EUROPEAN PARTNERSHIP

# Biodiversity monitoring knowledge gaps and research & innovation priorities

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# Acronyms

| | |
|---|---|
| CS | Citizen Science |
| R&I | Research & Innovation |
| SRIA | Strategic Research & Innovation Agenda |
| RS | Remote Sensing |

# General Introduction

*Context*

Biodiversa+, the European Biodiversity Partnership aims at increasing the quality, use and harmonization of biodiversity monitoring schemes to better produce biodiversity trends and better understand the relationships between the state and dynamics of biodiversity and drivers / pressures.

In this context, Biodiversa+ worked on the identification of knowledge gaps and research priorities related to - amongst others - the **testing and application of new tools, technologies and approaches for biodiversity monitoring by researchers (including approaches like citizen science) and the use of monitoring data by Research & Innovation (R&I)**.

The identification of these priorities will be used to prepare a major joint research call of over 40 Mio€ to be launched at the end of 2022, as part of the Biodiversa+ Flagship Programme "better transnational monitoring of biodiversity to better characterise, understand and report on biodiversity dynamics and trends".

In order to identify these knowledge gaps and research priorities, Biodiversa+ organised an online expert workshop on the 31st of January 2022 from 1 to 4.30pm to which 38 experts contributed (see Annex 1).

Based on their expertise, the participants were invited to discuss the three facets below:

- **FACET 1** testing and application of new tools, technologies and approaches for biodiversity monitoring
- **FACET 2** involvement of citizens in the biodiversity monitoring activities
- **FACET 3** use of monitoring data by R&I (including better understanding of biodiversity status, trends, drivers)

The workshop was divided into three sub-groups; each sub-group being composed of experts addressing a specific facet.

For each sub-group, the Biodiversa+ Partners in charge of the organisation of this workshop (LNV, IFD and GSRI) made sure to cover a broad range of expertise, environments/habitats and biological species (see Annex 2). Also, it was made sure that there was expertise on the workflow aspects (from observations to ecological applications and policy use).

The main aim of the contributions of the experts was to identify knowledge gaps and research and innovation priorities related to their respective facet, by providing inputs on broad priorities that should be taken into account in the framework of a new European research programme on biodiversity monitoring (Biodiversa+ Joint Call).

*Preparatory work*

Prior to this workshop, the experts were invited to submit, through an online survey, a list of knowledge gaps and research and innovation priorities of relevance for each of the facets.

35 experts answered this survey (14 for Facet 1, 8 for Facet 2 and 13 for Facet 3). The experts were also invited to read the Biodiversa+ Strategic Research and Innovation Agenda section on Cross-Cutting theme A “Better Knowledge on biodiversity and its dynamics (p.58).

Based on the survey and on the Biodiversa+ Strategic Research and Innovation Agenda (SRIA), a preparatory work document pre-identifying knowledge gaps (Annex 3) was drawn up by the three Biodiversa+ Partners in charge of the organisation of this workshop. In this document they pre-grouped the knowledge gaps and R&I priorities identified by the experts and laid out in the Biodiversa+ SRIA. This document was then used as a supporting guidance for the discussions in the sub-groups of the experts. The latter were more specifically invited to:

- reformulate the pre-identified knowledge gaps if needed
- adjust/ change the way these knowledge gaps were grouped
- add additional missing knowledge gaps.

The discussions in each sub-group were lively and moderated for Facet 1 by Lars Dinesen (IFD), for Facet 2 by Anna Rosenberg (GSRI) and for Facet 3 by Rob J. Hendriks (LNV). Three experts acted as rapporteurs during these sub-group discussions: Toke Thomas Hoye, Aarhus University, Denmark for Facet 1, Quentin Groom, Plantentuin Meise, Belgium for Facet 2 and Aino Juslén, Finnish Museum of Natural History, University of Helsinki, Finland for Facet 3.

*Report content*

**The present report showcases some of the biodiversity monitoring knowledge gaps and R&I priorities** that could be addressed by the Biodiversa+ 2nd call and also contains elements that could be useful for other biodiversity monitoring activities.

It was developed with the help of the three above-mentioned rapporteurs. All experts mobilised during the expert workshop were also consulted and actively provided feedback on the draft report.

In the first section, this report highlights for each facet which knowledge gaps and research & innovation priorities were identified by the invited experts. The second section offers a view that goes beyond these facets by presenting the links between those and cross-cutting knowledge gaps. The third section introduces elements that are not research gaps but are of relevance for biodiversity monitoring activities. Finally, some concluding remarks are provided.

# 1. Biodiversity monitoring knowledge gaps related to 3 facets

## Facet 1: Testing and application of new tools, technologies and approaches for biodiversity monitoring

Based on the Biodiversa+ SRIA and survey results sent to the experts ahead of the workshop, a pre-grouping of the knowledge gaps/ research and innovation priorities was made:

- Pre-identified facet 1a) eDNA and other molecular biology based approaches
- Pre-identified facet 1b) Mobile-sensing technology
- Pre-identified facet 1c) Remote sensing through satellites and Airborne campaigns and/or Drones / lidar systems
- Pre-identified facet 1d) Acoustics and Camera traps
- Pre-identified facet 1e) Artificial intelligence/machine learning/deep learning
- Pre-identified facet 1f) Networks of automated and standardised biodiversity sensors
- Pre-identified facet 1g) Data integration and linking to other sectors and policy
- Pre-identified facet 1h) Novel data testing and applying new tools incl. modelling

The expert sub-group focussing on Facet 1 discussed the grouping of the pre-identified sub-facets. There was agreement that sub-facet 1b "Mobile sensing technology" was ambiguous. As far as this sub-facet concerns data collection with mobile devices (e.g. mobile phones or drones), it is more relevant to discuss the sensors than whether these are stationary or mobile. Image-based tools were thus discussed under facet 1d, which the group recommended to split in separate sub-facets for acoustic and optical sensors. Moreover, the use of e.g. mobile phones in monitoring in this pre-identified facet was seen as more relevant for the discussion in facet 2 on Citizen Science. For these reasons the pre-identified facet 1c has been merged and split into a new facet 1b and 1d.

Together pre-identified sub-facets 1a to 1d were considered to have a focus on sensors whereas pre-identified sub-facet 1e was considered to focus on analytical tools of relevance mostly to 1c and 1d. Pre-identified sub facet 1e was moved and merged to a new sub-facet 1e with a focus on application of new monitoring tools.

Pre-identified sub-facet 1f about sensor networks, were revised to primarily focus on standardised data collection, whereas connected sensor networks, were maybe thought of more as ecological research tools.

There was considerable discussion around the final two pre-identified sub-facets 1g and 1h about data integration and application of tools and modelling. Experts identified testing and application of data integration and biodiversity models particularly important for developing the Essential Biodiversity Variables, but there was not enough time to define these sub-facets. Moreover, the pre-identified sub facet 1g on data integration and linking to other sectors and policies also relate to aspects beyond facet 1 and are also dealt with in facet 3 on use of monitoring data, further on in this report.

It was emphasised by several experts that data integration and modelling in pre-identified sub-facets 1g and h are part of facet 1. Thus, the advancement in the use, and development of data integration methods and models is seen as key for reducing spatiotemporal and taxonomic monitoring gaps and this cross-cutting issue could be elaborated further in the sub-facets 1a - e below. For that reason, it is listed as a new sub-facet 1f below but without further elaboration on its own.

The experts tried to identify knowledge gaps related to data collection, data processing, adhering to the FAIR data principles for these novel tools and standardisation for the individual sub-facets. This was more straightforward for some sub-facets than others. Below is the summary of this discussion for each of the new sub-facets including -when applicable- some identified biological science goals and break-through potential (innovative strength). There was some discussion on the relevance of discussing tools without identifying the monitoring applications (i.e. use of tools for biodiversity monitoring) as well as without examining them in relation to specific habitats or species groups. In this context, the importance of developing the "Essential Biodiversity Variables" was brought up. Also, the discussion revolved around the status of species and habitats in the "Birds, Habitats, and Water Framework Directives" and new monitoring needs for informing the European Biodiversity Strategy for 2030 (e.g. ecosystem restoration), as well as habitats and species for which our current knowledge is limited or underrepresented e.g. due to difficulties in detection and data collection by current methods and approaches.

The new grouping of sub-facets under facet 1 as a result of the workshop discussions are proposed as the following:

- Facet 1a - eDNA and other molecular biology approaches (focus on sensors)
- Facet 1b - Remote sensing across platforms and sensors
- Facet 1c - Acoustic and image-based methods (focus on sensors)
- Facet 1d - Standardised sensors
- Facet 1e - Application of AI and smart devices for biodiversity monitoring
- Facet 1f - Further advancement in data integration and modelling

## Facet 1a - eDNA and other molecular biology-based approaches (focus on sensors)

Biological science goals: Assessment of certain species/taxa covered e.g. by the Water Framework and Habitat Directives, invasive species monitoring, support for mechanistic modelling, species distributions, abundance and genetic diversity - especially for those that we have limited information and knowledge.

Breakthrough potential: 1) Data collection, 2) wildlife genomes, 3) bio prospecting and building of knowledge for monitoring of species difficult to assess (or even still undescribed) and thereby providing a more encompassing picture of species-level biodiversity.

