

Improved access to integrated biodiversity data for science, practice, and policy - the European Biodiversity Observation Network (EU BON)

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Abstract

Biodiversity is threatened on a global scale and the losses are ongoing. In order to stop further losses and maintain important ecosystem services, programmes have been put into place to reduce and ideally halt these processes. A whole suite of different approaches is needed to meet these goals. One major scientific

contribution is to collate, integrate and analyse the large amounts of fragmented and diverse biodiversity data to determine the current status and trends of biodiversity in order to inform the relevant decision makers. To contribute towards the achievement of these challenging tasks, the project EU BON was developed. The project is focusing mainly on the European continent but contributes at the same time to a much wider global initiative, the Group on Earth Observations Biodiversity Observation Network (GEO BON), which itself is a part of the Group of Earth Observation System of Systems (GEOSS). EU BON will build on existing infrastructures such as GBIF, LifeWatch and national biodiversity data centres in Europe and will integrate relevant biodiversity data from on-ground observations to remote sensing information, covering terrestrial, freshwater and marine habitats.

A key feature of EU BON will be the delivery of relevant, fully integrated data to multiple and different stakeholders and end users ranging from local to global levels. Through development and application of new standards and protocols, EU BON will enable greater interoperability of different data layers and systems, provide access to improved analytical tools and services, and will provide better harmonised biodiversity recording and monitoring schemes from citizen science efforts to long-term research programs to mainstream future data collecting. Furthermore EU BON will support biodiversity science-policy interfaces, facilitate political decisions for sound environmental management, and help to conserve biodiversity for human well-being at different levels, ranging from communal park management to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). Additionally, the project will strengthen European capacities and infrastructures for environmental information management and sustainable development. The following paper outlines the framework and the approach that are pursued.

Keywords

Biodiversity information, biodiversity observation/recording, monitoring, data interoperability, data management, biodiversity portal, earth observation, informatics infrastructure, bio-repository, GEOSS, GEO BON, science policy, dissemination

Background

The world's biodiversity is in a dramatic decline and in its speed is unprecedented. However, the target to “achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth”, formulated in the “2010 biodiversity targets” at different Conferences of Parties (COPs) of the Convention on Biodiversity (CBD), has not been met (Secretariat of the CBD 2010, but see Carvalho et al. 2013). The empirical basis for assessing the scale of biodiversity loss remains weak, and a comprehensive global analysis is lacking. A main obstacle in achieving the “2010 biodiversity targets” was the lack of integration of biodiversity information into decisions in sectors other than nature conservation (Mace et al. 2010). Thus, there is a need to acquire the capacity to assess the consequences of a range of political and economic decisions in many different sectors. However, these developments and assessments are limited by our ability to predict the future of biodiversity and its interactions with the anthroposphere. Therefore a wide range of different scenarios are required in order to improve the decision making capacity of those responsible for sound adaptive management of terrestrial, freshwater and marine ecosystems, as well as the sustainable govern-

ance of our planet's natural resources. For this purpose, scenarios need a sound scientific knowledge basis that is reliable, relevant, up-to-date, readily accessible and understandable. Only then will it be possible to achieve the five strategic goals of the "Strategic Plan for Biodiversity 2011–2020" and the Aichi targets for 2020 formulated therein.

All five strategic goals and the underlying twenty targets are important. The development of EU BON is directly linked to the target that states "By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied." (target 19 under strategic goal E; see <http://www.cbd.int/sp/targets/>). While a large quantity of biodiversity data have already been gathered, access to it remains difficult as it is often distributed in fragmented and heterogeneous datasets. Data are scattered across countries and continents with many differences due to countries' specific traditions and societal frameworks (Amano and Sutherland 2013; Vandzinskaite et al. 2010). Furthermore, there is often a heavy bias towards easily recognisable and high profile taxa. Research methodologies and monitoring schemes are largely conducted by different independent communities who rarely share concepts, data or infrastructure (Schmeller 2008, Schmeller et al. 2009, 2012). To meet Aichi target 19, the available biodiversity data needs to be reorganised in a Big Data platform, which allows sharing and easy transfer of the vast amount of biodiversity data collected in Europe each year (Schmeller 2008).

This Aichi target was motivated by the growing demand to provide readily accessible data that can be integrated and analysed to support political decisions (cf. Hardisty et al. 2013). This demand was first addressed by the Group on Earth Observations (GEO) and resulted in the idea of establishing GEOSS (Global Earth Observation System of Systems), with a focus on providing information on nine areas of social benefits (disaster, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity; <http://www.earthobservations.org/geoss.shtml>). The GEOSS biodiversity monitoring platform is organised through GEO BON (Group on Earth Observations – Biodiversity Observation Network; e.g. see Pereira et al. 2010, Scholes et al. 2008, 2012). Europe has high quality data as well as substantial capacities to contribute to such a platform (Schmeller 2008). Since 2005, the European Commission has invested in several large scale projects with that objective. Examples include the quest for a better understanding of the monitoring landscape in Europe (EuMon; Schmeller 2008), the development of a European Biodiversity Observation network with a focus on terrestrial habitat and ecosystem monitoring (EBONE; Halada et al. 2009) and a European contribution to GEOSS, which addressed interdisciplinary interoperability in three strategic areas (biodiversity, drought, forestry) (EuroGEOSS; Vaccari et al. 2012) and, most recently the successor of EBONE, to further build the European contribution towards a global Biodiversity Observation Network (EU BON; this paper).

