Deliverable 5.1 (D5.1)

Principles and guidelines for establishing and operating EU BON test sites

M26

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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	✓
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive summary

What is this report about?

This report summarises the cumulative effort of the biodiversity monitoring community of the EU-funded project EU BON (European Biodiversity Observation Network) 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.

The problem

A series of international agreement products, starting from the CBD and the UNCLOS documents and extending towards those of the Regional Treaties and European Framework Directives and recently summarised by the GEO BON objectives, clearly demonstrate the demand for continuous biodiversity monitoring activities in order to ensure the protection and sustainable exploitation of biodiversity. Although there is a serious effort on biodiversity monitoring, which provides large amounts of data across a vast area and for a diverse range of organisms by a motivated and highly skilled community, this community is fragmented and not evenly spread across Europe. Yet, the techniques used for monitoring vary, as do the vocabularies for communicating data and the standards for sharing them. Communication between the different monitoring networks is poor, both because of language and physical barriers, but also artificial impediments such as the uneven distribution of the available taxonomic expertise. The consequence is that large amounts of data are suitable for local studies, but few data are applicable at continent-wide scale. The latter renders the scientific community weak in providing clear answers to questions related to the status and change of biodiversity in Europe as a whole. Finally, the relevant community is still far from being able to quantify the impacts of different drivers of change on biodiversity.

The solution

EU BON promotes a realistic solution to this problem, which is to create a pan-European biodiversity observation network that can link these disparate people, organisations, and countries. Such a network should provide the communication channel through which plans, methods and data can be exchanged and a minimum level of standards and protocols for sharing information should be commonly adopted. This is the hard core of the EU BON project (Hoffmann *et al.* 2014). Within the project a number of survey sites are envisaged which will be used to test integrative standards and methods. In addition, these sites will showcase to stakeholders the value of an integrated, trans-taxonomic, Europe-wide monitoring network for biodiversity.

The opportunity

EU BON is now offering the opportunity to overcome the above problem through the Deliverable 5.1. The goal of the Deliverable is to: (A) provide an overview of what has already been achieved in the field of biodiversity site monitoring by the international community; (B) report a synthesis of the different initiatives and results obtained, and (C) provide an updated baseline that serves to delineate the principles and guidelines for establishing and operating an EU BON test site. In other words, this report can be seen as a handbook for existing and new biodiversity monitoring sites. It focuses on the state-of-the-art of the practices to be employed in biodiversity monitoring. The aim is to secure and promote quality standards, increase interoperability of data and formats, and ultimately to enhance the scientific impact and societal relevance of the data. The report is based on a literature review and builds upon a number of monitoring activities carried out in Europe and elsewhere over recent years (Section 2).

Plan and competitive advantage

A realistic plan has been set by the objectives of EU BON Work package 5 *"EU BON testing and validation of concepts, tools, and services"* which aims to test and demonstrate the fitness of use of concepts, tools, and techniques for data integration and analysis. The detailed objectives of WP5 are the following:

- ⇨ To test and validate EU BON data integration and information services in real settings, involving researchers, decision makers, and stakeholders.
- ⇨ To subject EU BON analytical tools and modelling techniques to field tests.
- ⇨ To test EU BON concepts and services for thematic, national, and regional level needs.
- ⇨ To establish and operate a network of EU BON sites for integrated biodiversity data recording, management, and analysis.
- ⇨ To expand EU BON services to other areas and sites in Europe and around the world.

There is a particular advantage in implementing the above design to specific local conditions, especially in field settings: EU BON test sites were selected as a representative sample of European ecosystems, by objectively applying a set of criteria, and where direct involvement of decision makers and local stakeholders occurs. Nonetheless, the number of test sites is planned to be increased to build a network of associated EU BON test sites. The selection, establishment, and longer term operation of EU BON test sites will be based on the standards, guidelines and protocols described in this document.

Progress made

This document contains two main parts: **(A)** Section 2 includes a review of several biodiversity monitoring initiatives that aims to monitor biodiversity at different spatio-temporal scales. Each single initiative has been designed and implemented to satisfy both local needs and international commitments. This combination of local and global requirement helps to explain the great diversity of approaches and solutions found in biological diversity monitoring. Some initiatives are focused on citizen scientists, while others use information collected by professional scientists. Some other monitoring schemes aim to gather scientific knowledge, while others pursue to solve well defined environmental problems; **(B)** Section 3 describes the lessons learned from the analysis of the above mentioned monitoring approaches. These lessons are transformed to a set of recommendations focused on four key elements of a monitoring schema: (i) what to measure, that is biotic, abiotic and socio-economic variables (section 3.1), (ii) where to measure, that is the selection of suitable monitoring sites, representative of the main habitats and land-use categories (3.2), (iii) how to measure (3.3), which includes methods/guidelines that should be taken into account when collecting and, (iv) how to manage the information collected (3.4).

Finally, a synthesis section (3.5) is provided where all the information of the report is integrated in order to boost the recommendations made. Technical parts, such as literature cited and appendix are placed at the end of the report.

Future developments

The EU BON consortium anticipates the recommendations made in this document to be suitably refined and extended to improve the quality and dissemination of the network's output. In the future, as the BON (Biodiversity Observation Network) is expanding, further effort will need to be spent to ensure communication and feedback around the network and also long-term sustainability of sites.

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1 Background

The biodiversity monitoring community in Europe is highly active, with the involvement of a large number of organisations and people. These organisations include private companies, governmental departments, scientific institutions and non-profit associations. The people involved range from professionals and experts to citizen scientists and enthusiastic beginners. Yet despite the large effort expended, the community is highly fragmented. Monitoring schemes are separated by their geography, their goals, different scientific communities, taxonomic scope and their approach to digitization (e.g. see special issue on biodiversity monitoring in “Biodiversity and Conservation”, year 2008, volume 17, issue 14). There is little harmonisation of monitoring approaches and methods applied. Therefore, despite the large number of monitoring programmes, it is extremely difficult to get a continental overview of biodiversity and environmental status; its changes and the consequences of these changes (see EuMon, section 2.1.6 for a review). The majority of European species have populations in multiple countries and many migratory species seasonally occupy habitats in multiple countries. It is only possible to understand the status of European species by using standard monitoring protocols across the whole range of countries and habitats.

Biodiversity monitoring must attempt to identify causes of change at different scales from local to continental. In particular, one of the main goals of monitoring is the better understanding of the processes that drive spatial and temporal patterns of biodiversity. Biological diversity is not evenly distributed over the surface of the planet, depending on their evolutionary history and macro, meso- and micro-environmental variables. Several studies have attempted to determine large-scale tendencies or patterns in the spatial distribution of biodiversity and to identify the main drivers influencing biological diversity (see e.g. Gaston, 2000; Lévêque and Mounolou, 2004; Wilson *et al.*, 2004). In short, large scale drivers of change include, among others, atmospheric nitrogen deposition and climate change, while local drivers include changes to land-cover; point source pollution episodes and land management changes. For this reason must be a balance between locally focused monitoring schemes, which focus on particular issues and taxa of local interest, and broad scale monitoring with standardised systems that can be used internationally.

In EU BON the consensus is that the Network should not only continue to encourage the large, ongoing monitoring activities, but also encourage harmonisation of some of the methods applied. This will ensure that data will be valuable at both a local and continental scale. It will also assist the establishment of monitoring schemes, particularly where such schemes fill gaps in our current knowledge.

The large numbers of pre-existing monitoring schemes have also generated knowledge capital on how and what to monitor. EU BON makes use of this investment, initially, by learning from best practice in such schemes and second by suggesting sensible aggregation techniques that bring together different data sources into a more complete, large-scale picture.

For all the reasons outlined above, continent-wide monitoring is here envisaged in the form of a network of organisations which both contribute to international monitoring priorities as well as to their own local targets. The Group on Earth Observations (GEO) has established the GEO Biodiversity Observation Network (BON) to launch such a network and guide its development globally (Pereira *et al*. 2010, Scholes *et al*. 2008, 2012).

The heterogeneity and complexity of biodiversity makes its monitoring difficult. However, biodiversity monitoring is increasingly seen as essential for driving decision-making, for species conservation, for controlling trends in biodiversity loss and also for environmental management and as an indicator of sustainable development.

The detection of environmental change arising from large-scale, long-term monitoring programmes has been of proven value in warning politicians and the public about threats to the environment and in informing policy responses (Parr *et al*. 2002). The impact of environmental change is not always clear and monitoring is the only way to realize early detection of change. At the level of policy many of the

Aichi Biodiversity Targets of the Convention on Biological Diversity's strategic plan relate directly to monitoring (see section 3). Several of these targets require that we either monitor biodiversity or will require the results from monitoring so that we know we have achieved the target. For example, target twelve requires monitoring to be evaluated. This target focuses on improving the conservation status of threatened species. In contrast, target nineteen specifically focuses on knowledge and understanding relating to biodiversity and specifically mentions knowledge of the status and trends in biodiversity. Many other targets also require biodiversity monitoring for their assessment, including target five on the loss of natural habitats; target six on the management of aquatic organisms; target nine on invasive species and target fifteen on the restoration of degraded ecosystems.

The monitoring approach of EU BON considers all of these political and scientific aspects to achieving useful, robust and up-to-date monitoring for Europe. This report summarizes the progress so far in developing the principles and guidelines for monitoring within the EU BON network of sites. This includes details of what should be monitored, where monitoring should occur and how it should be conducted. It covers also the important issue of data management. Descriptions of the EU BON sites are provided in appendix 5.2.

The report contains two main parts:

- ⇨ Section 2 reports an overview of the previous and ongoing site monitoring initiatives.
- ⇨ Section 3 provides the guidelines and principles to be adopted in establishing biodiversity monitoring sites in Europe within EU BON project.

2 Learning from previous and ongoing site monitoring initiatives

The large number of biodiversity monitoring initiatives can be investigated from several perspectives. One view is from the aspect of the observers, some initiatives use citizen scientists, while others use para-ecologists or professional scientists. Monitoring schemes can also be divided by their scope some are site-based schemes, while campaign-based approaches are national or even supranational. The site-based approach generally aims to monitor biodiversity over the long to medium term. Examples of the site-based approach are the Long Term Ecological Research Network Sites (LTER). Campaign-based approaches are often more limited in their time frame, though there is considerable overlap.

Campaign-based initiatives have their own budget dedicated to clear and achievable goals that constitute visible outputs, while site-based initiatives are normally envisaged for the long-term, they should cope with resource fluctuations, and they are more focused on gathering basic information on a regular basis (see NEON for a combined approach). Quite frequently, however, campaign-based initiatives are launched by sites as a way of boosting their activities, but also as a way of adding new capabilities to the site, thus extending the operation time of campaign-based initiatives. In general, the benefits of long-term monitoring at permanent sites have been well documented, as being useful to establish reliable estimates of baseline values for significant environmental variables and indicators. They also have the ability of providing early warning of any long-term changes in these variables, and allow developing generic models of predictive value as a basis for environmental management and use of natural resources (Parr *et al.* 2002). However, in many cases these programmes have narrow monitoring objectives because they focus on a single ecosystem type and/or a single issue. At a network level, potential users are often unable to make effective use of the whole set of environmental data because of the lack of common approaches to data collection, management and presentation (Parr *et al.* 2002). For this reason, a harmonisation process is essential in this context, even if it may represent a big challenge.

In the final analysis, once all these aspects dealing with biodiversity monitoring are taken into account, the key question is not what or how biodiversity is measured, but whether information coming from the different approaches can be integrated, analysed and reported in an effective way. Therefore, it is worth mentioning that monitoring data must be defensible against criticisms regarding their degree of representation, their precision, accuracy, consistency, and reproducibility (Parr *et al.* 2002).