Knowledge gaps related to data collection: Air-sourced DNA collection, monitoring genetic diversity, automatic DNA metabarcoding, what are the data bias risks in the sampling of the eDNA data?

Knowledge gaps related to data processing:

- Quantifying intraspecific diversity.
- Mechanistic models of eDNA ecology (origin, state, transport and degradation of eDNA in the air, soil, water etc.) as linked to the steps below (i.e. for understanding how the trace came about).

- Improved probabilistic methods of taxonomic assignment (i.e. for assigning the trace to a given taxon).
- Including uncertainties deriving from the observational process into downstream models that feed Essential Biodiversity Variables on species distribution or biodiversity in general (i.e accounting for how imperfect or biased detection of the trace affects further steps).
- Propagating uncertainty in taxonomic assignment of sequence yield to uncertainty in downstream models of species distribution (i.e accounting for how a potential misinterpretation of the trace affects further steps).
- Methods for quantification.

FAIR data limitations: Incomplete / partly inaccurate reference libraries.

Standardisation: Harmonised approaches for the use of environmental DNA / metabarcoding / barcoding and computing taxonomic lists from these data (data standards, references, field and lab protocols).

## Facet 1b - Remote sensing across platforms and sensors

Biological science goals: Classifying habitats, estimating animal population sizes, assessing vegetation composition and layering, assessing ecosystem functioning, assessing landscape fragmentation.

Breakthrough potential: Assess the state and extent of natural habitats enabling constant and efficient tracking changes and trends in Essential Biodiversity Variables related to ecosystem structure, function and composition.

Knowledge gaps related to data collection: Ability of unmanned aerial systems (UAS) to monitor wildlife, use of novel data types for monitoring species and communities over space and time (very high resolution, hyperspectral, sonar and LIDAR), how to scale up collection of validation and calibration data.

Knowledge gaps related to data processing: Produce distribution maps, Joining data sources including calibration and uncertainties, Upscaling protocols and in situ validation, How to translate observations from airborne RS and novel satellites (including future ones) into relevant biodiversity monitoring products and modelling, including the use of IA (se also Facet 1e), etc.

FAIR data limitations: Reproducible aggregate data, Availability of statistics derived from the spatial data, Open workflows.

Standardisation: Standardisation of biodiversity data collection using remote sensors, Development of Essential Biodiversity Variables and Essential Ecosystem Service Variables from remote sensing, Cloud computing for processing under standardisation with implications for FAIR data.

## Facet 1c – Acoustics and image-based methods (focus on sensors)

Biological science goals: Estimating abundance and population trends, species co-occurrence and diversity, species detecting/monitoring species interactions and monitoring behaviour, phenology and migration. Rapid biodiversity assessment.

Breakthrough potential: Fully automated species and stage (age, sex,...) identification in pictures from camera traps and in sound records from audio recorders. Automated, rapid assessment of ecological status (habitat quality, biodiversity, anthropogenic disturbance) from soundscape monitoring. Development of workflows for the harmonisation and integration of data (such as detection probability, abundance estimates, etc) from the different observation technologies.

Knowledge gaps related to data collection: Sampling strategies to reduce spatial and taxonomic observation gaps and biases, optimising detection of organisms of interests and/or otherwise difficult to detect, combining sensors of different resolution and modality to balance data volume and quality, Automated and near real time in situ monitoring including data transmission. Low-power smart data collection.

Knowledge gaps related to data processing: 'Dark matter' in biodiversity multimedia: unknown species, unknown sounds, unknown objects, Near-real-time data processing, detection of individuals and species identification, behaviour (tacking via crowdsourcing -> AI). Estimating true abundance from sound recordings/ images (challenges relate to e.g. estimating encounter rates/ vocalisation rates). Transferability of machine learning / deep learning image/ sound classification tools to new regions/ datasets (issues of intraspecific variation and geographically restricted training data).

FAIR data limitations: Databases for training detection and classification models are small and inaccessible.

Standardisation: Integration of data streams from multiple sensors (this goes beyond this sub-facet e.g. plant-pollinator monitoring), combining data from multiple programmes. Combine and compare data across domains by extending and using biodiversity standards.

### Facet 1d – Standardised sensors

We need automated and standardised biodiversity sensor networks and data receiving stations across Europe to integrate and channel this information through workflows to repositories that allow open access to this information and derived knowledge products. The goal is to detect trends for a broad spectrum of species. We need to increase the quality and breadth of species ID (and individual ID). Networking across user groups for specific sensors. Regarding standardisation, we need formalised acceptance criteria and formalised step by step pipelines and standardised workflows that aim to be used in routine use (e.g. legislative monitoring). Without either the commonly agreed upon criteria and no method acceptance pipelines, the uptake is entirely organic and not structured. Implementation of ongoing European infrastructures such as eLTER, DISSCO, LifeWatch.

### Facet 1e – Applications of AI and smart devices for biodiversity monitoring

Breakthrough potential: 1) High-risk-high-potential studies to develop new monitoring solutions (AI, acoustic recording devices, eDNA and cameras.

Knowledge gaps related to data collection:

- Durability and reliable use of biodiversity informatics infrastructures and tools including its hardware and software.
- AI for harmonising and integrating monitoring data from multiple observation systems and programs
- How feasible is the operation/implementation of new tools for those who will be using them (e.g. are there mental, practical, technical to its use barriers)?
- Are new tools able to operate at scale (e.g. is it possible for users to build the tools themselves or are they commercially accessible)?
- (Bio-) robots for monitoring; automatic processing of data.
- Enabling real-time integration and analysis of data, and from (passive) monitoring to real-time intervention (possibly with robots).

Knowledge gaps related to data processing:

- How can the data be analysed (e.g. protocols for machine learning analysis pipelines)?
- Coupling monitoring with biodiversity models and future projections (making sure the right data are collected for e.g. causal analysis, predictive ecology).
- On demand data collection.

FAIR data limitations:

- How should the data be organised and stored (FAIR data principle)?
- How can advanced data processing workflows be stored/shared following FAIR principles?
- What associated metadata is relevant to record and store?

Standardisation:

- How do the data from new tools align with data from existing tools in terms of temporal, spatial and taxonomic resolution and extent?
- Independent validation of sensor data.
- How sensitive is the monitoring data from new tools to hardware and software revisions?
- What are the costs and benefits of new versus existing biodiversity monitoring tools/approaches.
- Integration of data streams - Models to allow integration of data from different monitoring efforts done with different goals, modalities, methods, and assumptions.

### Facet 1f - Further advancement in data integration and modelling

The advancement in the use of and development of data integration methods and models is seen as key for reducing spatiotemporal and taxonomic monitoring gaps and this cross-cutting issue could be elaborated further in the sub-facets 1a - e.

As indicated in the introductory paragraph on this facet 1 (on new tools, technologies and approaches), it is listed here as an additional sub-facet but without further elaboration on its own.

Furthermore, the aspects of data integration and linking to other sectors and policies reach beyond facet 1 and are also dealt with in facet 3 on use of monitoring data, further on in this report.

### Additional reflections

After the workshop, one of the experts raised the comment that discussions had failed to identify how these technologies can actually help overcome key monitoring gaps. In other words, the main focus was on gaps for advancing each technology rather than on advancing their monitoring applications. The experts raised that a stronger focus on linking technologies with pressing biodiversity monitoring gaps is critical to ensure effective contributions to problem-oriented and user-oriented monitoring systems. For example: what technologies can be applied for early warning systems for alien species? What novel observations and models are needed to monitor the distribution and condition of habitats of conservation importance, the effectiveness of restoration, etc.?

## Facet 2: Involvement of citizens in the biodiversity monitoring activities

Based on the outcomes of the survey sent to the experts before the Workshop and on the Strategic Research and Innovation Agenda (SRIA), four sub-facets were pre-identified and knowledge gaps/ research and innovation priorities related to the involvement of citizens in biodiversity monitoring activities were grouped as follows:

- Pre-identified facet 2a) (How) can non-standardised citizen science data on biodiversity be filtered/ analysed to provide robust spatio-temporal insight into biodiversity patterns and processes?
- Pre-identified facet 2b) For which organisms/ habitats/ processes are citizen scientists a good supplement or even superior to standardised biodiversity monitoring?
- Pre-identified facet 2c) What is the democratic value of citizen science projects focussing on biodiversity?
- Pre-identified facet 2d) How can machine learning contribute to better citizen science?

The subgroup discussions were lively and addressed broad aspects related to citizen science in biodiversity monitoring activities. These elements were used to adjust the wording of the sub-facets pre-identified before the workshop (*see the new wording and explanations below*).

### Facet 2a) Improving the design of methods and data collection in citizen science for biodiversity monitoring

Through the survey one of the main questions that was raised related to this sub-facet was: (how) can non-standardised and often present only citizen science data on biodiversity be filtered/ analysed to provide robust spatio-temporal insight into biodiversity patterns and processes. Data quality and management for citizen science appeared to be a real issue to be tackled. As such, having more standardised data, ensuring continuity in the data collected and overcoming a trade-off between data quality and data number or coverage appeared to be of high importance.