The main aims of EU BON are to follow up the requirements set by GEO BON, while building on the groundwork set by the above mentioned projects, mainly following the footsteps of EBONE (see <http://www.wageningenur.nl/ebone>). To achieve this aim, a large collaborative network has been assembled with contributions from 30

institutions including research institutes, small companies (SMEs) and NGOs from 15 European countries, Israel, Brazil and the Philippines (see Figure 1), with the intention to subsequently involve additional associated partners around the world. The 4.5 year EU BON project period, which commenced in December 2012, is supported by the European Commission under the Seventh Framework Programme (FP7). Further details and updates can be found on the project's website at <http://www.eubon.eu>.

Additionally, the question arises how the above mentioned data and results are best presented to science, policy and the broader society (see discussion "Connecting policy, models and data" later in the paper. A more detailed discussion and results from a first workshop are presented separately (Vohland et al. in review).

What is needed to link science and conservation policy?

Networking for biodiversity science and conservation policy can occur at two main levels that need integration: (1) a science-based social network, comprising and linking the communities of practice engaged in collecting, managing, analysing, and using biodiversity data, and (2) a physical network of interoperating IT infrastructures and systems that store and distribute information of all kinds held by multiple organisations and partners, providing a platform for data analysis and interpretation. For resource efficiency, the establishment of EU BON is built on existing infrastructures and efforts to integrate monitoring schemes and their data across Europe and internationally, in particular the Global Biodiversity Information Facility (GBIF). In supporting GEO BON, EU BON has the specific objectives:

- Advance the technological and informatics infrastructures in close collaboration with GEO BON, by moving existing biodiversity networks towards standards-based, service-oriented approaches, enabling full interoperability through the "GEOSS Common Infrastructure".
- Increase data mobilisation and data publishing via scientific communities, citizen scientists and potential data users.
- Enhance our knowledge of biodiversity, biological resources, related habitat and environmental characteristics (e.g. measured via remote sensing), for Europe, and beyond, by integrating, harmonising and mainstreaming data and identifying current knowledge gaps.
- Improve the range and quality of methods and tools for assessment and analysis, as well as visualisation of biodiversity and ecosystem information, focussing particularly on predictive modelling, identification of drivers of change, biodiversity indicators, and supporting priority setting.
- Provide mechanisms for delivering integrated biodiversity information to EU member states, other governments, and sectoral stakeholders to support their reporting obligations under the CBD, the Nature Directives as well as other international conventions and mechanisms.

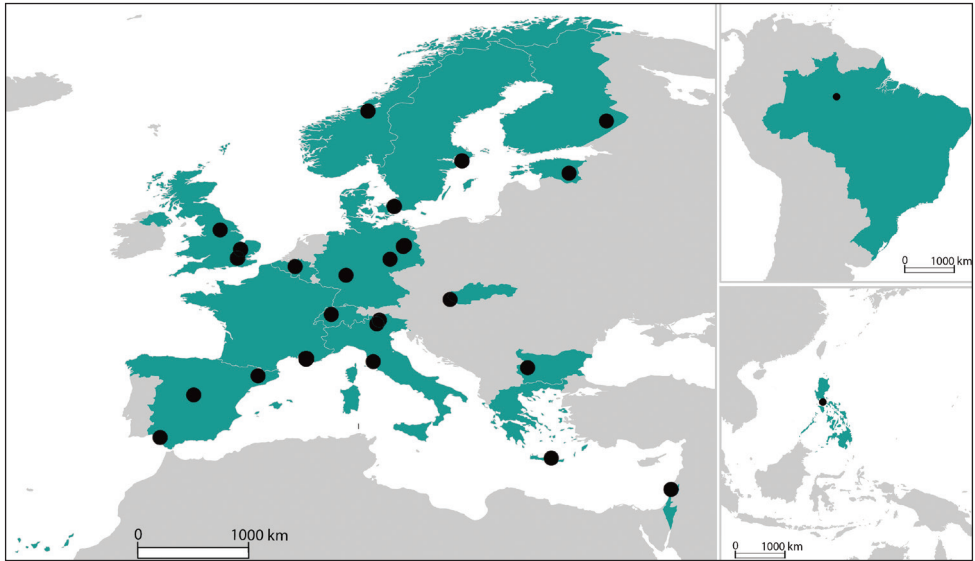


Figure 1. Geographic representation of the countries, where black dots on the map indicate the location of the EU BON partners (see <http://www.eubon.eu> for more details).

- Develop frameworks and strategies for future generations, management, and use of integrated biodiversity information at national and regional levels (towards full implementation of the GEO BON plan); this supports the science policy interface, in particular, for IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services) and existing national reporting obligations to European policies and international conventions.
- Design concepts to sustain future integrated environmental information systems, including active participation by citizen science as well as business and industry, thereby strengthening European capacities and infrastructures.

In addressing these objectives, EU BON directly engages with researchers, policy and other relevant stakeholders as end users of integrated biodiversity information. EU BON's main deliverables will be made available via a comprehensive "European Biodiversity Portal" designed to satisfy the data and information requirements of the different stakeholder communities, as well as through strategies allowing for a global implementation of GEO BON.

