Building the European Biodiversity Observation Network

Final summary report

31 July 2017

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1. Introduction and executive summary

Sustainable governance of our biological resources requires reliable scientific data and knowledge that meets the needs of research and society. Current biodiversity observation systems and environmental datasets are often unbalanced in coverage and not integrated, limiting integrative analyses and implementation of environmental policies.

The FP7 project EU BON 'Building the European Biodiversity Observation Network' aimed to improve access to integrated biodiversity data from earth observation and in situ realms in order to provide relevant information for evidence-based decision making at local, national, and global level. EU BON delivered a significant European contribution to the Group on Earth Observations Biodiversity Observation Network (GEO BON) by building a European portal for biodiversity information (http://biodiversity.eubon.eu), and by integrating and harmonising a wide range of biodiversity data from in-situ and remote sensing sources for the Global Earth Observation System of Systems (GEOSS), relying on existing information infrastructures such as the Global Biodiversity Information Facility (GBIF), and the Long Term Ecological Research Network (LTER).

EU BON established links between social networks of science and policy and technological networks of interoperating IT infrastructures, resulting in a new open-access platform for sharing biodiversity data and tools, and greatly advanced access to biodiversity knowledge in Europe. EU BON's core deliverables include a comprehensive 'European Biodiversity Portal', a blueprint for a future optimised organisation of biodiversity recording and information management in Europe, and strategies for a global implementation of GEO BON and supporting the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and other global policy processes. A key for the transformation of this concept into practical applications were the EU BON test sites which served as a reality check for the EU BON tools and services.

The project was funded for 4.5 years (2012-2017) in a joint effort of 31 partners from 15 European countries, Israel, the Philippines, Brazil and more than 30 associated partners. During the project phase a wide range of tools and products (40+) for data mobilisation, data sharing, and data integration as well as for data analysis and data publishing were developed and advanced. EU BON has significantly improved techniques for the biodiversity data life-cycle and data workflow - from collection and standardisation of data to the delivery of open access data and integrated data analysis. Furthermore, important advances have been made in the field of data management and interpretation for e.g. data capture, data processing, data re-scaling, data modelling. Integrating applied tools, software, derived products and knowledge, the 'European Biodiversity Portal' as well as the EU BON webpage (www.eubon.eu) serve as online library for manuals, guidelines, factsheets, case studies, policy recommendations and other documents and represent a communication interface between biodiversity researchers, data repositories, interested communities and policy makers. The main goal of the biodiversity portal is to make biodiversity data and information discoverable, accessible and digestible e.g. by visualising relative observation trends and to provide also a gateway for citizen science. EU BON's outcomes will impact the future of biodiversity data recording and information management within the GEO context as well its application and use, certainly within Europe but also globally.

The EU BON business plan builds a base for further communication of the outcomes of the EU BON project to a wider community. In addition, close links have been created with GEO BON, both in regard to the development and operationalisation of EBVs as well as contributions to GEO BON' "BON-in-a-Box".

2. A summary description of project context and objectives

The ongoing dramatic decline of the world's biodiversity and the increasing threats to its ecosystems functioning and services remains unprecedented in its speed and predicted effects on the future of our planet. While biodiversity has long been observed and monitored with differently focused initiatives and increasingly more detailed biosphere data layers from remote sensors are becoming available, current data on the state of the earth biological resources still remain fragmented. The need for usable biodiversity information for informed decisions in all sectors has thus been recognized as a main obstacle towards sustainable development by many national environmental policies, as well as the "Strategic Plan for Biodiversity 2011–2020" of the Convention on Biological Diversity (CBD), and its "Aichi Targets" towards 2020.

The Global Earth Observation System of Systems (**GEOSS**) and its biodiversity section, the Group on Earth Observations Biodiversity Observation Network (**GEO BON**) has set a framework to harmonise and standardise biodiversity information from on-ground to remote sensing data, in order to adequately address questions from decision makers. Europe's contribution towards these goals and initiatives was the FP7 project **EU BON** '**Eu**ropean **B**iodiversity **O**bservation **N**etwork'.

EU BON addressed biodiversity-related issues on a European scale (Hoffmann *et al.* 2014). A question of central concern was how data on biological diversity, such as on species state and trends, can be used for political processes and reporting (Wetzel *et al.* 2015), e.g. for tracking progress of Aichi targets, and the UN Sustainable Development Goals (SDGs), as well as for IPBES and other political mechanisms.

EU BON has taken on this challenge by enabling and improving access to highly integrated biodiversity data for research, as well as for decision processes by stakeholders and policy makers at local, national, and global level. EU BON aimed to advance biodiversity knowledge in building a new European portal for biodiversity information and by harmonising a wide range of biodiversity data, EU BON relied on existing components and information infrastructures, such as the Global Biodiversity Information Facility (GBIF), the Long Term Ecological Research Network (LTER), and EuroGEOSS. EU BON intended to provide integration between social networks of science and policy and technological networks of interoperating IT infrastructures, resulting in a new open-access platform for sharing biodiversity data and tools, and greatly advanced biodiversity knowledge in Europe.

In addressing its main objectives to enable greater interoperability of data layers and systems, increase data mobilisation and advance data integration, improve analytical tools and services for interpreting biodiversity data, link information to relevant stakeholders, and support the science-policy interface, EU BON focused specifically on: **i)** advancing the informatics infrastructures for GEO, by moving existing biodiversity networks towards standards-based, service-oriented approaches and cloud computing, enabling full interoperability through the GEOSS Common Infrastructure; **ii)** significantly improving our knowledge of biodiversity by identifying data gaps and addressing information needs; **iii)** enhancing the range and quality of methods and tools for assessment, analysis, and visualization of biodiversity and ecosystem information, particularly focussing on predictive modelling; **iv)** providing mechanisms for delivering integrated biodiversity information to EU member states, other governments, and stakeholders to also support their reporting obligations, and as a European contribution towards IPBES; **v)** developing frameworks and strategies for the future generation, management, and use of integrated biodiversity information at national and regional levels; and **vi)** designing concepts for sustaining future environmental information systems, including in particular active participation by citizen science.

In short, EU BON aimed at:

1. increasing data mobilisation via scientific communities, citizen scientists, and potential data users;
2. enabling greater interoperability of data layers and systems through both the establishment and adoption of new standards;
3. developing and validating new (modelling) technologies; this is particularly important in the context of enabling full and user-friendly interoperability between as yet distinct data layers, such as remote sensing and on ground observations, and records from individual organisms with species and habitats characteristics;
4. developing new strategies for future harmonising and mainstreaming of biodiversity recording and monitoring;
5. improving analytical tools and services for integrating and interpreting biodiversity data, and make them available not only to researchers, but also to decision makers and a variety of relevant stakeholders;
6. supporting the science-policy interface by the provision of timely information and by improved scenario development; this was particularly important in the context of upcoming IPBES and existing national reporting obligations to European policies and international conventions;
7. linking customized information to the needs of relevant stakeholders (from research, policy and citizen science);
8. strengthening overall European capacities and infrastructures for environmental information management and dissemination.

The EU BON work plan was organised accordingly spanning across a wider field of existing and ongoing developments, from the technical infrastructure to the stakeholder/political/policy side of information use and decision making. EU BON was structured in nine work packages: **WP1)** Data sources: requirements, gap analysis and data mobilisation; **WP2)** Data integration and interoperability; **WP3)** Improving tools and methods for data analysis and interface; **WP4)** Link environment to biodiversity: analyses of patterns, processes and trends; **WP5)** EU BON testing and validation of concepts, tools, and services; WP6) Stakeholder engagement and science-policy dialogue; **WP7)** Implementation of GEO BON: strategies and solutions at European and global levels; **WP8)** Dissemination and outreach; **WP9)** Consortium management and organisation. The scientific work packages were grouped into three larger activity themes, which built upon each other and follow a general workflow according to the WP numbers: i) Data and Infrastructure (WP1, WP2), ii) Science and Applications (WP3, WP4, WP5), and iii) Policy and Outreach (WP6, WP7, WP8).

Based on surveys and assessments of relevant data sources and information infrastructures, a gap analysis of data coverage and quality (WP1) was made, and targeted efforts were designed and tested for data mobilisation, from digitising collection-based historic information to emerging citizen-science monitoring schemes. The technological basis for significantly improved data integration and interoperability (WP2) was defined in an improved informatics architecture, which anchored EU BON developments, such as the registry and portal, in permanent infrastructures. In a second layer, which allowed EU BON to deliver tangible products for scientific and practical use, cutting edge analytical tools (WP3) and modelling techniques (WP4) were developed and improved. This showcased the use of integrated biodiversity data for future sound environmental decision making and other applications. These new tools as well as targeted data mobilisation efforts and emerging EU BON information services were tested, with on ground sites and local stakeholders (WP5). In a third layer, experiences gained and results obtained were used via a targeted stakeholder consultation process (WP6) to develop and present EU BON services in a suitable form to inform policy and international processes, and to design blueprints for future biodiversity information infrastructures (WP7), and to disseminate scientific outputs to a wider audience and end users (WP8).

The reader will learn more about the EU BON's outcomes in the description of main S&T results. Prerecording the key outcomes are specified here:

- Strategies for targeted biodiversity data mobilisation in Europe.
- European Biodiversity Portal with new functionalities, including a Citizen Science gateway.
- Software tools & improved models for better biodiversity data recording / mapping and analysis / visualization of patterns & trends.
- Results & lessons learnt from EU BON (& other) sites for regional/global network of long term recording/monitoring sites
- Recommendations for integrated national / regional biodiversity monitoring schemes and information infrastructures.
- Blueprint for a future optimised organisation of biodiversity recording and information management in Europe
- Strategies and business plan for a sustainable biodiversity information infrastructures

The European Biodiversity Portal (http://biodiversity.eubon.eu) as the main product of EU BON offers a wide range of derived products and tools (40+) for data mobilisation, data sharing, data integration, data analysis as well as for data publishing and serves as a communication interface between biodiversity researchers, data repositories, interested communities and policy makers. The biodiversity portal makes biodiversity data and information discoverable, accessible and digestible, e.g. by visualising species state and trends. EU BON supports the work of GEO and GEO BON in several ways. Tools developed in the project are part of GEO BONs BON-in-a-Box, an online toolkit for national and regional biodiversity observation systems. A prototype data browser was developed by GBIF and EU BON to make existing data discoverable, e.g. species occurrence datasets, and to evaluate species richness and population trends, applying the Essential Biodiversity Variable concept by using real data.

EU BON produced a business plan, building a base for further communication with scientists and policy makers about the sustainability of the outcomes of the EU BON project. The impact of the results from EU BON depends on the implementation of the business plan and the funding options available.

References

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Wetzel, F.T., Saarenmaa, H., Regan, E., Martin, C.S., Mergen, P., Smirnova, L., O Tuama, E., García Camacho, F.A., Hoffmann, A., Vohland, K., Häuser, C.L. 2015. The roles and contributions of Biodiversity Observation Networks (BONs) in better tracking progress to 2020 biodiversity targets: a European case study. B*iodiversity* 16: 136-148. doi: 10.1080/14888386.2015.1075902.

3. Description of the main S&T results/foregrounds

WP1: Data sources: requirements, gap analysis and data mobilisation

Assessment and evaluation of biodiversity data sources (Task 1.1)

In order to assess and evaluate biodiversity data sources (BDS) that are highly relevant on a European scale, an online database service hosted by PlutoF (https://plutof.ut.ee) was established. Data on BDSs are collected in an atomised way which enables the evaluation of their coverage, accessibility and format and a list was compiled for the upload into a relational database. The focus was on unpublished BDS which metadata are not available in any major repositories. The aim of this work was to make metadata of these datasets publicly available in our portal at http://biodiversity.eubon.eu/web/citizen-science/data-providers.

Also some key major datasets covering taxonomic backbone data, ecological data, current and historical specimen data from scientific collections and DNA sequence data were evaluated. Specimen and observation based taxon occurrences were analyzed using GBIF (Global Biodiversity Information Facility, see **Fig. 1**) datasets. The International Nucleotide Sequence Database Collaboration (INSDC: GenBank, ENA, DDBJ) datasets cover DNA sequence data, the Pan-European Species directories Infrastructure (PESI) is used for the analyses of taxonomic backbone data, and the Data Observation Network for Earth (DataONE) covers ecological data including LTER and Dryad datasets. In addition, third party annotated INSDC datasets of UNITE were used in the analyses. Results from this assessment were handed over to other tasks for the further analyses (e.g. the gap analyses).

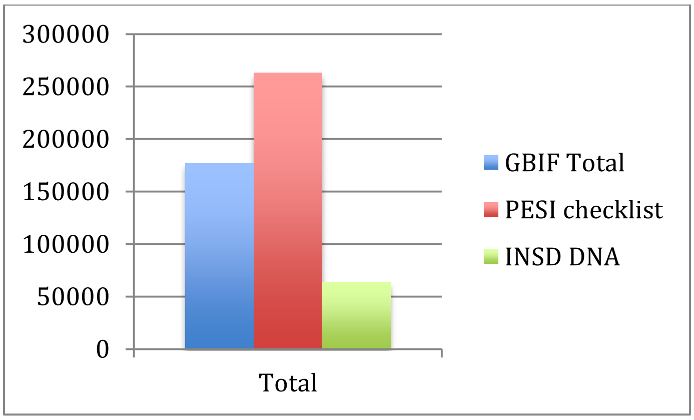

Figure 1: *Number of species in Europe based on GBIF taxon occurrences (specimens and observations), PESI checklist of European species names and INSD species with DNA sequences.*

Harmonisation of European taxonomic backbone and analysis of taxonomic coverage (Task 1.2)

The core objective of this task was to provide a harmonised European and national taxon level backbone service, which complies with the Appendix 3 of the INSPIRE Directive. The works involved i) the continuous improvement and completion of underlying data resources, ii) the harmonisation of data management systems based on the EDIT Platform for Cybertaxonomy (www.cybertaxonomy.eu), iii) the implementation of a central service layer providing unified access to the sources, which together form the EU BON taxonomic backbone (**Fig. 2**), iv) testing, hardening and registering this service layer and integrating it into the EU BON portal services.

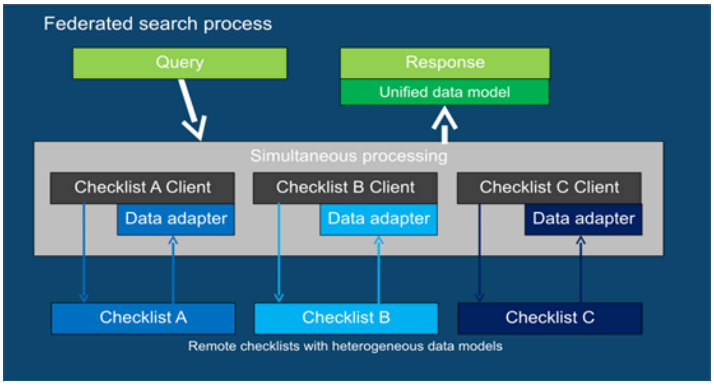

Figure 2: *The EU BON Taxonomic Backbone Services provide simultaneous and instant access to distributed information sources defined by the INSPIRE directive via a unified access protocol.*

As a result of these efforts, the EU BON "Unified Taxonomic Information Service" (UTIS, https://cybertaxonomy.eu/eu-bon/utis/1.2/) provides access to the Pan-European Species directories Infrastructure (EU-Nomen), EUNIS, Natura2000, the Catalogue of Life (CoL), the World Register of Marine Species (WORMS), the GBIF Checklist Bank, and PLAZI TreatmentBank. Updates are cyclically published via the PESI workflow for merging and publishing the major European checklist databases Euro+Med Plantbase, Fauna Europaea, European Register of Marine Species (ERMS), and Index Fungorum. For automated testing of services, a standardised Apache JMeter (https://jmeter.apache.org/) based platform has been set up which sends and evaluates service requests to UTIS. A detailed description of the EU BON Taxonomic Backbone Services has been published as a "Summary report of operational EU BON services and data provision for the European taxonomic backbone" (**D1.4**) and is available on the EU BON website and ResearchGate (http://tinyurl.com/m9bzqnz).

Gap analysis of available biodiversity information sources and identifying priorities (Task 1.3)

High-quality biodiversity data is essential for answering key questions on biodiversity in Europe, for example regarding the state and trends of species or for evaluating ecosystem services and functions on various scales. In the task on the gap analysis with its final report "Gap analysis and priorities for filling identified gaps in data coverage and quality" (**D1.1**), the state of available biodiversity information was evaluated and the most relevant gaps of available biodiversity information sources were highlighted.

The assessment particularly evaluated spatial, taxonomic and temporal gaps of available biodiversity information sources and, after outlining the most important gaps, identifies priorities for improving the data availability. The gap analysis has a focus on biodiversity information on a European scale (**Fig. 3**) and is based on an assessment of current marine, terrestrial and freshwater biodiversity data sources. The gaps are evaluated against the needs of the different stakeholders; this includes the demands from European policy (like the EU biodiversity strategy to 2020), international relevant processes (like the Convention on Biodiversity and the Aichi biodiversity targets) and the scientific community.

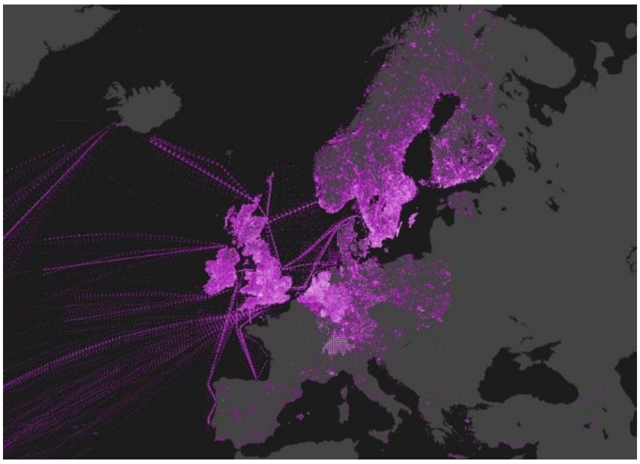

***Figure 3:** This figure illustrates geographical gaps in biodiversity data in Europe, using Arthropoda as an example. The figure uses 12.62 million occurrence records (globally) from 1970 to March 2015, accessed from the Global Biodiversity Information Facility (GBIF). Lighter colors indicate more available data (Wetzel et al. 2015).*

Overall the gap analysis can be divided into three main sections: Firstly, an overview of gaps and limitations of general biodiversity datasets. The second chapter outlines the key findings, i.e. it gives a brief overview of main gaps of global and European datasets and recommendations of how to close the gaps on different levels respectively for different stakeholders. These recommendations could be used for European biodiversity information management approaches, as well as for data mobilisation efforts and Citizen Science initiatives. Finally, the third chapter contains the extended version of the specific gap analyses of European and global databases.