2.1 Previous and ongoing biodiversity monitoring initiatives

While it is impossible to discuss all biodiversity initiatives, listed by the European Environmental Agency, some notable projects and pre-existing networks are mentioned here in alphabetic order as intrinsically linked to EU BON. They constitute either the framework where previous knowledge and skills have been acquired or "sibling" developments sharing a notable portion of their objectives with EU BON. A more comprehensive compilation on European projects also including initiatives less focused on monitoring can be found in D2.1 "Architectural design, review and guidelines for using standards". We highlight the specific strengths of each initiative. To that respect, these initiatives can be used as a role model for the establishment and operation of EU BON test sites as well as the network level (see also Table 1).

Table 1. Overview of some major site based biodiversity monitoring initiatives. EU BON test sites build upon their experience–and aim at a high degree of harmonisation in monitoring and data integration principles that are already established in these initiatives. A more thorough description of the initiatives presented in the table is provided in sections 2.1.1 - 2.1.8.

Initiative	Geographic focus	Goals	Main achievements
Arctic-BON	Arctic ecosystems around the North pole	Long-term establishment of the Arctic Biodiversity Assessment	Very high degree of standardisation → can act as model for Biodiversity Observation Networks
AP-BON	Asia-Pacific	Promote and integrate national Biodiversity Observation Networks at regional level	Integration of national Biodiversity Observation Networks, currently Japan (J-BON) & Korea (K-BON)
BIOMARE, MarBEF, EMBOS, MARS	Europe	Large-scale, long-term establishment of marine biodiversity assessments	First network on long-term research of marine environments; successful follow up with the establishment of a pan-European initiative, measuring marine biodiversity patterns in space and in time; Integration of ecosystem functions, valuation of their goods & services and different stakeholder levels
EBONE	Europe	Terrestrial Biodiversity	Coherent & cost effective system of data collection from national to regional level
ECOSCOPE (F-BON)	France	Become central integration & dissemination point for existing national efforts an all relevant levels	Concentration of efforts & facilitation information exchange on all levels
EuMon	Europe	Summarise existing biodiversity monitoring schemes with focus on citizen science, methods & tools	Large database gathered, facilitated priority setting & assisted in development of tools
LTER-Europe	Europe	Harmonised long-term ecosystem research	High degree of standardisation, widely distributed and accepted → the most important network on ecosystem monitoring in Europe
TEAM	Global tropical ecosystems	Real time early warning system on status of biodiversity	Excellent coverage of plants and ground living mammals and birds through camera trapping

2.1.1 ARCTIC-BON

The Circumpolar Biodiversity Monitoring Program (CBMP) is "an international network of scientists, governments, indigenous organisations and conservation groups working to harmonise and integrate efforts to monitor the Arctic's living resources" (http://www.caff.is/about-the-cbmp 26.1.2015). The CBMP organises its efforts around the major ecosystems of the Arctic. It coordinates marine, freshwater, terrestrial and coastal monitoring activities while establishing international linkages to global biodiversity initiatives. The CBMP emphasizes data management, capacity building, reporting, coordination and integration of Arctic monitoring, and communications, education and outreach. Its goal is to facilitate more rapid detection, communication, and response to the significant biodiversity-related trends and pressures affecting the circumpolar world. To that respect, CBMP can act as a role model for its high degree of standardisation of the ongoing monitoring (Gill *et al.* 2011) as well as a template for data integration and provision of stakeholder-oriented derived information through their homepage (http://www.caff.is/monitoring) as well as a series of printed publications.

2.1.2 AP-BON

AP-BON (Asia-Pacific Biodiversity Observation Network) is the integration point for national Biodiversity Observation Networks (BONs). Currently two national BONs are included: J-BON (Japan) and K-BON (Korea). Thus AP-BON is the regional intermediate network between the Global Earth Observation: Biodiversity Observation Network (GEO BON) and the national BONs. AP-BON currently covers many countries of the region and includes all levels of biodiversity and ecosystems. Main achievements are the establishment of a biodiversity database, two national monitoring networks in Japan and Korea as well as further research on biodiversity, including the integration and establishment of new methods and analyses for biodiversity studies (e.g. remote sensing).

2.1.3 BIOMARE, MarBEF, EMBOS, MARS

BIOMARE (Implementation and networking of large-scale long-term marine biodiversity research in Europe 2000-2002) was a Concerted Action (CA) aimed to establish the infrastructure and conditions required for marine biodiversity research at a European scale. The Consortium consisted of 23 actively participating European institutes and almost double associated ones. The overall objective of the CA was to act on the consensus that had grown that concentration and co-ordination at European scale is urgently required to implement long-term and large-scale marine biodiversity research and to plan the adequate use of the European research infrastructure. Many research questions cannot be addressed at local scales and require cooperation and the establishment of a committed network of scientists and institutes. There is no agreed common methodology from any aspects of biodiversity research; this needs careful preparation. The main achievements of the CA were a catalogue with the proposed EU marine biodiversity study sites and an exhaustive list of the possible indicators to be implemented. Many of the activities of the project are now carried out by the EMBOS (see below) and by MARS (The European Network of Marine Research Institutes and Stations)

MarBEF (Marine Biodiversity and Ecosystem Functioning. 2004 - 2009) was a Network of Excellence funded by the 6th EU FP. This project was consisting of 94 European marine institutes. It had been conceived as a platform to integrate and disseminate knowledge and expertise on marine biodiversity, integrating resources from researchers, industry, stakeholders and the general public. The main objectives of MarBEF were organised along the three main themes:

- ⇨ The exploration of large-scale, long-term marine biodiversity patterns across the European continent
- ⇨ The development of a research framework on marine ecosystem functioning, starting from theory developed in terrestrial ecosystems and further building on with experience and knowledge from the marine ones;
- ⇨ The development of a scientific framework for the economic valuation of the marine biodiversity goods and services.

The network of reference sites selected from BIOMARE was extended in MarBEF to include more sites, especially in pelagos and deep sea ecosystems.

MarBEF produced a series of instrumental publications on large-scale and long-term marine biodiversity patterns, on the relation of marine biodiversity with the functioning of the ecosystem and on the valuation of the marine biodiversity using both direct quantitative monetary and qualitative non-monetary approaches. Finally, a number of databases have been constructed with data sets on a pan-European scale and on the major components of the marine ecosystems, such as meiobenthos, hard and soft bottom macrobenthos and pelagos. Protocols and standards for marine biodiversity data and metadata supported the databases. The European branch of OBI, EurOBIS was established and populated in the context of MarBEF.

EMBOS (Development and implementation of a pan-European Marine Biodiversity Observatory System); is a COST Action project, which is developed on the observation that marine biodiversity varies over large scales of time and space and requires a research strategy beyond the tradition/capabilities of classic research. Research activity that covers the above scales requires a perpetual pan-European network of observation stations with an optimized and standardised methodology. The latter means a permanent network of observation stations where the biodiversity across the multitude of environmental conditions across Europe is adequately monitored. The solid basis upon which this network has been established has formed in previous projects such as BIOMARE and MarBEF, with more than 90 biodiversity observatory sites. EMBOS links, therefore, this network directly to the emerging needs of the EU. This cooperation addresses the EU needs for a focused and cost effective long -term research agenda for the EU marine observatories, and contributes to ERA, LIFEWATCH and GEOSS/GEOBON initiatives and addresses the EU legal obligations regarding the CBD, OSPAR and Barcelona conventions as well as EU Directives (Bird and Habitat Directive, WFD, MSFD, ICZM).

EMBOS so far has established a suite of marine biodiversity monitoring sites all over Europe and on multiple coastal habitats. The partners have already concluded the first round of sampling and soon the first results from the common analyses will be released.

2.1.4 EBONE

EBONE (European Biodiversity Observation Network. 2008 - 2012; Halada *et al*. 2009) was a European contribution to the terrestrial monitoring, focusing on habitat monitoring to GEO BON, the Group on Earth Observations Biodiversity Observation Network. "The EBONE project has focused on the development of a cost effective system of biodiversity data collection at regional, national and European levels" (de Blust *et al.* 2012). The project has developed first steps towards a coherent system for data collection that can be used for international comparable assessments".

The main products of EBONE are:

A. A harmonised European monitoring approach (with a focus on habitat mapping and recording).
B. A report "The selection of biodiversity indicators for EBONE development work" (Parr *et al.* 2010).
C. The development of a European and Global environmental stratification (see also section 3.2).
D. A computer programme for facilitating standardised data collection in the field.

With these products, EBONE can be seen as a direct precursor of the current initiative of EU BON that has already established a body of theory as well as applied tools that can be directly implemented and used by EU BON test sites as well as for data integration in the network.

2.1.5 ECOSCOPE (F-BON)

F-BON is a French National Biodiversity Observation Network of research observatories on biodiversity to understand and anticipate the changes in biodiversity and associated ecosystem services. It started recently in 2011 and is developing a platform for the coordination of national French observatories and other data holders. The main objective of this federal and multi-agency project is the coordination and reinforcement of biodiversity observatories to better organise the collection, exchange and use of the data with a special focus on Essential Biodiversity Variables (see section 3.1).

2.1.6 EuMon

EuMon (EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest, from 2005 – 2008) collected meta-data of biodiversity monitoring initiatives across Europe. It provided a first overview of the Monitoring landscape in Europe (see Figures 1 & 2) and a European framework that standardises, focuses and coordinates existing monitoring programs by comparing and integrating existing methods and monitoring schemes of species and habitats of community interests. EuMon evaluated the cost effectiveness and regional robustness of both terrestrial species and habitat monitoring. Based on the analysis EuMon also developed recommendations how new and successful monitoring programs can be established, making it an important predecessor of current attempts of GEO BON to develop a BON in a Box handbook. EuMon also-focuses on participatory monitoring and citizen science, because the relationship between amateurs and professionals are meant to be most important for implementing a successful monitoring regime.

The main products of the EuMon project that are relevant for the establishment of a biodiversity monitoring network in Europe are:

A. An online web-based Biodiversity Monitoring & Assessment Tool (BIOMAT).
B. Guidelines to integrate biodiversity data from species and habitat monitoring programs varying in their applied methodology.
C. A tool to prioritize biodiversity monitoring and conservation by defining national responsibilities (e.g. Schmeller *et al.* 2014).
D. A database on habitat and species monitoring schemes across Europe with a search interface.

These products help to coordinate and interlink new with ongoing monitoring initiatives, as well as identifying gaps which can be filled by new monitoring initiatives.

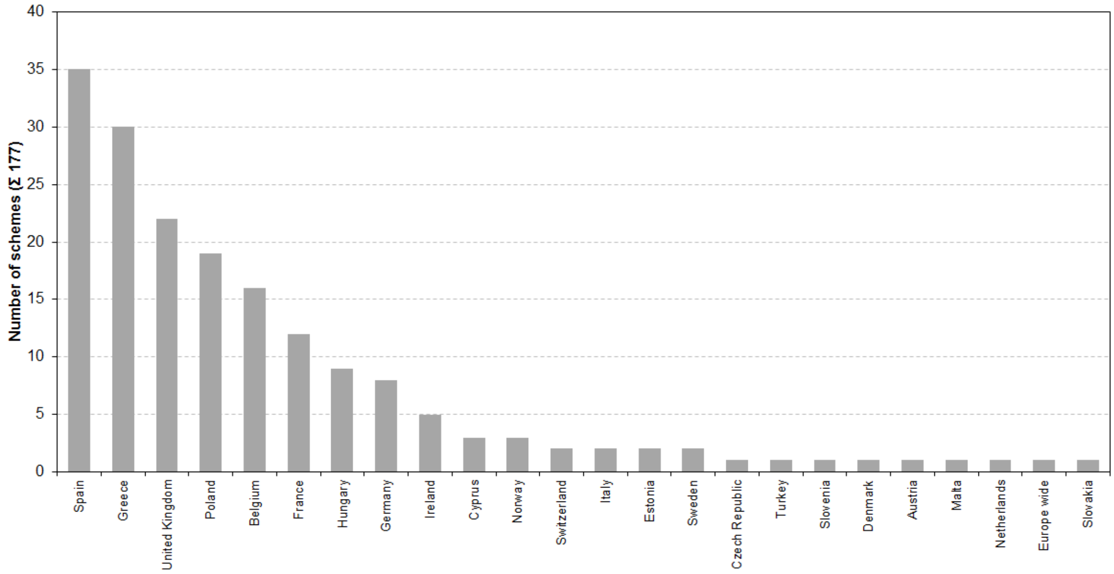


Figure 1. Summary graph of habitat monitoring schemes by country across Europe, extracted from the EuMon database (http://eumon.ckff.si/index1.php).