During the workshop, it was discussed that one of the solutions that could ensure a stronger continuity in the available data would be to involve more people with diverse profiles in citizen science activities, especially young people/ students and other relevant targeted groups, such as female citizens to participate in these processes (links with facet 2b).

At the end of the workshop, the experts complemented the survey by stating that citizen science methods have to be improved so that data can be standardised. Standardisation of data is however not easy to achieve in citizen science and to better standardise data, it would both be needed to encourage citizen scientists and to assess how citizen science data affects sensible monitoring. There is a general consensus that non-standardised citizen science data is highly biased. The solutions to this are threefold: Firstly, finding approaches to analysing the data to account for the underlying bias; secondly adapting current methods to capture more information about the recording process so that corrections can be made; and, finally, embracing the biases of people to increase their engagement and to use citizen science only in situations where it is advantageous to do so. In collecting data, it is often assumed that there is a trade-off between the quality of the data and the amount of engagement. Nevertheless, technology might provide solutions for this. Applications already automatically record the time, date and location of observations and there may be other ways that technology can reduce the less appealing aspects of collecting data while increasing the more enjoyable parts (link sub-facet 2d).

The experts also agreed that there is a lot of interest in new biodiversity monitoring data that can be collected through citizen science. As such, it might be interesting to encourage citizen scientists to collect new types of data, such as species interactions.

The experts also stressed that methods to collect biodiversity monitoring data should be designed by taking into account the specificities of each situation (i. e. different habitats, different number of species in the different parts of Europe which create different situations for citizen scientists). Overall, investing a lot in method development is needed.

## Facet 2b) Co-design and co-create with communities and citizens to monitor biodiversity

The Biodiversa+ SRIA indicate that "*Research should also study how indigenous people and local communities in Europe pursue to adapt to environmental changes by exploring holistic solutions able to increase their response capacity and resilience to a broad range of perturbations. Drawing upon different knowledge systems, including indigenous and local knowledge, is appropriate. Stakeholders diversity is therefore a source of resilience, and for which citizen science might be an important asset*." The SRIA also mentions "*the contribution of citizens and NGOs to monitoring programs through citizen sciences that have not yet delivered their full potential, both in terms of possible research impact and public engagement and awareness raising about biodiversity among citizens*".

The survey aligned with the elements from the SRIA and added that it would be positive:

1. to match data needs with people's motivations.
2. involve practitioner groups with direct management roles (e.g. small forest owners, farmers etc.) in citizen science.

3. provide better feedback: value of data, context of records, benefit of records, action resulting from monitoring to better show why biodiversity monitoring data should be collected.
4. create stronger synergies with museums, official administrations, associations.
5. better integrate citizen science in universities and research institutions.
6. further focus on neglected species and look at under-studied environments.

During the workshop, the experts concurred with these elements and showed that to broaden the use of citizen science on biodiversity monitoring, it is important to engage broader communities, stakeholders and motivate more people to participate. They concluded that:

- For biodiversity monitoring, not only should an online platform reinforce data quality/ facilitate data management and open-access, but that it should also create a sense of community. As such, it was explained that a cornerstone for a successful biodiversity monitoring platform is to be interactive and provide the contributors with the possibility to learn more and see how their data are used in a long-term commitment and process.
- reaching out to new local communities/ stakeholders on habitats on which few data is available: freshwater, marine (eg. diver organisations), soils would result very helpful. For habitats, involving relevant stakeholders and people on projects in a specific setting (restoration, protection, monitoring) it is often successful. In a similar way, it is possible to reach out to new actors who specialise more on a species on which few data are available or on species interactions (under-studied).
- reaching out to new groups of actors often, but not always, under-represented: students, women, indigenous people… would also be positive. People from inner cities also have a stake in biodiversity and just because they are not in biodiversity hotspots doesn't mean they should be ignored in citizen science. New technologies, especially internet and mobile applications can help reach out to these actors (link with subfacet 2d).
- citizens can co-design studies and go beyond the collection of data. As a matter of fact, citizens can be in places and times where and when scientists cannot.
- co-design on the other hand is not a strict prerequisite for successful citizen science. It is just one of the tools, and is useful for groups with high engagement and clear objectives. Non-co-designed projects which are enjoyable and motivating can be just as and even more effective, depending on the expected outcomes.

## Facet 2c) Assessing the added-value of citizen science for biodiversity monitoring

Through the survey, two questions on citizen science were raised:

- regarding the democratic value of citizen science projects focussing on biodiversity and that one way to make citizen science more democratic was by making citizen science data more meaningful to people and actionable.
- and regarding the fact that citizen science is rapidly evolving and very diverse in methodologies and "design". Hence, it would be valuable to know if there is a systematic assessment of "what works", of the strengths and weaknesses, best practice in different settings of citizen science.

During the workshop, the experts discussed the use of citizen science and agreed that it was not always a suitable / adapted tool for all the research questions. They mentioned that the most cost-effective method for addressing a specific research question has to be looked for. They explained that it was important to know when it is appropriate to engage citizen science, and for which reasons.

As a conclusion of the workshop, it was mentioned that education and outreach on citizen science can help to make citizen science on biodiversity monitoring more democratic and accessible.

Finally, the experts stressed that it was necessary to focus on the extra-value of citizen science. There are some elements that citizen science can do that professional science cannot and those advantages should be leveraged rather than competing against each other. In that sense, it was suggested that sometimes it is an opportunity to have different kinds of data: citizen science data and traditional/ professional data. With good tools, methods and interesting research questions to combine these data, it is possible to get a lot of information.

### Facet 2d) New technology opportunities to improve the involvement of citizens in biodiversity monitoring (transversal sub-facet for FACET 2)

Through the survey, it was emphasised that technologies such as machine learning, artificial intelligence or drones can contribute to citizen science. Examples of such contributions were:

- how technologies could help overcome the frequent lack of data management plans in citizen science activities.
- how to identify the best technologies / tools (i.e. applications, deep learning, training workshops, handouts) to strengthen the data quality of citizen science activities.
- how and where to organise the interface between lay people in the field and open databases, typically managed by scientific organisations, in accordance with FAIR, open-access/open data principles.
- how technologies can facilitate the validation of reports/ species identity.

During the workshop, the experts agreed that in the world, there is a global trend to use more and more internet and applications. They stressed that it would be beneficial to roll out these technologies to improve the involvement of citizens in biodiversity monitoring. Up to now, several apps to monitor biodiversity already exist, but it would be useful to have a network of networks that brings all the data collected in these apps together in a transparent and open way (GBIF and iNaturalist were mentioned as examples). There is a knowledge gap related to FAIR data, data workflow and interoperability. Artificial intelligence was also described as a great tool to scale up citizen science data.

At the end of the workshop and following in depth discussions on the use of new technologies, three main contributions of technologies to citizen science were identified:

- technologies can be used for analysing biodiversity monitoring data collected through citizen science (links with facet 2a),

- technologies can incent citizen/ scientists to go in a specific area to perform biodiversity monitoring activities (links with facet 2b),
- vast opportunities related to artificial intelligence, data mining, DNA analysis and other technologies seem to exist when combined with citizen science. Such opportunities should all be further investigated. (links with facet 2b)

Overall, new technologies appeared to be tools with strong potential for citizen science in biodiversity monitoring. Assessing when, how and where these new technologies would be beneficial for citizen science related to biodiversity monitoring would provide better knowledge to improve biodiversity monitoring.

## Facet 3: Use of monitoring data by R&I

The pre-grouping to better producing biodiversity trends (facet 3a), better understanding the relationships between the state and dynamics of biodiversity and drivers & pressures (facet 3b) and reinforcing modelling and scenarios (facet 3c) was fully agreed by the expert group, but it was stressed that there is a need to integrate the whole of these three. Furthermore, it was emphasised concerning all the themes, that the high quality and the harmonisation level of the data are critical for the usefulness and the quality of research results. There is a need to strengthen the link between data and research to indicators and policies, for which the expertise of the research sector (including political and social sciences) is needed. In addition to a steady flow of long-term monitoring data and strong basic research, there is a need for more transdisciplinarity and interdisciplinarity. It was also suggested to understand monitoring really as monitoring and not only as long-term observation. I.e. to make a closer link to policies and their impact on land use and to be able not only to observe in all details how we lose biodiversity but also to be able to counteract this loss.

### FACET 3a) Better produce biodiversity trends (including better characterization of the uncertainties associated)

Under this theme the SRIA in section A.1. lists as major knowledge needs the definition of operational metrics; of evolutionary potential; and of the level of interaction within and between communities and ecosystems. The survey recognised several knowledge gaps related to this area, e.g. changes in lesser-known but species-rich taxa, changes of biodiversity in less studied habitats and connection of monitoring in different geographical and time scales (see Annex 3).

The SRIA in section A.2. indicates as a major 'knowledge and approach need' the definition of common indicators to communicate the results of biodiversity monitoring, on which there is a lot of ongoing work. The survey underlined the need for development of new evidence-based biodiversity indicators and the present lack of consensus on what biodiversity metrics are most informative to guide policy and change. The indicators are essential for enhancing cross-sectoral co-development with significant biodiversity targets (see Annex 3).