The research approach

The work programme of EU BON has been developed to advance social as well as scientific networks, and to provide at each step valuable products which serve the broader community. In a first step, a gap analysis on available data sources is being

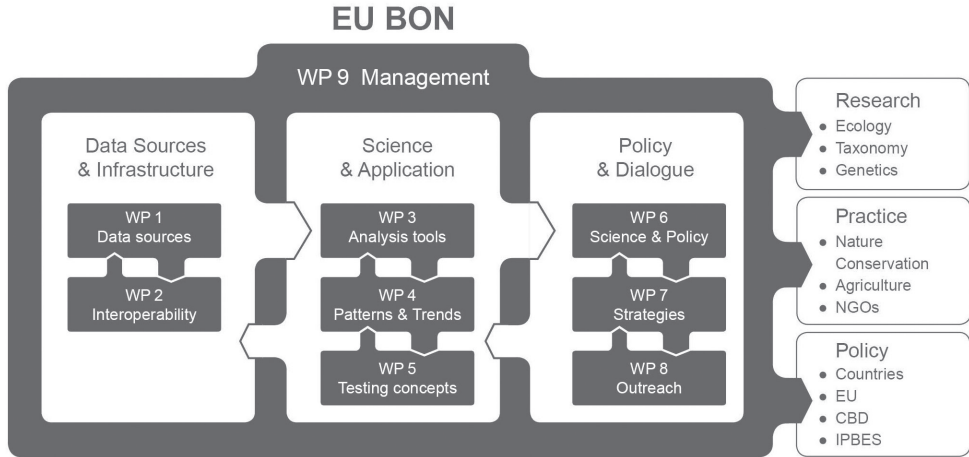


Figure 2. Structure and work flow within the EU BON project.

performed and strong efforts are being directed at mobilising fragmented or hidden but valuable biodiversity data. The interoperability between the different resources is being enhanced, and tools for interpretation, modelling and visualisation developed and applied at the global scale to identify the main drivers. A key for transformation of this concept into practical applications are the EU BON testing sites which provide additional scientific information and serve as a reality check for the EU BON tools. Last but not least, the progress and development direction of the project is being continually discussed with different stakeholder groups addressing different scales, in order to play a fundamental role in GEO BON and IPBES. The EU BON work programme has been structured along nine themes (see Figure 2).

Gap analysis and mobilisation of fragmented data sources

Biodiversity data are demanding to gather, manage, and analyse because: i) they include many different types of data; ii) the amount of data is large; iii) relevant data sources are still largely fragmented and coverage is often incomplete. Relevant data types include remote sensing data and products such as land cover, habitat information as well as land use intensity, water quality estimates and climate proxies (cf. BIO_SOS project, www.biosos.eu); taxonomic backbone data including nomenclatural information; genetic sequences and genomics data; observation and monitoring data or specific organisms or taxa; ecological data; data from bio-repositories, and species profile data (e.g. functional traits, conservation status, distribution, abundance data, invasiveness). The amount of biodiversity data is rapidly expanding not only with innovations in genome sequencing technologies but also with new tools for efficient field recording becoming available (Eyermann et al. 2010) or different techniques in the realm of remote sensing. Therefore biodiversity data has to be regarded as Big Data, which

requires flexible information systems (Marx 2013). For example, The European Bioinformatics Institute, one of the world's largest biology-data repositories, currently stores 20 petabytes of data (Boyle 2013). Another challenge for managing biodiversity data, particularly from meta-genomics, is the traditional classification of individuals into unique entities called species. All trait or associated biodiversity data are anchored to these species. Over time, however, one species can split into many species, and there are also cases that two or more species can be lumped together. In addition, there are also competing taxonomic concepts for many organisms, for example if one study supports single species but another study endorses two species. Solutions for this challenge are available. Kóljalg et al. (2013) for example suggest means for managing multiple species hypotheses (and associated data) that change in time and space.

The structural complexity of biodiversity data and the collection process itself are some of the reasons why important data sources are still fragmented and nearly every data type and every monitoring organisation has developed its own information system. EU BON will assess and generate a gap analysis of different data types and make recommendations as well as working examples for future integrated biodiversity mobilisation policies. The project will provide solutions for the storing and managing of selected biodiversity data types such as taxonomic backbone data, data generated by bio-repositories, species profile data, and citizen-science based data.

Integration and interoperability of data

EU BON will develop recommendations for data integration and interoperability. Starting from the previous work done on-ground by GEO BON (Ó Tuama et al. 2010), GBIF (Hobern et al. 2013) and for remotely sensed data by BIO_SOS, MS.MONINA (www.ms-monina.eu/), and the EAGLE working group (Blonda et al. 2013) it will address the heterogeneity of data types, projects and networks by designing the information architecture for EU BON. Furthermore, the project reviews state-of-the-art needs for improvement of current data standards and will make recommendations for their use. Tools for data sharing will be developed and an information hub, the European Biodiversity Portal (EBP), backed by a registry and metadata catalogue, will be developed for unified and easy access to data, services and analyses provided by the network. The EBP will serve as a gateway to the different data layers and individual data sets. It will be designed to facilitate access to relevant information and analyses for various stakeholders and decision makers on different political and spatial levels. The EU BON architecture will need to be linked closely to the existing European infrastructures such as LifeWatch (Hernández-Ernst et al. 2009), GBIF, LTER and related networks in other parts of the world. Therefore, an international informatics task force has been invited to advise the EU BON project. The key question of how a user-friendly interface for those myriads of data sources and services that exist in Europe and across the globe can be combined with the GEOSS Common Infrastructure will need to be explored in detail. Selected priority use cases from the wider GEO BON

community will guide this work. To reach all the different potential users, a helpdesk will be established and a comprehensive training programme developed. It will include in addition to the usual functions, an applications and documentation repository.

Improving tools and methods for data analysis and interface

One important barrier to global biodiversity assessment is the shortage of appropriate analytical tools, and poor accessibility for non-specialist users of those tools that have been developed. Tools and methods for analysing biodiversity monitoring data will be improved and an interface developed to assure the best possible presentation of biodiversity data. EU BON will implement new and existing tools and methods in accessible software packages to make them more widely available to non-specialist users. Remote sensing data provide an important source of habitat information that may improve biodiversity assessment and modelling, yet such data are typically used in isolation, allowing only very coarse categorisation. The EU BON project will help to develop and promulgate recent advancements in interpretation and classification methods (e.g. learning and random forest algorithms, multi-scale methods; cf. Bradter et al. 2011). The project will also help to improve access to novel techniques for downscaling species' distributional information (Azalee et al. 2012) and upscaling biodiversity data, two key challenges in the application of biodiversity datasets in conservation planning. We also work on developing enhanced species distribution models, also called environmental niche models, to better incorporate information on spatial patterning (Keil et al. 2013). We also help in the development of tools to mine biodiversity data directly from the published literature, thus making it easier and faster to access new species records.