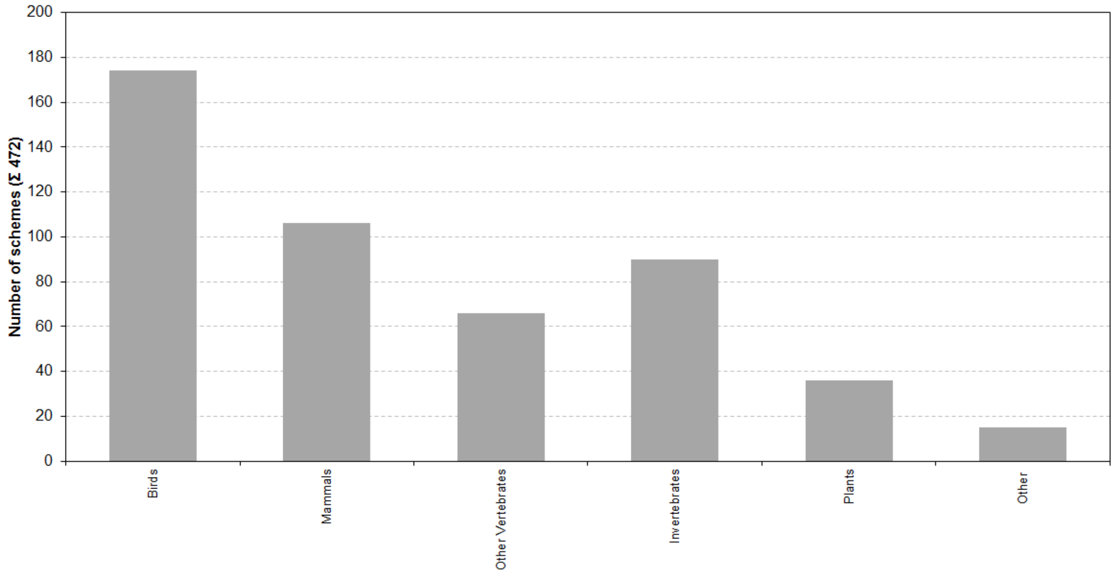


Figure 2. Summary graph of species monitoring schemes by country across Europe, extracted from the EuMon database (http://eumon.ckff.si/index1.php).

2.1.7 LTER-Europe (EnvEurope/ExpeEr),

The European regional sub-network of the global ILTER (International Long-Term_Ecological Research Network) helps to coordinate ILTER activities in Europe and represents European-level interests in ILTER. Currently, more than 450 monitoring sites, holding very diverse datasets on both biotic and abiotic environmental variables (see Figure 3), form this network of 24 National LTER-Networks. Recently, LTER-Europe joined DataONE as member node of the DataONE community. The focus of this network is on ecosystem research, in which biodiversity research plays an important role. Some sites have more than 100 years of data. These European national networks add approximately 170 data objects to the over 250,000 data objects discoverable via DataONE. One of the core interests of the LTER-Europe community are data and method harmonisation. To facilitate this, a number of EU projects with key LTER-Europe partners have been executed, for example "EnvEurope" (Environmental quality and pressure assessment across Europe; 2010-2013), which aimed at establishing monitoring workflow based on the distributed network of LTER-Europe sites through common information management systems, harmonisation of parameters and methods and a cross-domain data integration approach, and "ExpeEr" (Experimentation in Ecosystem Research; 2010-2014), which aimed to bring together the fragmented scientific community with regard observational, experimental, analytical and modelling research in ecosystem science in Europe and thereby improving the quality and the performance of these ecosystem research infrastructure components in a durable and sustainable manner. Key products of the LTER community that are highly relevant for a biodiversity observation network in Europe are A) the metadata portal "DEIMS" (drupal Ecological Information Management System), B) the multilingual online thesaurus "EnvThes" (http://vocabs.lter-europe.net/EnvThes3.html) which merges a number of existing topical thesauri to enable a full semantic interoperability of all kinds of environmental data and metadata, both for unambiguous description of data and metadata as well as to ensure information retrieval through search engines, and C) the interactive database "ECOPAR" (http://www.ufz.de/lter-d/index.php?en=32141&contentonly=1), which is a web tool for the exchange between scientists and other stakeholders on indicators, parameters and corresponding methods in environmental monitoring. ECOPAR covers terrestrial, river, lake and marine ecosystems. The aim of this web tool is to support harmonisation of both monitoring techniques and data integration.

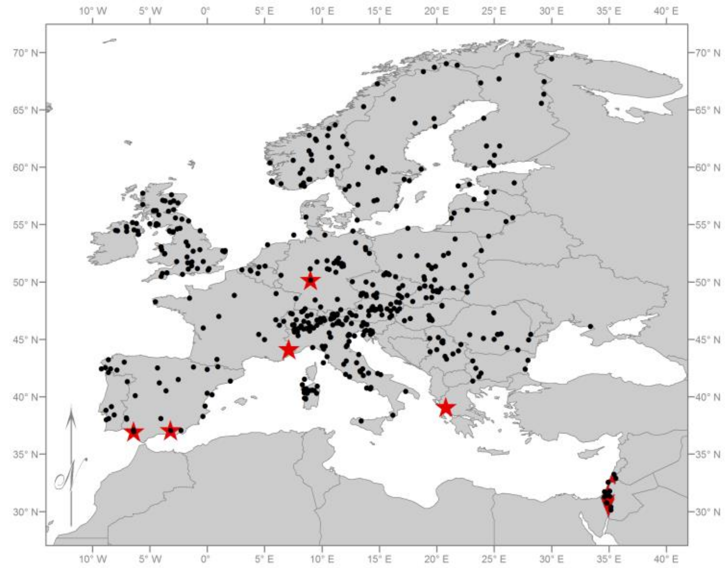


Figure 3. Distribution of LTER and similar sites across Europe (black dots). EU BON test sites and associated sites are added in red, from west to east: Doñana Biological Station, Sierra Nevada Observatory (both ESP), European Natural Park Mercantour/Alpi Marittime (FRA/ITA), Rhine-Main-Observatory (GER), Amvrakikos Wetland (GRE) and Israel's National Biodiversity Monitoring Program Hamaraag) are marked in red. Another associated site (Brazilian Research Program in Biodiversity, BRA) is not shown. Modified from ALTER-NET 2009.

2.1.8 TEAM

The TEAM initiative (Tropical Ecology Assessment and Monitoring) is a network of scientists committed to the establishment of standardised methods of data collection to quantify how plants and animals respond to pressures such as climate change and human encroachment. The focus of the initiative is on plants, terrestrial mammals, ground-dwelling birds in tropical forests around the globe which are comparatively untouched by humans. The network encompasses currently seventeen sites situated in Africa, Asia and Latin America. With their standardised set of methods that is also harmonised throughout the network, as well as with their clear focus on specific questions (e.g. spatial effects like fragmentation of habitats, human encroachment, habitat degradation) that are addressed with their monitoring, TEAM can be a role model for the development of the EU BON network.

2.2 The EU BON experience

The core sites which build the European Biodiversity Observation Network (Hoffmann *et al*. 2014) are the so-called “test sites”. They are: the Doñana Biological Reserve, the Sierra Nevada Observatory (both Spain), the Rhine-Main Observatory (Germany), and the Amvrakikos Wetland (Greece), representing European terrestrial (Doñana & Sierra Nevada), freshwater (Rhine-Main) and marine ecosystems (Amvrakikos) respectively. As an example of tropical systems the Brazilian Research Program in Biodiversity is included as an “associated site”. Two additional “associated sites” are linked to the EU BON consortium: the European Natural Park Mercantour/Alpi Marittime (France/Italy) and Israel's National Ecosystem Assessment Program (Hamaarag). This section gives an overview of the development, the ongoing monitoring activities, the research conducted at each of the sites and the implemented principles and guidelines (see also Table 2). Furthermore, the challenges that are encountered at each site are discussed and particular strengths of each site are highlighted. This self-assessment of the sites helps to identify strengths that can be developed further and strategically add new partners to the consortium that can offer solutions for the weaknesses that are still encountered. Additionally, to the concise information on each site that is given in this section, a more detailed description of each site can be found in appendix 5.2.

Table 2. Overview of the organisation of the test sites those are currently included in the EU BON consortium, as well as their individual strengths and challenges. A more detailed description of the sites is available in sections 2.2 and in appendix 5.2.

Site: Doñana Biological Station **Hosts:** Consejo Superior de Investigaciones Científicas (CSIC) **Data documentation:** In progress (EML) **Data publication:** Metadata (DEIMs/Lter) **Major challenges:** Inherited lack of clear objectives and overall working framework. Lack of a well-designed path and supporting system for the whole process of converting field data into knowledge. **Major achievements:** Owners of the “Lab in the field” with all required facilities, services and personnel Own staff, highly qualified.
Site: Rhine-Main-Observatory **Host:** Senckenberg Gesellschaft für Naturforschung (SGN) **Data documentation: EML (**DEIMS) **Data publication:** Yes; metadata: DEIMS; data: upon request through DEIMS **Major challenges:** Lack of sustainable funding. Analyses of data are mostly project-based. **Major achievements:** Highly equipped lab, office and accommodation facility at site; Parameterized hydrological model of the Kinzig catchment.
Site: Amvrakikos Wetland **Hosts:** Amvrakikos Management Body **Data documentation:** In progress (DwC) **Data publication:** Both data and metadata through MEDOBIS IPT **Major challenges:** Inherited lack of clear objectives and overall working framework. Lack of a well-designed path and supporting system for the whole process of converting field data into knowledge. Lack of sustainable funding. Lack of standardised protocols. **Major achievements:** Integration of the data at the MEDOBIS IPT. Design and implementation of the AmvrakikosBirds smartphone application.
Site: Brazilian Research Program in Biodiversity **Hosts:** Several academic and research organisations in Brazil. **Data documentation:** EML + Metacat. **Data publication:** Data and metadata available through Morpho + Metacat. **Major challenges:** Lack of sustainable funding for monitoring and data management. **Major achievements:** Quality of data and metadata. Data management workflow. A very large standardised sampling system distributed across Brazil.