Data and information generated by task 1.1 and task 1.3 was also directly used for policy reporting processes. Charts generated from the analytics of GBIF were used by the CBD in the Fourth Global Biodiversity Outlook (GBO4) to illustrate mobilisation of species occurrence records over time, as an indicator of progress towards Aichi Target 19 (https://www.cbd.int/gbo/gbo4/publication/gbo4-en.pdf, p 119). They are also included in the 'Aichi Passport' produced by the Biodiversity Indicators Partnership (http://www.bipindicators.net/numberofgbifrecordsovertime). Furthermore, data and analyses were used specifically for the UNEP GEO-6 regional assessment, where EU BON partners contributed as Lead Authors.

Integrated approaches for focused biodiversity data mobilisation (Task 1.4)

With this task, EU BON has advanced mobilisation of collection-based and molecular biodiversity data through the development of tools and services (**D1.3**), and through data mobilisation projects. The development work has focused on the DINA (http://dina-project.net), JACQ (http://herbarium.univie.ac.at/database/) and Pluto-F (https://plutof.ut.ee) systems, and on integrating these systems with each other and with other biodiversity informatics resources. The result is a range of powerful online services for the mobilisation and management of biodiversity data, and sophisticated platforms for future development of such tools (**Fig. 4**). The data mobilisation efforts have targeted a wide range of biodiversity data sets from countries across the European continent (Denmark, Slovakia, Israel, Estonia, Ukraine, and Sweden, among others). The projects have also included mobilisation of published biodiversity data in the scientific literature, and innovations in the biodiversity data publishing process.

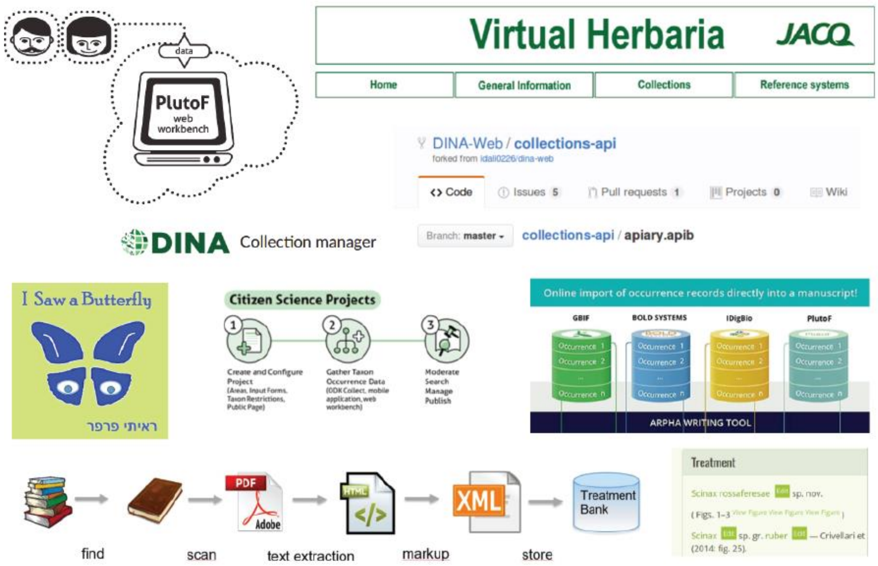

Figure 4: *Selection of tools, services and system platforms for mobilising and managing biodiversity data developed by EU BON task 1.4.*

Exploring citizen science – based approaches for mobilising and generating biodiversity data (Task 1.5)

EU BON has explored the potential of citizen science for mobilising biodiversity observations. Opportunities and risks of citizen science were analyzed and presented in a report "Summary report and strategy recommendations for EU citizen science gateway for biodiversity data" (**D1.2**) https://doi.org/10.3897/rio.2.e11563. Some of the practical conclusions of this work were also implemented in the EU BON biodiversity portal http://biodiversity.eubon.eu, including a directory of citizen science tools (http://biodiversity.eubon.eu/web/citizen-science/directory-of-cs-tools), the review of citizen science data providers (http://biodiversity.eubon.eu/web/citizen-science/data-providers) and guidelines for citizen science project management (http://biodiversity.eubon.eu/web/citizen-science/start-your-cs-project). The citizen science section of the EU BON biodiversity portal will visualize the recommendations for European citizen science gateway for biodiversity data.

Mobile applications were developed and tested for opportunistic citizen science observations – I Saw a Butterfly by GlueCAD (Israel) and My Naturesound by UTARTU (Estonia). Data sharing with tools were tested and documented http://doi.org/10.15156/bio/587439. As a separate module of biodiversity platform PlutoF, a dedicated tool for citizen science project management was developed by the University of Tartu https://plutof.ut.ee/#/citizenscience.

WP2: Data integration and interoperability

The tasks (T) in WP2 can be divided in three groups, which results are considered below in integrated way. These task groups are data standards and data sharing (T2.2, T2.3), information architecture and the portal (T2.1, T2.4, T2.5), and outreach (T2.6, T2.7, T2.8).

Data standards and data sharing

A major objective of the project has been linking incidental observation data with quantitative ecosystem monitoring data. While the data standards for the former are in good shape, it became clear from the review of data standards which was made early in the project (**D2.1**) that new standards and tools need to be introduced to enable open data sharing of sample-based, quantitative data. Until now, only the Ecological Metadata Language (EML) has been available for this, but it covers only dataset/project level metadata.

Five new terms were defined for the Darwin Core data standard in discussions with the GEO BON and TDWG community and ecosystem monitoring practitioners. These are parentEventID, sampleSizeValue, sampleSizeUnit, organismQuantity, and organismQuantityType. It was determined that these terms, together with already available ones, allow representing sampling events and related quantitative data in most sample based datasets. Based on the proposal put forward by EU BON partners, these new terms were ratified by the Biodiversity Information Standards organisation TDWG.org on 19 March 2015. This was named by the GEO BON Chairman as major achievement.

These new terms were implemented in GBIF Integrated Publishing Toolkit (IPT) version 2.3, which was launched in June 2015. This version introduced sampling event as new core data type into which quantitative measurements could be tied through so-called star-schema data model (**Fig. 5**). The IPT is being used by hundreds of GBIF data providers, and until now (May 2017) 83 datasets, which use the Event Core, have been shared. This includes major data providers such as Ocean Biogeographic Information System (OBIS). Still, introduction of a new data model into a global network of hundreds of data publishers will take years to implement fully. Experiences have been gained, and now there are proposals of five additional terms to the Darwin Core standard related to quantitative data, which are under consideration.

The project also surveyed other data sharing tools (**D2.2**). From among about 30 tools, six were recommended, namely the GBIF IPT, spreadsheet processors, the ARPHA Publishing Platform, TreatmentBank, PlutoF, and Metacat with the Morpho client. This survey of tools is being included in the GEO BON toolbox BON-in-a-Box. A paper, based on D2.2, on the data sharing tools adopted by EU BON has been published in the RIO Journal.

Information architecture and the portal

Early in the project (D2.1), a service-oriented information **architecture** was drawn for the project, where a portal would act as the front-end for the users. It would be powered by an integrating layer of GBIF and GEOSS registries, and link to the GEOSS Common Infrastructure. A service layer of data and computing resources would feed content into the system (**Fig. 6**).

The portal (**D2.5**) offers a user interface structured after the logic of A) data access, B) data analysis, C) services and support for users, and D) a directory of products/outputs. To assist in navigation, four major use cases supported by the portal have been highlighted in the home page. These include 1) piloting the workflows of Essential Biodiversity Variables, 2) support to Citizen Science projects, 3) services for field test sites, and 4) AquaMaps for decision support on marine biodiversity. In addition, about a dozen Flagship products of the EU BON project have been elevated to the home page (**Fig. 7**).

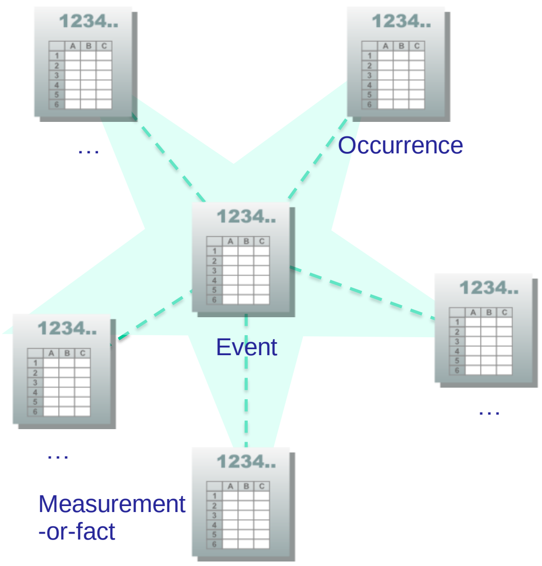

Figure 5: *Sampling event as the core object ties together observations and measurements.*

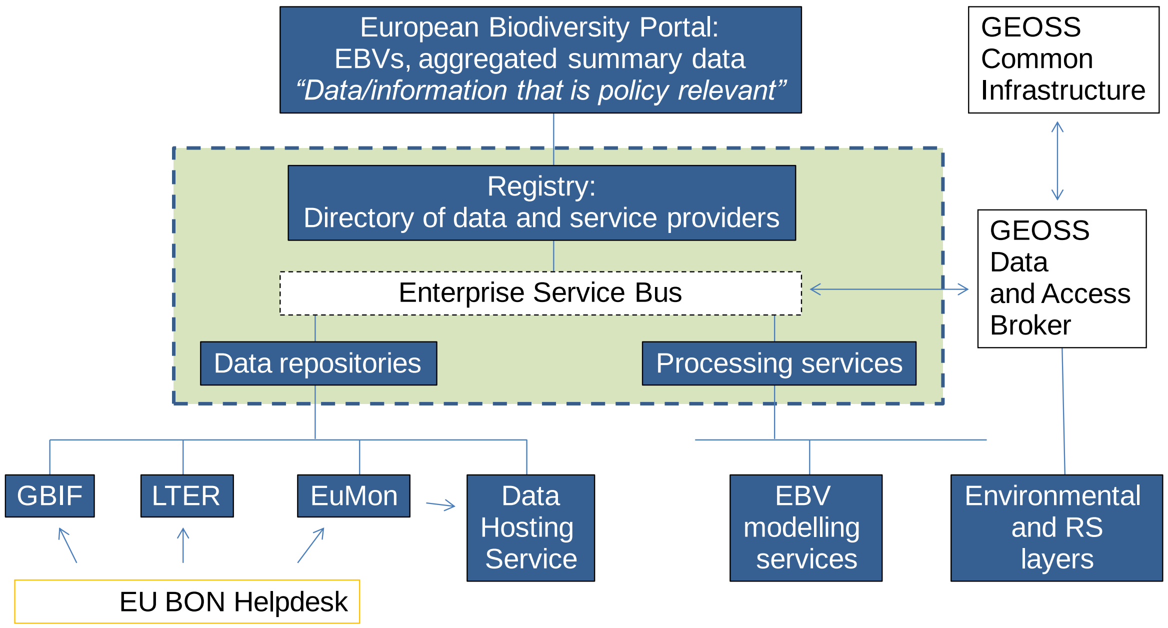

Figure 6: *Components of the EU BON information system.*

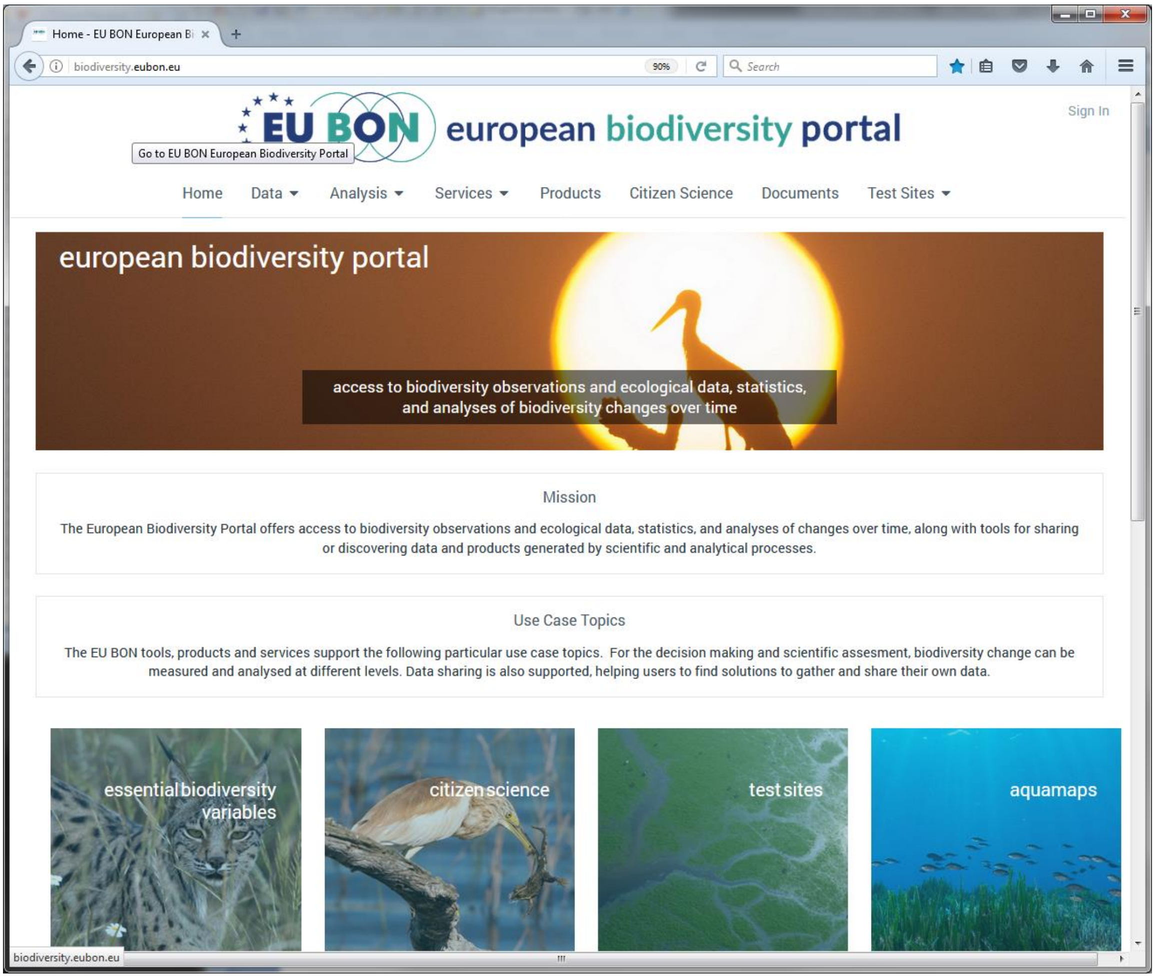

Figure 7: *Home page of the EU BON portal highlights use cases and flagship products.*

The data section A) provides the user with an interface for retrieving datasets from the data providers linked or harvested by the EU BON Metadata Broker, an instance of GEOSS GI-cat. The dataset search tool corrects the taxonomy constraints entered by the users, requesting data from the EU BON Taxonomic Backbone. The user can enter taxa by vernacular or scientific name, exactly or approximately, or by the identifier assigned by the data provider. After performing a search, a list with the previously-harvested datasets will be listed, including links to the original metadata and their geographic coverage. The data section also includes a Spatial Dataset Browser.

The Analysis section B) lists a set of tools for data analysing and knowledge discovery. Given that GBIF provides access not only to metadata but also to harmonised data, all analytical tools use GBIF as data backbone, either by accessing its APIs or by retrieving data from a periodical snapshot of the GBIF occurrences across Europe. This section puts at users' disposal the Species richness application, the Relative observation trends pilot tool, and a Business intelligence dashboard.

The Services section C) offers a set of tools for helping users to share data. It also provides a collection of tools, services and data layers helpful in order to fulfil a proper data analysis. It includes a directory of tools for data sharing, list of Environmental data layers, AquaMaps for EU BON, the EU BON instance of GBIF IPT, guidance to using the EU BON Taxonomic Backbone, guidance to using the eLab functions, and the link to the EU BON Helpdesk.

The Products section D) provides the user with an interface for identifying EU BON products from a set of more than 40 elements, either tools, factsheets, or other products. The list can be filtered by audience (scientists, decision-makers, citizens, etc.), and by topic.

The use cases, mentioned above, then tie these technically organised data, tools and services together. Introductory texts for each use case should guide the users in their exploration of the various tools in their own work.

Outreach

The EU BON project had a training programme which held a total of 5 training workshops and numerous related dissemination events (**D2.4**). A total of 104 people have attended the workshops. The training covered mainly the various data sharing tools, in particular the new version of GBIF IPT for sample-based data. The Empowering biodiversity research conference was an occasion to further test the system with real data coming from research institutions and universities field work and monitoring activities.

A Helpdesk website was opened in early 2013 and gathered the training materials and other advice for users. Helpdesk and training were integrated closely throughout the project.

The Informatics and Data Standards Task Force (ITF) was invited in early 2013 to advise the EU BON project. It consisted of 13 members from across major research infrastructure projects around the world. The ITF held one physical meeting and annual teleconferences. The ITF members have attended the conferences of the project, and individual discussions have been held. In particular the ITF has advised in how to develop the portal.

Intensive work on defining the use case for Essential Biodiversity Variables (EBV) has been carried out in collaboration with the GEO BON, BioVeL, COOPEUS, Creative-B, and GLOBIS-B projects. This provided focus and helped prioritising components and functions in the implementation of the information architecture. The joint EU BON / GEO BON workshop in the autumn of 2014 resulted in the first operational definition of the EBVs for species populations: “*Relative abundance of a taxon in space and time, measured repeatedly using a consistent methodology”*. Using this definition, the data flows for producing the EBVs have been piloted, and a new paper on the methodology has been submitted. It describes how to derive measures of relative abundance from occurrence records in big data mediated by GBIF. Two tools to demonstrate this have been made available on the EU BON portal’s EBV use case section. Cooperation with the GLOBIS-B project has continued on this matter and results have been shown in their three workshops. Towards the end of the project, global coordination has progressed through cooperation with GEO BON in their Open Science Conference and work on the EBVs spearheaded now by the GLOBIS-B project.

The GEO Handbook on Biodiversity Observation Networks was published in November 2016. Authored by EU BON Partners and one ITF Member, its chapter 11 “Global infrastructures for biodiversity data and services” summarises the results of D2.1 in a concise form, and gives perspective for future technical development of BONs.