The SRIA in section A.2. further lists examples on model-based statistical analyses needed for data analysis for assessing status and trends and emphasises the need of mobilising biostatisticians. The survey pointed out the need for development of sound methodological approaches to combine different data sources (e.g. scale, presence only vs. presence-absence, structured vs. unstructured sampling, citizen science-based and standardised expert assessments) for biodiversity status, trend analysis and better understanding of ecosystem dynamics. There is also a need for mobilising old, existing data (see Annex 3).

The discussion in the workshop highlighted the data aspect. There are still large spatial and taxonomic gaps in capturing the data needed. On the other hand, the new methodologies have opened new cost-effective possibilities on collecting the data. The high quality of the data is closely related to improving the metadata and easy, centralised availability of metadata. Following the FAIR principles in sharing the monitoring data should be a premise. Estimation of the uncertainties in space and time in the biodiversity trends based on monitoring data adds credibility of the biodiversity indicators.

Harmonising and standardising the methodology of monitoring would highly increase the possibilities of wider analysis. Promoting entities and structures that can work with the different communities to propose common methodologies and how to integrate them in trends estimation would benefit harmonisation processes. However, due to strong national preferences and monitoring traditions standardising the existing monitoring schemes is challenging. The standardisation is also taxa dependent to a certain level. In parallel to standardisation and metadata improvements, the experts suggested putting strong effort on integrating and combining different types of monitoring data. That could result in analytical pipelines. Standardisation of methods and data as well as integration of data are meaningful and timely research questions as such.

The cost–information value evaluation of most of the monitoring schemes are lacking. Long-term monitoring data are unique as they have predictabilities, and can allow analysis of the gaps in the settings of the monitoring schemes. This way, with the same resources, you can improve monitoring schemes by adjusting the gaps in the existing designs.

As a written input to this report one participant suggested changing the description of this sub-facet into: “Better capture and describe biodiversity trends (including better characterization of the uncertainties associated).

## Facet 3b) Better understand the relationships between the state and dynamics of biodiversity and drivers / pressures

The SRIA in section A.1. indicates as a major knowledge gap the need to characterise the threats of biodiversity in a global context including climate change, land use change, overexploitation, pollution, (re)emerging pathogens and biological invasions. The survey recognized several related knowledge gaps hindering research, such as availability of more precise European land-use data, development of frameworks which allow the use of driver trends and species sensitivity to those drivers as powerful monitoring tools, as well as better interpretation of the underlying factors behind the biodiversity change (see Annex 3).

The SRIA in section A.1. also recognises that long-term cumulative effects on some taxonomic groups and ecological communities are not yet well understood. Similarly, the survey brought up the need for studying the responses of different taxa and the lack of European systematic biodiversity monitoring scheme. Having the focus on Red Listed species does not capture the extent of biodiversity change and does not provide sufficient information on cause-consequence that could be used to guide policy and action.

The SRIA in section A.1. urges identifying phase-shift thresholds of direct and indirect stressors to guide in particular decisions over limits to extractive activities. It also states that specific threats to animal breeds and plant varieties should be better understood to guide efficient strategies to conserve and manage genetic resources and their wild relatives. The survey suggests ecosystem-based approaches to better link biological data to environmental and anthropogenic drivers (see Annex 3).

The SRIA in section A.1 furthermore points out that we need knowledge on the effects of multiple stressors and extreme events, including understanding the impact of climate change in combination with context-specific drivers on biodiversity and ecosystem services, especially with respect to tipping points and planetary boundaries. The survey also referred to the need to understand the relative impact of different drivers, combining high quality models with monitoring data to improve understanding on biodiversity status, key ecosystem processes, and large-scale and long-term effects. It also asked for better coordination among disciplines, including experts on drivers of global change and other initiatives promoting integrated studies.

The discussion added the need for including the ecosystem dynamics and understanding the dynamics of management and restoration practices. The restored areas should be monitored, and the management and restoration practices adjusted based on research. The management also offers opportunities for preserving biodiversity. The experts noted that currently unclear definitions of specific threats, drivers and measures hinder meaningful analyses. Standardised way of collecting data on threats would allow meta-analyses carried out at European level. The discussion reflected hesitance to use the term tipping points but rather searching for thresholds. For the cumulative effects the value of the data in natural history collections was brought up. Large European digitisation efforts offer an increasing amount of data through GBIF and DiSSCo, of which especially fully georeferenced data brings added value.

As a written comment to this report one expert again (re)emphasised the importance of not only gathering biodiversity data but at the same time also monitoring the human impact (and maybe its history) on the landscape / land cover / land use / habitat / context where these biodiversity data stem from. Only with that information will we be able to better understand (and possibly change) the role of humans in the context of the development of biodiversity. Similarly, another expert pointed out that for the marine ecosystems an ambitious EU directive, the Marine Strategy Framework Directive (MSFD) aiming to achieve Good Environmental Status (GES) and sustainable use of marine resources, is linking the biodiversity status with pressure and impact descriptors of the marine environment. However, a major gap is the lack of knowledge concerning the impact of different pressures on several biodiversity components in these ecosystems.

## Facet 3c) Reinforce modelling and scenarios built on monitoring data

The SRIA in section A.1. emphasises that research should better characterise the sources of flexibility and transformability for species, populations, ecosystems and socio-ecological systems. Monitoring-data provides the basis for the development of indicators on such flexibility and transformability. The survey recognised that solid links between biodiversity change and ecosystem level processes in natural/semi-natural ecosystems are still lacking (see Annex 3).

The SRIA in section A.1. suggests to use research for proposing indicators of adaptation potential, for the development of which the monitoring-data provides the basis. The survey emphasised a need for a wide array of inter- and transdisciplinary analyses supporting decision-making (see Annex 3).

The SRIA in section A.2. encourages to match the biodiversity monitoring data with data for environmental drivers. A concrete output could be automated, semi-automated or machine learning systems for analysis of biodiversity data. This would also reinforce modelling and scenarios built on monitoring outputs. Following this theme, the survey suggested explicit linking of monitoring efforts with scenario frameworks using common biodiversity monitoring indicators. Improving knowledge on biodiversity hotspots (i.e. MPAs) was specifically mentioned. Also, stronger linkage to research and innovation projects focusing on solving other environmental challenges was brought up (see Annex 3).

The workshop participants pointed out that permanent systematic plots for survey of different taxonomic groups would strengthen produced models, as the quality of the data is also a key for scenarios. The discussion agreed with the importance of developing indicators, scenarios, and communication tools and saw that these will benefit decision-making especially when they can be extended beyond the natural sciences only. Also, the discussion around reference values (how much of habitat or species is enough?) refers to a need for modelling.

Perhaps not so extensively discussed during the meeting, but emphasised by one participant afterwards, is the notion that advances in data integration and model applications for monitoring biodiversity are fundamental for connecting observations with monitoring. Implicitly however, during the exercise it seemed obvious that both aspects need to be better interlinked. This is also critical e.g. in the context of developing the Essential Biodiversity Variables and policy-relevant biodiversity indicators.

# 2. Knowledge gaps going beyond the 3 Facets

## 2.1 Links between the 3 Facets

Overall, the three facets appeared to be related (sometimes, distinguishing what belonged to one facet rather than to another was difficult), as such the discussions showed that there is a need to bring the whole of these three facets together.

As such, Facet 1 is of relevance for Facet 2 (see especially sub-facet 2d) as the testing and application of new tools, technologies and approaches can benefit citizen science, and Facet 3 was recognised to be linked with Facet 2 in the sense that there is a continuum between citizen science data and biodiversity monitoring data relevant for use for research and for innovation.

As a review comment after the meeting it was noted by some experts that the aspect of citizen science was overemphasised ("Yes, it may generate public awareness and facilitate implementation of policies - and that is great. But at the end, it is but ONE biodiversity data source, and a challenging one"). On the other hand, it was also mentioned that for several species there are examples of monitoring schemes in which citizen science produces high quality data comparable to agency driven monitoring ("It is just a matter of training in methods and accuracy").

## 2.2 Identified cross-cutting themes

A couple of general knowledge needs were pre-identified (see Annex 3) and confirmed by the experts during the workshop:

- Monitoring efforts are particularly needed for the lesser-known organism groups and ecosystems/ environments/ compartments as well as the interaction amongst them.
- All dimensions of biodiversity (taxonomic groups, functional groups, ecosystem services) could be considered.
- Re-using existing datasets and information from biological collections will be very useful. FAIR, open data/open access principles need emphasis.
- The need of linking monitoring approaches and methods to monitoring needs related to specific habitats and species.
- Need of standardisation of monitoring data across geographical scale to get the "bigger picture".
- Need to link biodiversity monitoring to data to policy decisions on big drivers (urbanisation, agriculture, infrastructure etc.).

As regards data quality, in the workshop it was signalled that data quality is subjective and dependent on the scientific questions at hand. More focus on a good description of data is needed (provide relevant metadata). However, work on data standards can support innovation.

# 3. Going beyond the knowledge gaps: other relevant elements for biodiversity monitoring activities

Relevant elements for biodiversity monitoring activities that could not be considered as research gaps were also raised by the experts who contributed to the survey. These elements were grouped to fit in the Biodiversa+ work plan on biodiversity monitoring and will be shared with the Biodiversa+ Partners in charge of the implementation of the relevant tasks.