Linking biodiversity trends to natural and anthropogenic drivers

A key prerequisite for sustainable management and conservation of biodiversity is a good understanding of how natural and anthropogenic drivers determine spatial and temporal trends of biodiversity. Drivers as well as biodiversity patterns and trends strongly depend on the scale of the analysis even for the same dataset (e.g. Keil et al. 2012, Kühn and Klotz 2007, Tzanopoulos et al. 2013), providing major challenges for understanding the effects of drivers on biodiversity. Through the rapid advancement of remote sensing capabilities, as well as new analytical techniques to interpret and transform digital data, a wealth of pertinent information has become available that is not yet fully used and integrated with on-ground data (e.g. Rocchini et al. 2011, Blonda et al. 2013, Nagendra et al. 2013).

The outcomes of traditional species distribution models yield substantial uncertainty originating from various ecological processes and ignorance of the diversity of life-history patterns. In EU BON, we aim at implementing methods to quantify un-

certainties propagated as a result of using different sources and modules of models. An important recent advance is the development of dynamic simulation modelling approaches explicitly including ecological processes (e.g. Bocedi et al. 2012). Furthermore, new approaches exist to incorporate species interactions into species distribution models (Kissling et al. 2012, Schurr et al. 2012, Wisz et al. 2013). EU BON builds on these advances to make projections of possible future trends in both populations and distributions for real species in real landscapes. Even with improved models, predictions still depend on the availability of monitoring data which is spatially highly heterogeneous. Despite considerable advances in the theory and practice of optimal spatial sampling (e.g. Braunisch and Suchant 2010, Lin et al. 2008), trade-offs between optimal spatial and optimal temporal sampling are not yet completely resolved. The advances for habitat monitoring achieved by the EBONE project (Brus et al. 2011, Metzger et al. 2013) will be taken up and EU BON will tackle these challenges with new statistical and virtual ecological approaches (Railsback and Grimm 2012).

Testing and validation of concepts, tools, and services

The data integration and analytical work undertaken in EU BON are applied to real, on ground situations, as it is important to validate the new tools and the results gained and apply to actual, smaller-scale levels. So far, three European test sites for the envisioned results are part of EU BON: Doñana Biological Reserve (Spain), LTER Rhine-Main Observatory (Germany) and Amvrakikos Wetlands National Park (Greece). Planned additional sites are the Mercantour National Park (France) and those managed by the Sierra Nevada Observatory (Spain), the Israel National Ecosystem Assessment Program (Israel) and the Fundação Amazonica de Defesa da Biosfera/Instituto Nacional de Pesquisas da Amazonia (Brazil). These sites also provide direct links to the wide range of stakeholders involved in, and using biodiversity information, such as agriculture, forestry, and tourism. Based on the experiences with the test sites, a strategy for long-term monitoring and observatory data harmonisation will be developed including a business plan for obtaining and managing the necessary financial and other resources.

As a Biodiversity Observation Network (BON) needs to inform policy, a successful development will need to understand the expectations and needs of policymakers. Therefore, four work packages of the project engage in science policy dialogue (mainly IPBES), the implementation of EU BON in the global biodiversity observation network (GEO BON), general outreach and the dissemination of results, and the management of the project including its linking to other EU initiatives and projects, such as LifeWatch.

Connecting policy, models and data

Currently, for biodiversity there is typically a mismatch between the knowledge requirements of policy makers and the information available to them (Sutherland et al. 2011).

There seems to be also a data quality problem in common reports (ETC 2008). This can lead to both less efficient policy-making and to reduced political support for science if the outcomes are not perceived as useful. There are a host of reasons for this mismatch, including a lack of horizon scanning to identify future issues, a failure to identify critical issues for monitoring and research, and a gap between the manner in which biodiversity information is presented and how it is required. It is obviously important that any biodiversity programme considers how it could be used and how it can be most efficient in aiding practice and policy making.

Identifying the use of research and policy issues and their attempted resolution will show what has been effective in the past. The information needs of the policy makers require to be identified and connected to the required monitoring activities (see Vohland et al. in review). Anticipating the possible policy responses to actions in a changing world, including developments such as artificial life, nanotechnology and geo-engineering is challenging. It is an ambitious but important objective to achieve the integration of all stages in the process, including monitoring, research, modelling, dissemination and policy development. We see this as providing monitoring help to improve the rigour of assessments such as IPBES and CBD (Sutherland 2013).

Implementation of GEO BON: strategies and solutions at European and global levels

As EU BON is intended to be a major contribution to GEO BON, it is necessary to closely link the EU BON work with the GEO BON agenda and also to provide an outlook and refine the GEO BON goals, especially at the policy science interface. Within EU BON we will formulate recommendations for all aspects covered in EU BON on national, regional and global levels with a special focus on monitoring schemes and biodiversity information structures. Outputs of EU BON are also expected to contribute to the work of IPBES, on reducing or even halting the global loss of biodiversity through provision of sound information on the current status as well as future trends of biodiversity. IPBES was established following a gap analysis of the Environmental Programme of the United Nations (UNEP) (UNEP 2010) and the last Conference of the Parties (COP 11) of the Convention of Biological Diversity (CBD). EU BON therefore engages on a more global level in science policy dialogue and by that also contributes to the fulfilment of the European obligations following the CBD and IPBES. EU BON also evaluates possible paths for a European or global BON business plan to assure persistence of large-scale biodiversity observation networks and infrastructures.