WP3: Improving tools and methods for data analysis and interface

One of the main missions of EU BON was to increase the efficiency by which biodiversity data is used to inform policy. In most cases, raw data does not flow into policy instruments directly, but rather through an intermediate stage of data analysis. The main aim of WP3 was to contribute to the data analysis stage by developing novel analytical tools and ensuring their accessibility to relevant stakeholders with various levels of expertise. We have focused on four main areas of activity: **1. Data capture**: Automatic extraction and mining of biological records, images and traits from published literature and submission of the extracted information to relevant data repositories (e.g. GBIF). **2. Data processing**: Usage of remote-sensing and machine learning algorithms to predict the distribution of habitats, land-covers and environmental conditions. **3. Data re-scaling**: Scaling up and down of important biological properties (e.g. species' area of occurrence and species richness) from scales in which their true value is relatively known to scales in which it is unknown yet required for conservation and management. **4. Data modelling**: Developing advanced species distribution models (SDMs), which predict the geographical distribution of species, for both data-deficient and data-rich systems. Together, these activities increase the amount and quality of data and provide advanced analytical pathways for the main types of data that flow into policy instruments.

For the first area of activity we have developed the **GoldenGate Imagine tool** that semi-automatically extracts user-defined information from published data. Many taxonomic and faunistic/floristic publications contain high-quality biodiversity data on species distribution and traits that can be used to complement existing distribution information or parameterize process-based models. Although information from new publications may be archived independently, most of the embedded biodiversity data is not submitted to any data repository. The GoldenGate Imagine tool fills this gap by using advanced data mining and mark-up techniques to screen and extract records from the most prolific taxonomic journals. The tool is based on Java and implements the Darwin Core Archive (DwC-A) standard for its data transfer protocol. It became operational as part of **TreatmentBank** around June 2016 and at the end of April 2017 had already contributed 90,154 occurrence records and 193,708 species taxonomic treatment to GBIF from 19,500 articles, along with 108,838 images extracted and submitted to the Biodiversity Literature Repository. Sustainability plans for the tool, including a collaboration with Zenodo at CERN as repository, ensure that it would continue to generate new biodiversity data on a daily basis for the next few years.

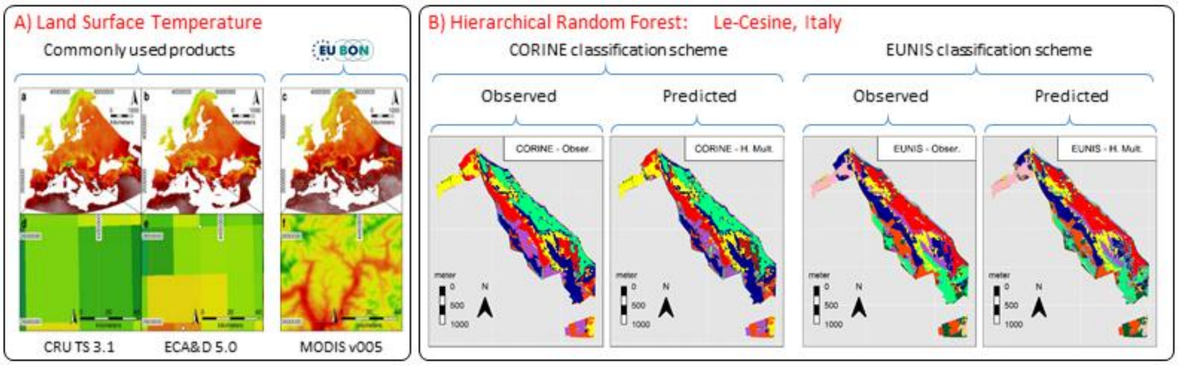

Figure 8: A) *Comparison of the land-surface temperature maps generated by commonly used products and by the tool developed under EU BON at continental and landscape scales.* ***B)*** *The observed map and the map predicted by the hierarchical random-forest model for the Italian NATURA 2000 site.*

For the second area of activity we explored novel ways to use fine-scale, multi-spectral remotely-sensed imagery when projecting the distribution of environmental conditions, habitats and land-covers in space and time. Among others, we have focused on the usage of remotely sensed imagery to quantify landscape fragmentation in a continuous manner, to predict the transferability of models in space and time and to quantify patterns of alpha and beta diversity. Furthermore, we contributed to the development of remotely-sensed based Essential Biodiversity Variables. In addition, we developed and implemented a tool that reconstructs continental-scale land surface temperature (LST) maps at much finer resolution (250m) than commonly used products (**Fig. 8A**). Using advanced spatial and temporal extrapolation methods to fill gaps caused by cloud cover, the **LST tool** generated daily coverage for eleven years, from 2002 to 2013. The LST tool was developed using the free and open access GRASS GIS and MODIS products to ensure transparency, sustainability and availability for potential users. Integration of the LST map into the European Biodiversity Portal is currently underway. Finally, we have developed an application of the machine learning algorithm Random-Forest that follows the pre-defined tree-like hierarchical structure of most national and international land-use/land-cover (e.g. CORINE) and habitat classification schemes (e.g. EUNIS). The **Hierarchical Random-Forest** (HRF) approach has been implemented as an R package, and was explored in one of EU BON's focal observatory sites (the Rhine-Main-Observatory) and in a NATURA 2000 site in Italy (**Fig. 8B**). These two case studies revealed that HRF slightly outperformed the original flat classification approach in the validation dataset, while providing additional information on variable importance along the class hierarchy. For example, in the Rhine-Main-Observatory the HRF model revealed that variables derived from remotely-sensed imagery are important when distinguishing coarse thematic land-cover classes from one another, while ancillary environmental variables are important lower down the hierarchy of the thematic tree.

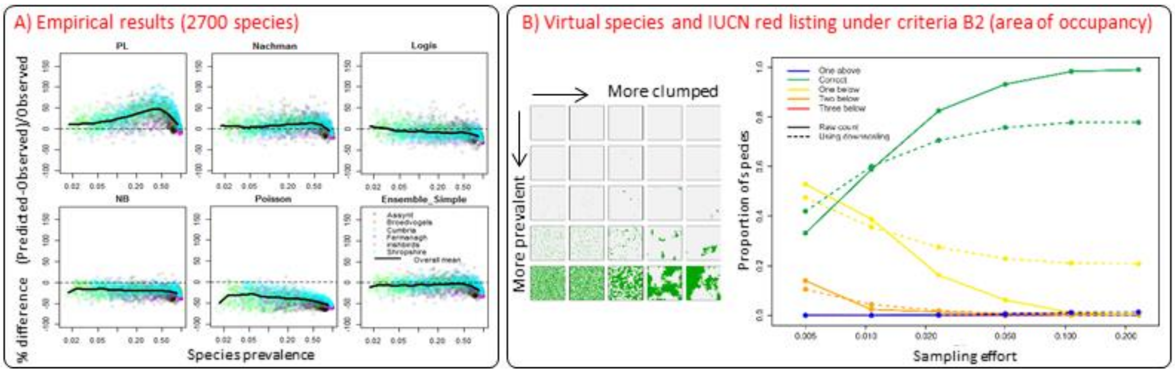

***Figure 9:** The ability of downscaling models to predict the correct area of occupancy and IUCN red list category (based on criteria B2) for **A)** 2700 bird and plant species and **B)** Virtual species.*

For the third area of activity we developed tools that use readily available data sources at certain scales to predict hard-to-measure properties of biotic datasets at other scales. For species richness, we codified in a **new R package** several published and novel up-scaling models, which can use a limited number of sparsely distributed fine resolution samples of assemblages to predict the number of species in a larger spatial extent, while accounting for the non-additivity of species diversity. We invested considerable time and effort in developing tools for assigning species to IUCN red-list categories, based on the area of occupancy (criteria B2). IUCN guidelines suggest assessing the area occupied by a given species at a 2×2 km resolution. However, in most cases reliable distribution data is only available at much coarser resolutions. To scale down the area of occupancy from coarse to fine resolution, we codified ten published downscaling models in a new R package. We carried out extensive analysis of approximately 2,700 species to explore the ability of the downscaling models to predict known distribution patterns (**Fig. 9A**). We also created virtual species with variable prevalence values and distribution patterns to explore the ability of downscaling models to deal with various data biases (number of samples and their spatial distribution) **(Fig. 9B**). From the results we identified several rules of thumb for using downscaling models for IUCN red-listing. We also used virtual species to create a virtual ecologist tool – a sampling tool that interfaces with existing individual-based simulation models (e.g. **RangeShifter**) to understand the link between local processes and large-scale patterns.

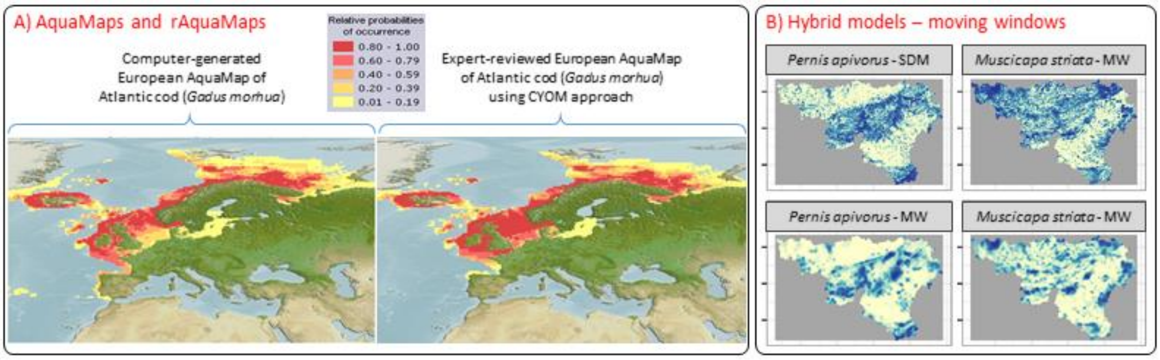

Figure 10: *Examples of distribution maps generated by:* ***A)*** *the standard AquaMaps' algorithm and an expert using AquaMaps' Create Your Own Map (CYOM) tool.* ***B)*** *one of the hybrid SDM models for two bird species from Wallonia.*

For the fourth area of activity we developed methods that increase the ability of SDMs to predict the actual distribution of species, under various scenarios. SDMs are very efficient at identifying correlative links between environmental variables and species occurrences. There remain however several areas for improvement. First, for systems with limited distributional information, robust systems are required to integrate data with expert assessments. Second, for data-rich systems, advanced SDMs that incorporate additional processes (e.g. dispersal limitations and biotic interaction) into the modelling framework are required. We thus developed solutions for both data-deficient and data-rich systems. For data-deficient systems we added considerable capabilities to AquaMaps' model with the Create Your Own Map (CYOM) tool. The **CYOM tool** provides an easy-to-use user interface by which experts can edit, save and correct computer-generated distribution maps generated by standard AquaMaps algorithm (**Fig. 10A**). We improved the tool, applied it to approximately 25,000 marine species, wrote a detailed tutorial on it and took active steps to increase the usage of the tool by experts of various taxonomic groups. In addition, we have created a new R package that implements the AquaMaps algorithm in an open-access R environment, thus allowing efficient batch analyses. For data-rich systems we developed a set of hybrid models that account for both spatial and environmental aspects when predicting species probability of occurrence and presence/absence maps (**Fig. 10B**). Two of the models integrate information from the downscaling models described above. We have applied the models to 83 bird species from Wallonia. Finally, we also invested considerable effort in the freshwater ecosystems whose particular physical properties make them fundamentally different from other ecosystems. Applying SDM models to these ecosystems requires adapting both the models and the predictors to account for the directional flow of water and to the accumulating effect of the catchment area. Thus, we developed a framework for adapting SDMs to freshwater ecosystems and explored its applicability for 195 species in one of EU BON's test sites. We further developed the framework to account for the effect of barriers and dams on species distribution patterns and extrapolated it in space and time.

To summarize, the tools described above (as well as additional ones) cover the distribution of environmental conditions, habitats, land-uses, species and communities, under various data availability and quality conditions and at various scales. We made considerable effort to make the tools accessible for relevant audience in the appropriate platforms and to disseminate the tools in various ways, to increase their potential impact.

WP4: Link environment to biodiversity: analyses of patterns, processes and trends

One of the most urgent challenges in ecology is to depict the current status and future trends of biodiversity in response to the on-going global changes in order to avoid or mitigate their impacts. As part of EU BON's "Science and Application" component, WP4 addressed the following EU BON objectives: to improve analytical tools and services interpreting biodiversity data, and to support the science-policy interface by timely information, as well as development of biodiversity predictions using existing scenarios of global changes.

For this purpose, WP4 developed, applied and made analytical tools, methods, and services for analysing biodiversity status, patterns, and trends available. This included the improvement and adaption of currently existing approaches. Results of the analyses were translated into recommendations to help decision making cope with pressing challenges regarding biodiversity conservation and to build the European biodiversity observation network. Key analytical tools were incorporated into GEO BON to support capacity building for biodiversity observation networks.

In particular, based on advanced existing integrative methods, and new tools developed by WP3 and WP4, WP4 analysed various biodiversity responses to environmental changes across different temporal and spatial scales (from local to regional to global), across various organisational levels (from genes to populations to communities and ecosystems), as well as across different realms (freshwater, marine and terrestrial). This resulted in an advanced understanding of past and current patterns of biodiversity and of the processes underlying these patterns, including the identification of main drivers of change and of relevant biodiversity indicators. WP4 also showed a mismatch between the availability of trend data for biodiversity and the temporal onset of major drivers of biodiversity and developed recommendations towards improving our ability to provide scenarios that integrate climate change and land use change for better predictions of likely future trends in biodiversity. Furthermore, WP4 developed strategies and guidelines for optimising current and future biodiversity monitoring. Finally, along all the steps of the scientific procedure, the reliability and transparency of results were considered as priorities. Thus, WP4 strived to provide information on the uncertainty accompanying recommendations in a form relevant to several types of stakeholders including policy makers and environmental managers.

Integrative analyses of distribution status and trends (Task 4.1)

Species distribution modelling (SDM, also: environmental niche modelling) has become a paramount tool to predict current species distributions in space, and time but also to assess the effect of environmental drivers on past changes in species distribution and to predict likely future changes. WP4 scoped out existing approaches for biodiversity distribution modelling. More particularly, WP4 identified a set of SDMs that account for the variety of data available (e.g. GBIF, remote sensing data, national and regional survey data) that are or can be implemented in free and open source software (e.g. R, QGIS). It also provided workflows, scripts, and algorithms for exchange platforms (e.g. Mirroreum) and decision-support platforms (e.g. GeoCAT). This ensures the availability of these tools for a great variety of users and supports the reproducibility of the methods. Improved mapping tools (e.g. AquaMaps, EuroBirdPortal) and new advanced modelling methods were developed along with WP3 to account for sampling biases (e.g. hierarchical modelling), scale effects (e.g. hybrid SDMs), biotic interactions (e.g. alpha-adjusted models), and various sources of uncertainty. Using several sources of biodiversity (from remote sensed and ground observations) and environmental large-scale databases (e.g. Land Surface Temperature), WP4 applied these new techniques on different taxa and realms, from the marine (e.g. bony fishes from the North Sea) and freshwater (e.g. benthic communities in the Rhine-Main Observatory EU BON test site in Germany) to the terrestrial realm (e.g. timber tree distribution in Europe).

Status and trends in populations in relation to associated drivers (Task 4.2)

In order to deepen our understanding of processes underlying species trends, WP4 described methods, developed modelling frameworks and analysed species abundance trends from monitoring data of several taxonomic groups in response to environmental and anthropogenic drivers while taking into account ecological characteristics of species (i.e. species traits). A set of provided guidelines supports the selection of appropriate methods (e.g. simple vs. complex) for the analysis of abundance trends according to the characteristics of the available data, e.g. to handle imperfect detection effects in occupancy (e.g. occupancy models), and missing values (e.g. TRIM), overdispersion (mixed modelling), or zero-inflation (e.g. N-mixture modelling) in abundances. The recommendations for data analysis were implemented on the web (http://eumon.ckff.si/biomat/). WP4 provided several pilot case studies to illustrate the insights that can be gained from biodiversity assessment using such approaches, primarily for birds, butterflies, freshwater fishes, and herpetofauna for which monitoring data with a sufficient historic temporal baseline was available.

Furthermore, WP4 provided substantial progress in identifying the best early-warning signs for biodiversity changes (e.g. the Essential Biodiversity Variable of abundance as a better early-warning indicator than occurrence) and for population declines using multi-taxa assessments. The **Figure 11** illustrates an example for the effects of urbanisation on bird abundance. Particular attention was paid to the relationships between drivers, species' ecological characteristics (e.g. habitat preference for birds, phenology for butterflies, and trophic level for marine benthos communities) and the population trends of the species.

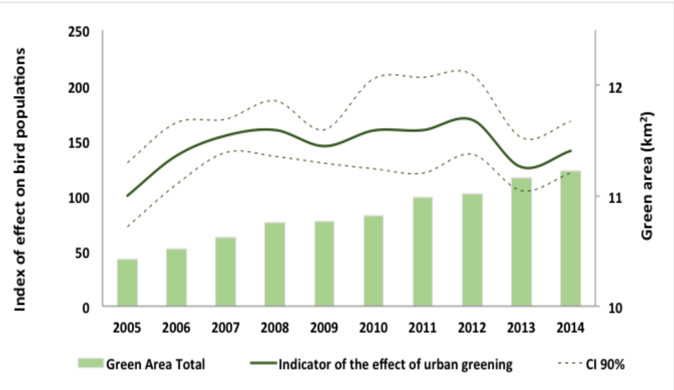

Figure 11: *Temporal change in the indicator of the effect of urban greening on bird populations in the city of Barcelona. This composite index was calculated using species yearly abundance indices from bird monitoring data and population responses to that habitat change. The indicator of the effect of urban greening was set to a reference value of 100 in 2005. Change in the area of urban green in Barcelona is also shown (Source: Barcelona City Council 2014). From: Herrando et al. 2017.*

Scenarios of biodiversity change for a risk assessment, integrating migration and dispersal mechanisms (Task 4.3)

Projecting future biodiversity trends under scenarios of global changes is one of the major challenges in biodiversity conservation. WP4 identified and reviewed the current main conceptual and technical issues related to the improvement of biodiversity projections: i) we need to better define the temporal baseline of biodiversity data for assessing environmental effects on biodiversity trends, ii) biodiversity scenarios neglect future land use changes, as compared to climate change, and iii) improving the forecast for biodiversity under climate change requires both improved (process-based) models integrating information on mechanisms and the appropriate data to feed them.