Site: Sierra Nevada Observatory **Host:** Andalusian Regional Government and University of Granada **Data documentation:** EML + metacat **Data sharing:** Data through GBIF and metadata through metacat **Major challenges:** Lack of sustainable funding. Some monitoring protocols are not focused on relevant environmental variables. **Major achievements:** Excellent data management.
Site: Israel's National Biodiversity Monitoring Program **Hosts:** Israel Academy of Sciences **Data documentation:** Online **Data publication:** Online **Major challenges:** Program is fairly new (since 2012). Time will tell. **Major achievements:** Support and involvement of most stakeholders. Clear objectives and questions. Strong, top down management.
Site: European Natural Park Mercantour/Alpi Marittime **Hosts:** Parco natural Alpi Marittime & Parc national du Mercantour **Data documentation:** Online **Data publication:** Online **Major challenges:** Analysis and interpretation of the big amount of data gathered. **Major achievements:** Listed as European Park, huge biodiversity inventory with more than 10000 species recorded, some of them new to science

2.2.1 Doñana Biological Station

It is a research institute that leads, assists and conducts monitoring in Doñana National Park since the earliest 1970's, although this activity was not structured and organised as monitoring program until the beginning of the 2000's. The programme is structured in three sections: biotic, abiotic, and management monitoring. Its main goal is "to achieve long-term knowledge on the dynamics of Doñana natural processes and the conservation management effects on its biodiversity" (Diaz-Delgado 2010). The conceptual approach focused on monitoring species, habitats and ecological processes. Regarding species, monitoring focuses on key, endangered and threatened species. Regarding habitats, the focus is on the most representative habitats within the area and those underrepresented in existing long-term ecological research. Regarding ecological processes, both natural processes interlinking ecosystem functioning and structure and the human driven impacts (resulting from management decisions, including the conservation measures) are considered. Overall, 34 monitoring protocols are implemented in Doñana National Park. From them, only the international waterbird census (Wetland International) of Doñana is integrated in an international monitoring network from the beginning, while the migrating passerine ringing station recently adopted the international standard (EURING; constant effort ringing) but it is not officially integrated. More recently, passerine counts were modified to adopt international standards (Pan European Common Bird Monitoring Scheme) as well as butterflies counts (European Butterfly Monitoring Scheme). As part of the Spanish National Park Network, monitoring information was yearly reported to the National Government since the very beginning, but in the form of regular written reports. In 2007, the Institute joined the REDIAM (regional, Andalusian environmental information network) as initial network member, and the LTER-Europe network, and it has participated in several European projects aiming at networking environmental information. The most challenging issues regarding these initiatives were:

A. Shift from the local to the global perspective.
B. Get more familiar to data sharing tools.
C. Implement a data management plan where data from the field are digitized, curated, stored, annotated with metadata and shared.
D. Build, maintain and provide with personnel the storage facilities.
E. Get staff researchers more involved in the monitoring program.

Overall, the main strengths of the site are the high qualified staff exclusively devoted to monitoring and the full availability of the field site, its infrastructures and facilities to implement and conduct monitoring. Regarding limitations, the main objective of the monitoring program should be better delineated to improve the assessment of the ecosystem status and their related services in the international context while coping with periodic funding fluctuations. Data sharing is also limited in its current version. A better path and supporting system for the whole process of converting field data into knowledge is required.

2.2.2 Rhine-Main-Observatory

The Rhine-Main-Observatory (RMO), comprising the entire catchment area of the river Kinzig in Hesse, Germany, is run by Senckenberg since the early 2000´s, but some of the time series date back longer. The RMO is a node of the German Long-Term Ecological Research network (LTER-D). The research at the RMO focuses on the long-term changes in land use, climate and resulting hydrological regime, and the impacts of these changes on animal and plant communities. The key habitats under study are streams and their floodplains, which are underrepresented in existing long-term ecological research. At the same time, these ecotones are hotspots of biodiversity in Europe. Being excellent indicators of environmental status and changes, the taxonomic groups that are regularly monitored comprise stream benthic invertebrates, riparian vegetation, carabid beetles and spiders; a range of additional taxonomic groups are studied on project base. Additionally, we receive floristic and faunistic data from databases in regional environmental administration. Including data series on abiotic environmental pressures that affect biodiversity in river-floodplain environments, more than 30 monitoring protocols are implemented. These monitoring protocols follow the standards defined by the EU Water Framework Directive (EU WFD) and are thus highly comparable. Metadata on the monitoring is documented in DEIMS, where also contact points are indicated through which data can be obtained.

The monitoring data from the RMO is integrated and used in coupled hydrological and species distribution models that can be used to assess current distribution of biodiversity in dynamic habitats as well as for forecasting biodiversity under different future scenarios. Hence, data are well organised and data processing routines to generate derived biodiversity information are implemented. As an additional asset promoting also international scientific exchange, the RMO features a fully equipped lab, office and accommodation facility in the centre of the monitored area at which also guest researchers can be housed. As a downside, not all of this work that is carried out at the RMO is funded sustainably, but through sequential scientific projects inhibiting long-term planning in the monitoring and research at the RMO.

2.2.3 Amvrakikos Wetland

The lagoons of the Amvrakikos wetland are irregularly monitored since the early eighties. Most of the monitoring effort has been spent on the soft bottom habitats, both on abiotic and biotic variables. Lots of monitoring activity was also on bird watching by both professionals and amateurs.

The major challenge for the study and monitoring of the biodiversity hosted by the Amvrakikos lagoons is to derive data from different levels of the biological organisation (e.g. genes, species, communities/ecosystems) and compare their information patterns. Currently, five monitoring protocols are implemented. Meta data are documented through the DwC and stored in the IPT MedOBIS server, which is the Mediterranean node of the European one.

Among the weaknesses of the approach one can cite the lack of clear objectives and overall working framework when the monitoring started in the early eighties. In addition, there is a lack of a well-designed path and supporting system for the whole process of converting field data into knowledge. Constant state funding is also missing. Finally, there were no standardised protocols for the storage of the data in the past.

In the strengths of the approach are included the integration of the data at the MedOBIS IPT server, the data are quality controlled, the targeted sampling protocol implemented along the marine-lagoonal habitat axis and the multiple levels of the biological organisation from which data are collected, including the abiotic ones. Finally, the design and implementation of the AmvrakikosBirds smartphone application for a citizen science project to be implemented and sustained by the managing authority of the Wetlands.

The guidelines/principles followed so far are:

A. To include this area of natural beauty to the NATURA 2000 Network.
B. Spread a set of stations to cover the main habitats.
C. Try to cover as many components of the transitional (lagoonal) ecosystem as possible (e.g. water column: plankton and fish, sediments: macrobenthos).
D. Secure monitoring effort through the funding of various projects.
E. Include sampling stations of the lagoons in the grid of stations monitored in the context of the Water Framework Directive.
F. Inform local communities about the research work carried out and analysing the incentives.
G. Build capacity and trust of the local authorities by participating to the events organised by the region of Epirous and Municipality of Arta.
H. Involve the local people and the personnel of the managing authority.
I. Increasing effort to include monitoring of the genetic diversity in macrobenthic species populations and bacteria.
J. Trying to measure nutrient fluxes.
K. Expand the knowledge by conducting manipulative experiments.
L. Developing a network of citizen scientists.

2.2.4 Brazilian Research Program in Biodiversity

Created in 2004, the Brazilian Research Program in Biodiversity - PPBio was developed in line with the Convention on Biological Diversity and the Brazilian National Biodiversity Policy. PPBio has the mission to articulate regional and national competence to expand and disseminate biodiversity information in a planned and coordinated form. To achieve this, PPBio adopted a model of decentralized logistic management associated with a system of standardised sampling design and a centralized data management (methodological details can be found here: http://ppbio.inpa.gov.br/metodos). PPBio logistic management is organised by a system of several local hubs distributed across the major Brazilian biomes that follow some general guidelines:

A. The sampling design is spatially standardised.
B. Allow integrated studies.
C. Is compatible with other surveys currently being conducted (i.e. TEAM, CTFS, WCS).
D. Is modular, to allow comparative analysis between different sampling intensities.
E. The data and metadata must be fully available for the community in feasible time.

The last guideline is the most challenging. The data management is centralized and uses the Metacat system that is used by the International Long-Term Ecological Research (ILTER) sites throughout the world. The system does not allow automatic upload of data by individual researchers, because we, and many other programs, found that it was not possible to guarantee adequate quality control, and all data are verified by a full-time staff member before being made available in the repository. The lack of sustainable funding for the data management staff and to promote regular general meetings is our major challenge.

The strengths of PPBio program relies on the quality of data and metadata; the standardised sampling design, which makes the data integration and analysis easier; the decentralized logistic management; and a strong training program for local hub members. Each local hub defines its priorities and appropriate targets always related to its own implementation capacity and following the Program general guidelines. This strategy results in a bottom-up knowledge construction directly connected to local needs. As some general information is important across all local hubs, such as topographical, soil and vegetation data, the monitoring of general targets can be scaled up relatively easy with appropriate funding. Videos and leaflets that describe field and laboratory methods for environmental and many target taxa are available from http://ppbio.inpa.gov.br/metodos.

2.2.5 Sierra Nevada Observatory

The Sierra Nevada Global Change Observatory (Aspizua *et al.* 2013) was created (in 2007) to address the convergent needs: a) both local and international scientists showed their interest in doing research in this natural laboratory that contains several ecosystem types, high biodiversity and a great wealth of abiotic conditions. b) local managers have the responsibility to improve the capacity of ecosystems to adapt themselves to the impact of global change. In order to satisfy these needs, both the Andalusian government and the University of Granada, designed a conceptual framework that considers both bottom-up and top-down approaches. Sierra Nevada Global Change Observatory operates in a well-defined area, but put into practice monitoring methods that have been implemented also in other territories. GLOCHAMORE (GLObal CHAnge in MOuntains REgions) strategy provided the thematic conceptual framework to design an international compliant monitoring program in Sierra Nevada.

At the moment, the Observatory has four fundamental parts:

A. A monitoring program that aims to collect socio-ecologic data in Sierra Nevada. It currently comprises 48 different monitoring methods that gather information about composition, function and structure of the socio-ecological system of Sierra Nevada.
B. An information system to manage all the collected information. We are following the data management philosophy proposed by US-LTER network. All the collected information is documented using international standards (EML, INSPIRE). It is also stored in relational databases. We are also using model repositories to document algorithms and models. Finally all the information is accessible via web portal (http://linaria.obsnev.es).
C. Mechanism to promote outreach of results to citizens and stakeholders.
D. Procedures to enrich the environmental decision process with the knowledge created in the monitoring program. This is one of the key pillars of the Observatory. The idea is to implement an adaptive management cycle that helps to minimize the impact of global change on local ecosystems.

Many of the sampling points used to gather biophysical information are spatially clustered in areas containing high density of points. These areas are called Highly Monitored Areas (EMI, in Spanish). Each EMI contains also a meteorological station. But as Sierra Nevada is located in a historically human managed area, we are also investing effort in gather historical information on the structure and dynamics of local ecosystems. The idea is that understand the past can also help us to understand the present time and even forecast the status of the system in a global change scenario.

Sierra Nevada Global Change Observatory becomes a LTER site in 2008. At the moment we have contributed to create a regional network of observatories. Sierra Nevada site is also involved in a national network to monitor the impact of global change in Spanish National Parks. We have strong links with LTER Europe and LTER USA. Sierra Nevada Observatory is also integrated in REDIAM (regional, Andalusian environmental information network). Finally we are involved in the building of LifeWatch.

During its first seven years, the Sierra Nevada Observatory has demonstrated to be a useful tool that can help both scientists and managers to satisfy their needs. However, we still have to overcome some relevant weaknesses:

- ⇨ Sustainable funding: the current economic crisis has provoked a strong cutting in the amount of data collected. We must find alternative ways of attracting resources.

⇨ Some monitoring protocols are not focused on relevant environmental variables. GLOCHAMORE was a good conceptual framework at the beginning, but we have to address the adaptation of our monitoring program to novel approaches.

On the other hand, the most important strengths are:

⇨ Data management. We have been able to create a comprehensive information system that can be applicable to other sites sharing similar objectives.

⇨ Good balance between local needs (bottom-up approach) and international commitments (Top-down approach).