**Task 2.1 Priorities, Coverage, Indicators for biodiversity monitoring *(led by the French Biodiversity Office, OFB)***

Sub-task 2.1.1 Refine priorities and needs for adequate coverage for biodiversity monitoring to better fit research, society and policy needs (*led by the French Biodiversity Office, OFB*)

Several elements to help refine priorities and needs for adequate coverage for biodiversity monitoring to better fit research, society and policy needs were raised by the experts in the survey:

- How to adapt long-term monitoring to new pressures and threats (and political agendas) without destroying time series?

- Existing monitoring does not sufficiently cover all biodiversity facets, e.g. Water Framework Directive monitoring in freshwater.

- Severe knowledge gaps/ lack of monitoring schemes in several organism groups: insects, fungi, soil organisms.

- Development of a dedicated freshwater biodiversity monitoring scheme (preferably type-specific and including an appropriate and seasonal sampling frequency) as existing monitoring schemes of freshwater habitats (e.g.Water Framework Directive) insufficiently capture biodiversity trends.

- Lack of appropriate freshwater biodiversity time series also covering seasonal variation (that could result from the first point).

- Policy - If we are using our data to influence policy decisions (as we should be), are we monitoring the impact of those policies at a European and global level?

Sub-task 2.1.2 Common indicators to communicate to users, deduce variables/ methods/ data/ information flux needed (*led by the Swedish Environmental Protection Agency, SEPA*)

- Use monitoring data to ensure that reporting on conservation status of species and nature types is compatible across the European member states.

### Task 2.2 Harmonise protocols, methods, databases and data format (MUR)

Sub-task 2.2.1 Harmonise operationalised protocols and inventory methods across regions and countries (*led by the French Biodiversity Office, OFB*)

For biodiversity monitoring, the following points were raised by the experts:

- Monitoring intervals are too long.
- The collection of bird data at European level is a best practice example with high-quality methods and monitoring expertise. The practices could be shared and compared to other organism groups.
- Regarding bird's data, the added-value of a centre that coordinates / harmonises data with a stable funding was stressed: "*Important in the quality of the bird data is the coordinating role of the European Bird Census Council, who harmonises e.g. the taxonomy and observation efficiency of the data, which allows using the data for European level analysis and producing of European level indicators. However, the funding of EBCC is not stable*". It was added that this could be extended to butterflies, vegetation plots etc. "*Harmonisation requires coordination structures/resources which are very weak especially in the long term*".
- Investments in the development, testing and automation of monitoring methods needed.
- Many R&I projects are focusing more or less on biodiversity and may also involve monitoring of biodiversity, but knowledge is lacking on how data is used, how monitoring is done, how data is eventually affecting the R&I projects.
- International standardisation of biodiversity assessment tools/methods considering cost-effectiveness and broad applicability.

Sub-task 2.2.2 Harmonise databases and data interoperability (led by the *Italian Ministry of Universities and Research, MUR*)

Elements to take into account to help harmonise databases and data interoperability are:

- Make monitoring data accessible and free access: Free access to monitoring data, monitoring data hardly accessible, Biodiversity monitoring data is scattered, not available from one or few infrastructures. Additionally, it is important to make sure that the data are understandable.
- Ensure high quality data to ensure that researchers don't go wrong because of wrong interpretation of data quality. Since data quality always depends on the intended use (data may be of high quality for one question and the same data may be of low quality for another one), high META-data quality (including information about why the data was collected, what was not collected, what methods were used and what their error rates are), seems at least as important.
- Strengthen and further develop a clearing-house mechanism for sharing scientific data on ecosystem dynamics and biodiversity to promote and facilitate technical and scientific cooperation within and in between the European member states.
- Development of a European database for freshwater biodiversity (according to FAIR principles).
- How to effectively involve volunteers in the monitoring of different groups of organisms.

### Task 2.3 Emerging/ new methods, technologies, approaches (*led by the Innovation Fund Denmark, IFD*)

Sub-task 2.3.1 Develop and/or deploy new technologies/approaches (*led by the Innovation Fund Denmark, IFD*)

- PM (this report, facet 1 and sub-facet 2d)

Sub-task 2.3.2 Better involve citizens in the biodiversity monitoring activities (*led by the General Secretariat for Research and Innovation, GSRI*)

Two elements are of relevance:

- Achieving a stronger culture of recognition of citizen Scientists' contributions within projects, for example through co-authorships, honorary allowances, or similar mechanisms is needed
- Ethical and legal guidelines for citizen science would also be needed.

### Task 2.4 Support monitoring data by research / decision makers (*led by the Ministry of Agriculture, Nature and Food Quality of the Netherlands, LNV*)

Sub-task 2.4.1 Use of biodiversity monitoring data by R&I (*led by the Ministry of Agriculture, Nature and Food Quality of the Netherlands, LNV*)

- PM (this report, facet 3)

Sub-task 2.4.2 Use of biodiversity monitoring data in decision-making (public and private) (*led by the Flemish Region, VL O*)

In relation to this sub-task, it was raised that the connection of biodiversity monitoring in different geographical areas and time scales would provide a better global understanding for public and private decision making.

### Task 2.5 Establish a transnational network of national biodiversity monitoring schemes (for specific domains) (*led by the Ministry of Environment of Finland, MoE_FI*)

Four elements relevant for the Biodiversa+ task 2.5 were identified:

- How to secure long-term financing for monitoring?
- How to improve national coordination of biodiversity monitoring?
- Knowledge gaps are connected to the lack/ scarcity of taxonomic experts.
- Supporting long-term monitoring data for biodiversity changes/trends, and data collection on priority species and habitats.

# Concluding remarks

Europe will not be able to achieve its targets laid out in the EU Biodiversity Strategy for 2030 if urgent action is not taken during the next 10 years. The need to halt biodiversity loss and to preserve and restore ecosystems is now recognised at the highest political level and also exemplified by the declarations by G7/G20 and the World Economic Forum declarations. Improved knowledge and innovative solutions are pivotal to meet these needs. Measuring the status and trends in different dimensions of biodiversity at multiple scales requires advancing information frameworks such as the Essential Biodiversity Variables and biodiversity change indicators, but also demands inclusive collaboration across borders in support of national, European and global research and policy. One of the five overarching objectives of the European Biodiversity Partnership is to improve biodiversity monitoring across all land and sea reinforcing links with research and innovation, as well as mainstreaming biodiversity status and trends. To safeguard biodiversity for future generations it is crucial to ensure the continuation of ecological and evolutionary processes at the species and ecosystem levels as well as to be able to follow and document trends of such processes and biodiversity per se. Moreover, research in biodiversity monitoring is needed in order to develop and enhance novel tools and approaches to as smart as possible register the effects of biodiversity conservation, restoration and sustainable management and the fulfilment of national, European and global targets on biodiversity.

The Biodiversa+ expert workshop on monitoring provided rather clear results in relation to the importance of R&I in the three facets. **Facet 1** on new tools, technologies and approaches resulted the proposal for R&I in six themes including eDNA and other molecular biology approaches (focus on sensors); remote sensing across platforms and sensors; acoustic and image based methods (focus on sensors); standardised sensors and application of AI and smart devices for biodiversity monitoring. These new tools and approaches will be linked through workflows and information frameworks, to the specific monitoring requirements for species, ecosystems and their functions, thus providing cost-effective and enhanced data collection and analysis. **Facet 2** on the involvement of citizens in biodiversity monitoring activities also shows the importance of R&I. R&I can improve the design of methods and data collection, better co-design and co-create with communities and citizens to monitor biodiversity, assess the added-value of citizen science and allow new technologies to support the involvement of citizens in biodiversity monitoring. Finally, **Facet 3** resulted in showing that producing better biodiversity trends, better understanding the relationships between the state and dynamics of biodiversity and drivers & pressures and reinforcing modelling and scenarios would allow better use by R&I of biodiversity monitoring data which will result in a better understanding of biodiversity.