Nevertheless, when both appropriate biodiversity data and relevant scenarios were available, WP4 successfully reported on projections of range and biodiversity changes, while no proper data were available for European-wide assessments. Because of the difficulties of finding appropriate datasets for different taxa and land use change scenarios that could be applied to different realms, EU BON used primarily regional databases which were very valuable as exemplary show cases to predict likely future species distribution, and diversity under different types of scenarios (e.g. climate, land-cover/land-use, such as land abandonment, fire regime, urbanisation, and maritime activity), and even more importantly, the interaction of them. The future (2030 or 2050) effectiveness of different networks of protected areas was also evaluated (e.g. Natura 2000, Green and Blue Infrastructures). Three main approaches have been used to produce these projections: i) quantitative SDMs integrating environmental drivers, ii) dynamic mechanistic models integrating ecological processes and scenarios (e.g. projection of benthic community composition under climate change scenarios), and iii) qualitative approach of biodiversity risk assessment under prospective future land management based on high resolution land-use and land-cover change data. By improving large-scale biodiversity data (e.g. from crowd-sourced databases), finding appropriate scenarios and guiding modelling approaches, WP4 contributed to identify needs for improving our monitoring data and the availability of scenarios to enhance the reliability of predictions of biodiversity patterns and changes under global change.

Optimising monitoring designs and improving their cost efficiency (Task 4.4)

Optimisation of monitoring is a first prerequisite of getting sufficient data for analysing status, trends and drivers of biodiversity. WP4 provided strategies and applied approaches and guidelines for biodiversity monitoring, especially in terms of optimising spatio-temporal monitoring efforts. Attention was paid to consider the trade-offs involving cost-efficiency of limited available resources (time, efforts, etc.), and the reliability of the scientific outcomes (e.g. getting minimum bias and errors, representative sampling design, satisfactory robustness, accuracy of estimates). WP4 built up a constructive set of guidelines for improved monitoring based on the experience and knowledge brought in by the EU BON consortium. These advances were applied to various taxonomic groups (e.g. microbial communities, plants, macrobenthos, butterflies, and vertebrates) across realms and targeted different aims related to biodiversity monitoring, such as status and trends as well as different components of biodiversity (e.g. species distribution or abundance and community diversity). A diversity of methods were developed allowing e.g. optimising SDMs, finding optimal locations for, or coverage of sampling (e.g. **Fig. 12**), assessing spatio-temporal trade-offs in sampling, evaluating observer biases, using omics-approaches for cost-efficient monitoring of marine taxa, using taxonomic surrogates to evaluate biodiversity, and using the Virtual Ecologist approach to test and compare the performance of different sampling methods.

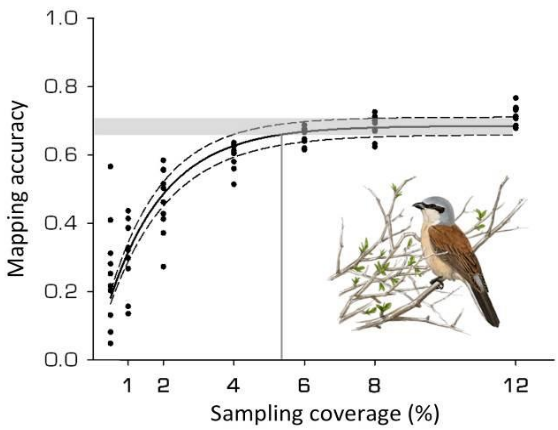

Figure 12: *Estimation of the minimum sampling coverage needed in a bird monitoring scheme to create accurate distribution maps for the Red-backed shrike (Lanius collurio) in southern Belgium, in this case ~5% of the total study area. From: Aizpurua et al. 2017.*

Quantifying uncertainty from different sources (Task 4.5)

Uncertainty is an inherent property of data, models, subsequent results and recommendations derived from biodiversity models, which needs to be reduced where possible, characterised and prioritised when several sources are involved, and taken into account when communicating scientific results to a variety of stakeholders. WP4 elaborately reviewed and summarised different sources of uncertainty, such as data (environmental and biological), model calibration (algorithmic uncertainty), validation (measures of accuracy), and projections (reliability of scenarios). Partners further reviewed, adapted, developed and made new methods and tools available to quantify, visualise and communicate this uncertainty (e.g. **Fig. 13**). WP4 finally provided a conceptual framework outlining the different steps along the scientific procedure of biodiversity modelling, in which uncertainty can arise, with several implications and needs to be addressed and integrated into the modelling process, to finally communicate model uncertainties and reliabilities sufficiently.

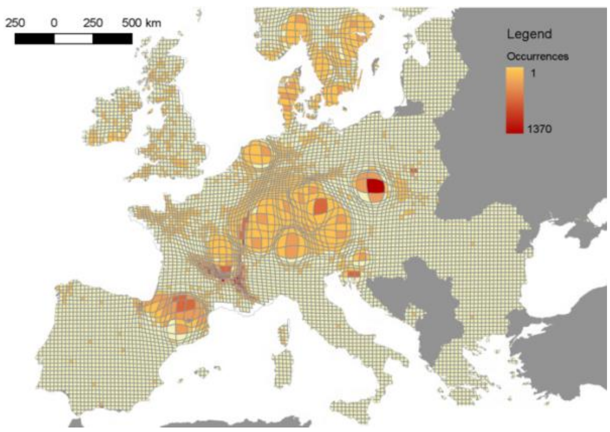

Figure 13: *Cartogram representing the sampling effort bias (cell distortion) of the GBIF dataset related to the distribution of the silver fir Abies alba in Europe. This species is not native in Northern Europe, although it is widely cultivated as a timber tree (data accessed in December 2014). The yellow-red gradient represents the species abundance distribution, from low to high densities.*

WP5: EU BON testing and validation of concepts, tools, and services

Work package 5 (WP5) was thought to test and demonstrate fitness of use of EU BON concepts, tools, and techniques for data integration and analysis.Their performance at specific local conditions was expected to serve as a first check of their utility in the real world. In this sense one major contribution of WP5 was serving as both data and metadata provider of biodiversity information. During the project, existing biodiversity information of EU BON test sites greatly increased, bridging many of the gaps found by the “Preliminary gap analysis for established EU BON test sites” done by WP1 in the first year of the project (MS131). Improvements were made in all the four main topics identified in this document: taxonomy, temporal resolution, accuracy and spatial resolution and data availability. More importantly, metadata integration was completed not only at the level of test sites, where information is periodically updated, but also at the level of the EU BON biodiversity portal due to the strong collaboration between WP2 and WP5. Such collaboration resulted in a compilation of end points made available by test sites that is currently being consumed by the data broker (GI-CAT) of the EU BON biodiversity portal. This allows biodiversity information to be discovered in a single step. This exercise served as perfect framework to know the scenario of heterogeneous information sources and tools used by partners to share metadata, as well as the number of constraints found when trying to integrate all this information in a web platform. Two of the products of WP5 deal with these issues:

1) The evaluation of the main tools used by sites to share metadata; delivered as an additional report ”*Introducing & integrating EU BON common tools*” (Milestone MS517) to the DoW and therefore included in the 3rd scientific report.

2) The experience of integrating the heterogeneous set of metadata provided by test sites was presented as a talk during the GEO BON conference held in Leipzig in 2016. It also constitutes the core of the manuscript “The key role of metadata in Biodiversity Information networks: the EU BON experience” planned to be submitted to RIO journal in 2017.

These products are extensively described (or drafted) in Deliverable **D5.1** “Principles and guidelines for establishing and operating EU BON test sites”, which summarized the cumulative effort of the biodiversity monitoring community of the EU BON project on the principles and guidelines for the establishment and operation of relevant test sites mainly in Europe. The report focuses on the requirement to meet the challenges of the biodiversity monitoring in the twenty-first century, as set by the GEO BON (Group on Earth Observations Biodiversity Observation Network) and the European and international legislation, building on the experience gained so far by the relevant monitoring networks.

WP5 also contributed to develop and test tools to analyse and interpret integrated biodiversity data. In a matching procedure data needs and required technical expertise to the application of the EU BON tools that were developed by partners in WP3 and WP4 were identified and related to data and expertise availabilities at the individual test sites. For each tool, test teams comprising tool developers and potential users from one or multiple test sites were set up and these teams discussed feasibility and timeline of the tests. Tests may comprise both the topical application of tools with the intention to publish a joint paper and/or user-friendliness and intuitiveness of the tools. The testing was refocused to tools that can be applied at the individual site level, as EU BON test sites and data services were still too few and too scattered at the time tools were developed (**Table 1**) to be able of testing them at the supra-site level.

Table 1: *Tools developed by WP5 during the EU BON project*

Number	Name
1	Advanced tools for interpreting satellite or aerial imagery using environmental datasets and machine learning methods
2	High-resolution Land Surface Temperature datasets method and applications for SDM
3	Techniques for up-scaling and downscaling biotic datasets
4	Improved freshwater species distribution models (SDMs)
5	Species distribution model (SDM) profiling
6	Alpha-adjusted species distribution models (SDMs)

A number of papers describing and applying these tools have been already published or submitted for their publication (cf. www.eubon.eu/documents/3/).

Because EU BON is expected to constitute a valuable resource for policy makers, biodiversity information provided by EU BON should be useful to get informed decision on biodiversity management. For this reason, WP5 was especially active at organising and attending EU BON stakeholder roundtables in order to ascertain which are their demands, and match them with EU BON abilities to provide this information. In this sense, Deliverable **D5.3** "*Evaluation of EU BON information services and the potential to support decision makers*" serves as a perfect example of the capabilities of EU BON to help during the decision making process at different spatial scales.

The EU BON network has expanded during the project, adding support from many sites and already ongoing networks. This helped identifying constraints in the integration of data from multiple sources, which were used to write **D5.2** "*Recommendations and strategies for building and sustaining a network of EU BON sites*". A strong collaboration with the LTER (Long-Term Ecological Research) network was established, and common interests were found that could result in joint products. The structure of this collaboration is depicted in **Fig. 14**, where both clear objectives and the responsible of each task were identified.

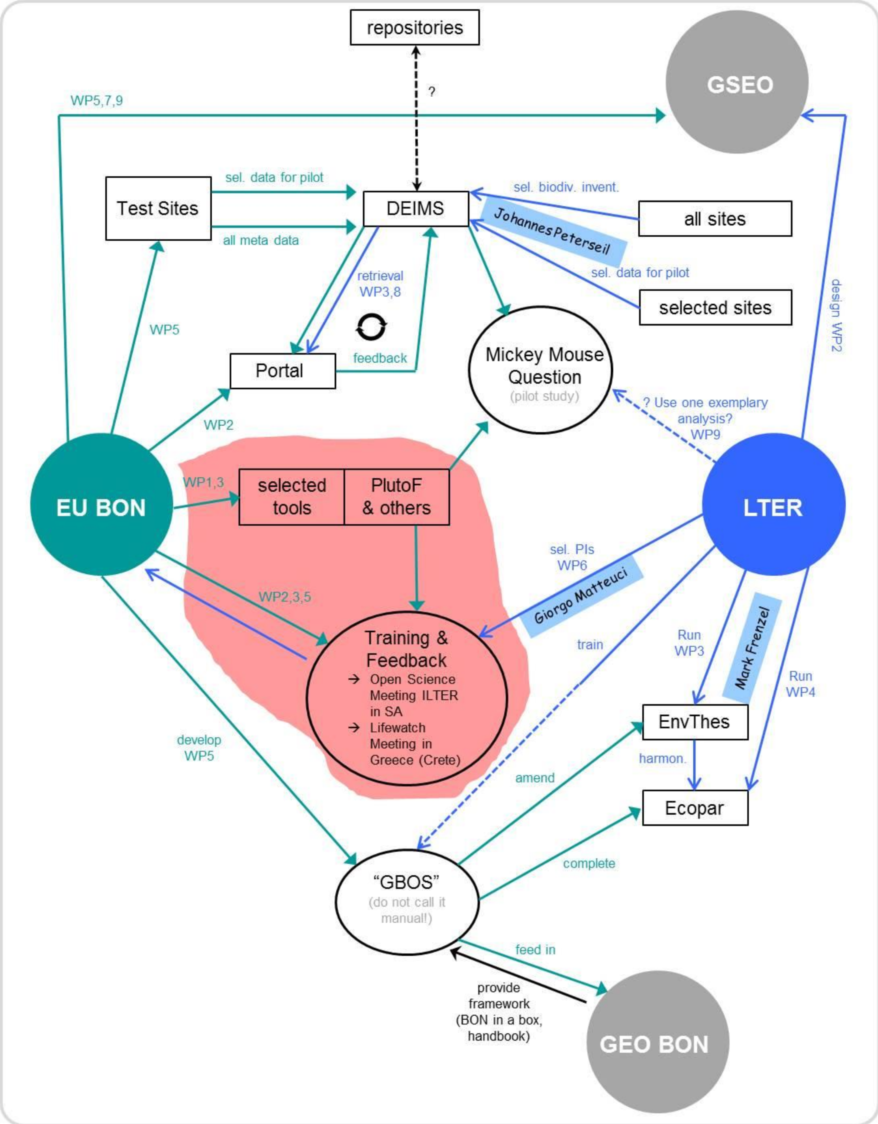

Figure 14: *Collaboration of EU BON and LTER-Europe structured at the Granada meeting (Dec 2015). Green-shaded areas and arrows identify EU BON responsibilities, and blue-shaded areas and arrows identify LTER responsibilities.*

Several products delivered by WP5 fits within this structured collaboration. Some of them came from well defined project's outputs, such as MS517, where further improvements to the DEIMS system were suggested, or the tools summarized in **Table 1**, but others consist in contributions made by particular test sites, such as the so-called Mickey Mouse question (pilot study with an easy to answer research question, the aim is to demonstrate a functioning work flow), or the several citizen-science initiatives carried out by several partners within WP5, and the whole project.

WP6: Stakeholder engagement and science-policy dialogue

A work package centered on stakeholder engagement and science-policy dialogue

Work around "stakeholder engagement and science-policy dialogue" (WP6) was organised around five main tasks, whose objectives were to:

1. review policy requirements for biodiversity data at European and national levels;
2. carry out regular engagement with relevant political authorities and other stakeholders at European and national levels in support of the delivery of the EU BON project;
3. identify and pilot new approaches (i.e. strategies, processes) to overcome barriers to the effective mobilisation and use of biodiversity data in conservation policy at European and national levels;
4. build up stakeholder dialogue with exemplar sector-specific user communities (including business); and
5. test and refine interactive user interfaces for data visualisation and decision support tools, so as to support decision-making effectively.

Outputs and outcomes of this work package are described in detail in three deliverables, including extensive annexes, which can be accessed at http://eubon.eu/documents/1/:

- "Report on stakeholder engagement for integrated biodiversity information" (**D6.1**);
- "Policy paper on strategies to overcome barriers for data mobilisation and use in conservation policy" (**D6.2**);
- "Biodiversity visualisation and public interface software operational" (**D6.3**).

Outputs are comprised of peer-reviewed publications (sometimes provided in draft form in the deliverables), traditional reports, workshop reports, infographics, factsheets, annotated list, and online tools - highlights of this work are given below. Much of the work presented here is also directly relevant to Work Package 7 "Implementation of GEO BON[1]: strategies and solutions at European and global levels" and, indeed, many outputs were produced jointly with participants of that other work packages. Finally, due to the integrative role of WP6 in EU BON, a number of outputs is of relevance to other EU BON work packages, and was produced jointly with participants of these other work packages.

There were high expectations placed on WP6 in terms of integrating EU BON's work across work packages; this integration has been achieved. The EU BON consortium has clear technical strengths in biodiversity data collection, management, collation, documentation, standardisation, licensing, analysis, modelling, publication, sharing, and much more. Although a number of WP6 partners also belonged to work packages related to these very technical and specialised activities, many others understood better (or belonged to) the sphere of users of biodiversity information and knowledge, rather than that of users of (raw) data. This "barrier" was brought down via extensive cross-work package consultation and engagement as part of project meetings, stakeholder roundtables, workshops, conferences and team meetings, leading to a mutual understanding of the two groups' strengths and needs.

[1] Group on Earth Observation Biodiversity Observation Network, http://geobon.org/

Identifying policy requirements for biodiversity data

There are many and diverse requirements by policies for biodiversity data on status and trends of species and habitats. Wetzel *et al.* (2015) produced an Euro-centric overview of the biodiversity policy landscape (**Fig. 15**), which is particularly complex as national governments can be parties to a number of regional instruments (e.g. European Union Directives, Regional Seas Conventions), and global ones (e.g. Convention on Biological Diversity CBD, Convention on Migratory Species CMS). Countries are also committed to take part in global assessment processes such as the Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES) or the World Oceans Assessments (WOA). In this context, an European Biodiversity Observation Network has an essential role in bringing down barriers that prevent existing data from being *discoverable*, *accessible* and *digestible*, and hence used to support the needs of the biodiversity policy sphere; for example the tracking of progress against biodiversity targets.

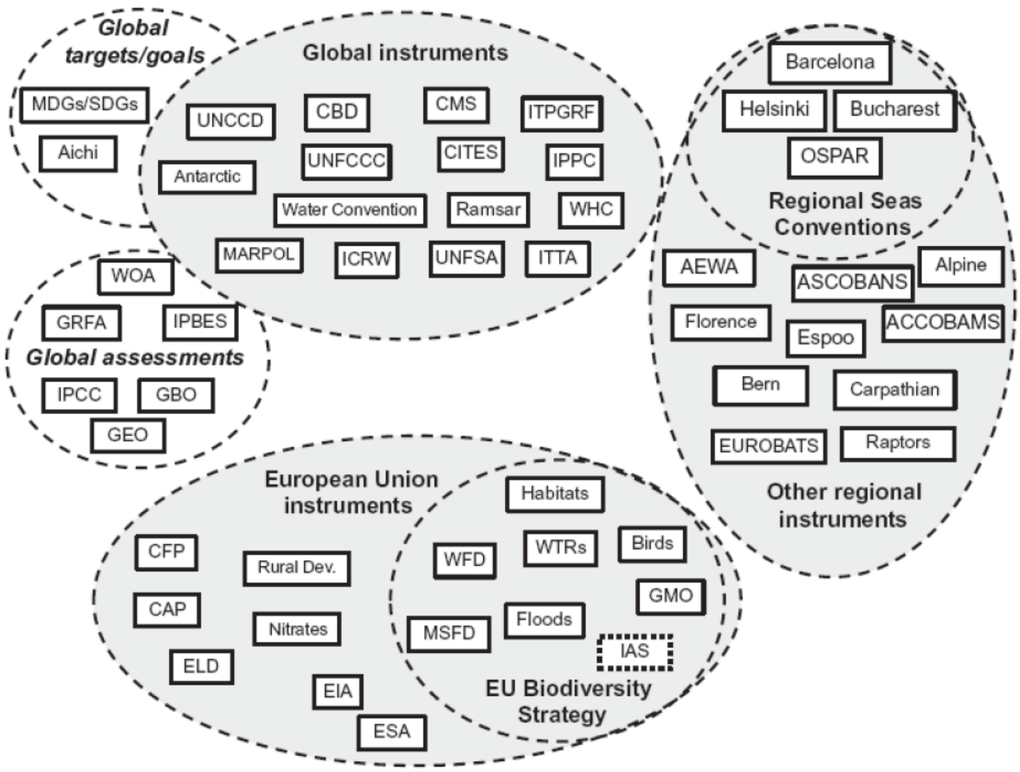

Figure 15: *Euro-centric overview of the biodiversity policy landscape (Wetzel et al. 2015).*

To better understand policy-level data needs, Geijzendorffer *et al.* (2015) examined in detail the reporting requirements for seven European and global policy instruments: CBD, Ramsar, CMS, the Nature Directives (Birds and Habitats), the Marine Strategy Framework Directive (MSFD), and the Water Framework Directive (WFD). The authors found that taking an 'Essential Biodiversity Variables' (EBV) (Pereira *et al.* 2013) approach is useful to bridge the gap between biodiversity data and policy reporting needs, with Essential Biodiversity Variables playing an "adaptor" role between the two. However, and so as to clarify the relationship between Essential Biodiversity Variables and indicators of biodiversity change, Brummitt *et al.* (2016) explained this relationship with a stock market analogy (**Fig. 16**).