2.2.6 Israel's National Biodiversity Monitoring Program

Israel's National Biodiversity program, commonly known under the name "Hamaarag" (the word means "web", as in food web in Hebrew), was founded in 2006, following a decade's worth of research in the Long Term Ecological Research stations. Hamaarag is a consortium of the organisations that manage Israel's "open landscapes" - the Israeli Nature and Parks Authority (INPA), the Ministry of Environmental Protection (MEP) and the Jewish National Fund (JNF, the Israeli forestry service). Hamarrag works to promote science-based management of open landscapes and natural resources, for human well-being and for long-term sustainability of nature in Israel. Hamaarag's key objective is to publish periodic State of Nature Reports. The first such national report was published in 2011 and since then the State of Nature Report - Mediterranean Sea (2013) as well as the State of Nature - Aquatic Habitats (2014) were published. The next national report is coming up.

In 2010 the decision was made in Hamaarag to develop a National Program for Terrestrial Biodiversity Monitoring. The national monitoring program was developed during 2010-2011 by an interdisciplinary team of over 70 scientists, professionals from different fields and open landscape managers. The process included dividing Israel into 12 units (ecosystems or geographic regions). For each unit a dedicated team of experts determined the most significant processes taking place within that unit, including threats to nature, and the relevant indicators for monitoring. These indicators included, among others, annual and perennial vegetation, mammals, birds, reptiles and arthropods.

Monitoring commenced in early 2012, using advanced scientific tools and methods, including development of software for collecting field data, use of surveillance cameras for monitoring mammals, and remote sensing tools (satellite images and aerial photographs) for monitoring changes in the vegetation. The first full cycle of the monitoring program was completed in 2014, and the second cycle has been initiated.

The objective of the monitoring program is to generate a quantitative and qualitative characterization of Israel's major ecosystems within a systemic and long term framework. This will enable an assessment of the state of Israel's nature and an identification of major changes and trends, specifically those that indicate deterioration in the ecosystems functions and biodiversity. The insights from the monitoring program should enable managers and decision makers to make informed decisions regarding the future of Israel's "open landscapes".

The monitoring program is comprised of the following components:

A. Data collection: primarily performed by field technicians or through the analysis of remote sensing data.
B. Data Management: the set of tools that is used to collect the data (apps), store it and manage the lifecycle.
C. Data Analysis: statistical analysis and synthesis of the data.
D. Dissemination: through reports, publication of raw data, a web site intended for the general public and social media. Dissemination is intended for a local audience and is primarily in Hebrew.

The National Monitoring Program is a new program and as such is still in development. While the data collection and dissemination components of the program are fairly robust and well developed, data management and data analysis still require further investment in order for the monitoring program to meet its objectives. The main challenge facing the monitoring program, and Hamaarag in general, is securing long term sustainability for the program. Hamaarag is funded by the partner organisations and substantial donation from a philanthropic fund. However, in order to ensure long term existence the activity should eventually be based on a government decision and statutory obligation to perform these activities. Achieving this goal is a major challenge for Hamaarag.

2.2.7 European Natural Park Mercantour/Alpi Marittime

The protection and conservation of the exceptional natural heritage of the Maritime Mercantour area constitute the institutional aims of both the Mercantour National Park (France) and the Alpi Marittime Natural Park (Italy). Both natural areas have been twinned since 1987, with the common ambition of enhancing territorial continuity that ignores any border. This strong collaboration, probably one of the most successful among European contiguous parks, allowed them to become, in 2011, the first real European Park. It was selected as a pilot area for the first All Taxa Biodiversity Inventory + Monitoring (ATBI+M) in Europe with the major involvement of the Muséum national d'Histoire naturelle in Paris and the Museo Regionale di Scienze Naturali in Turin, which keep and display the specimens found in the park.

Today, more than 12.000 species are inventoried, and around 100.000 data have already been acquired on the park. Monitoring is also being conducted in the park, mainly by rangers with existing monitoring protocols on the most well-known or patrimonial species: bats, galliforms, ungulates, wolves and protected flora, some of them running for more than 20 years. The main aim is "to define sampling and identification protocols and to introduce innovative techniques for establishing a research strategy that may be used in future monitoring and similar projects" (De Biaggi *et a*l. 2010). Since 2009, the activity is organised in workgroups "to improve the efficiency of the inventorying activities in collected species, shared experience, sampled biological material distributed to a pool of experts, etc. These groups focus on specific taxonomic groups, habitats and sampling methods. Workgroups are indeed important because it is their duty to produce such protocols with the help of a scientific advisory board that reunites several Italian and French taxonomists and other conservation experts. As the inventory includes all living species, we are currently trying to involve experts on less studied groups or on higher taxa on which information is still scarce. Some workgroups are involved in ecological studies on specific areas. The inventory is an important opportunity for scientists to carry out wider research on habitat conditions and on the impact of human activities on the environment" (De Biaggi *et al*. 2010).

However, some analysis and interpretation of this big amount of data are still missing. Therefore, Mercantour Alpi Marittime European Park encourage scientists to work on their dataset, in order to better understand the functioning of their ecosystem and to better manage and protect their fauna and flora populations.

3 Guidelines and principles for establishing biodiversity monitoring sites in Europe

The criteria proposed in this document are set in a way that allows: (A) a self-evaluation of existing sites with respect to their contribution to a biodiversity monitoring network and towards the overarching high-profile targets and indicators raised in the CBD and in the EU relevant Framework Directives. (B) Provide recommendations for the start-up of new monitoring sites and on best practice in the field of biodiversity monitoring. (C) Facilitate a self-assessment of existing networks with respect to their strengths and gaps and thereby their capacity to address overarching questions on biodiversity patterns and trends.

As a rule of thumb, there are many ways in which a monitoring network could be designed, and the design process has different parts. In this document we will focus on the following aspects: the target population (what to measure, section 3.1), the selection of suitable monitoring sites, representative of the main habitats and land-use categories (where to measure, section 3.2), and the methods/guidelines that should be taken into account when collecting (how to measure, section 3.3) and the biodiversity data storing (data management plan, section 3.4) of the EU BON network.

Proper design always implies clear understanding of the monitoring objectives. However, there are some general requirements common to all monitoring programmes (see Eberhardt and Thomas, 1991; Parr *et al.*, 2002):

A. Monitoring should be able to distinguish between ‘noise’ (random variation) and ‘signals’ (real directional trend) and this is related with the type of study on which monitoring is based, the sampling density, and the indicators used. In this context, a proper selection of Essential Biodiversity Variables is an example (see section 3.1);
B. Monitoring should allow inferences on the target variable (in this case different levels of biodiversity: gene (molecule), individual, species, population, community, ecosystem, biome, global). However, the strength of inferences (e.g. the value of the conclusion) is based on the sampling strategy and tactics of the programme (Stevens, 1994; Ferretti and Erhardt, 2002). In these respects, questions about the representativity and the rigorous sampling designs of EU BON test sites (see sections 2.2 and 2.3) are important challenges;

Design means decisions to be made during the development phase, and decisions need documentation. This part of the design has a great deal to do with Quality Assurance (QA), and Quality Management (Shampine, 1993; Brunialti *et al.*, 2004; Ferretti, 2009). In line with this, other parts of the design process should consider QA procedures (Cline and Burkman, 1989; Ferretti, 2011), network management, data management (e.g. Lane, 1997; Stafford, 1993) and reporting rules (Shampine, 1993). In the context of the EU BON network all these issues with regard to information and data management should be also taken into account (see sections 3.4).

These guidelines are thus a cornerstone to the intents of EU BON to develop a full-scale model for a durable mechanism for higher-level integration of biodiversity information providers and users through a network of networks approach scalable from local to global biodiversity observation systems. To achieve this ambitious target, a key feature is the delivery of near-real-time relevant data to the various stakeholders and end users ranging from local to global levels. To achieve this goal, relevant and coherent information on biodiversity of defined spatial and temporal contexts are necessary. The following recommendations provide advice on how to make perform operational biodiversity assessments. Likewise, a number of recommendations are given after each topic, which draft different levels of maturity for test sites, helping them in establishing clear and measurable guidelines to be adopted or work towards. We formulated a number of recommendations that monitoring sites should adhere to. For most of the recommendations, two-stage graded recommendations are made. Adhering to these recommendations made for “regular biodiversity survey sites” ensures that the monitoring program follows well-defined protocols, and data are suitable for integration in a network of biodiversity monitoring at larger than local spatial scale. All sites are encouraged to follow these recommendations. Expanded and/or more strict recommendations must be followed to be recognised as a “detailed biodiversity survey site”. Sites that follow recommendations at this second level have more comprehensive monitoring programs, a more detailed documentation, and their data are more readily available to the scientific community. Hence, such sites are particularly suited for integrated biodiversity assessments.

3.1 What to measure?

The first question when designing a monitoring scheme is what the relevant aspects of biodiversity to be monitored are. Traditionally, biodiversity is recognised at three key levels: genes, species, and ecosystems. We may distinguish also different dimensions of biodiversity, i.e. composition, structure and function (see Figure 4, Noss, 1990 and Table 3 on EBVs).

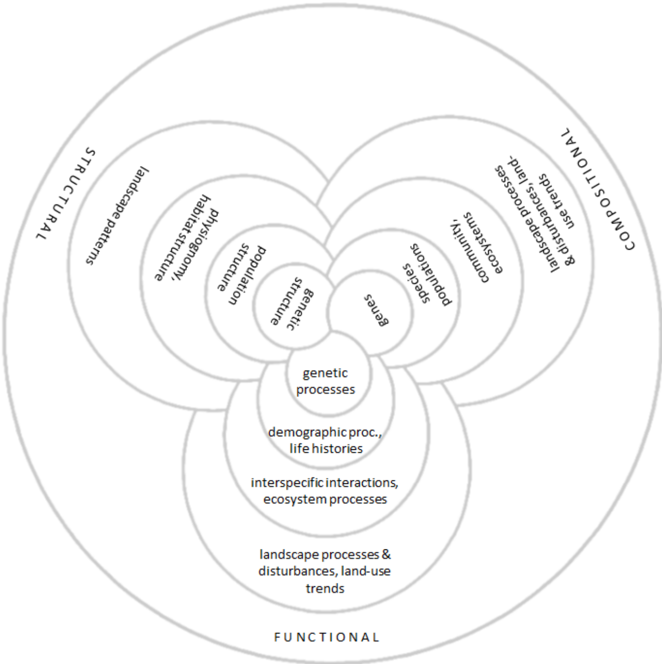


Figure 4. Three different dimensions of biodiversity: compositional, structural and functional. Redrawn from Noss (1990).

Given the ongoing debate on what are the most important aspects of biodiversity, it is often desirable to measure as much as possible. However, this is not feasible because resources are limited and unfocused monitoring activities that produce a plethora of incoherent data are not useful either. To develop a robust monitoring scheme, it is firstly important to identify key biodiversity variables to measure through selection criteria. We suggest the measured variables should be selected in light of the following points:

A. Sensitivity to natural or anthropogenic drivers;
B. Scientific validity;
C. Ecological relevance;
D. Relevance to and resonance with diverse stakeholders;
E. Sustainability of monitoring capacity;
F. Practicality.

In fact, according to Lindenmayer and Likens (2010), issues arise with monitoring programs when attempting to overcome uncertainties in selection of variables to monitor by: 1) monitoring too many variables and, 2) monitoring indicator species. Lindenmayer and Likens (2010) suggest the key phase to avoid these issues is by thinking early on and carefully about the questions that are being asked.

Asking well-defined questions will inevitably lead to selecting the right variables to monitor. Consequently, already existing test sites that were all started with an own background of research questions typically will monitor different biodiversity elements, partly also employing different methodologies that were developed in their research community.

There are other approaches for measuring biodiversity, such as using surrogates or proxies. For instance, for simplicity and cost-effectiveness the EBONE approach considers habitat to be a conservation umbrella for biodiversity (de Blust *et al.* 2012). They use this term in its broader sense, where habitat is “an element of land that can be consistently defined spatially in the field in order to define the principal environments in which organisms live” (Bunce *et al.* 2011). Of course, when habitats are highly fragmented, local habitat quality may not represent biodiversity adequately.