# Annex 1: List of experts who contributed to this report

| First name | Last name | Expert organisation | Facet |
|---|---|---|---|
| Ella | Browning | University College London | Facet 1 |
| Ricardo | Diaz-Delgado | Estación Biológica de Doñana | Facet 1 |
| Néstor | Fernández | German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig | Facet 1 |
| **Thomas** | **Hoye** | **Aarhus University** | **Facet 1** |
| Birgitta | König-Ries | Friedrich Schiller University Jena | Facet 1 |
| Theis | Kragh | University of Southern Denmark | Facet 1 |
| Florian | Leese | University of Duisburg-Essen | Facet 1 |
| Dan | Stowell | Naturalis Biodiversity Center / Tilburg University | Facet 1 |
| Konstantinos | Topouzelis | Department of Marine Science, University of Aegean | Facet 1 |
| *5 additional experts contributed to the discussions on Facet 1. Their names are not mentioned here due to GDPR restrictions.* | | | |
| Gary | Banta | University of Southern Denmark | Facet 2 |
| **Quentin** | **Groom** | **Plantentuin Meise** | **Facet 2** |
| Jacob | Heilemann-Clausen | University of Copenhagen | Facet 2 |
| Michael | J O Pocock | UK Centre for Ecology & Hydrology | Facet 2 |
| Katrin | Vohland | Naturhistorisches Museum Wien (NHMW) | Facet 2 |
| Silke | Voigt-Heucke | Museum für Naturkunde Berlin - Leibniz Institute for Evolution and Biodiversity Research | Facet 2 |
| *4 additional experts contributed to the discussions on FACET 2. Their names are not mentioned here due to GDPR restrictions.* | | | |
| Mora | Aronsson | Swedish University of Agricultural Sciences, Swedish Species Information Centre | Facet 3 |
| Florian | Borgwardt | University of Natural Resources and Life Sciences, Vienna | Facet 3 |
| Lluis | Brotons | CREAF Centre for Ecological Research and Forestry Applications | Facet 3 |
| Jonathan | Chase | German Centre for Integrative Biodiversity Research (iDiv) / University Halle-Wittenberg | Facet 3 |

| First name | Last name | Expert organisation | Facet |
|---|---|---|---|
| **Aino** | **Juslén** | **The Finnish Museum of Natural History, University of Helsinki** | Facet 3 |
| Christoph | Kleinn | University of Göttingen | Facet 3 |
| Kurt | Pinter | University of Natural Resources and Life Sciences, Vienna. | Facet 3 |
| Sofia | Reizopoulou | Hellenic Centre for Marine Research (HCMR) | Facet 3 |
| Johannes | Rüdisser | University of Innsbruck, Department of Ecology | Facet 3 |
| Egemose | Sara | University of Southern Denmark | Facet 3 |
| Astrid | Schmidt-Koiber | University of Natural Resources and Life Sciences, Vienna | Facet 3 |
| 3 additional experts *contributed to the discussions on FACET 3. Their names are not mentioned here due to GDPR restrictions.* | | | |

Rapporteurs indicated in **bold**.

# Annex 2: Expertise covered by the invited experts in each Facet

- **Facet 1 testing and application of new tools, technologies and approaches for biodiversity monitoring**

### TOPICS
•AI
•Machine learning
•Data management, FAIR data
•Molecular bioassessment
•eDNA and DNA
- genetics
- sequencing
- metabarcoding

•Computer vision
•Automatic image based
•Deep learning
•Real time tracking
•Modelling
•Computer sciences
•Bioinformatics
•Biogeochemistry
•Image recognition
•Audio dataset, animal vocal communication, acoustics
•GPS data, Remote sensing, spatial information systems
•Drones
•Datasets

### ENVIRONMENTS
•Terrestrial
•Inland water (lakes/ peats)
•Urban
•Marine and coastal
•Regions: Arctic and tropical

### SPECIES
•Invertebrates
•Invasive alien species
•Fungi
•Soil fauna
•Mammals
•Pathogens/ bacteria

•Fish
•Amphibians
•Birds

- **Facet 2: involvement of citizens in the biodiversity monitoring activities**

TOPICS :
•Citizen science
•Data management, use of data, citizen reported data, FAIR biodiversity model
•Public engagement
•Next generation sequencing, DNA barcode, data streams, eDNA, metabarcoding
•Models
•AI
•Ecological interactions
•Ecology
•Conservation biology
•Climate-socio-environmental changes
•Bioacoustics

ENVIRONMENTS :
•Terrestrial
•Freshwater inkl. groundwater
•Urban
•Coastal / salt marshes

SPECIES :
•Insects (including pollinators)
•IAS
•Crustacea
•Plants (including trees)
•Wildlife
•Fungal
•Mammals
•Birds
•Mangrove
•Macrofauna

- **Facet 3: use of monitoring data by R&I (including better understanding of biodiversity status, trends, drivers)**

TOPICS
•Ecology (inc. landscape ecology, conservation ecology, ecosystem ecology)

•Climate change
•Conservation biology
•Community structure, metacommunities, population trends
•Species diversity
•Land use
•Modelling, statistical modelling
•Remote sensing, Spatial analysis, geoinformation, remote sensing application
•Citizen Science
•Fisheries management
•Forest monitoring
•Taxonomy
•Habitats
•Policies, Environmental Impact Assessment, Business intelligence
•Data infrastructures, open data
•Genomics, genotype, eDNA
•Drones and image analysis, geoengineering
•Epidemics
•Functional traits
•Evolution
•Ecosystem services
•Multi-scale landscapes

## ENVIRONMENTS

•Terrestrial
•Inland water
•Coastal / Marine
•Regions: Alps, Arctic, Boreal tropical

## SPECIES

•Invertebrates
•Amphibians
•Invasive Alien Species
•Insects (butterflies, Anthropos…)
•Birds
•Fish
•Plants (incl. trees, wild plants..)
•Virus / pathogens

# Annex 3: Preparatory work document pre-identifying knowledge gaps report

**Biodiversa+ January 2022 Expert Workshop**
**Knowledge Needs pre-identified ahead of the workshop**

The knowledge needs pre-identified comes from:

- The survey sent to the experts participating in the workshop
- The Biodiversa+ Strategic and Research Innovation Agenda (SRIA, see specific session on Cross-Cutting Theme A p.58); these knowledge needs are often quite general in nature. The references/quotes below are referring to the cross-cutting sub-themes A.1. (CHARACTERISING AND UNDERSTANDING BIODIVERSITY STATUS, TRENDS AND DRIVERS, p.60) and A.2. (SETTING UP A PAN-EUROPEAN NETWORK OF HARMONIZED MONITORING SCHEMES, p.64).

These pre-identified knowledge needs will guide the discussions of the expert workshop that will be organised by Biodiversa+ on the 31st of January 2022.

## GENERAL KNOWLEDGE NEEDS

- SRIA A.1.: "Efforts are particularly needed for the less known organism groups (like microbial or arthropod diversity), environments, compartments (such as soils and deep seas) and dimensions (such as functional diversity and food webs), as well as threatened species, biodiversity-rich areas and hotspots that remain uncharacterized in some parts of mainland Europe and OCTs and ORs,.."
- SRIA A.2.: "More monitoring efforts should be devoted to lesser-known ecosystems, e.g. soils, calcareous grasslands, Arctic systems, seabeds, etc."
- SRIA A.2.: "All dimensions of biodiversity (taxonomic groups, functional groups, ecosystem services directly linked to biodiversity) could be considered"
- SRIA A.1.: "research re-using existing datasets and information from biological collections will be very useful to perform meta-analyses on the dynamics of biodiversity and ecosystem services and their drivers"

## FACET 1 testing and application of new tools, technologies and approaches for biodiversity monitoring

SRIA A.2.: "development and deployment of new technologies and approaches (such as eDNA and other molecular biology based approaches, mobile-sensing technology, remote sensing through satellites, airborne campaigns and/or drones, acoustics, camera traps, etc.) whose potential still has to be explored by biodiversity research and monitoring activities."

SRIA A.2.: "This requires the development, transfer and operational use at a transnational level of these new monitoring tools/approaches, including better use of emerging technologies and algorithms to process this new type of information (for instance artificial intelligence/machine learning/deep-learning).

SRIA A.2.: "The deployment of automated and semi-automated high-tech field methods for biodiversity monitoring should be considered, e.g. lidar systems for cover/biomass; automated species identification; and non-destructive invertebrate traps with automatic species recognition"

### Keep in mind: Extend the focus to poorly known species groups and ecosystems and linking to functions

- More comprehensive integration of biodiversity monitoring in large area forest monitoring
- Habitat assessment as proxy for biodiversity monitoring
- Species identification as a challenge in all monitoring exercises
- Exploring the potential of more landscape-based assessment of biodiversity, in both aquatic and terrestrial habitats, using any and all of the above approaches.
- Early detection system and monitoring of alien invasive species
- Extend the focus: How does biodiversity change in all other groups than vertebrates (fungi, protists, nematodes, insects, other arthropods...)?
- Link between biodiversity and major ecosystem functions in order to develop functional approaches to conservation

### Facet 1a) eDNA and other molecular biology based approaches

- SRIA A.1.: "bio-prospection of new genes, functions and natural substances harboured by aquatic and terrestrial organisms – including microorganisms - can offer great economic opportunities"
- SRIA A.1.: "comprehensive description of European wildlife genomes, including those of wild relatives of domesticated breeds, to support the preservation of European ecosystems and their biodiversity"
- SRIA A.1.: "Possible perspectives are to monitor all species-level biodiversity (by DNA barcoding and metagenomics) and genetic diversity within a broad selection of species in Europe; and to relate genetic diversity over given geographical areas to historical land use and cover (this could be done in relation to restoration activities also,..)"
- Harmonised approaches for the use of Environmental DNA / Metabarcoding / Barcoding and computing taxonomic lists from these data (data standards, references)
- Environmental DNA (including quantitative and "semi-quantitative" monitoring, especially in aquatic habitats); Enhancing taxonomic expertise including automated or semi-

automated assisted taxon identification; theoretical and practical enhancement of classical taxonomy with genetic-based perspectives on biodiversity.
- Air-sourced DNA collection - its efficiency and usefulness are unknown yet
- Automatic and affordable meta-barcoding for species identification
- Develop standardised approaches for novel molecular methods to make biodiversity monitoring data comparable (see e.g. https://ab.pensoft.net/article/68634/)
- Develop and implement novel genomic tools for assessing intraspecific diversity (beyond the Swiss way of using microsatellites for few species)
- Develop and implement novel genomic tools
- monitoring of genetic diversity
- Reference Libraries: Molecular tools in monitoring- incomplete reference libraries

### Facet 1b) Mobile-sensing technology

### Facet 1c) Remote sensing through satellites and Airborne campaigns and/or Drones / lidar systems

- Exploring the potential of existing or foreseen technologies related to remote sensing (satellite-based), robotic or drone supported sensing and survey
- Standardisation of biodiversity data collection using remote sensors
- Potentials (and limits) of remote sensing technologies for monitoring
- Usability of UAS to monitor wildlife producing distribution maps and of UAS and remote sensing to assess the state of natural habitats enabling constant and efficient tracking of habitat dynamics, change and trends
- Drones: Linking biodiversity to high-frequency monitoring data

### Facet 1d) Acoustics and Camera traps

- Regional training data for automated sound/vision classification tools
- Dark matter in biodiversity multimedia: unknown species, unknown sounds, unknown objects
- Fully automatised species identification in pictures from camera traps and in sound records from audio recorders.