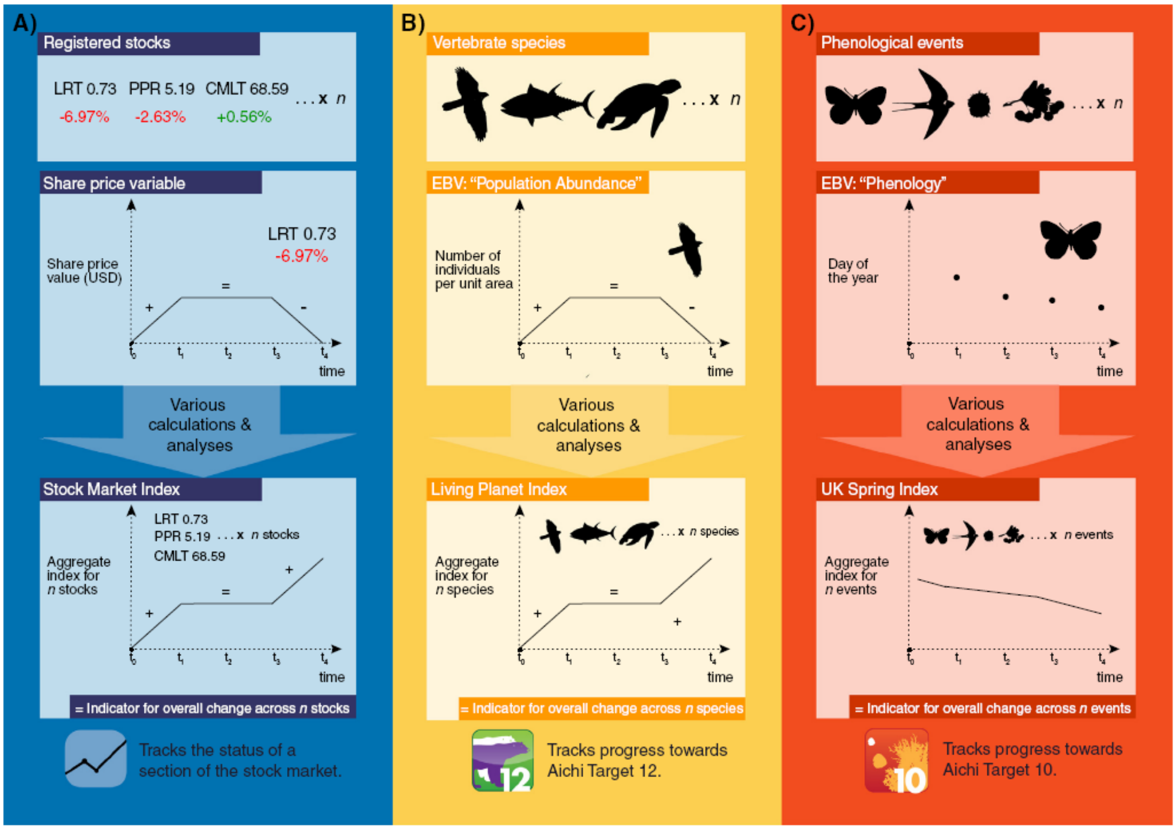

Figure 16: *Infographic illustrating hypothetical scenarios to reflect analogy between (A) the Stock Market Index, (B) the Living Planet Index, or LPI, and (C) the UK Phenology Network's UK Spring Index (Brummitt et al. 2016).*

Catering for a range of biodiversity data users

During the course of the project, there was a realisation that whilst a number of EU BON products is indeed relevant to policy-level end-users, many more are actually relevant to other users of biodiversity data, in particular specialised users such as scientists and researchers, but also conservation/environmental managers, citizen-scientists, spatial planners, data managers/curators/creators, and the wider public. One key achievement of WP6 has been to translate EU BON's outputs in meaningful language/formats suited to a broad range of end-users, from the policy and conservation spheres, but also decision-makers more broadly (e.g. including small and medium enterprises of the environmental sector). This has meant promoting the use non-specialist language to describe what question a given "product" was aiming to help answer, and who could use the product and/or the results of its use. While a scientist may be able to use e.g. a "R package" or a modelling methodology, a conservation manager is more likely to prefer using a Web-based decision-support tool that requires limited technical skills. Project partners hence used various approaches to package, communicate and promote their scientific outputs, e.g. annotated product list[2] with associated product factsheets[3], infographics[4], and online decision-support tools and visualisations (see dedicated section below).

[2] http://wcmc.io/EUBON_Products
[3] http://wcmc.io/EUBON_Factsheets
[4] http://wcmc.io/EUBON_Infographics

Whilst Essential Biodiversity Variables appear to be a promising framework for looking at biodiversity change, policy-makers and other decision-makers may find it a difficult framework to use in practice. As part of a joint workshop with the Eklipse project[5], entitled "Identifying joint pathways to address the challenges of 'biodiversity data provision' and 'decision-making", a "Researcher's brief" was drafted, aimed at scientists and researchers, notably those of GEO BON who work on Essential Biodiversity Variables. The brief provides 'guiding principles', in the form of an infographic (**Fig. 17**), for promoting the application of Essential Biodiversity Variables for answering the needs of decision-makers (Despot-Belmonte *et al.* 2017).

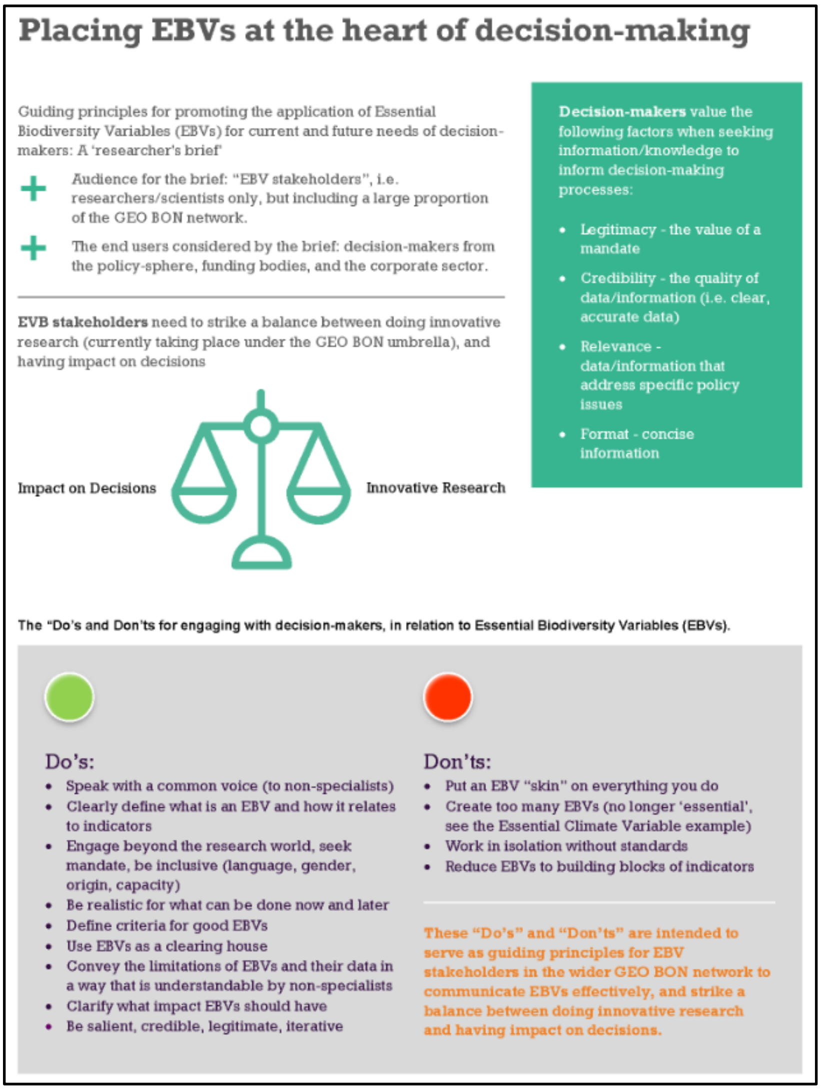

Figure 17: *"Researcher's brief" providing 'guiding principles' for promoting the application of Essential Biodiversity Variables for answering the needs of decision-makers (Despot-Belmonte et al. 2017).*

[5] http://www.eklipse-mechanism.eu/

Engagement with a range of stakeholders in support of project delivery

Outputs from this and other work packages were informed during the course of the project by four 'EU BON Stakeholder Roundtables' (**Table 2, Fig. 18**). The main purpose of these roundtables was to carry out regular engagement with relevant policy and conservation organisations (at the national, European and global scales) and other key stakeholders (e.g. from small and medium enterprises of the environmental sector, citizen scientists, etc), in support of the delivery of the project. Stakeholder roundtables represented an important feedback and quality control mechanism for the project, providing opportunities for adaptive management to tackle unforeseen requirements and shifting priorities.

Table 2: *Overview of the four EU BON stakeholder roundtables.*

Year	Title	Main stakeholder targeted	Host and location	Full details
2013	Biodiversity and requirements for policy	European policy (European Commission and agencies, researchers), International Networks (Group on Earth Observations), EU funded projects with linkage to biodiversity data	Leibniz Association, Brussels, Belgium	Vohland et al. (2016a)
2014	How can EU BON support citizen science?	Citizen Science projects, citizen science networks such as the European Citizen Science Association (ECSA), researchers and biodiversity networks	Museum für Naturkunde, Berlin, Germany	Vohland et al. (2016b)
2015	Workflow from data mobilisation to practice	European, national and regional networks (biodiversity data, Group on Earth Observations, ecological research), researchers from the field / sites, EU BON test site partners, political administration	University of Granada, Granada, Spain	Wetzel et al. (2016)
2017	Pathways to sustainability for EU BON's network of collaborators and technical infrastructure	European funded projects, networks (LTER-Europe, ECOPOTENTIAL, EKLIPSE, OPPLA), "European customers" (EC, EEA), and global initiatives (GEO BON, UNEP, LifeWatch)	Museum für Naturkunde, Berlin, Germany	Wetzel et al. (2017)

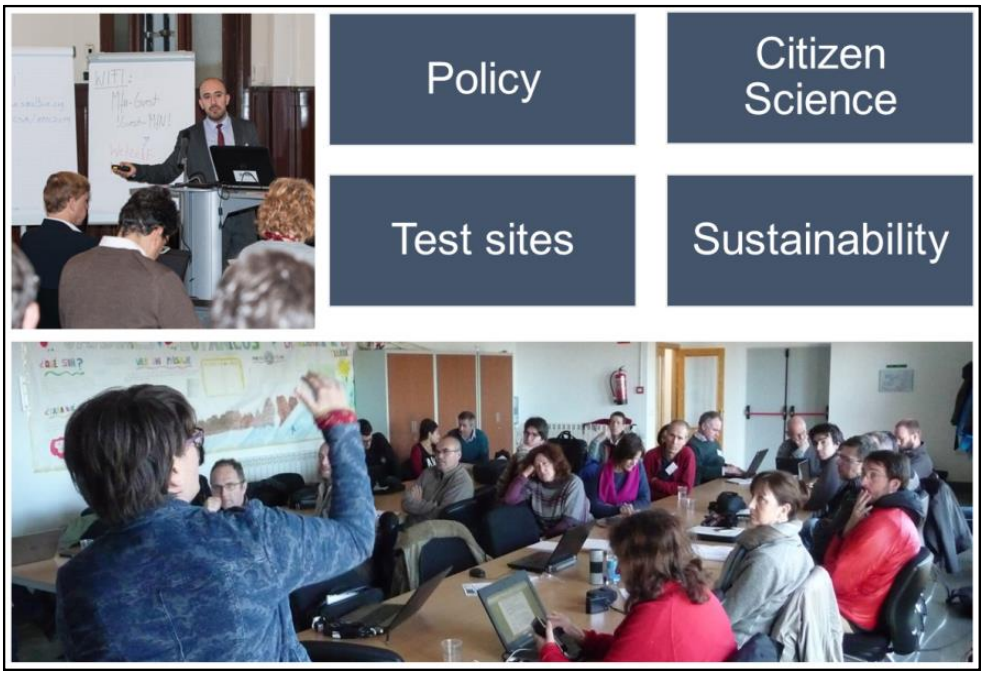

Figure 18: *The main topics of the four EU BON Stakeholder Roundtables, and some of the participants.*

Tackling the barriers to using biodiversity data in conservation policy

EU BON highlighted barriers to the use of evidence in conservation policy, and worked to find solutions to overcome them. Actors involved in conservation science-policy interfaces were asked about their perception of barriers and solutions to evidence use. Then, work was done to investigate whether conservation scientists can seize upon political windows of opportunity for evidence uptake. The results of this work were written up as manuscripts for publication in the peer-reviewed literature.

The first manuscript currently is in revision with the journal 'Environmental Science & Policy' about how conservation scientists can engage more constructively with 'policy windows' for uptake of scientific knowledge. The manuscript argues that scientists can foresee and respond quickly to emergent windows, and frame science in a salient, relevant way for policy-makers in order to improve the chances of uptake. Advice is also given about what to do in a period where the ground might not be fertile for knowledge uptake.

The second manuscript presents results from a global survey of academic, policy-makers, and practitioners about barriers and solutions to the use of conservation science in policy. 881 responses were gained and different barriers and solutions were ranked in order of importance. The manuscript will be submitted to the journal 'Nature Sustainability' at the end of June 2017.

Sector specific stakeholder engagement with user communities

The role of users of natural resources in data collection, mobilisation and use was explored under EU BON, along with the use of biodiversity data in policy-making and policy implementation in the European Union. A review was conducted of the bottom-up biodiversity data gathering activities of different stakeholder sectors, and whether they could be enhanced by the types of tools and services that EU BON is developing. Four sectors were prioritised because of their current use of biodiversity data and their potential to contribute to data provision and monitoring; these were:

- farmers and agricultural organisations,
- hunters and hunter groups,
- anglers and angler groups, and
- planning authorities and developers (e.g. the construction industry).

The review examined the extent to which biodiversity data are already curated and made available by the sector due to policy reporting obligations or own initiatives; it also highlighted the key factors that influence their capacity to do so and, finally, it provided an indication of the extent of the likely motivation of these sectors to engage in biodiversity data mobilisation and collection. The key factors that influence the potential of stakeholder groups to contribute to biodiversity data collation were found to be: relevance of data, quality of data collection and curation, and data ownership and recognition of effort.

A review of biodiversity data use for marine environmental impact assessments (EIAs) and spatial planning (Underwood, Taylor & Tucker 2017) found that both marine and terrestrial spatial planners and EIA practitioners face problems in using spatial data for the preparation of environmental reports, mainly related to finding and accessing data of the quality needed for the purpose, which increase the cost and time needed to carry out the assessments. Public authorities face challenges in assuring the quality of the data submitted in EIA reports. The European Commission is funding the development of tools to assist with marine spatial planning, but it appears that practitioners rarely use the EU platforms, because they rely heavily on the national government-approved data sets and their own compiled datasets, even if they are quite out of date. Some interesting initiatives are using GIS systems and geo-physical datasets made available by governments and other institutes under INSPIRE rules to map biodiversity data on habitats and species occurrence and distribution, in order to facilitate public participation in spatial planning.

Interactive user interfaces for decision support tools and data visualisation

Visualisations and decision-support tools are very effective ways to convey, to a non-technical audience, simple messages that are built from complex biodiversity data. In this context, EU BON delivered a number of interactive user interfaces[6], which are available online to the public via the European Biodiversity Portal[7] - selected examples are featured below.

AquaMaps[8] is an approach to generating model-based, large-scale predictive maps of where aquatic species naturally occur. Under EU BON, the number of species considered has grown (globally) from around 11,500 in 2012 to over 25,000 in 2016 for marine species (i.e. 94.2% coverage of marine fishes and marine mammals native to Europe), and from 632 to 965 for freshwater species. The *Explore AquaMaps for EU BON* section features “Marine AquaMaps” where users can search and explore modelled distribution maps for marine species in Europe (**Fig. 19**).