Dissemination and outreach

The goals and objectives of EU BON are ambitious and can only be achieved with outstanding engagement in both dissemination and outreach. Project partners are ex-

pected to put considerable efforts into communicating the outcomes of their scientific work. As funding comes from EU taxpayers, letting the public know how this money is spent is an obvious obligation of every FP7 project (European Commission 2012a). However, most of the publicly-funded research results that exist in the form of data are still not made available for others, which makes the investment highly inefficient (European Commission 2012b). With the aim of ensuring that communication and dissemination are properly developed, implemented and managed throughout the project lifetime, EU BON is developing a comprehensive communication strategy, so that the EU BON brand will be widely recognised and its results and achievements reach a broad audience across different stakeholder levels, including policy, administration, conservation managers, scientists, journalists and the general public. This “Communication and Dissemination Strategy” will be of foremost importance for the success of the project.

Furthermore, we will work on a comprehensive data publishing, citation and usage strategy, including IPR and license issues. Special efforts will also be put into a novel peer review strategy for publishing research data. As a basic dissemination principle, EU BON has adopted open access and multi-targeted popularisation of outputs, to comply with the decision of the Council of Europe recognising “the strategic importance for Europe’s scientific development of open access to scientific information” and the European Commission’s communication and recommendation to the member states that they should aim at improving the access to scientific information produced in Europe. “The open access to scientific research data enhances data quality, reduces the need for duplication of research, speeds up scientific progress and helps to combat scientific fraud.” (European Commission 2012c).

The core output will be the development of a fully integrated data publishing and dissemination toolbox helping data providers to find the best way to publish differently structured biodiversity data. It will also integrate workflows between data journals and the leading aggregators and repositories, such as GEO BON, the Biodiversity Information System for Europe (BISE) run by the European Environment Agency (EEA), GBIF, Scratchpads, the International Nucleotide Sequence Databases Consortium (GenBank, ENA, DDBJ) and others.

Summary and vision for the future

The main impact from EU BON will be through increased interoperability and mobilisation of data and systems through adoption of new standards and technologies, towards the development of strategies for future harmonisation and mainstreaming of biodiversity recording and monitoring, and strengthened European capacities and infrastructures by providing a comprehensive “European Biodiversity Portal” for all stakeholder communities. In addition, public awareness of biodiversity, one of the prominent targets of the CBD Strategic Plan for Biodiversity 2011–2020, as well as of many national biodiversity plans, will be increased. The implementation and fur-

ther enhancement of analytical methods and visualisation and interpretation tools will provide completely new insights on biodiversity and will strengthen the usefulness of the available information which then can be used for sound political decisions to help safeguard biodiversity in the future. In this way, GEO BON will emerge as the integrating network of networks, as foreseen in the GEO BON Concept Document (<http://www.earthobservations.org/geobon.shtml>). There will be increased intention to see that various networks and projects pursue the same aim and to share and use biodiversity data freely across borders and regions.

Recently, GEO BON set the goal to achieve an operational system by 2015, the year when GEOSS’s 10-year implementation plan comes to an end. The Essential Biodiversity Variables (EBV) as proposed by GEO BON (Pereira et al. 2013) will help to focus what is meant by “operational”. The use case that EU BON and GEO BON will jointly work on is making EBVs operational by streamlining and automating the data flows from the many disparate biodiversity observation systems towards EBVs, and further to useful indicators (Figure 3). Our vision for the EU BON Portal is that it will act as a window to facilitate looking into all these observation systems, how data flows are working and possibly showing how the “Shared Environmental Information System” (SEIS) of the EU (cf. Hřebíček and Pillmann 2009) works for biodiversity.

In conclusion, EU BON will use its potential to change the interrelation between citizens, science and policy for biodiversity. Decision makers at different levels will be able to make use of biodiversity information adapted to their specific requirements. Disparate and unconnected databases will be integrated to allow monitoring and evaluation of measures at different spatial and temporal scales. This requires strong efforts

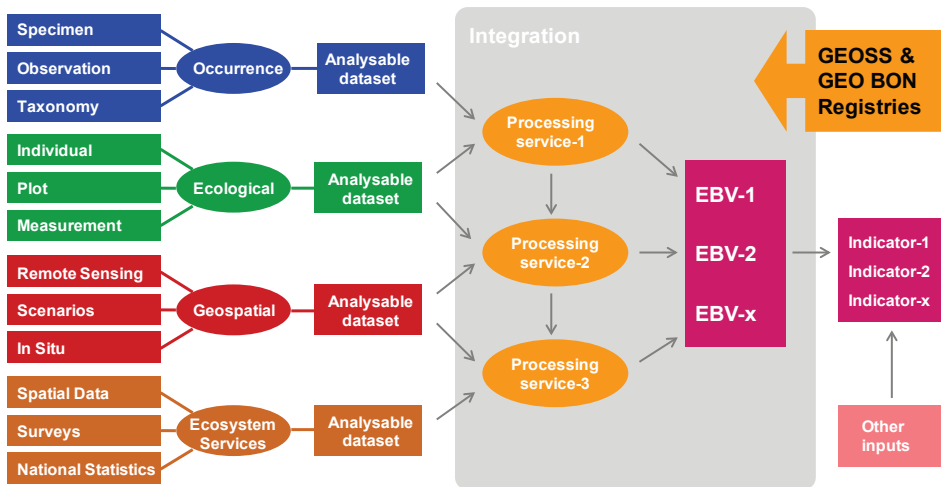


Figure 3. EU BON will be implementing the GEO BON vision of automated, streamlined data flow, end-to-end, from observations to Essential Biodiversity Variables (EBV), using a plug-and-play service-oriented approach, coordinated through the GEO BON registry system and linked to the GEOSS Common Infrastructure, and transparent to users through portals.

not only in regard to technical harmonisation between databases, models and visualisation tools, but also in the dialogue with the associated social networks, spanning a variety of scientific as well as civil science organisations.