It is critical to ensure transferability and common parameters that can be implemented and reported on across locations, organism groups, and habitat types. Given the wide range of organisms and ecosystems, the range of potential variables that can be measured at a biodiversity monitoring site is extensive. Significant effort has been made in the past decade to synthesise and optimise methods, in order to be repeatable and consistent between sites and monitoring networks, both in Europe and abroad. One such example on a global scale to harmonise existing monitoring schemes and the development of new monitoring schemes, particularly where there are gaps in current knowledge and biodiversity data remains sparse, is the Essential Biodiversity Variables (EBVs) approach (Pereira *et al.* 2013).

Pereira *et al.* (2013) identified six classes of EBVs in an attempt to operationalise biodiversity assessments. The full suite of candidate EBVs developed under this program is available at https://www.earthobservations.org/geobon_ebv.shtml (see also Table 3). There are different ways to measure EBVs; some are typically measured through local sampling (human assessment or sensor-based), others can also be measured through remote sensing and across large areas. Particularly the rapid development of remote sensing techniques currently offers new types of biodiversity data at previously not achieved spatial and temporal resolutions. However, the adequacy of earth observation products for obtaining useful data largely varies between the different EBVs, as it was also shown for biodiversity related policies (Secades et. al 2014).

EBVs are unique in that they allow changes to monitoring techniques and technological advances (Pereira *et al.* 2013). More specifically, they were developed to provide an intermediate layer between primary observations from biodiversity networks and higher level aggregated indicators. With its broad applicability, the framework of EBVs also lends to comparative large-scale and cross-realm biodiversity assessments. Several important policy instruments already require biodiversity information from several EBVs. Examples for the Habitats Directive (HD), the Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD) or the Birds Directive (BD) are presented in Table 3 (see Geijzendorffer *et al.* in review for more details). The EU BON network sees a great potential to EBVs as a framework to construct data flows, indicators computation and harmonise monitoring schemes for biodiversity observation networks.

However, representation of these EBVs in existing biodiversity monitoring schemes is variable. A gap analysis conducted within EU BON revealed that comprehensive biodiversity data are predominantly available for three EBV classes only: species populations, species traits, and community composition (Geijzendorffer *et al.* in review; Wetzel *et al.* 2014). In contrast, well-structured, long-term information on other EBVs such as genetic composition and ecosystem function are particularly lacking. Where gaps are evident for certain EBV classes, Geijzendorffer *et al.* (in review) identified the following options to improve them:

- ⇨ Ecosystem structure: existing data needs better mobilisation, integration or modelling.
- ⇨ Genetic composition and ecosystem function: primary data are lacking and thus requires more monitoring on all levels (including microbial communities).
- ⇨ Community composition, ecosystem structure and ecosystem function: existing indicators could be used as proxies to improve reporting.

Table 3. Correlation between the Essential Biodiversity variables (EBVs) and their current requirement for the reporting under the respective European policy instruments: the Habitats Directive (HD), the Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD) and the Birds Directive (BD) (based on Geijzendorffer *et al.* in review for more details). Full details of the EBVs and their measurement, scalability, temporal sensibility, and relevance and relationship to CBD 2020 targets can be found here: https://www.earthobservations.org/geobon_ebv.shtml.

EBV class	**EBV**	**EBV demanded for by respective directive**			
		HD	**WFD**	**MSFD**	**BD**
Genetic composition	Co-ancestry	No	No	No	No
	Allelic diversity	No	No	No	No
	Population genetic differentiation	No	No	No	No
	Breed and variety diversity	No	No	No	No
Species populations	Species distribution	**Yes**	**Yes**	**Yes**	**Yes**
	Population abundance	**Yes**	**Yes**	**Yes**	**Yes**
	Population structure by age/size class	No	**Yes**	**Yes**	**Yes**
Species traits	Phenology	No	**Yes**	No	**Yes**
	Body mass	No	No	**Yes**	No
	Natal dispersal distance	No	No	No	**Yes**
	Migratory behaviour	No	**Yes**	No	No
	Demographic traits	No	No	No	**Yes**
	Physiological traits	No	No	No	No
Community composition	Taxonomic diversity	No	**Yes**	**Yes**	No
	Species interactions	No	**Yes**	**Yes**	No
Ecosystem structure	Net primary productivity	No	**Yes**	**Yes**	No
	Secondary productivity	No	No	**Yes**	No
	Nutrient retention	No	No	No	No
	Disturbance regime	**Yes**	**Yes**	**Yes**	**Yes**
Ecosystem Function	Habitat structure	**Yes**	**Yes**	**Yes**	**Yes**
	Ecosystem extent and fragmentation	**Yes**	**Yes**	**Yes**	**Yes**
	Ecosystem composition by functional type	No	No	**Yes**	No

Nevertheless, EBVs were developed specifically to provide a basis of monitoring programs worldwide, and thus provide an ideal set of variables to form the basis across the board in the EU BON network of sites. But even in EBVs that are frequently monitored, monitoring is commonly biased towards some taxonomic groups, which are often regarded more charismatic than others. Commonly surveyed taxonomic groups include birds, butterflies, bats and vegetation (Wetzel *et al.* 2014). To enhance the sensibility in the detection of biodiversity change, there is also the need to include additional terrestrial, freshwater or marine taxa in the monitoring efforts.

The ‘intermediate layer’ focus of EBVs enables cross-disciplinary and cross-location monitoring. However, it does not provide a highly specific set of measurements to make for practitioners. Given the variable nature of sites and organisms monitored in the EU BON network, it is not possible to provide specific variables to measure across all disciplines. However, excellent examples of the types of approach that could be taken are available in the Arctic marine biodiversity monitoring plan (Gill *et al.* 2011). For instance, for the category fish, under the focal ecosystem component pelagic fish, they specify the key parameters as: relative abundance; number of each species; age/size distribution; fish length; geographic coordinates and depth; temperature, salinity, substrate; barcoding, other genomics; preservation of voucher specimens. They go on to provide the following set of indicators for each of these key parameters: Species composition, diversity indices; relative abundance; size ranges; geographic and bathymetric distribution of species; habitat variable associations; taxonomic resolution, species identification; primary documentation for species identifications and distributions. Given this level of detail, it is not possible to replicate a specific set of parameters and indicators for all habitats and organisms in the EU BON network.

Recommendation 1 (Sampling effort for EBVs):

- ★ For “regular biodiversity survey sites”: The monitoring program of such a site should include monitoring protocols representing at least 6 different essential biodiversity variables (EBVs) from at least 2 EBV classes.
- ★ For “detailed biodiversity survey sites”: The monitoring program of such a site should include monitoring protocols representing at least 9 different EBVs from at least 3 EBV classes.

Many pan-European initiatives have attempted to streamline and increase the comparability of biodiversity monitoring programs across habitats and organisms, using pre-existing guidelines. These initiatives include EBONE, Streamlining European 2010 Biodiversity Indicators (SEBI2010), and EnvEurope. These scientific efforts are flanked by political declarations of intents and standard specifications as for example the Habitats Directive (HD), the EU Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). All these initiatives of streamlining monitoring schemes are intrinsically tied to simultaneous efforts to achieve a higher methodological comparability between monitoring data. This aspect is dealt with in section 3.3 of this report.

In the field of National Forest Inventories, Winter *et al.* (2011) provide an example of process to select essential forest biodiversity variables. In particular, the first step in the procedure to select the essential forest biodiversity features was to identify a set of relevant candidate forest management and ecological variables. The selection was based on information from multiple sources including the Convention on Biological Diversity (CBD 1992; UNEP 2003), the indicators for sustainable forest management established by the Ministerial Conference on the Protection of Forests in Europe (MCPFE 1997, 2003a, b), the Biodiversity Evaluation Tools for European Forests developed in the BEAR project (Larsson *et al.* 2001), the European Environmental Agency (EEA) Core Set of Indicators for Biodiversity and Nature Protection (EEA 2003).

To contextualize biodiversity data and analyse the reaction of biodiversity to different environmental pressures as well as the drivers that stand behind them, monitoring should include also these relevant pressures. Without these data on the environmental, but also socio-economic developments, observed trends in biodiversity cannot be explained. We suggest the use of the “Driver-Pressure-State-Impact-

Response"-model (DPSIR model) developed by the EEA to structure thinking about the interplay between biodiversity, the environment and socio-economic activities of man (EEA 1999).

These pressures differ, depending on the research question of the institution running a test site, and therefore will not be fully compatible. Common pressures that are considered are climate change (in which case climatic variables will be monitored) as well as land use change (in which case land use types and intensities, habitat fragmentation, pollution, may be monitored).

With the many different research questions that can be addressed, this document cannot give an exhaustive overview of which variables have to be measured in which field. However, it is important to be informed in the respective research community of the scientific state-of-the-art in monitoring. It is furthermore important that spatial and temporal scales of biodiversity monitoring and the monitoring of additional data on environmental pressures fit together.

Recommendation 2 (Sampling effort for pressures):

- ★ For "regular biodiversity survey sites": The monitoring program of such sites should cover 5 to 10 associated data series on environmental pressures that affect the biodiversity elements under investigation.
- ★ For "detailed biodiversity survey sites": The monitoring program of such sites should cover more than 10 associated data series on environmental pressures that affect the biodiversity elements under investigation.

3.2 Where to measure?

Sampling, on the one hand, controls the inferential process and on the other, the precision of the estimates of a survey (e.g. Parr *et al.*, 2002). For this reason, sampling design is a critical part of the design process and is considered here in relation to the selection of monitoring sites.

A large number of different analyses exists which divide space into different unique units. Besides the desire to identify unique regions, which would require specifically tailored conservation assessments and strategies, the different concepts are often used to prioritise resources. In the following, we focus on Europe. However, the European aspects of the results of global studies are considered as well and for other regions the overall principles remain the same, only the underlying data have to be adapted. We start with the broad categories and move gradually to the more detailed studies. It should be noted here that the EU BON Consortium has no desire judge the different studies but, rather, to present the main ones and assess what this means where EU BON testing sites should measure biodiversity and related aspects.

General aspects from a biodiversity point of view are:

- ⇨ Independent of which of the schemes mentioned below are used to stratify biodiversity observation sites within the larger regions, it makes sense to distribute measurement sites so that environmental gradients are taken into account. For example reflecting latitudinal gradients in the climate and therefore many other linked gradients such as altitude and precipitation.
- ⇨ Furthermore, the "Natura 2000" network can be used to establish measurement sites which measure inside and outside protected areas. The main effect will be to enable conclusions on the effectiveness of the protection.
- ⇨ Choose appropriate spatial resolution and extent to match biodiversity elements to be measured and the environmental pressures that are expected to affect biodiversity. Simply speaking it means that large areas need relatively more measurement sites than smaller ones (see also section 3.3 for details on sampling effort).

Areas and regions can be important from a historic and evolutionary and perspective. Climate and habitats have changed in the past. These changes had a strong influence on the current distribution of biodiversity. Areas with strong climatic changes experienced large changes in biodiversity whereas other areas were relatively stable. These climatically stable habitats were one important component for speciation processes and they often harbour endemic species (e.g. Haffer 1969). In addition, these areas commonly coincide with areas of high biodiversity (e.g. Graham *et al*. 2006). So their value stems not only from the historic perspective and the current high diversity but it is also expected that they are relatively stable under projected future climate changes. A systematic overview of the exact location of these climate refugia is not available and is beyond the scope of this deliverable. However, a vast number of detailed analyses of selected species groups exist. They highlight for example the importance of areas south of the Pyrenees and the Alps, meaning the Iberian Peninsula, Italy and the Balkan region, including Greece.