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[6] Full details are available in Deliverable D6.3 (“Biodiversity visualisation and public interface software operational”) available at http://eubon.eu/documents/1/

[7] http://biodiversity.eubon.eu

[8] http://www.aquamaps.org ; access via the European Biodiversity Portal: http://biodiversity.eubon.eu/aquamaps; visualisation: http://aquamaps-viz.herokuapp.com

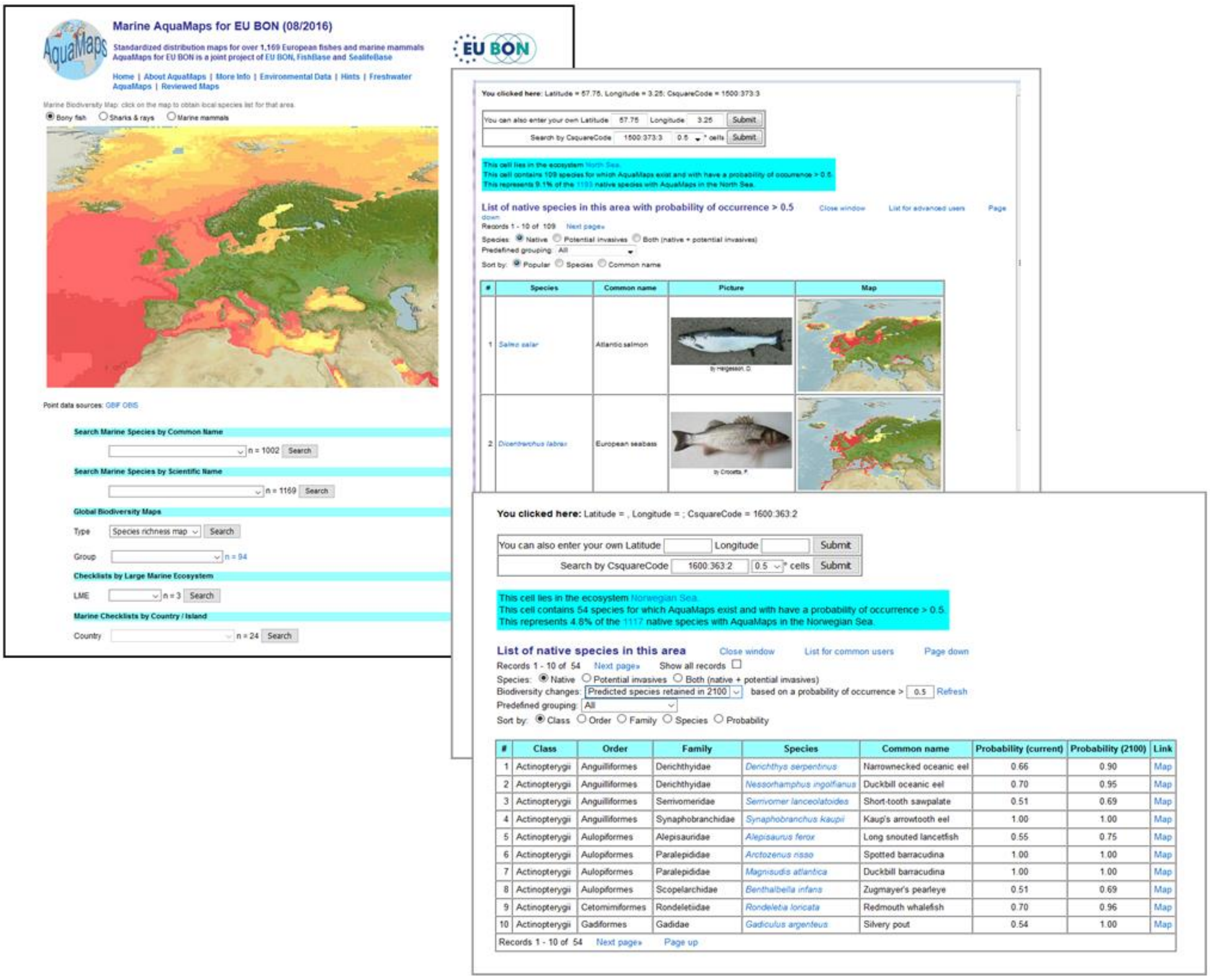

Figure 19: *Search page of the Marine AquaMaps interface (top), accessible via http://biodiversity.eubon.eu/aquamaps. Clicking a point on the map returns, for that location, a list of native species with probability of species occurrence > 0.5, together with individual modelled spatial distributions, and common and Latin names (middle). One can also access a 'species list for advanced users' that allows regenerating the list based on user-specified probability of species occurrence in year 2100 (bottom).*

The tool entitled "Possible climate change impact on the spatial distribution of threatened species" (**Fig. 20;** http://www.aquamaps.org/am_eubon/otherspecieslist.php?type=threatened) illustrates how the modelled spatial distributions of IUCN Red Listed marine species may change, based on the Intergovernmental Panel on Climate Change (IPCC) "A2 emissions scenario".

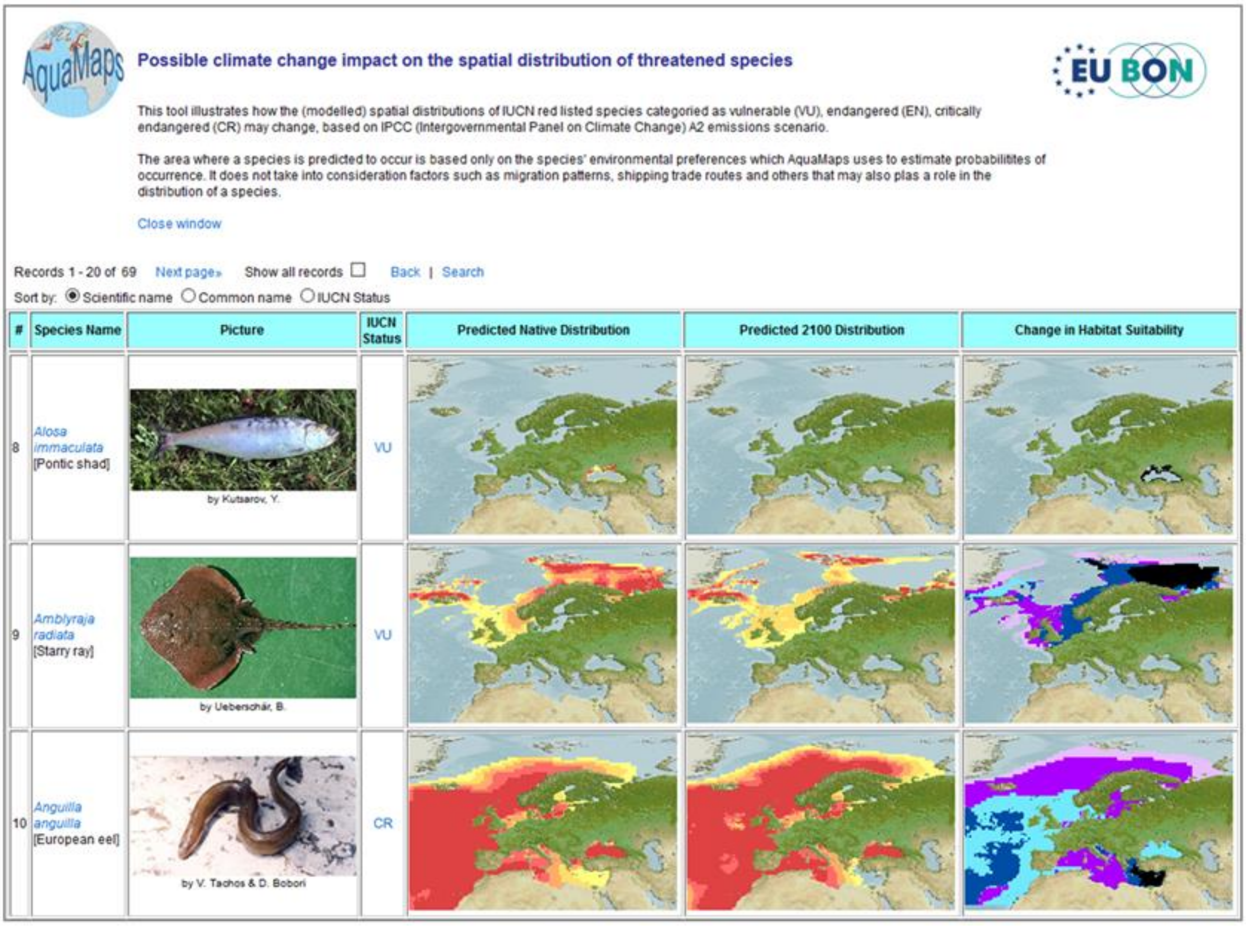

Figure 20: *List of species available via the tool entitled "Possible climate change impact on the spatial distribution of threatened species". It features side-by-side maps of the species' predicted native distribution, distribution in year 2100, and the change in suitable habitat over its range.*

The Geospatial Conservation Assessment Tool (GeoCAT; http://geocat.kew.org/) is an open source, browser based tool that performs rapid geospatial analysis for Red List assessment. Developed to utilise spatially referenced primary occurrence data, the analysis focuses on two aspects of the geographic range of a taxon: the extent of occurrence (EOO) and the area of occupancy (AOO). These metrics form part of the IUCN Red List categories and criteria and have often proved challenging to obtain in an accurate, consistent and repeatable way. Within a familiar Google Maps environment, GeoCAT users can quickly and easily combine data from multiple sources such as GBIF (Global Biodiversity Information Facility), Flickr, Picasa and iNaturalist, as well as user generated occurrence data. EU BON, in close collaboration with Kew Royal Botanic Gardens (the curator of the tool) and other EU BON Work Packages (3 and 4), further improved GeoCAT (fixing bugs, usability issues) and incorporated additional analytics capabilities (the "area of occupancy calculator" tool).

WP7: Implementation of GEO BON: strategies and solutions at European and global levels

In 1980, the term biological diversity, or short biodiversity, was introduced to conservation biology Soule & Wilcox 1980), 12 years after Sears & Dasmann (2005) had coined that term. It took another 12 years to make the term more widely accessible in the Convention on Biological Diversity (CBD) adopted by national governments at the 1992 Rio Earth Summit (Balmford & Bond 2005, Balmford *et al.* 2005a,b). In the CBD context, biological diversity is defined as follows: "Biological diversity" means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems”. However, global biodiversity monitoring is still insufficient to fulfill the data requirements necessary to robustly inform the progress towards the Aichi Targets of the UN Strategic Plan for Biodiversity 2010-2020, conservation targets in a larger sense, and also to provide the necessary data to produce robust regional and global assessments of biodiversity and ecosystem services as currently undertaken by the Intergovernmental Platform for Biodiversity and Ecosystem Services (Schmeller & Bridgewater 2016, Schmeller *et al.* 2017).

It is therefore utmost relevance for the policy arena to support the development of an operational global biodiversity system. Those still need to be developed; existing monitoring programmes need to be integrated, and the necessary global data infrastructures to be set up. The biodiversity informatics landscape is indeed very complex already, and the risk of effort duplication is high. The global and European-level map of the biodiversity informatics landscape (**Fig. 21**) has led to a better understanding of the landscape’s current structure and functioning. This will enable key players to establish or strengthen collaborations, avoid effort duplication, and facilitate access to the biodiversity data, information and knowledge required to support effective decision-making.

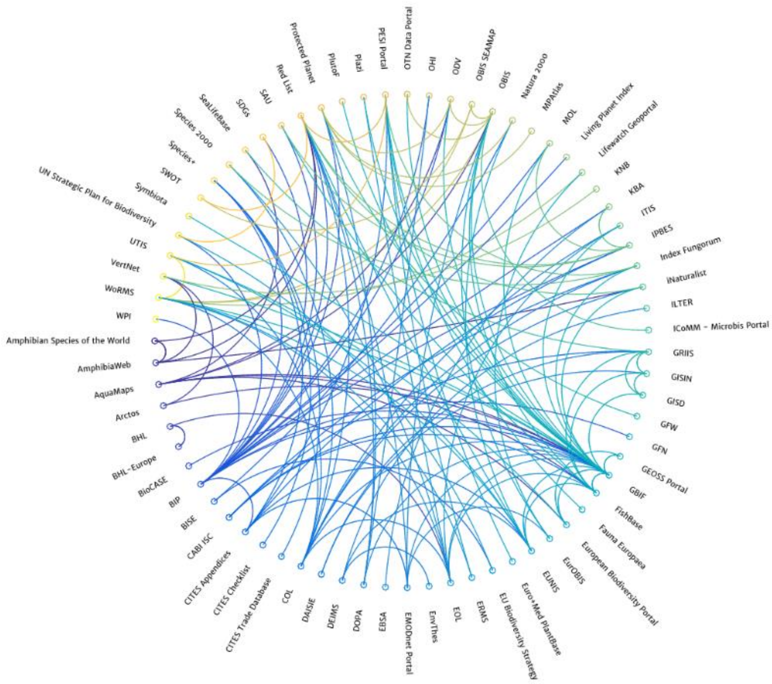

***Figure 21:** A global and European-level map of the biodiversity informatics landscape (http://wcmc.io/BiodiversityInformatics).*

Furthermore, there is not one single valid way to create such a global monitoring programme, and any system is highly dependent on the socio-ecological conditions in which observation sites, monitoring schemes etc. are to be set up. The EU BON project was financed to contribute to the Group on Earth Observation Biodiversity Observation Network (GEO BON) and to establish a first version of a European Biodiversity Observation Network. EU BON was to address one of the problems that policy-makers and biodiversity managers are facing: biodiversity change is often detected or revealed when effective responses are no longer feasible, ecosystem damage is considerable, such as when species become extinct and the major impacts of anthropogenic changes have not been captured well by monitoring data (**Fig. 22**; Mihoub *et al.* 2017).

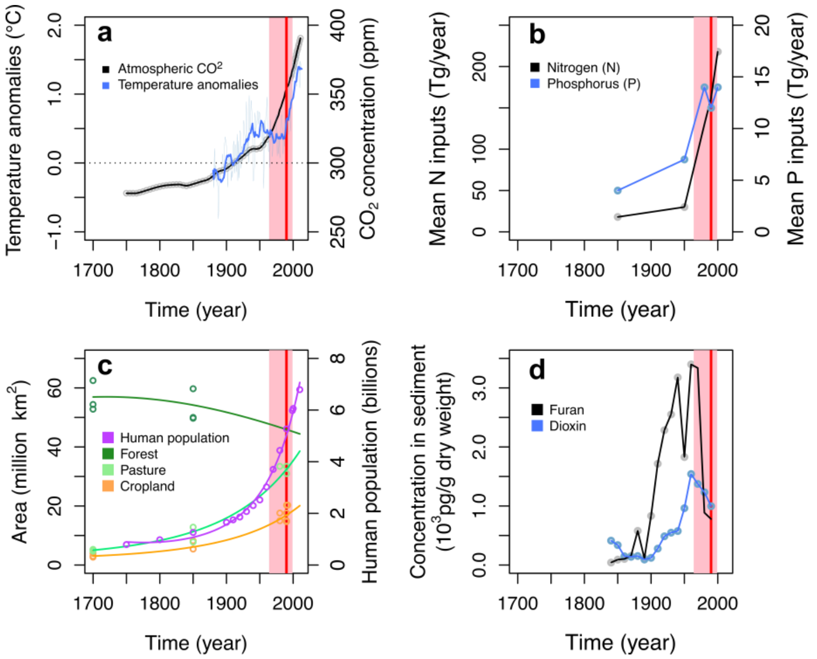

Figure 22: *Temporal mismatch between biodiversity monitoring schemes in Europe and major global or regional anthropogenic pressures known to impact biodiversity. The onset of biodiversity monitoring is represented using the median value (vertical red line) and the first and third quartiles (light red area) of the starting years of biodiversity monitoring schemes. Major pressures include (a) climate: global temperature anomalies and European atmospheric concentrations of carbon dioxide, (b) global anthropogenic nitrogen and phosphorus, (c) global human population sizes and global land use changes and (d) pollutant emissions in the United Kingdom (UK). From* Mihoub *et al.* 2017*.*

In order to obtain best possible data on the status and trends of biodiversity and the pressures affecting it, a cross-scale perspective (local to global) is needed to devise, deliver, and support capacity building in biodiversity monitoring across systems (terrestrial, freshwater, marine), geographic regions, and taxa (Schmeller *et al.* 2015). Such efforts are also important to support international conservation policy by providing coherent, standardised, and harmonised global data sets (Schmeller & Bridgewater 2016). The Global Earth Observation System of Systems (GEOSS) aims to fill knowledge gaps in earth observation by linking up existing resources and facilitating the creation of new monitoring initiatives (Conference of Parties COP 10 decision X/7; http://www.cbd.int/decision/cop/?id=12273). GEOSS is being implemented by the Group on Earth Observation (GEO). The Group on Earth Observation – Biodiversity Observation Network (GEO BON) is one of nine societal-benefit areas under GEO and is the main global facilitator network for biodiversity monitoring. GEO BON is focused on building capacity and facilitating the tracking of biodiversity change in the context of progress towards global biodiversity policy targets, thus allowing the evaluation of the current status and future trends of global biodiversity. The efforts to implement GEO BON have been recognized as important by the Parties to the Convention on Biological Diversity (COP 9 decision IX/15; http://www.cbd.int/decision/cop/default.shtml?id=11658) and by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, **Fig. 23)**.

EU BON has made important advances in a range of relevant areas to improve the current situation of biodiversity observation in Europe and globally following recommendations made by work package 7 (**Fig. 23**).

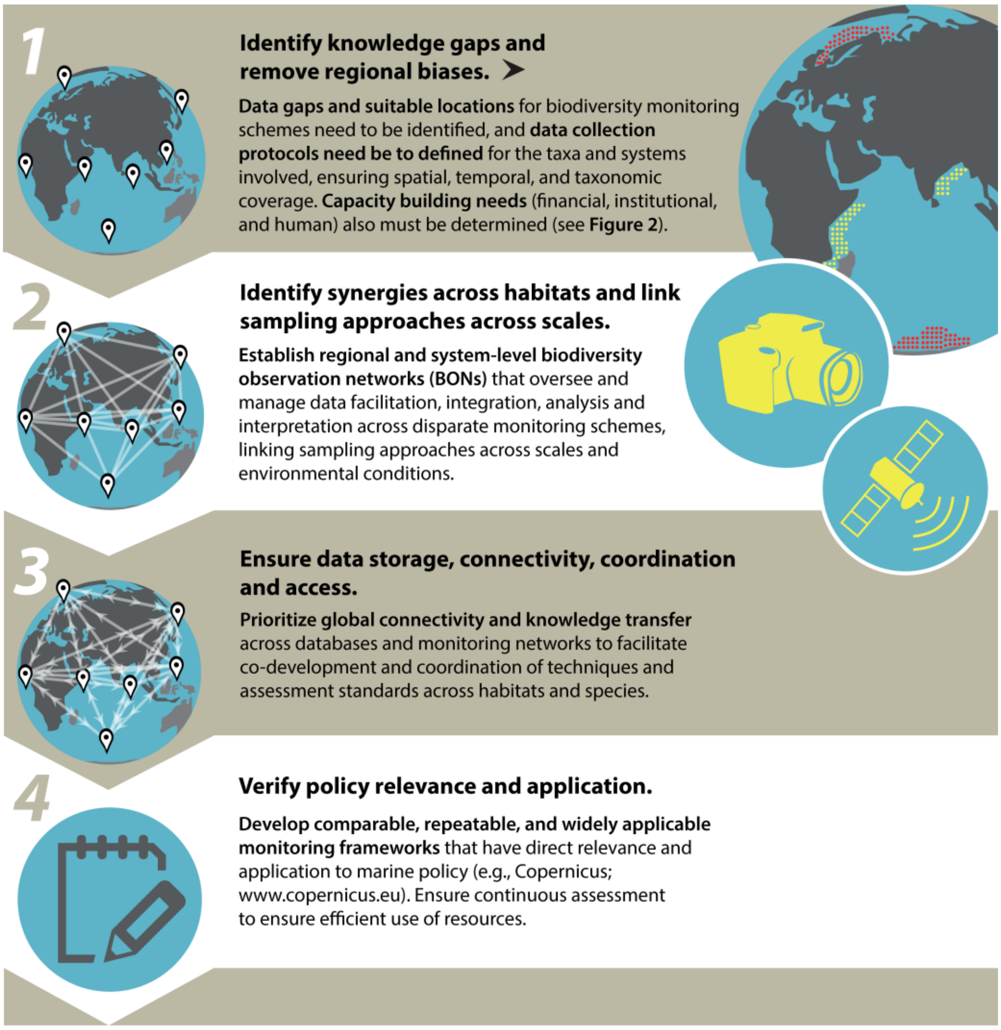

Figure 23: *Framework for Biodiversity Observation Networks (BONs) to build capacity in biodiversity monitoring.*

One important contribution of EU BON was also the advancement of the GEO BON initiatives in developing the concept of Essential Biodiversity Variables (EBV). Key global indicators of biodiversity decline for the Strategic Plan for Biodiversity 2011-2020 include the IUCN Red List Index (Butchart *et al.* 2006, Butchart *et al.* 2010), and the Living Planet Index (Loh *et al.* 2005, McRae *et al.* 2012). However, there is a time lag to consider in what change these indicators can detect, in particular in the IUCN Red List Index where intervals between assessments of the same species group may take up to ten years or longer. During this period, species can go from being relatively abundant to being on the verge of extinction or at least regional extirpation. In effect, these indicators function as late-warning signals that are retrospective, rather than proactive, a notion which was subject of many studies (Graham & Grimm 1990). It is crucial, therefore, to improve our capacity to detect early signs of critical biodiversity change so that effective management responses can be enacted promptly where required. Despite the unquestionable importance of these indicators for informing biodiversity conservation, detection of early warning signs of unfavorable biodiversity change is necessary to ensure that effective management responses can be enacted promptly where required. A key difficulty lies with the scattered distribution of biodiversity data, which lead to the proposed development of Essential Biodiversity Variables. A set of 22 EBVs was proposed (Pereira *et al.* 2013), yet none of these EBVs is currently operational, although efforts are made toward their implementation - this remains a massive challenge. EU BON's participants prioritized EBV development and implementation based on their capacity to provide information on critical ecological change across the organisational levels of biodiversity, going from gene to ecosystem. Based on scientific knowledge, EU BON provided a shortlist of eight candidate EBVs that provide early detection of critical and potentially long-lasting biodiversity change (Schmeller *et al.* in press) (**Fig. 24**).