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References

- Amano T, Sutherland WJ (2013) Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. *Proceedings of the Royal Society B: Biological Sciences* 280: doi: 10.1098/rspb.2012.2649
- Azaele S, Cornell SJ, Kunin WE (2012) Downscaling species occupancy from coarse spatial scales. *Ecological Applications* 22: 1004–1014. doi: 10.1890/11-0536.1
- Blonda P, Marangi C, Inglada J, Manakos I, Múcher CA, Lucas R (2013) Recommendations on how Copernicus (GMES) can contribute to Biodiversity (BD) policies. *BIO_SOS Deliverable No D8.9*. 33p. <http://www.biosos.eu/deliverables/D8-9.pdf>
- Bocedi G, Pe'er G, Heikkinen RK, Matsinos Y, Travis JMJ (2012) Projecting species range expansion dynamics: sources of systematic biases when scaling up patterns and processes. *Methods in Ecology and Evolution* 3: 1008–1018. doi: 10.1111/j.2041-210X.2012.00235.x
- Boyle J (2013) Biology must develop its own big-data systems. *Nature* 499: 7. doi: 10.1038/499007a
- Bradter U, Thom TJ, Altringham JD, Kunin WE, Benton TG (2011) Prediction of national vegetation classification communities in the British uplands using environmental data at multiple spatial scales, aerial images and the classifier random forest. *Journal of Applied Ecology* 48: 1057–1065. doi: 10.1111/j.1365-2664.2011.02010.x
- Braunisch V, Suchant R (2010) Predicting species distributions based on incomplete survey data: the trade-off between precision and scale. *Ecography* 33: 826–840. doi: 10.1111/j.1600-0587.2009.05891.x
- Brus DJ, Knotters M, Metzger MJ, Walvoort DJJ (2011) Towards a European-wide sampling design for statistical monitoring of common habitats. Wageningen, Alterra Report 2213. <http://www.wageningenur.nl/de/Publicatie-details.htm?publicationId=publication-way-343039343731>
- Carvalho LG, Kunin WE, Keil P, Aguire-Gutierrez J, Ellis WN, Fox R, Groom Q, Hennekens S, Van Landuyt W, Maes D, Van de Meutter F, Michez D, Rasmont P, Ode B, Potts

- SG, Reemer M, Roberts SPM, Schaminee J, WallisDeVries MF, Biesmeijer JC (2013) Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. *Ecology Letters* 16: 870–878. doi: 10.1111/ele.12121
- ETC (2008) Habitats directive article 17 Report (2001–2006) - Data completeness, quality and coherence. 1–24. http://bd.eionet.europa.eu/activities/Reporting/Article_17/Reports_2007/chapter2
- European Commission (2012a) Communicating EU Research & Innovation – A guide for project participants. Luxembourg: Publications Office of the European Union, 20pp. doi: 10.2777/7985
- European Commission (2012b) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. Towards better access to scientific information: Boosting the benefits of public investments in research. Brussels, COM (2012) 401 final. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0401:FIN:EN:PDF>
- European Commission (2012c) Commission Recommendation of 17.7.2012 on access to and preservation of scientific information. Brussels, C (2012) 4890 final. http://ec.europa.eu/research/science-society/document_library/pdf_06/recommendation-access-and-preservation-scientific-information_en.pdf
- Eymann J, Degreef J, Häuser C, Monje JC, Samyn Y, Vanden Spiegel D (2010) Manual on field recording techniques and protocols for All Taxa Biodiversity Inventories and Monitoring. Abc Taxa (Brussels), 1–653.
- Halada L, Jongman RHG, Gerard F, Whittaker L, Bunce RHG, Bauch B, Schmeller DS (2009) The European Biodiversity Observation Network – EBONE. In: Hřebíček J, Hradec J, Pelikán E, Mírovský O, Pilmann W, Holoubek I, Legat R (Eds) Towards eEnvironment. Challenges of SEIS and SISE: Integrating Environmental Knowledge in Europe. Masaryk University. <http://www.e-envi2009.org/proceedings/>
- Hardisty A, Roberts D, The Biodiversity Informatics Community (2013) A decadal view of biodiversity informatics: challenges and priorities. *BMC Ecology* 13: 16. <http://www.biomedcentral.com/1472-6785/13/16>
- Hernández-Ernst V, Poigné A, Giddy J, Hardisty A, Voss H (2009) Towards a reference model for the LifeWatch ICT infrastructure. In: Fischer S, Maehle E, Reischuk R (Ed) Informatik 2009: Im Focus das Leben, Beiträge der 39. Jahrestagung der Gesellschaft für Informatik e.V., Lübeck (Germany), September/October 2009. Gesellschaft für Informatik / University of Trier (Lübeck) 654–668. <http://dblp.uni-trier.de/db/conf/gi/gi2009.html#ErnstPGHV09>
- Hobern D, Apostolico A, Arnaud E, Bello JC, Canhos D, Dubois G, Field D, García EA, Hardisty A, Harrison J, Heidorn B, Krishtalka L, Mata E, Page R, Parr C, Price J, Willoughby S (2013) Global Biodiversity Informatics Outlook. GBIF Secretariat (Copenhagen): 1–41.
- Hřebíček J, Pilmann W (2009) Shared Environmental Information System and Single Information Space in Europe for the environment: Antipodes or associates? In: Hřebíček J, Hradec J, Pelikán E, Mírovský O, Pilmann W, Holoubek I, Bandholtz T (Eds) Towards eEnvironment. Opportunities of SEIS and SISE: Integrating Environmental Knowledge in Europe. Masaryk University. <http://www.e-envi2009.org/proceedings/>