- ⇨ Test sites should take historic and evolutionary gradients (e.g. Pleistocene refugia) into account if information is available for the taxa under investigation and invest resources in making old time series usable.

Traditional approaches are the definitions of biogeographical regions, based on data mainly of plants but occasionally including selected animal taxa (e.g. the hotspot concept developed by Conservation International; Myers 1988, 1990; Myers et al. 2000). For Europe, a large number of different approaches came forward over time. The most recent one was developed within the frame of the "Natura 2000" which was initiated to develop a comprehensive network of protected areas in Europe. In total eleven biogeographic regions and five sea regions were marked (http://bd.eionet.europa.eu/activities/Natura_2000/chapter1 (26.1.2015, see also Figure 5).

- ⇨ All biogeographic regions have to be covered by networks of biodiversity observation sites with a special focus on those that harbour a high biodiversity and/or rare habitats.

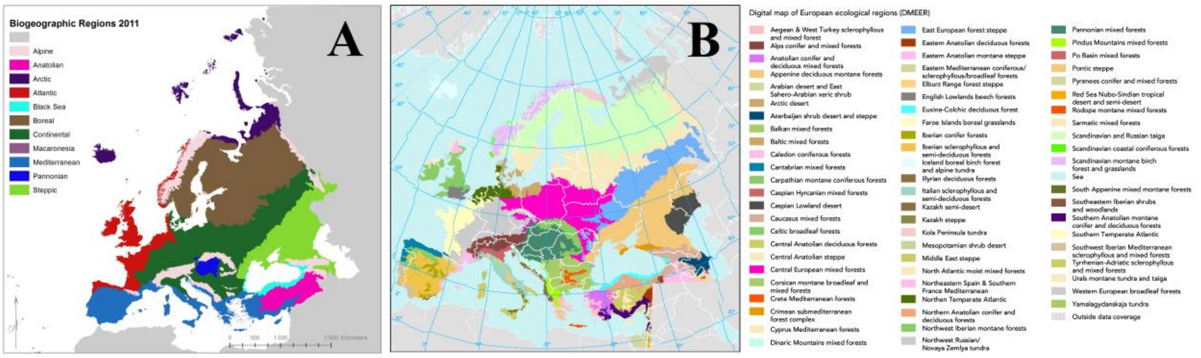


Figure 5. Biogeographic regions of Europe as identified by the European Environmental Agency within the Natura 2000 framework (A). The marine regions "Atlantic", "Baltic", "Black Sea", "Macaronesia" and Mediterranean are not displayed, and ecological regions of Europe (DMEER) (B) (both modified from http://www.eea.europa.eu/ last access 26.1.2015).

One of the most prominent global investigations, initiated by Conservation International, identified a number of so called biodiversity hotspots, meaning regions which have a large number of threatened and endemic taxa to that particular region. According to that Europe contains one hotspot, the Mediterranean Basin (Myers 1988, 1990; Myers *et al.* 2000).

⇨ The Mediterranean basin has to contain biodiversity observation sites.

In another approach by the Wildlife Conservation Society the emphasis was laid more on anthropogenic influences and two indices were calculated: the Human footprint index and the Human influence index. The combination resulted in areas which were called "last of the wild". The largest areas of this kind were located in Scandinavia and Iceland. A large number of smaller areas were dispersed throughout the European continent with larger agglomerations in the Mediterranean biome as well as adjacent to it in areas of France and Italy (see Figure 6A-C; Sanderson *et al.* 2002, LWP-2 2005). Ellis and Ramankutty (2008) focused even more on the anthropogenic impact and defined a number of so called "anthropogenic biomes". Overall results are similar to the "last of the wild" analysis but the results are more differentiated (see Figure 6D). Subsequently, together with others they then assessed areas of biggest changes over the last few centuries (Ellis *et al.* 2010, 2012, 2013).

⇨ Ideally biodiversity observation sites have to be located along a gradient of disturbance, ranging from "natural" areas to highly transformed landscapes by considering existing classification schemes such as "last of the wild" areas or anthropogenic biomes.

There are a number of threats to biodiversity which are not included in the works mentioned above. For some of these threats, maps without gaps have only been recently provided. One example of a major threat to biodiversity is nitrogen (see review by Hicks *et al.* 2011, Sutton *et al.* 2014, see Figure 7).

⇨ Biodiversity observation sites should cover these threats and measure in areas with lowest threats (baseline) and areas with different degrees of threats (to assess influence of threats).

A global analysis of the World Wide Fund for Nature (WWF) distinguished so called ecoregions (Olson & Dinerstein 1998, Olson *et al.* 2001). The analysis came up with 825 terrestrial ecoregions in the world of which 65 are found in Europe. Concerning conservation priorities, the ecoregions were ranked and the top 200 ("Global 200") showed four ecoregions within Europe (Caucasian-Anatolian-Hyrcanian temperate forests; European-Mediterranean montane forests; Fenno-Scandia alpine tundra and taiga; Mediterranean forests, woodlands and scrub). Besides other habitats, forests are one of the most important sources of biodiversity. Thus, it makes sense to analyse the distribution of forests in more detail, including different levels and types of forests. The analysis is of high interest because it employed the same methods to include the freshwater and marine realms. In Europe 23 marine and 44 freshwater ecoregions are found. Six of these “Global 200” water ecoregions are found in Europe. A much more fine grained but methodologically similar approach used data from a “Shuttle Radar Topography Mission” (SRTM) to derive hydrological basins at so called “Pfafstetter” levels from 1 to 12. Data are available at three arc-seconds even (ca. 90m at equator) (HydroSHEDS database, Lehner *et al.* 2008; see also Lehner & Grill 2013 for more recent developments).

Besides the comparison of the conservation status of the ecoregions, the analysis also classified the G200 by their vulnerability to climate change into three categories: low, medium and high.

- ⇨ The biodiversity observation sites should get data at least from the G200 which are located in Europe. Ideally they should cover as much diversity as possible and thus sample in each ecoregion their area is covering.
- ⇨ For freshwater the unique realms have to be considered and ideally diversity should be measured in different hydrological basins. The resolution depends on a number of factors (see 3.3).
- ⇨ Marine measurement sites should be located in each marine ecoregion.
- ⇨ Ideally each climate change category, as developed by the WWF, for each ecoregion should be covered.

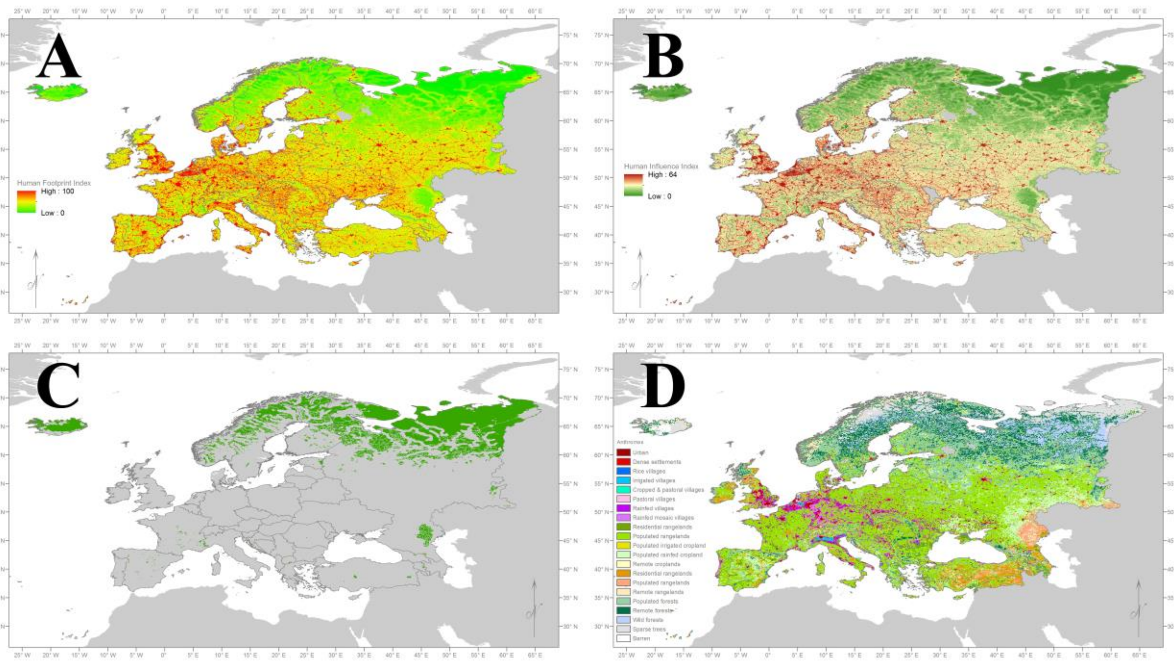


Figure 6. European distribution of the human footprint index (A), the human influence index (B) and the “last of the wild areas” (C). Modified from Sanderson et al (2002) and WCS & CIESIN (2005) as well as the current state of the anthropogenic biomes of Europe (D; modified from Ellis & Ramankutty 2008).

As the EU BON specific gap analysis on biodiversity data shows, there are major spatial gaps for biodiversity information existing on different spatial scales (Wetzel et.al 2014). For example when analysing data availability in Europe, the analysis shows that while for countries of Scandinavia and Western Europe data availability is often satisfying, East and South-East European countries are often covered only poorly or not at all. There is also the need to cover the different biomes and biogeographic regions in Europe appropriately, and to reach out for an integration of datasets from marine, terrestrial as well as freshwater areas. Specifically for some species the monitoring efforts have to be increased, for example for marine species where data are often scarce.

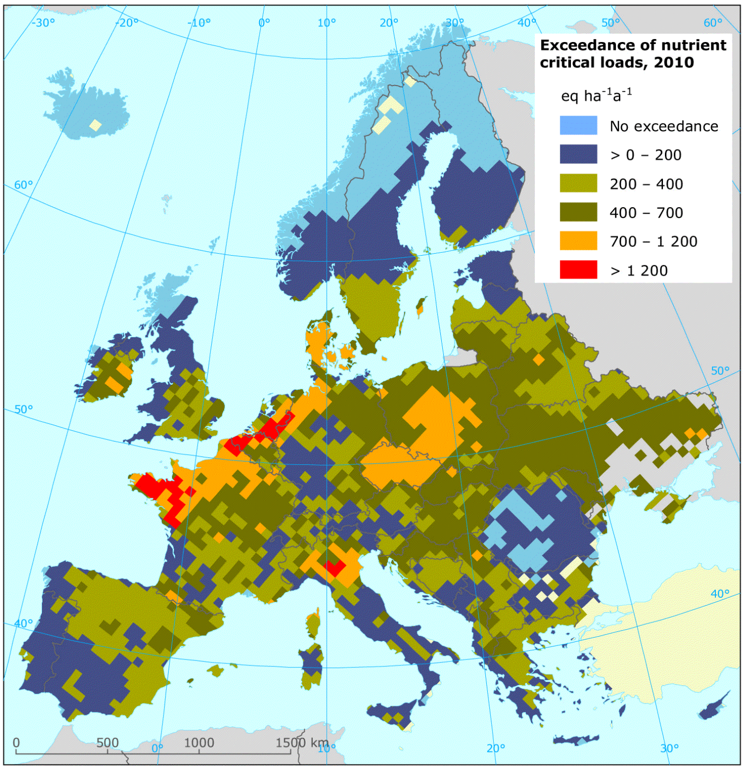


Figure 7. Nitrogen input across Europe. Analyses were conducted with the 2008 Critical Loads database hosted by the Coordination Centre for Effects (CCE). Modified from http://www.eea.europa.eu/ (last access 26.1.2015).