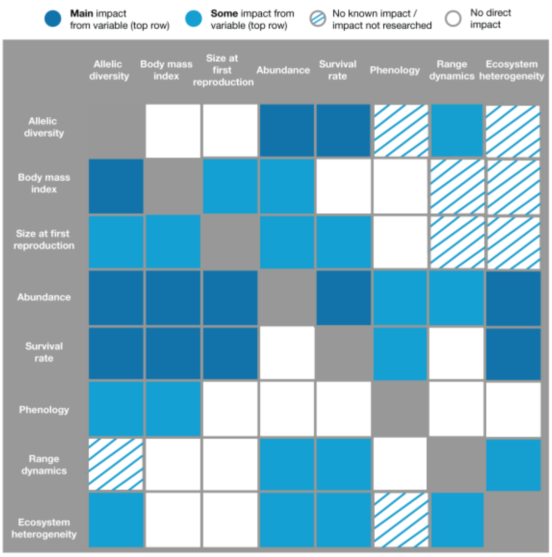

Figure 24: *The different "early warning" Essential Biodiversity Variables (EBV) proposed in (Schmeller et al. in press) have important relationships with each other and act at different organisation levels. Allelic richness, Boby Mass Index, size at first reproduction, abundance, phenology and survival react on the population level and may determine the range dynamics on the species level. Ecosystem heterogeneity acts on an ecosystem and community level and may influence all lower level EBVs. Especially on the population level, interactions and relationships between the different proposed EBVs are manifold. For example, allelic richness is dependent on abundance and survival, but may itself influence these two EBVs and also body mass and/or size at first reproduction and other fitness related species traits (which may also be explaining phenological changes). Phenology itself can impact on the abundance and survival, depending on how much a phenology change would hamper reproduction.*

Importantly, EU BON was one of the first biodiversity-related EU-funded projects to develop a business plan aimed at identifying ways to sustain a functioning biodiversity observation network after the funded phase. The European Commission and Member States spend millions of Euros on various forms of biodiversity observations each year. Yet, much of this investment is short-term in nature (i.e. limited to the funded phases of projects), thereby limiting the opportunity to detect, understand, and respond to important patterns and trends in biodiversity change. The business plan identified several options for sustaining the European Biodiversity Observation Network in the long-term, once of which being a decentralised organisational structure ("teal organisation"). This type of organisational structure is suitable for networks as it provides the flexibility to develop teams around products and services that are demand-driven (i.e. users/customers). An example of a successful network that runs as a teal organisation is the Enspiral network (https://enspiral.com/). This network keeps a lean decentralised structure, members share a common purpose and mission, resources are shared, and income re-invested in the network through collaborative funding. EU BON could follow a similar format (**Fig. 25**) to avoid fragmentation and to allow different teams to emerge organically for future projects/services that are demand-driven. The network could remain connected through a core team (i.e. in the form of a Foundation, Secretariat or Steering Committee) to look after legal, administrative, financial, and fundraising matters. The main advantages of a decentralised structure are its flexibility and low fixed costs.

Figure 25: *One possible organisational structure for EU BON: a decentralised structure. EU BON teams would develop organically depending on the skills and expertise required for products and services that add value and meet the needs of specific end-users.*

Europe needs a structure that provides a role model for biodiversity monitoring programmes worldwide, while tailored to address European-level biodiversity conservation challenges, without which its own contribution to international commitments is also compromised. In addition to providing policy-relevant services to national environmental agencies, policy-advisors, and sector stakeholders, a European Biodiversity Observation Network will support global monitoring efforts through GEO BON. One key achievement of EU BON (http://wcmc.io/EUBON-AichiTarget19) has been to mobilise biodiversity data at the European-level, thereby contributing to achieving Aichi Biodiversity Target 19 (*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*) (*Conference of the Parties to the Convention on Biological Diversity (2010) The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets (Decision X/2). https://www.cbd.int).*

WP8: Dissemination and outreach

Dissemination and Communication Strategy and Implementation Plan (Task 8.1)

The EU BON Dissemination and Communication Strategy and Implementation Plan was developed in the very beginning of the project. Its main aim was to guide the communication and dissemination efforts, targeting various audiences and spreading out clear, understandable, coordinated and effective messages, in order to raise awareness and maximize visibility of EU BON's results during the whole project lifetime. The document identifies relevant target groups and the ways to adapt information on project results according to their specific needs and characteristics. An Implementation plan, developed as an integral part of the strategy was drafted to describe the concrete measures, timeframe and responsibilities of partners during the project. It also facilitated the monitoring and reporting on project goals. An internal review of the strategy and implementation plan made towards the end of the project showed that objectives were strictly followed. In addition, extra dissemination and communication activities were undertaken on suitable occasions. Evaluation of the effectiveness of the communication and dissemination activities revealed that the targets were achieved and most of them were even largely surpassed.

Website, online libraries, Internal Communication Platform (ICP) (Task 8.2)

The project website (eubon.eu) was launched at the very beginning of EU BON, designed to be attractive for different target groups, user-friendly, interactive and kept up to date with information. The website has two distinct areas: i) public area containing general information about the project and its development, accessible to anyone and ii) private (password protected) website layer called Internal Communication Platform (ICP) which supported the smooth interactions between project partners. To broaden the impact of EU BON and to promote its results to wider communities, project profiles were created on Twitter, Facebook, Google+ and LinkedIN. From 1 December 2012 to 31 May 2017 a total of 30,255 users have interacted with the EU BON website, realizing 151,009 page views and 49,857 sessions. The website has been visited from nearly 200 countries, with most visitors coming from: Germany, Bulgaria, United Kingdom, United States and Spain, followed by Belgium, Brazil, Italy, France and Norway.

Design, production, publication and distribution of the project results and outreach materials (Task 8.3)

Through its duration, the project and its outcomes were widely popularized using a basket of communication and dissemination approaches. Designing the **EU BON logo** ( ) was one of the first steps taken. A variety of **outreach materials**, in both electronic and printed form were produced and widely disseminated with the aim to announce the project and provide relevant information to a diverse set of stakeholders. EU BON produced: two EU BON introductory leaflets; a general EU BON poster; thirty three partner posters; numerous posters have been prepared by partners to show at suitable events. A total of twenty five **press releases** have been prepared and published, some of them got widely reflected by the world media. Six **policy briefs** were produced to support decision-makers. A number of **infographics** are created to communicate complex yet important project data and information in an easy to comprehend visual format. Factsheets providing additional information for selected EU BON products, such as expected advantages, applicability, potential users and examples of tools were produced and can be found on the EU BON European Biodiversity Portal. Eight issues of the **EU BON newsletter**, containing a synthesis or the most important news and results achieved during the relevant period, were produced and broadly disseminated. **Electronic news digests** by 6 month periods are also available on the project website. Project partners and stakeholders shared viewpoints, experience, visions for the future and recommendations for EU BON in nine **interviews**, including a **video interview**. An EU BON promotional **video clip** was produced. To ensure longevity and re-usability of the EU BON results a number of EU BON outcomes including reports, policy briefs and factsheets, which aim to advance biodiversity knowledge, have been published in a dedicated open access **collection** in the innovative peer reviewed journal Research Ideas and Outcomes (RIO). An **EU BON's Final Brochure** which summarises the major project outcomes was published to stimulate decision-making, policy implementation and awareness.

Project information and results were widely distributed via **news** and **events** announcements. During the whole EU BON duration the project social media accounts in Facebook, Twitter, Google+ and LinkedIn have been actively used for promotion of project results and the number of their users keeps increasing. EU BON research has been published in more than 120 peer-reviewed papers of leading journals in the spheres of Biology, Biodiversity and Ecology. Various general dissemination activities were performed by the project participants. EU BON appeared in many web publications across Europe. The good interaction with key stakeholders was insured by EU BON partners' participation in and organization of more than 300 international and national conferences, workshops and meetings. A training programme on data and metadata integration strategies, use of standards, and use of data tools was developed and operated, thereby contributing to the communication and dissemination activities and also to the long-term impact of the project.

Effective stakeholder engagement and science-policy dialogue were ensured by the **EU BON Stakeholder Roundtables**. Representatives of the EU BON project and participants from global, European and regional projects, institutions, citizen scientists, governmental organisations and universities met four times to discuss issues such as: biodiversity data workflows across different scales and their current limitations; tools and products from EU BON and other projects that may help to improve data collection and evaluation; workflows of data/information and the further usage for policy reporting and political processes; improvements of existing biodiversity data workflows and sustainability issues, etc. Finally, EU BON was featured as success story on the EC Research and Innovation website (Combining citizen and satellite biodiversity data). EU BON was also featured as successful project by the European Commission in its Earth Observation focused publication (Investing in European success – A Decade of Success in Earth Observation Research and Innovation).

Data Publishing, Data Citation and Data Usage Strategy and Guidelines (Task 8.4)

Strategy and guidelines for biodiversity data publishing, citation and usage were developed and openly published in an EU BON dedicated collection in the open science journal Research Ideas and Outcomes (RIO). The document discusses some general concepts, including a definition of datasets, incentives to publish data and licences for data publishing. Furthermore, it defines and compares several routes for data publishing, namely: providing supplementary files to research articles; uploading them on specialised open data repositories, where they are linked to the research article; publishing standalone data papers; or making use of integrated narrative and data publishing through online import/download of data into/from manuscripts. The document also contains detailed instructions on how to prepare and peer review data intended for publication. Special attention is given to existing standards, protocols and tools to facilitate data publishing, such as the Integrated Publishing Toolkit of the Global Biodiversity Information Facility (GBIF IPT) and the Darwin Core Archive (DwC-A). Most leading data hosting/indexing infrastructures and repositories for biodiversity and ecological data are described.

Development of a Data Publishing and Dissemination Toolbox (Task 8.5)

The EU BON's Toolbox for Scholarly Publishing and Dissemination of Biodiversity Data (ARPHA-BioDiv) (**Fig. 26**) is one of the major modules of the European Biodiversity Portal and represents a set of standards, guidelines, recommendations, tools, workflows services, journals, and tools designed to ease scholarly publishing of biodiversity and biodiversity-related data that are of primary interest to the EU BON and GEO BON networks. Advanced semantic markup layer for each publication within the ARPHA-BioDiv tool facilitates discoverability, re-use and archiving. Based on the technologically advanced ARPHA Platform, the toolbox features novel data publishing workflows that allow streamlined publication of occurrence records and metadata from major data repositories. Novel article templates were developed to meet the needs of biodiversity data publishing.

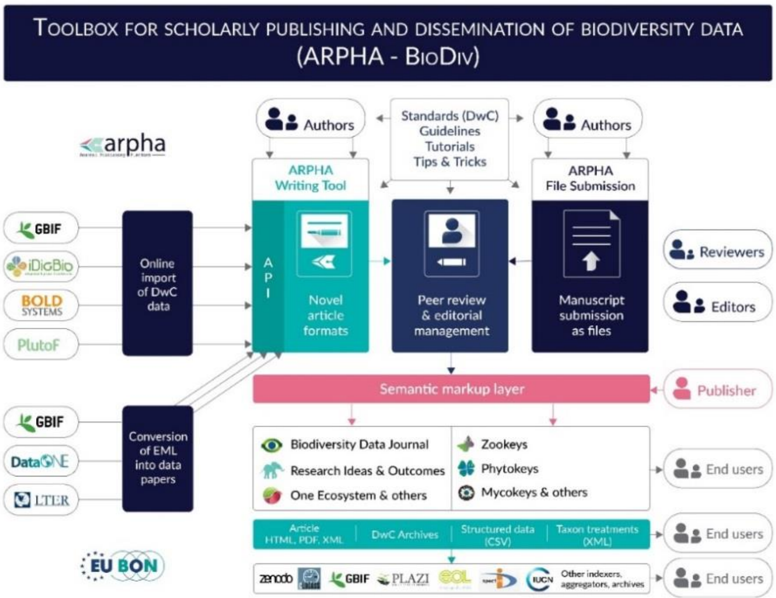

Figure 26: *EU BON's Toolbox for Scholarly Publishing and Dissemination of Biodiversity Data (ARPHA-BioDiv).*

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4. The potential impact and the main dissemination activities and exploitation of results

WP1: Data sources: requirements, gap analysis and data mobilisation

The Work Package on biodiversity data sources developed several products and worked on a variety of topics that aim to improve biodiversity data mobilisation, standardisation, curation and availability.

The online database of unpublished biodiversity data sources is available for the continuous management by different parties, e.g. the upload of new data, and gives important background information for data mobilisation initiatives. Stakeholders can browse the list of unpublished biodiversity data sources (BDS) in our portal and if necessary initiate mobilisation of such datasets. Through this we ameliorate the process of biodiversity data mobilisation.

The newly developed EU BON Taxonomic Backbone Services are primarily used by system developers requiring fast and instant access to multiple taxonomic data resources without having to understand or negotiate individual access service protocols. The potential applications of the backbone services go therefore far beyond the integration into EU BON portal services. In fact, several data management platforms have already integrated EU BON taxonomic services into their software systems. To promote their use in the global biodiversity informatics infrastructures, we have registered EU BON services in both the GEOSS Component Service Registry (CSR) and the BiodiversityCatalogue. The BGBM will continue to host and maintain the services and advertise their use in the context of biodiversity informatics workshops, conferences, and committees.

The results of the gap analysis was summarized in a specific report (Deliverable), in scientific papers and reports (such as the regional UNEP Global Environment Outlook 6) to give recommendations how to close existing gaps on a regional and European scale. Data mobilisation efforts in the project (e.g. in Eastern European Countries) show the effectiveness and importance of a thorough and structured gap analysis. The results were widely disseminated in order to raise the awareness of gaps and limitations of biodiversity data. Moreover, stakeholders were addressed and specific recommendations were given in order to fill data gaps and to improve data sharing as well as to increase open access to data.

During the project period, the task on data mobilisation has contributed to a significant increase in the quantity and quality of European biodiversity data available to basic and applied research. Even more importantly, the tools and services developed in the task will continue to support the European research community in mobilising and managing biodiversity data for years to come.

Dissemination has included a range of workshops and outreach activities aimed at developers, system administrators and end users. The online web services developed provide important functionality for amateur naturalists as well as for professional biodiversity researchers of all kinds, from museum curators to molecular ecologists. The task has also contributed a platform for efficient open-source development of biodiversity informatics software components, and for integration of such components into complex and easily deployable systems. This will help to support the community in the years to come in developing more sophisticated tools and services for the mobilisation and management of biodiversity data.

The report and the strategy recommendations for the EU citizen science gateway for biodiversity data will serve as a guideline in order to effectively apply citizen science methods for biodiversity data mobilisation. It summarizes the current knowledge with regards to the benefits of citizen science to biodiversity research. The development of dedicated tools for biodiversity observations will push forward systematic data sharing of citizen science projects. Through the EU BON biodiversity portal scientists, policy makers and active citizen scientists can access recommendations for citizen science tools, data sharing practices and find major European citizen science data providers. During the project lifetime the cooperation with citizen science networks such as European Citizen Science Association helped to disseminate the project results, this will be carried on by involvement of project partners in CS networks in the future.

WP2: Data integration and interoperability

The EU BON project set out to pull together fragmented biodiversity data. This goal has been partially reached and now it is technically possible to share quantitative, sample-based data through standardised mechanisms. Until now, this was only possible for simple point occurrences. The ecological community will benefit from this. Also agricultural, forestry, and fisheries communities are in good position to make use of these new capabilities. More cross-disciplinary communication will be needed in the GEOSS community to share these experiences.

This will boost open data and open science. Modern science requires open access to data, and data that is not openly shared, will remain increasingly underused. There is a wealth of quantitative data in government organisations that now can be made freely and openly accessible. However, it will take years to introduce new ways of working across organisations.

The quest is out for making operational the concept of Essential Biodiversity Variables. As any such system has to integrate data from a multitude of sources, opening data sources for quantitative data is instrumental towards this goal. EU BON has demonstrated this workflow in its pilot tool for species population trends, albeit using a very simple reporting rate algorithm. More sophisticated methods will be developed in coming years and the challenge of putting EBVs in action will be met. This will allow us to take the pulse of biodiversity change in near real time.

Sustainability of the infrastructure built by EU BON will of course be a question. It should be made clear that EU BON was not an infrastructure project but a research project. Even if the EU BON biodiversity portal might not be maintained indefinitively, the solutions packaged in the EU BON portal will live their own life in their originating partner organisations.