- Keil P, Schweiger O, Kühn I, Kunin WE, Kuussaari M, Settele J, Henle K, Brotons L, Pe'er G, Lengyel S, Moustakas A, Steinicke H, Storch D (2012) Patterns of beta diversity in Europe: the role of climate, land cover and distance across scales. *Journal of Biogeography* 39: 1473–1486. doi: 10.1111/j.1365-2699.2012.02701.x
- Keil P, Belmaker J, Wilson AM, Unitt P, Jetz W (2013) Downscaling of species distributional models: a hierarchical approach. *Methods in Ecology and Evolution* 4: 82–94. doi: 10.1111/j.2041-210x.2012.00264.x
- Kissling WD, Dormann CF, Groeneveld J, Hickler T, Kühn I, McNerny GJ, Montoya JM, Römermann C, Schiffers K, Schurr FM, Singer A, Svenning J-C, Zimmermann NE, O'Hara RB (2012) Towards novel approaches to modelling biotic interactions in multi-species assemblages at large spatial extents. *Journal of Biogeography* 39: 2163–2178. doi: 10.1111/j.1365-2699.2011.02663.x
- Kóljalg U, Nilsson RH, Abarenkov K, Tedersoo L, Taylor AFS, Bahram M, Bates ST, Bruns TD, Bengtsson-Palme J, Callaghan TM, Douglas B, Drenkhan T, Eberhardt U, Dueñas M, Grebenc T, Griffith GW, Hartmann M, Kirk PM, Kohout P, Larsson E, Lindahl BD, Lücking R, Martín MP, Matheny PB, Nguyen NH, Niskanen T, Oja J, Peay KG, Peintner U, Peterson M, Pöldmaa K, Saag L, Saar I, Schüßler A, Scott JA, Senés C, Smith ME, Suija A, Taylor DL, Telleria MT, Weiss M, Larsson K-H (2013) Towards a unified paradigm for sequence-based identification of Fungi. *Molecular Ecology*. doi: 10.1111/mec.12481
- Kühn I, Klotz S (2007) From Ecosystem invasibility to local, regional and global patterns of invasive species. In: Nentwig W (Ed) *Biological Invasions*. Springer (Berlin, Heidelberg, New York): 181–196. doi: 10.1007/978-3-540-36920-2_11
- Lin YP, Yeh MS, Deng DP, Wang YC (2008) Geostatistical approaches and optimal additional sampling schemes for spatial patterns and future sampling of bird diversity. *Global Ecology and Biogeography* 17 (2): 175–188. doi: 10.1111/j.1466-8238.2007.00352.x
- Mace GM, Cramer W, Diaz S, Faith DP, Larigauderie A, Le Prestre P, Palmer M, Perrings C, Scholes RJ, Walpole M, Walther BA, Watson JEM, Mooney HA (2010) Biodiversity targets after 2010. *Current Opinion in Environmental Sustainability* 2: 3–8. doi: 10.1016/j.cosust.2010.03.003
- Marx V (2013) Biology: The big challenges of big data. *Nature* 498: 255–260. doi: 10.1038/498255a
- Metzger MJ, Brus DJ, Bunce RGH, Carey PD, Goncalves J, Honrado JP, Jongman RHG, Trabucco A, Zomer R (2013) Environmental stratifications as the basis for national, European and global ecological monitoring. *Ecological Indicators* 33: 26–35. doi: 10.1016/j.ecolind.2012.11.009
- Nagendra H, Lucas R, Honrado JP, Jongman RHG, Tarantino C, Adamo M, Mairota P (2013) Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats. *Ecological Indicators* 33: 45–59. doi: 10.1016/j.ecolind.2012.09.014
- Ó Tuama É, Saarenmaa H, Nativi S, Bertrand N, van den Berghe E, Scott L, Lane M, Cotter G, Canhos D, Khalikov R (2010) Principles of the GEO BON information architecture. Group on Earth Observations (Geneva): 1–42. http://www.earthobservations.org/documents/cop/bi_geobon/geobon_information_architecture_principles.pdf

