: https://doi.org/10.3897/arphapreprints.e84517

Musvuugwa, T., Dlomu, M. G., & Adebowale, A. (2021). Big Data in Biodiversity Science: A Framework for Engagement. *Technologies,* *9*(3), 60. Available at: https://doi.org/10.3390/technologies9030060

Navarro, L. M., Fernández, N., Guerra, C., Guralnick, R., Kissling, W. D., Londoño, M. C., ... & Pereira, H. M. (2017). Monitoring biodiversity change through effective global coordination. *Current opinion in environmental sustainability*, *29*, 158-169. Available at: https://doi.org/10.1016/j.cosust.2018.02.005

Neville, P., & Bastrup-Birk, A. WORKING GROUP ON FOREST BIODIVERSITY (2006): Forest Focus Demonstration Project BioSoil 2004–2005, the BioSoil Forest Biodiversity Field Manual, Version 1.1, for the Field Assessment 2006–07. Available at: https://cdn.forestresearch.gov.uk/2022/02/biosoil_biodiversity_field_manual_v1_0.pdf

Nichols, J. D., & Williams, B. K. (2006). Monitoring for conservation. *Trends in ecology & evolution*, *21*(12), 668-673. Available at: https://doi.org/10.1016/j.tree.2006.08.007

Oppermann, R., Schraml, A., Sutcliffe, L., Ludemann, J. (2018). European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL) - Final Report. *Institute for Agroecology and Biodiversity (IFAB).* Available at: https://ec.europa.eu/environment/nature/knowledge/pdf/embal_report.pdf

Oppermann, R., Aguirre, E., Bleil, R., Calabuig, J. D., Šálek, M., Schmotzer, A., & Schraml, A. (2021). A Rapid Method for Monitoring Landscape Structure and Ecological Value in European Farmlands: the LISA approach. Landscape Online, 90, 1-24. Available at: https://doi.org/10.3097/LO.202190

Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., & Fernández-Ugalde, O. (2018). LUCAS Soil, the largest expandable soil dataset for Europe: a review. *European Journal of Soil Science*, *69*(1), 140-153. Available at: https://doi.org/10.1111/ejss.12499

Pe'er, G., Birkenstock, M., Lakner, S., & Röder, N. (2021). The Common Agricultural Policy post-2020: Views and recommendations from scientists to improve performance for biodiversity. Volume 2-Annexes (No. 175-Volume 2). *Thünen Working Paper*. Available at: https://econpapers.repec.org/paper/agsjhimwp/311098.htm

Pocock, M. J., Chandler, M., Bonney, R., Thornhill, I., Albin, A., August, T., ... & Danielsen, F. (2018). A vision for global biodiversity monitoring with citizen science. In *Advances in ecological research* (Vol. 59, pp. 169-223). Academic Press. Available at: https://doi.org/10.1016/bs.aecr.2018.06.003

Poikane, S., Zampoukas, N., Borja, A., Davies, S. P., van de Bund, W., & Birk, S. (2014). Intercalibration of aquatic ecological assessment methods in the European Union: Lessons learned and way forward. *Environmental Science & Policy*, *44*, 237-246. Available at: https://doi.org/10.1016/j.envsci.2014.08.006

POST (Parliamentary Office of Science and Technology). 2021. POSTbrief 41, Biodiversity indicators. UK Parliament. Available at: https://www.researchgate.net/profile/Lauren-Henly/publication/351824116_POSTbrief41_Biodiversity_Indicators_Parliamentary_Office_of_Science_and_Technology/links/60abf56345851522bc1512b8/POSTbrief41-Biodiversity-Indicators-Parliamentary-Office-of-Science-and-Technology.pdf

Proença, V., Martin, L. J., Pereira, H. M., et al. (2017). Global biodiversity monitoring: from data sources to essential biodiversity variables. Biological Conservation, 213, 256-263). Available at: https://doi.org/10.1016/j.biocon.2016.07.014

Roy, D.B., Bourn, N., Collins, S., Dennis, E.B., Schmucki, R., Settele, J., Sevilleja, C.G, Van Swaay, C.A.M. & Wynhoff, I. (2020). Assessing Butterflies in Europe: Executive Summary. Butterfly Conservation Europe. Available at: https://butterfly-monitoring.net/sites/default/files/Pdf/Reports/Assessing%20Butterflies%20in%20Europe%20-%20Executive%20Summary%20Final%20Revised.pdf

Schmeller, D. S., HENRY, P. Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F., ... & Henle, K. (2009). Advantages of volunteer-based biodiversity monitoring in Europe. *Conservation biology*, *23*(2), 307-316. Available at: https://doi.org/10.1111/j.1523-1739.2008.01125.x

Schmeller, D., Henle, K., Loyau, A., Besnard, A., & Henry, P. Y. (2012). Bird-monitoring in Europe–a first overview of practices, motivations and aims. *Nature Conservation*, *2*, 41-57. doi: 10.3897/natureconservation.2.3644. Available at: http://www.scales-project.net/files/DOWNLOAD2/3644-G-3-layout_1.pdf

Schmeller, D. S., Julliard, R., Bellingham, P. J., Böhm, M., Brummitt, N., Chiarucci, A., ... & Belnap, J. (2015). Towards a global terrestrial species monitoring program. *Journal for Nature Conservation*, *25*, 51-57. Available at: https://doi.org/10.1016/j.jnc.2015.03.003