### Facet 1e) Artificial intelligence/machine learning/deep learning

- Couple different biodiversity monitoring approaches (e.g. artificial-intelligence based optical identification with DNA-based methods (see e.g. https://www.pnas.org/content/118/2/e2002545117/tab-article-info)
- automated species identification / non-destructive invertebrate traps with automatic species recognition

### Facet 1f) Networks of automated and standardised biodiversity sensors

- We need in all European regions' networks of automated and standardised biodiversity sensors, and receiver stations for data that allow open access to information. The goal is to detect trends for a broad spectrum of species.
- For all new tools and approaches- the lack of formalised acceptance criteria and formalised step by step pipelines for methods that aim to be used in routine use (e.g. legislative monitoring). Without either the commonly agreed upon criteria and no method acceptance pipelines, the uptake is entirely organic and not structured.

### Facet 1g) data integration and linking to other sectors and policy

- Data integration methods from different sources to improve the spatial and temporal coverage of a study.
- Combining/integrating standard biodiversity data with socio-economic data to improve predictions of biodiversity responses to change.

### Facet 1h) Novel data testing and applying new tools incl. modelling

- How durable and reliable is the hardware and how stable is the software?
- Can the data from new tools be validated by independent data?
- How do the data from new tools align with data from existing tools in terms of temporal, spatial and taxonomic resolution and extent?
- How feasible is the operation/implementation of new tools for those who will be using them (e.g. are there mental, practical, technical to its use barriers)?
- Are new tools able to operate at scale (e.g. is it possible for users to build the tools themselves or are they commercially accessible)?
- How sensitive is the monitoring data from new tools to hardware and software revisions?
- What are the costs and benefits of new versus existing biodiversity monitoring tools/approaches
- How should the data be organised and stored (FAIR data principle)
- What associated metadata is relevant to record and store
- How can the data be analysed (e.g. protocols for machine learning analysis pipelines)
- Loosely-coupled integration of observations from multimodal data streams
- Models to allow integration of data from different monitoring efforts done with different goals, modalities, methods, and assumptions
- (bio-) robots for monitoring; automatic processing of data
- Coupling monitoring and simulation (and making sure the right data are collected for e.g. causal analysis); on demand data collection

- Enabling real-time monitoring (or rather: real-time integration and analysis of data) and from (passive) monitoring to real-time intervention (possibly with ecobots)
- High-risk-high-potential studies to develop new monitoring solutions (AI, acoustic recording devices, eDNA, cameras, …) including citizen science application

## FACET 2 involvement of citizens in the biodiversity monitoring activities

- SRIA A.1.: "Research should also study how indigenous people and local communities in Europe pursue to adapt to environmental changes by exploring holistic solutions able to increase their response capacity and resilience to a broad range of perturbations. Drawing upon different knowledge systems, including indigenous and local knowledge, is appropriate. Stakeholders diversity is therefore a source of resilience, and for which citizen science might be an important asset."
- SRIA A.2.: "promote the contribution of citizens and NGOs to monitoring programs through citizen sciences that have not delivered yet their full potential, both in terms of possible research impact and public engagement and awareness raising about biodiversity among citizens"

### Facet 2a. (How) can noisy citizen science data on biodiversity be filtered/ analysed to provide robust spatio-temporal insight into biodiversity patterns and processes?

- understanding the value of and barriers for structured v opportunistic monitoring, and additional methods to add value to data, e.g. semi-structured and targeted recording.
- matching data needs with people's motivations (when, where, why and how do we most need new data?
- using information technology to support targeting of recording from times and places where the data are most needed
- better feedback (value of data, context of records, benefit of records, action resulting from monitoring)
- potential for citizen science in practitioner groups (e.g. small forest owners, farmers etc.)

- data quality and management;

  * genetic methods for CS; there are technological developments with minions which are cheap and easy - how to make this really available for CS

  ***Data quality:***

- More standardised monitoring within citizen science can be promoted, by revisiting the same sites, reporting according to checklists (to also note when species are missing), use the same standardised method repeatedly (similar to e.g. the butterfly monitoring)?

- What are the most important factors to create continuity, so that citizens are willing to continue their reporting?
- Citizen Science (CS) is rapidly evolving and very diverse in methodologies and "design". There needs to be a systematic assessment of "what works", strengths and weaknesses, best practice in different settings
- potential trade-offs: data quality vs. date numbers or data coverage. Status and analyses of different data sets from CS studies
- Key is to motivate citizens to "cover" less interesting aspects of a project (in time or space, e.g., bad times of the year or uninteresting sites)?
- Development of a Technical infrastructure for Citizen Science Reliable monitoring by Citizens Integration of technical tools with citizen observations Privacy issues

### Facet 2b. For which organisms/ habitats/ processes are citizen scientists a good supplement or even superior to standardised biodiversity monitoring?

- CS in new fields of application, e.g. medicine and health;
- stronger synergies with museums, official administrations, associations;
- better CS integration in universities and research institutions (e.g. include CS in university curricula; have a CS contact person at universities)

* neglected species (a key focus of citizen science (CS) is on birds and butterflies. There are many other species which are relevant for biodiversity and ecosystems

***Monitoring of marine environments:***

- How can citizens (divers) be involved in the monitoring of the marine fauna?
- What are the specific challenges with citizen science in the marine environment?

### Facet 2c). What is the democratic value of citizen science projects focussing on biodiversity?

***Broadening monitoring away from species recording, to recording that is more attainable and more meaningful for more people:***

- broadening the range of participants (not just nature lovers)
- making the case for biodiversity monitoring (how does it affect people, their lives, wellbeing and economy right now?)
- making monitoring more 'actionable': linking recording to change and action by individuals and by decision-makers

- more diverse participants (understanding barriers to participation)

***Knowledge gaps include:*** ethical and legal guidelines;

- What are the interfaces between public agencies that need biodiversity data and Citizen Science activities that could provide needed data?
- How do we achieve a stronger culture of recognition of Citizen Scientists' contributions within projects, for example through co-authorships, honorary allowances, or similar mechanisms?Citizen Science activities are often characterised by the participation of academics - how do we achieve greater diversity of participants and the inclusion of under-reached audiences?

* how to integrate citizens in target discussions: the linkage between managed/artificial ecosystems and wilderness - or its idea

* How can it be more attractive for women to report species observations (at least in Sweden the majority of those who report species observations are men)?

### Facet 2d). How can machine learning contribute to better citizen science?

***Research & Innovation priorities include:*** AI and drones;

- From our experience, many Citizen Science activities do not have data management plans yet - how can we support Citizen Scientists here to fill this gap?
- What are the best tools (i.e. apps, deep learning, training workshops, handouts) to strengthen the data quality of Citizen Science activities?

* FAIR data; where and how to organise the interface between lay persons in the field and open databases, typically managed by scientific organisations

* How can validation of reports/species identity be facilitated?

## FACET 3 use of monitoring data by R&I (including better understanding of biodiversity status, trends, drivers)

### Facet 3a) Better produce biodiversity trends (including better characterization of the uncertainties associated)

- SRIA A.1.: “definition of operational metrics, e.g., of *genetic*, *functional* and *cultural diversity*; of *evolutionary potential*; and of the level of *interactions within and between communities and ecosystems*”

Related bullet points from the survey:

- Connection of monitoring in different geographical and time scale for better understanding

- How biodiversity changes across spatial/temporal scales

- Changes of populations in insect populations

- Changes of biodiversity in less known habitats (e.g. aquatic, mires, mountains)

- Focus on species-rich but lesser-known taxa

● SRIA A.2.: "definition of common indicators to communicate the results of biodiversity monitoring, taking into consideration – amongst others - ongoing streams of work in the context of the Convention on Biological Diversity, Essential Biodiversity Variables supporting regional and global synthesis, and SEEA EA indicators that can integrate biodiversity values into economic systems."