WP3: Improving tools and methods for data analysis and interface

In total, in WP3 we created approximately 17 new tools to generate and analyse biodiversity data. The improvements in performance varied from modest to profound; we believe most of the tools will have considerable impact after the termination of EU BON. The GoldenGate Imagine tool in TreatmentBank is already one of the biggest providers of taxonomic names and occurrence records of rare species to GBIF and is expected to continue to contribute biodiversity data in the coming years. GoldenGate Imagine submits links to taxonomic treatments and illustrations, which are crucial in identifying the proper identification for names that can change over time. As manually marking-up old publications is extremely expensive, such published records would have never have found their ways into appropriate digitized repositories if the process was not automated. The Land-Surface Temperature tool provides continental-scale information on a variable that is highly important for diverse tasks (e.g. planning of agricultural crops) at unprecedented spatial and temporal resolution. The underlying methods of spatial and temporal extrapolation to account for cloud-cover can easily be converted to other earth-observation missions. The Hierarchical Random-Forest model's impact is two-fold. First, it generates habitat/land-cover maps with various thematic resolutions, which lies at the basis of most natural capital assessments. Second, it forms a bridge between machine-learning and knowledge-based classification methods. As for the scaling tools, we have made considerable progress in implementing the downscaling models in the GeoCAT platform - a decision support tool used in IUCN red-listing. When implemented, we expect downscaling to become a common practice in red-listing based on Criteria B2, as the platform is widely used by IUCN practitioners and is part of IUCN official training courses. Similarly, the improvements made to AquaMaps' user interface and the ability of experts to correct computer-generated species maps will increase our ability to project reliable distribution maps for important aquatic fauna. For example, AquaMaps was recently used to project the distribution of all bony fishes in the North Sea, and to explore the economical outcomes of climate-change induced changes in species distribution patterns. Finally, the freshwater SDMs framework allowed better understanding of the current and future impact of barriers on species distribution patterns in stream networks. This approach can be explored in additional places and is expected to have considerable impact on our ability to manage and protect freshwater ecosystems under climate and land-use change.

We have made considerable effort to disseminate WP3 products to a wide audience of potential users. First, for the majority of tools we created non-technical factsheets, which were disseminated widely by WP6/7/8. We also presented our products at various conferences and meetings, and actively followed potential high-impact links. For many of the tools we have already published case studies in the peer-reviewed literature, and additional papers are currently under way. These published case-studies ensure the sustainability of the scientific framework of the tools and verify that their theoretical/mathematical base is solid. In addition to these general dissemination activities, we also made sure that all our products have been created in open access platform such as GitHub, R and GrassGIS. For many of the tools we have done our best to fit the platform of dissemination to the main expected group of users. For example, for the tools whose main potential users are scientists we have released the products as R packages ('*HieRanFor*', '*UpSCaling*', '*downscale*', '*VirSysMon*', '*raquamaps*') or R code (Hybrid models, Fourier transform, alpha-adjusted SDM). For tools whose main users are non-professionals, we are either implementing them as ready-to-use products within the European Biodiversity Portal (the land surface temperature), or promoting their implementation in established platforms (GeoCAT, AquaMaps). Finally, GoldenGate Imagine lies at the basis of a commercial service to publishers, which convert their unstructured publications into data that is submitted, among others to GBIF.

WP4: Link environment to biodiversity: analyses of patterns, processes and trends

We achieved strong scientific impacts with respect to current challenges in biodiversity conservation. Based on advanced integrative methods, and newly developed tools, we have integrated and interpreted data from several resources, explicating links between patterns, processes and drivers across scales (from local to regional to global), various organisational levels (from genes to populations to communities and ecosystems), and across realms.

WP4 has provided overarching scientific advances in a number of current issues in ecology, which radiate within the scientific community through the consortium of EU BON partners, our peers, and beyond. Our recommendations consist in monitoring programme optimisation, and guidelines for carrying out reliable biodiversity assessments, and projections of future biodiversity under scenarios of global changes. WP4 identified integrative indicators that can serve as early-warning signs of species trends.

Results were translated into recommendations to help decision making cope with pressing challenges regarding biodiversity conservation and to build the European biodiversity observation network. Key analytical tools were incorporated into GEO BON to support capacity building for biodiversity observation networks.

With its tools, methodological advances, and recommendations, WP4 contributes to on-the-ground conservation (planning, management and policy) and to decision making.

Furthermore, WP4 has illustrated the importance to account for, minimise when possible, and provide clear information on, uncertainty accompanying results and recommendations, thereby reinforcing the reliability and the impact of recommendations offered to decision making.

Overall, WP4, with its core position within EU BON, has consolidated the flow between data and background knowledge and analytical methods; that is between method development, application and validation and the production of recommendations for policy and applied biodiversity conservation. WP4 has implemented key methodological advances as open access tools, which will facilitate addressing current challenges in biodiversity conservation, ecosystem protection, sustainable use of nature (e.g. Aichi Targets) and support global networks (e.g. GEO BON) and international conventions (e.g. CBD, IPBES).

WP4 activities have covered a wide range of issues, from data harvesting and processing to biodiversity modelling to decision support. As a consequence, WP4 products are aimed at a broad range of stakeholders. Nevertheless, the most direct end-users of these products are scientists (researchers, modelers, etc.), governmental and non-governmental environmental organisations, such as EEA and national environmental protection agencies, GEO BON, and GBIF.

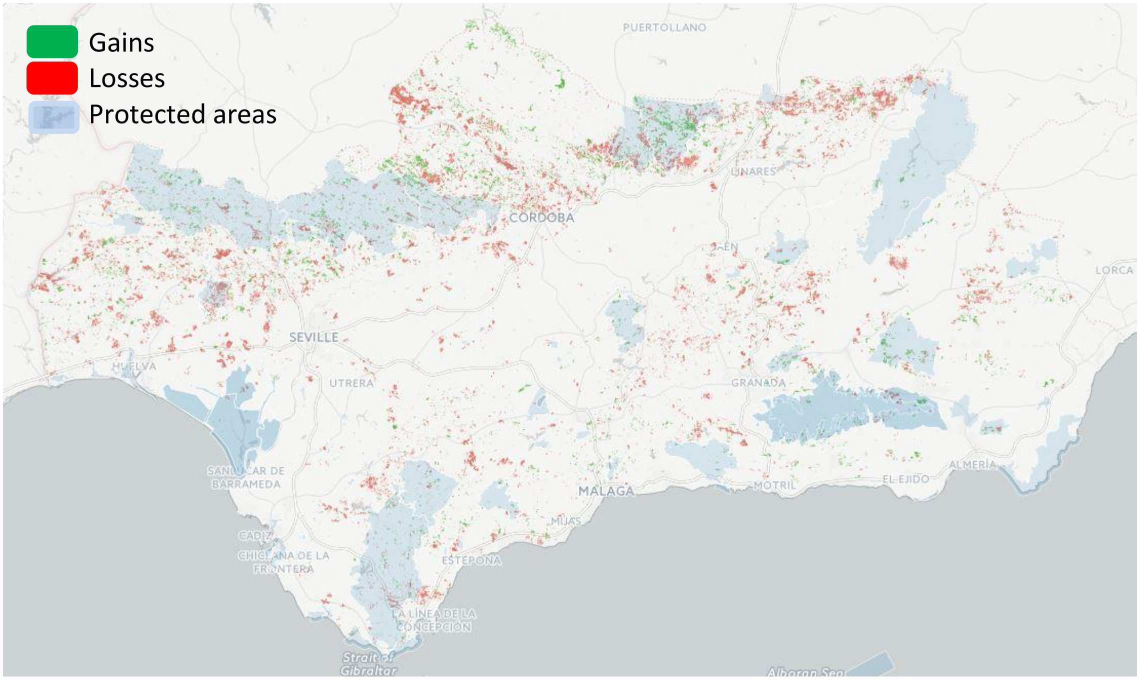
The whole body of the analytical frameworks, models and computing tools have been made available to scientists through several media, such as the European Biodiversity Portal (http://biodiversity.eubon.eu/), platforms, like GeoCAT or the Mirroreum which allows sourcing coded scripts (e.g. R scripts) for running analyses, but also customised Graphic User Interfaces to run specific models, and free and open software packages written in R. The results, advances and knowledge produced by us were transferred to other scientists also through peer-reviewed publications, and national and international communications.

The recommendations and knowledge targeting stakeholders in applied biodiversity conservation have been transferred through a diversity of supports; among those are infographics e.g. depicting workflows or methodologies, maps e.g. representing species status, roadmaps e.g. giving guidelines for analysing biodiversity, and policy briefs informing decision-makers.

Finally, with a view to the sustainability of all EU BON products, WP4 along with other EU BON WPs has built a sustainability task force. In a workshop with representatives of GEO BON, a ‘BON in a Box’ has been designed to incorporate key tools from all WPs. BON-in-a-Box is a regionally customisable and continually updated online toolkit for facilitating the start-up or enhancement of national or regional biodiversity observation systems. This interface aims to serve as a technology transfer mechanism that allows countries all over the world to access to the most advanced and effective monitoring protocols, tools and software in order to harmonise national monitoring schemes and mutualise and optimise our efforts for a global strategy of biodiversity conservation.

WP5: EU BON testing and validation of concepts, tools, and services

WP5 was very active at both organising and attending meetings of different types, but always having a notable impact on the targeted audience including the EU BON test-sites and their related stakeholders, different technical or scientific communities: bioinformatics, citizen-science, scientists, biodiversity information networks, managers and decision makers. In addition to the documents produced during the project, several showcases on the potential impact of WP5 activities on the society are discoverable through the EU BON biodiversity portal under the tab dedicated to test sites. They range from documents that inform the user on the criteria to conduct monitoring, processed data to get informed decision on different management actions or analyses on the trend of different natural resources of wide interest. For instance, the trend of Mediterranean Oak forest in Andalusia from 1956 to 2007 was presented as EU BON storyline *from data to reporting* during at the final meeting in Brussels/Meise in March 2017 (Figure below). Because this information is presented together with protection figures, this may help managers to acknowledge this changes, and plan future managing decision based upon this information.



WP6 & 7: Stakeholder engagement and science-policy dialogue and implementation of GEO BON: strategies and solutions at European and global levels

The outputs and outcomes of the four 'EU BON Stakeholder Roundtables' are captured in journal articles published in EU BON's collection in the online journal "Research Ideas and Outcomes" (http://riojournal.com/collection/2/), along with other of EU BON's results. The main impact of these Roundtables includes greater interaction with, and a shared understanding among, relevant scientific, policy-maker and other stakeholder communities, which have been used to guide the project's work.

The EU BON product list and associated factsheets[9] were transferred to the European Biodiversity Portal[10], and to GEO BON's BON-in-a-Box[11], which is a regionally customisable and continually updated online toolkit for facilitating the start-up or enhancement of national or regional biodiversity observation systems. EU BON partners have also been encouraged to submit their products to the "Oppla platform"[12], a EU-funded virtual hub where the latest thinking on nature-based solutions is brought together from across Europe.

Showcases (i.e. demonstrations) of what a particular product "can do" are helpful to communicate its value to potential end-users. Infographics[13] were used in EU BON for this purpose, for instance one on the possible impacts of climate change on community composition of bony fishes in the North Sea (Weatherdon *et al.* 2015; **Fig. 26**).

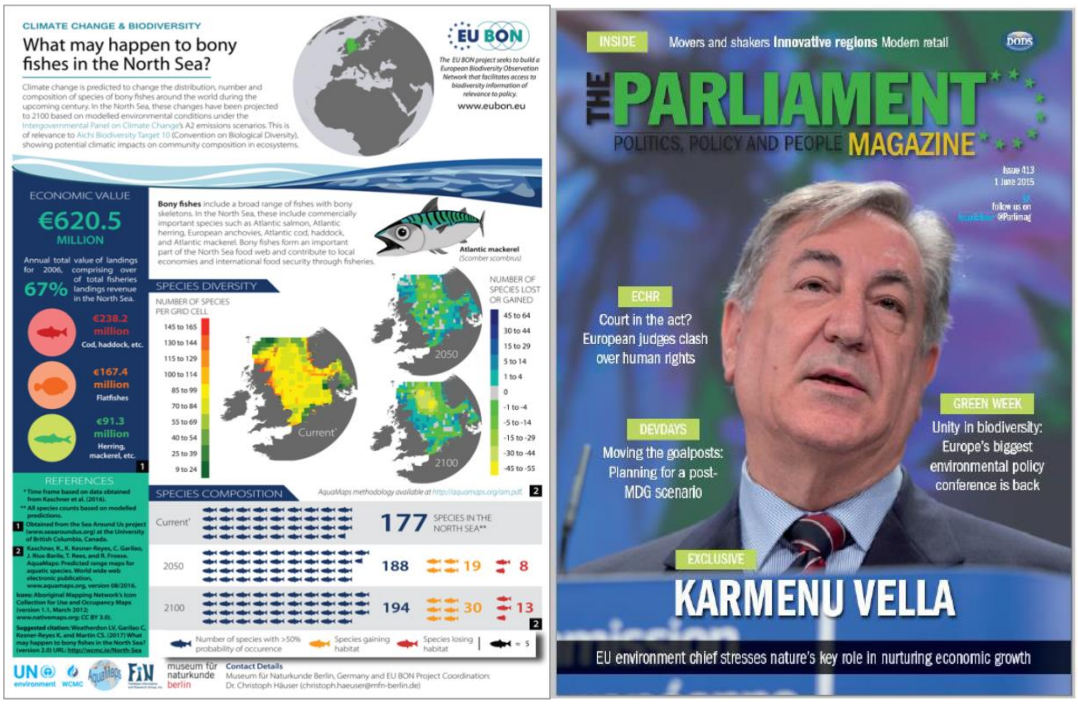


Figure 26: *Infographic on the possible impacts of climate change on community composition of bony fishes in the North Sea, which was published in the 'Green Week' issue of The Parliament Magazine (Weatherdon et al. 2015).* ***Source:*** *Weatherdon, L.V., Garilao C., Kesner-Reyes K., Martin C.S. 2015. What may happen to bony fishes in the North Sea. An infographic based on AquaMaps. Version 2.0 (2017). Originally published* in: The Parliament Magazine (Green Week issue) 413. URL: http://wcmc.io/TPM-413, http://wcmc.io/North-Sea

This infographic was published in the "green week" issue of The Parliament Magazine, aiming to answer a clear question of policy relevance. This infographic is based on an online decision-support tool[14] that uses the AquaMaps database: it shows how fish community composition in the North Sea may change as a result of climate change, highlighting how many species would be gained and/or lost. The issue containing the infographic was distributed to over 4,000 delegates in

[9] http://wcmc.io/EUBON_Products, http://wcmc.io/EUBON_Factsheets
[10] http://biodiversity.eubon.eu/products
[11] http://geobon.org/bon-in-a-box/what-is-bon-in-a-box/
[12] http://www.oppla.eu
[13] http://wcmc.io/EUBON_Infographics
[14] http://www.aquamaps.org/am_eubon/SpecRichLME.php

attendance. Furthermore, as the magazine for the European Parliament and European Commission, this issue was also distributed to members of these institutions, the Presidency Office, party political groups and various other EU institutions. Additionally, a digital version of the magazine was distributed to over 50,000 contacts globally, including journalists, the public affairs contacts from EPAD (European Public Affairs Directory), bulletin subscribers, from EU officials/Commission staff to public affairs consultants.

The decision-support tools relating to AquaMaps and GeoCAT will continue to be curated and developed by the FishBase Information and Research Group (FIN) and Kew Royal Botanic Garden, respectively. With regards to GeoCAT, GeoCAT was cited 274 times in peer review journals (an increase of 120 on the last year), whilst within IUCN, GeoCAT was cited 715 times (an increase of 509 on last year).

The partners involved in WP6 and 7 also produced a business plan, building a base for further communication of the outcomes of the EU BON project to a wider public. A solid financial support for continuing the EU BON will have major impacts on the information flow towards better decision making. While other projects provide the network, EU BON is the sole data and information provider able to bridge science and policy information transfer. While the project has ended further dissemination is foreseen and has been agreed on during the last workshop in May 2017 in Leipzig. In addition, close links have been created with GEO BON, both in regard to the development and operationalization of EBVs as well as contributions to BON-in-a-Box. The impact of the results from EU BON depends on the implementation of the business plan and the funding options available.

WP8: Dissemination and outreach

The EU BON website will be maintained and kept alive for further 5 years after the project's end. To address issues of sustainability of results hosted on the website, the project has created an open science pilot with the RIO Journal, where important results and documents are published with a stable DOI and exported and indexed in a number of repositories thus ensuring those outputs will remain accessible and searchable after the 5-year website maintenance. RIO collections will continue to accept project outputs even after the project end in an attempt to collect a comprehensive compilation of EU BON results.

Recognising that the data publishing has become increasingly important and already affects the policies of the world's leading science funding frameworks and organisations, WP8 has elaborated and updated strategies and guidelines for scholarly publishing of biodiversity data. The document outlines what is needed to support the scholarly publishing and dissemination of biodiversity and biodiversity-related data that is publishing through the academic journal networks. The document discusses some general concepts, including a definition of datasets, incentives to publish data and licenses for data publishing and contains comprehensive instructions on preparation and peer review of data intended for publication. These strategies and guidelines were openly published in the Open Science Pilot Collection in Research Ideas & Outcomes (RIO) journal and could be of use to anyone interested in biodiversity data publishing.

The EU BON’s Toolbox for Scholarly Publishing and Dissemination of Biodiversity Data (ARPHA-BioDiv) as one of the major modules of the European Biodiversity Portal is expected to provide numerous advantages: 1) Increased efficiency of data publication through novel tools and workflows; 2) Mobilization of non-conventional research outputs via novel article formats; 3) Innovative forms of community engagement (data papers, open science collections); 4) Machine-readable content available for harvesting and re-use; 5) Streamlined creation and import of complex data-rich manuscripts via an Application Programming Interface (API); 6) Automated export facilitating data dissemination and re-use; 7) Data publishing strategies and guidelines supporting data interoperability; 8) Additional incentives for researchers (permanent scientific record, citations) for their effort to collect, maintain and publish biodiversity data. Virtually all researchers and institutions from all scientific disciplines who want to publish their biodiversity-related data in scholarly articles are potential users of the Data Publishing and Dissemination Toolbox.

Being part of the ARPHA Platform, all features and tools within ARPHA-BioDiv will be continuously updated. Moreover, new tools and workflows will be added in future. And since the scholarly publishing is a very dynamic field with new technologies being invented and applied every day, one of the major challenges in academic publishing lies in creating linked content - embedding machine readable data in scientific articles that links to global knowledge hubs. The next steps for the development of ARPHA-Biodiv will be to apply linked data and nano-publications principles in the biodiversity domain. All developments of ARPHA-BioDiv date are also published in an open access paper in RIO journal.

5. Project public website and contact details

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