Schmidt, A.M. & Van der Sluis, T. (2021). E-BIND Handbook (Part A): Improving the availability of data and information on species, habitats and sites. Wageningen Environmental Research/ Ecologic Institute /Milieu Ltd. Wageningen, The Netherlands. Available at: https://www.ecologic.eu/sites/default/files/publication/2021/A_EBind_Handbook.pdf

Schmucki, R., Pe'Er, G., Roy, D. B., Stefanescu, C., Van Swaay, C. A., Oliver, T. H., ... & Julliard, R. (2016). A regionally informed abundance index for supporting integrative analyses across butterfly monitoring schemes. *Journal of Applied Ecology*, *53*(2), 501-510. Available at: https://doi.org/10.1111/1365-2664.12561

Scholes, R. J., Walters, M., Turak, E., Saarenmaa, H., Heip, C. H., Tuama, É. Ó., ... & Geller, G. (2012). Building a global observing system for biodiversity. *Current Opinion in Environmental Sustainability*, *4*(1), 139-146. Available at: https://doi.org/10.1016/j.cosust.2011.12.005

Sevilleja, C.G.1 , van Swaay, C.A.M.1,2, Bourn, N.3 , Collins, S.2 , Settele, J.4 , Warren, M.S.2 , Wynhoff, I.2 and Roy, D.B. 5 (2019). Butterfly Transect Counts: Manual to monitor butterflies. Report VS2019.016, Butterfly Conservation Europe & De Vlinderstichting/Dutch Butterfly Conservation, Wageningen. Available at: https://butterfly-monitoring.net/sites/default/files/Pdf/Butterfly%20Transect%20Counts-Manual%20v1.pdf

Sevilleja, C. G., Collins, S., Warren, M. S., Wynhoff, I., Van Swaay, C. A. M., Dennis, E. B., ... & Roy, D. B. (2020). European Butterfly Monitoring Scheme (eBMS): network development. Technical report. Available at: https://butterfly-monitoring.net/sites/default/files/Pdf/Reports/Assessing%20Butterflies%20in%20Europe%20-%20Network%20Development%20Revised.pdf

Sutcliffe, L. M., Schraml, A., Eiselt, B., & Oppermann, R. (2019). The LUCAS Grassland Module Pilot–qualitative monitoring of grassland in Europe. *Palearctic Grasslands*, *40*, 27-31. Available at: https://edgg.org/sites/default/files/page/Sutcliffe_et_al_PG40_27_31.pdf

UNEP/EUROBATS. (2022). *Database of Monitoring Results*. Available at: https://www.eurobats.org/node/963

UNEP/EUROBATS. (2022). *Monitoring & Indicators. Available at:* https://www.eurobats.org/node/876

van Roomen, M., Schekkerman, H., Delany, S., van Winden, E., Flink, S., Langendoen, T., & Nagy, S. (2011). Overview of monitoring work on numbers, reproduction and survival of waterbird populations important in the Wadden Sea and the East Atlantic Flyway. *SOVON Information Report*, *2*, 1e64. Available at: https://stats.sovon.nl/static/publicaties/Inf_2011-02_Flywaymonitoring.pdf

van Strien, A. J., Pannekoek, J., & Gibbons, D. W. (2001). Indexing European bird population trends using results of national monitoring schemes: a trial of a new method. *Bird Study*, *48*(2), 200-213.

Van Swaay, C., Regan, E., Ling, M., Bozhinovska, E., Fernandez, M., Marini-Filho, O.J., Huertas, B., Phon, C.-K., K"orösi, A., Meerman, J., Pe'er, G., Uehara-Prado, M., Sáfián, S., Sam, L., Shuey, J., Taron, D., Terblanche, R., and Underhill, L. (2015). Guidelines for Standardised Global Butterfly Monitoring. Group on Earth Observations Biodiversity Observation Network, Leipzig, Germany. Available at: https://www.geobon.org/downloads/biodiversity-monitoring/technical-reports/GEOBON/2015/Global-Butterfly-Monitoring-Web.pdf

Vandzinskaite, D., Kobierska, H., Schmeller, D. S., & Grodzińska-Jurczak, M. (2010). Cultural diversity issues in biodiversity monitoring—cases of Lithuania, Poland and Denmark. *Diversity*, *2*(9), 1130-1145. doi:10.3390/d2091130. https://doi.org/10.3390/d2091130

Voříšek, P. (Ed.). (2008). *A best practice guide for wild bird monitoring schemes*. Ceska Spolecnost Ornitologicka Cso. Available at: https://pecbms.info/best-practice-guide/

Wetlands International (2015). "Waterbird Population Estimates". Retrieved from wpe.wetlands.org on Friday 22 May 2015.

Wetzel, F. T., Bingham, H. C., Groom, Q., Haase, P., Kõljalg, U., Kuhlmann, M., ... & Häuser, C. L. (2018). Unlocking biodiversity data: Prioritization and filling the gaps in biodiversity observation data in Europe. *Biological conservation*, *221*, 78-85. Available at: https://doi.org/10.1016/j.biocon.2017.12.024

Willby, N., Birk, S., Poikane, S., & van de Bund, W. (2014). Water framework directive intercalibration manual. *Procedure to fit new or updated classification methods to the results of a completed intercalibration. Ispra, Italy*. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC89002/final%20report_march.pdf

Ziche, D., Grüneberg, E., Riek, W., Wellbrock, N. (2022). Comparison of the LUCAS 2015 inventory with the second National Forest Soil Inventory: Comparability and representativeness of two soil inventories conducted in Germany. 10.3220/REP1651759791000. Available at: https://literatur.thuenen.de/digbib_extern/dn064841.pdf