- Pereira HM, Ferrier S, Walters M, Geller GN, Jongman RHG, Scholes RJ, Bruford MW, Brummitt N, Butchart SHM, Cardoso AC, Coops NC, Dulloo E, Faith DP, Freyhof J, Gregory RD, Heip C, Höft R, Hurtt G, Jetz W, Karp DS, McGeoch MA, Obura D, Onoda Y, Pettorelli N, Reyers B, Sayre R, Scharlemann JPW, Stuart SN, Turak E, Walpole M, Wegmann M (2013) Essential Biodiversity Variables. *Science* 339: 277–278. doi: 10.1126/science.1229931
- Pereira HM, Belnap J, Brummitt N, Collen B, Ding H, Gonzalez-Espinosa M, Gregory RD, Honrado J, Jongman RH, Julliard R, McRae L, Proenca V, Rodrigues P, Opige M, Rodriguez JP, Schmeller DS, Van Swaay C, Vieira C (2010) Global biodiversity monitoring. *Frontiers in Ecology and the Environment* 8: 459–460. doi: 10.1890/10.WB.23
- Railsback SF, Grimm V (2012) Agent-based and individual-based modeling: A practical introduction. Princeton University Press, Princeton, N.J., 1–352.
- Rocchini D, McGlenn D, Ricotta C, Neteler M, Wohlgemuth T (2011) Landscape complexity and spatial scale influence the relationship between remotely sensed spectral diversity and survey-based plant species richness. *Journal of Vegetation Science* 22: 688–698. doi: 10.1111/j.1654-1103.2010.01250.x
- Schmeller DS (2008) European species and habitat monitoring: where are we now? *Biodiversity and Conservation* 17: 3321–3326. doi: 10.1007/s10531-008-9514-1
- Schmeller DS, Henry PY, Julliard R, Gruber B, Clobert J, Dziock F, Lengyel S, Nowicki P, Deri E, Budrys E, Kull T, Tali K, Bauch B, Settele J, Van Swaay C, Kobler A, Babij V, Papatsergiadou E, Henle K (2009) Advantages of Volunteer-Based Biodiversity Monitoring in Europe. *Conservation Biology* 23: 307–316. doi: 10.1111/j.1523-1739.2008.01125.x
- Schmeller DS, Henle K, Loyau A, Besnard A, Henry P-Y (2012) Bird-monitoring in Europe - a first overview of practices, motivations and aims. *Nature Conservation* 2: 41–57. doi: 10.3897/natureconservation.2.3644
- Scholes RJ, Mace GM, Turner W, Geller GN, Jürgens N, Larigauderie A, Muchoney D, Walther BA, Mooney HA (2008) Toward a Global Biodiversity Observation System. *Science* 321: 1044–1045. doi: 10.1126/science.1162055
- Scholes RJ, Walters M, Turak E, Saarenmaa H, Heip CHR, Ó Tuama É, Faith DP, Mooney HA, Ferrier S, Jongman RHG, Harrison IJ, Yahara T, Pereira HM, Larigauderie A, Geller G (2012) Building a global observing system for biodiversity. *Current Opinion in Environmental Sustainability* 4: 139–146. doi: 10.1016/j.cosust.2011.12.005
- Schurr FM, Pagel J, Cabral JS, Groeneveld J, Bykova O, O'Hara RB, Hartig F, Kissling WD, Linder HP, Midgley GF, Schröder B, Singer A, Zimmermann NE (2012) How to understand species' niches and range dynamics: a demographic research agenda for biogeography. *Journal of Biogeography* 39: 2146–2162. doi: 10.1111/j.1365-2699.2012.02737.x
- Secretariat of the Convention on Biological Diversity (2010) Global Biodiversity Outlook 3. Montréal, 94 p. <http://www.cbd.int/doc/publications/gbo/gbo3-final-en.pdf>
- Sutherland WJ (2013) Review by quality not quantity for better policy. *Nature* 503, 167. doi: 10.1038/503167a
- Sutherland WJ, Bellingan L, Bellingham JR, Blackstock JJ, Bloomfield RM, Bravo M, Cadman VM, Cleevely DD, Clements A, Cohen AS, Cope DR, Daemmerich AA, Devecchi C, Anadon LD, Denegri S, Doubleday R, Dusic NR, Evans RJ, Feng WY, Godfray HCJ,

- Harris P, Hartley SE, Hester AJ, Holmes J, Hughes A, Hulme M, Irwin C, Jennings RC, Kass GS, Littlejohns P, Marteau TM, McKee G, Millstone EP, Nuttall WJ, Owens S, Parker MM, Pearson S, Petts J, Ploszek R, Pullin AS, Reid G, Richards KS, Robinson JG, Shaxson L, Sierra L, Smith BG, Spiegelhalter DJ, Stilgoe J, Stirling A, Tyler CP, Winickoff DE, Zimmern RL (2011) A collaboratively-derived science-policy research agenda. *PLoS ONE* 7(3):e31824. doi: 10.1371/journal.pone.0031824
- Tzanopoulos J, Mouttet R, Letourneau A, Vogiatzakis IN, Potts SG, Henle K, Mathevet R, Marty P (2013) Scale sensitivity of drivers of environmental change across Europe. *Global Environmental Change* 23: 167–178. doi: 10.1016/j.gloenvcha.2012.09.002
- United Nations Environment Programme (2010) UNEP Annual Report 2009 – seizing the green opportunity. http://www.unep.org/PDF/UNEP_AR_2009_FINAL.pdf
- Vaccari L, Craglia M, Fugazza C, Nativi S, Santoro M (2012) Integrative Research: The Euro-GEOSS Experience. Selected Topics in Applied Earth Observations and Remote Sensing, *IEEE Journal of*, 5: 1603–1611. doi: 10.1109/JSTARS.2012.2190382
- Vandzinskaite D, Kobierska H, Schmeller DS, Grodzińska-Jurczak M (2010) Cultural Diversity Issues in Biodiversity Monitoring - Cases of Lithuania, Poland and Denmark. *Diversity* 2: 1130–1145. doi: 10.3390/d2091130
- Vohland K, Adem C, Arvanitidis C, Chatzinikolaou E, Costello MJ, Haston EM, Hoffmann A, Kehoe L, Rocchini D, Schleicher J, Schmiedel U, Wetzel F, Häuser CL (in review) Building the European Biodiversity Observation Network - EU BON – requirements from policy, science, and society. *Nature Conservation*.
- Wisz MS, Pottier J, Kissling WD, Pellissier L, Lenoir J, Damgaard CF, Dormann CF, Forchhammer MC, Grytnes J-A, Guisan A, Heikkinen RK, Høye TT, Kühn I, Luoto M, Maiorano L, Nilsson M-C, Normand S, Öckinger E, Schmidt NM, Termansen M, Timmermann A, Wardle DA, Aastrup P, Svenning J-C (2013) The role of biotic interactions in shaping distributions and realised assemblages of species: implications for species distribution modelling. *Biological Reviews* 88: 15–30. doi: 10.1111/j.1469-185X.2012.00235.x