Related bullet points from the survey:

- How different measures of biodiversity change

- How to enhance cross-sectoral co-development with significant biodiversity targets

- We lack consensus on what biodiversity metrics are most informative to guide policy and change

- Evident based selection of indicator-taxa

- Standardisation of biodiversity variables

- development of new evident based biodiversity indicator that are easy to communicate

● SRIA A.2.: "For instance, trend estimation (i.e. data analysis for assessing status and trends) implies mobilising biostatisticians and applying model-based statistical analyses such as GLMM, GAMM, statespace models like occupancy models, N-mixture models, MRR models, etc."

Related bullet points from the survey:

- Bridging the gap between data acquired at various spatial scales to provide a better understanding of ecosystem dynamics

- Trends - reasonably well known in Western Europe, less so elsewhere.

- Development of sound methodological approaches to combine different data sources (e.g. scale, presence only vs. presence-absence, structured vs. unstructured sampling) for biodiversity status and trend analysis

- Studies integrating different approaches e.g. Citizen science + standardised expert assessments

- Development of "higher-taxon approaches" for the monitoring of species rich taxa

- Lack of (raw) freshwater biodiversity data availability including availability of old/existing data; requirement of data mobilisation (extracting species occurrence information from the WFD monitoring could be a first step

## Facet 3b) Better understand the relationships between the state and dynamics of biodiversity and drivers / pressures

- SRIA A.1.: "characterise the threats to all aspects of biodiversity, including functional diversity, in a global change context: this includes the effects of *climate change*, *land use change*, *overexploitation*, *pollution*, *(re)emerging pathogens*, and *biological invasions*."

  Related bullet points from the survey:

  - Better interpretation of the underlying factors behind biodiversity change (as measured by cost-effective biodiversity indicators)

  - Development of frameworks which allow the use of driver trends and species sensitivity to those drivers as powerful monitoring tools

  - For the identification and study of drivers, more precise data and information on land use change would be needed. CORINE data is at a fairly rough level. The analysis would need more detailed information on changes within the land use categories. Possibly more detailed national data can be difficult to access for research (how to affect this?)

  - Consultants etc are often involved in R&I projects due to the need of legislative permissions etc. and very often some kind of biodiversity monitoring is included here, but knowledge is lacking on the knowledge level that is actually coming out of this monitoring

- SRIA A.1.: "Long-term (possibly transgeneration), cumulative effects on specific taxonomic groups and ecological communities are not yet well understood and deserve further attention."

  Related bullet points from the survey:

- How different taxa vary in response

- Europe lacks a systematic biodiversity monitoring scheme. Focus on Red Listed species does not capture the extent of biodiversity change and does not provide sufficient information on cause-consequence that could be used to guide policy and action

- The push for interdisciplinary ecosystem research within the framework of long-term studies.

- SRIA A.1.: “Research identifying phase-shift thresholds of direct and indirect stressors is urgently needed, in particular to guide decisions over limits to extractive activities, such as fishing or logging. Specific threats to animal breeds and plant varieties should also be better understood to guide efficient strategies to conserve and manage genetic resources and their wild relatives”

  Related bullet points from the survey:

  - Promote ecosystem-based approaches to better link biological data to environmental and anthropogenic drivers

- SRIA A.1.: “knowledge is particularly needed on the effects of multiple stressors and extreme events. This includes understanding the impact of climate change in combination with context-specific drivers on biodiversity and ecosystem services, especially with respect to tipping points and planetary boundaries”

  Related bullet points from the survey:

  - Drivers of change - We think we know what the main drivers are, but I don't think we have a good understanding of the relative impact of different drivers

  - Combine high quality models with monitoring data to improve understanding on biodiversity status, key ecosystem processes, and large-scale and long-term effects

  - Better coordination among disciplines, including experts on drivers of global change and other initiatives promoting integrated studies

### Facet 3c) Reinforce modelling and scenarios built on monitoring data

- SRIA A.1.: “Research should better characterise the sources of flexibility and transformability for species, populations, ecosystems and social-ecological systems, in the face of global change. This should include studies on *phenotypic plasticity*, *evolution*, *behaviour and migration*, *reshuffling of biological assemblages*, and the dynamics of strategies, knowledge and practices, as well as the relative roles of these different flexibility sources at a range of spatial and temporal scales.”

Monitoring-data provide the basis for the development of indicators on such flexibility / transformability.

Related bullet points from the survey:

- Solid links between biodiversity change and ecosystem level processes in natural/semi-natural ecosystems are still lacking

- SRIA A.1.: "Research could be used to propose indicators of adaptation potential. This research is also needed to develop scenarios of biodiversity and a new generation of integrated tools for providing quality-controlled, usable information for nearterm decisions with long-term implications"
  Monitoring-data provide the basis for the development of such indicators of adaptation potential.

  Related bullet points from the survey:

  - Inter- and transdisciplinary analyses
  - Use of new modelling tools to analyse long-term changes in community composition in aquatic systems, the multifunctionality by integrating social indicators; analysing the co-evolution of social-ecological systems, considering the social metabolism as one key driver

- SRIA A.2.: "biodiversity monitoring schemes and databases should be articulated with relevant metadata/databases on key drivers, adjusting the biodiversity monitoring schemes accordingly as needed to match biodiversity monitoring data with data for environmental drivers, which makes it difficult to raise robust conclusions about the relative role of different drivers. One output could be to advance automated/semi-automated/machine learning systems for analysis of biodiversity data. Another outcome would be the reinforcement of modelling and scenarios built on monitoring outputs;"
  In facet 3b also the relationships between biodiversity monitoring data and environmental drivers are being addressed. There the emphasis is on understanding individual drivers, whereas here the focus is on the reinforcement of modelling and scenarios using multiple drivers. Furthermore in Facet 1 also machine learning / AI is being addressed. The emphasis here is on the use of machine learning for (integrated) scenarios, whereas in facet 1 the relevance of machine learning /AI is related to automated interpretation of the raw outputs of the new technologies and approaches.

  Related bullet points from the survey:

  - Explicit linkage of monitoring efforts with scenario frameworks using common biodiversity monitoring indicators

- Many R&I projects are aiming to solve a specific problem (removal of nutrients, CO2 capture, sustainable production) but many of these projects have or could have effects (positive or negative) on biodiversity too. But focus is often lacking on counting biodiversity as a goal too. Usually economy, market potential, climate benefits are the main drivers, but biodiversity should and could be a driver too

- Improve knowledge on biodiversity hotspots (i.e. MPAs) for a wide range of biodiversity components

**Bullet points mentioned in the survey results on facet 3 related to other tasks within WP2 on Biodiversity Monitoring (Non- research call related )**

- How to secure long term financing for monitoring?
- How to adapt long term monitoring to new pressures and threats (and political agendas) without destroying time series?
- Connection of monitoring in different geographical and time scale for better understanding
- Free access to monitoring data
- How to ensure high quality data, and how to ensure that researchers don't go wrong because of wrong interpretation of data quality
- Existing monitoring do not sufficiently cover all biodiversity facets, e.g. WFD monitoring in freshwater
- Monitoring data hardly accessible
- Monitoring intervals are too long
- Biodiversity monitoring data is scattered, not available from one or few infrastructures
- The collection of bird data at European level is a best practice example with high quality methods and monitoring expertise. The practises could be shared and compared to other organism groups.
- Important in the quality of the bird data is the coordinating role of the European Bird Census Council, who harmonises e.g. the taxonomy and observation efficiency of the data, which allows using the data for European level analysis and producing of European level indicators. However, the funding of EBCC is not stable
- Severe knowledge gaps/lack of monitoring schemes in several organism groups: insects, fungi, soil organisms
- Knowledge gaps are connected to lack/scarcity of taxonomic experts
- In some organism groups the use of citizen science would be possible the same way as in bird monitoring
- Investments in the development, testing and automation of monitoring methods needed"

- Important in the quality of the bird data is the coordinating role of the European Bird Census Council, who harmonises e.g. the taxonomy and observation efficiency of the data, which allows using the data for European level analysis and producing of European level indicators. However, the funding of EBCC is not stable

-Many R&I projects are though focusing more or less on biodiversity and may also involving monitoring of biodiversity, but knowledge is lacking on how data is used, how monitoring is done, how data is eventually affecting the R&I projects

- Strengthen and further develop a clearing-house mechanism for sharing scientific data on ecosystem dynamics and biodiversity to promote and facilitate technical and scientific cooperation within and in between the European member states

- Use monitoring data to assure that reporting on conservation status of species and nature types is compatible across the European member states

- Policy - If we are using our data to influence policy decisions (as we should be), are we monitoring the impact of those policies?

- International standardisation of biodiversity assessment tools/methods considering cost-effectiveness and broad applicability

- Development of a dedicated freshwater biodiversity monitoring scheme (preferably type-specific and including an appropriate and seasonal sampling frequency) as existing monitoring schemes of freshwater habitats (e.g.WFD) insufficiently capture biodiversity trends

- Lack of appropriate freshwater biodiversity time series also covering seasonal variation (that could result from the first point)

- Development of a European database for freshwater biodiversity (according to FAIR principles)

- Support long-term monitoring data for biodiversity changes/trends, and data collection on priority species and habitats

- How we could make the most effective use of different techniques (e.g. e-DNA, remote sensing) in monitoring and study of different organism groups in different habitats/land use categories

- How to effectively involve volunteers in the monitoring of different groups of organisms