Describing the land cover of Europe has been a challenge, as in other parts of the world. The broad scales are well known but the classification on a fine grained level, e.g. derived from satellite data, is still ambitious. For Europe the most advanced results are from the CORINE land cover project where results are available in 44 classes for the years 1990, 2000, 2006 and 2012 (http://www.eea.europa.eu/publications/COR0-landcover).

⇨ Biodiversity sites should measure in each land cover category.

Other parameters which are spatially important for biodiversity and which are not explicitly recognised in the above mentioned analyses are numerous. One example of a data type which we think is important and where recent coherent data set exists is soil. In a recent project the Joint Research Centre has accumulated a European soil database (see http://esdac.jrc.ec.europa.eu/ and also Jeffery *et al.* 2010). Soil is also of importance concerning climate change, i.e. it has a strong impact on the global carbon cycle.

⇨ Test sites should take such information into account as well and measure biodiversity in and on different soil types.

A proposed typology described in the EU Interpretation Manual (Evans 2010) lists 233 habitat types for Europe and distinguishes twelve main ecosystem types (see also Evans 2006) based on the higher levels of the EUNIS Habitat Classification, which is a European reference classification with cross linkages to the habitat types listed in Annex I of the Habitats Directive.

Meta-analysis incorporating a large number of different parameters have also been published and resulted for example in a global stratification of ecosystems (see Figure 8; Metzger *et al.* 2013a). The work identified five "general habitat categories": Urban Constructed, Cultivated, Sparsely Vegetated, Herbaceous, Trees and Scrubs and resulted in a key for the detailed 125 categories: http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra/Projects/EBONE-

2/Products/Annex-I-Habitats-key.htm. Please refer to Metzger *et al.* 2005 and Jongman *et al.* 2006 for more details on the methods. Basically the results are a synthesis of the analysis of a large extent, but fine grained resolution and incorporate many different data sources. One main methodological advantage of such an approach is that it does not result in sharp boundaries and that transition zones are much better represented and pictured. Similar work, resulting in so called ecosystem types, is ongoing (e.g. the DMEER approach by the EEA http://www.eea.europa.eu/data-and-maps/data/digital-map-of-european-ecological-regions). A preliminary map is available but no results have been published yet.

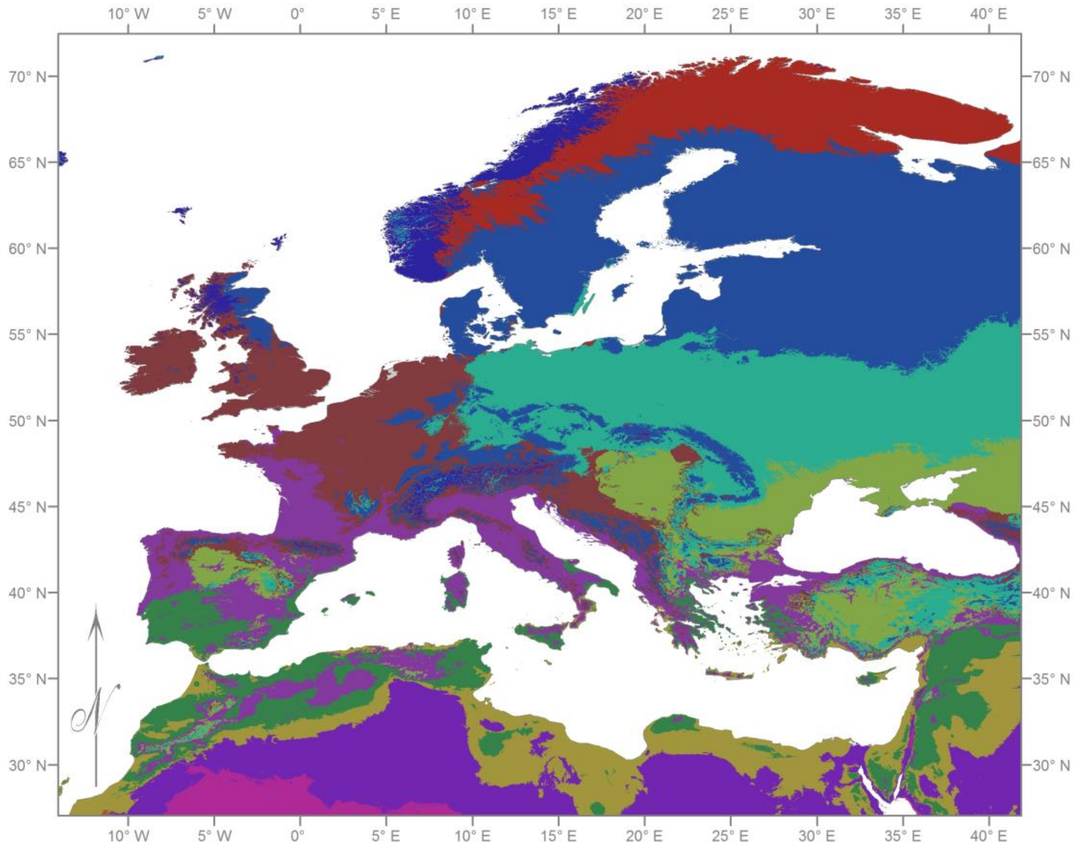


Figure 8. Environmental stratification of Europe, redrawn from the global environmental stratification (Metzger *et al.* 2013a). The dataset revealed 125 different strata (homogenous bioclimatic condictions) which can be grouped into 18 environmental zones. These 18 zones are depicted in the map (for further details see Metzger *et al.* 2013a, Metzger *et al.* 2013b).

All of the previously-mentioned only concerns macrohabitats and allows the spatial distribution of biodiversity measuring sites on a macrohabitat level. However, reducing the scale, microhabitats gain importance. The details on where to measure microhabitats depend largely on the taxa under investigation and furthermore have to consider environmental heterogeneity at the relevant scale for the taxa under investigation. For example, microhabitats for European bison (*Bison bonasus*) would be mostly equal to macrohabitats (e.g. types of forest used, meadows). However, for example for lichen besides other things it would matter what substrate they live on (rock type, bark type), the exact height of the place where they grow as well as the position with relation to the sun. Thus point measurements of, for example temperature or light intensity, can differ markedly between different microhabitats. Choice of microhabitats should also represent a representative cross section of the existing biodiversity.

A synthesis is challenging, especially under the light of the numerous studies and the large variety of different areas encountered in Europe. Overall, sites should take three main points into account when choosing measuring sites:

A. Unique habitats of any kind, as well as habitats with locally endemic species and Pleistocene refugia.
B. Different threats to biodiversity, ideally measuring a gradient across areas under high and low to zero threats.
C. The different ecoregions, biomes, habitats, land cover categories and ecosystem types encountered available.

It is even more challenging to provide some kind of a gap analysis for the whole of Europe. A comprehensive spatial overview does not exist. Gaps can be partly derived from the EuMon database (EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest: http://eumon.ckff.si/). Summary graphs show that recorded monitoring schemes are unevenly distributed (see Figures 1 & 2). Though, it is important to note that a large number of local monitoring projects are not listed in the database. Another important monitoring scheme for biodiversity is LTER (European Long-Term Ecosystem Research Network: http://www.lter-europe.net/) with a broad spatial coverage but also not a well-balanced spatial representation (see Figure 3). Overall, a comprehensive spatial gap analysis of biodiversity measuring sites, including the information on all biodiversity measurement elements (see also sections 3.1 and 3.3) is highly recommended.

Recommendation 3 (Spatial context of sites):

★ All sites should become part of a network of sites in order to cover the gradients mentioned above. Networks should be associated to other networks. Sites should also provide their metadata (what is measured where) to enable others to put the sites in a regional and global context (see section 3.4 for more details on metadata aspects).

Recommendation 4 (Provision of spatial information):

★ “Regular biodiversity survey sites” should provide at least five types of “simple“ information (e.g.: historic environmental context, biogeographic region, disturbance regime, threats to biodiversity in and around the site, ecoregion, soil types, main land cover classes).

★ “Detailed biodiversity survey sites” should provide in addition at least two types of “complex” information (e.g.: all land cover classes, “environmental stratification”, ecosystem types).

3.3 How to measure?

A key aspect in producing relevant biodiversity monitoring data is to use best practice monitoring techniques. This is not trivial, as especially in long-term monitoring, monitoring techniques commonly advance. Additionally, different monitoring sites will have individual interests and scientific questions, monitoring techniques may differ, accordingly. To ensure full data comparability within a time series, changes in monitoring techniques should be made carefully. Changes in monitoring techniques should always be accompanied by parallel monitoring experiments that allow determination of conversion factors, and hence, transferability of data between different methods. Such parallel monitoring, known as ring testing, is equally important if different methodologies are applied at different sites within one monitoring network (e.g. for stream benthic invertebrate monitoring, see Haase *et al.* 2004). In cases where full data compatibility cannot be reached, within a time series or across a monitoring network, data often has to be aggregated to coarser scales, which always causes a loss of information.

Recommendation 5 (Consistent methodology):

★ For “regular biodiversity survey sites”: The data produced in the monitoring program should be consistent and fully comparable between spatial and temporal replicates of the samples.

★ For “detailed biodiversity survey sites”: The data produced in the monitoring program of such sites should be consistent and fully comparable between spatial and temporal replicates of samples, not only for all samples taken at the individual site, but also across the network.

A further important aspect is to choose the appropriate temporal resolution for monitoring. This appropriate temporal resolution depends (1) on the pressure and rate of change that is expected to affect biodiversity and (2) on the temporal properties such as generation time and periodicity of the monitored biodiversity element. Meaningful causal analyses on biodiversity change can be carried out only if the temporal resolution of the monitoring matches the temporal properties of the biodiversity element of interest and adequately captures the relevant environmental pressure under consideration. For many large-scale processes, annual repetition of monitoring is the minimum temporal resolution recommended. However, to detect shifts in seasonality or other more frequent patterns, a higher repetition of sampling is necessary.

Recommendation 6 (Temporal resolution):

★ For “regular biodiversity survey sites”: The temporal resolution of the monitoring program should be at least annual, i.e. data series should contain at least one measurement per year.

★ For “detailed biodiversity survey sites”: The temporal resolution of the monitoring program should cover within-year seasonal variability, i.e. data series should contain multiple measurements per year.

Typically, biodiversity monitoring is not only interested in the status quo of specific elements of biodiversity, but also in the change of these elements of biodiversity over time, for example in response to an environmental pressure. To address such questions as they are posed for example in the Aichi biodiversity targets of the Convention on Biodiversity Diversity (CBD 2010), long-term time series on biodiversity are extremely important. Therefore, we advocate for consistent long-term commitments to monitoring, preferably over time periods of decades. As seasonal and interannual variability is often high in biodiversity measurements, trends can only be safely detected if time series cover a minimum length. In many fields of environmental monitoring, a pragmatic distinction of long-term monitoring series is a minimum time interval of 10 years (e.g. in LTER). We adopt this convention and recommend to base analyses of temporal trends in biodiversity of time series exceeding this time span.

Recommendation 7 (Time series):

- ★ For “regular biodiversity survey sites”: The monitoring program of such sites should include data from at least 5 consecutive years.
- ★ For “detailed biodiversity survey sites”: The monitoring program of such sites should last for already at least 10 consecutive years.

In biodiversity monitoring, the importance of voucher specimens has to be highlighted. Not only should the actual monitoring data should be stored appropriately (see section 3.4) but also raw sample material itself, if possible. This includes the deposition of specimens, microscopic slides, remaining from analyses, etc. in accessible collections. There are always novel analyses in the future that can provide more information. Furthermore, taxonomy is under constant revision, and individuals may have to be re-determined.

Recommendation 8 (Documentation of data collection):

- ★ For “regular biodiversity survey sites”: The monitoring program should include the storage of vouchers at least for some of the biodiversity monitoring series, i.e. not only data are stored but also raw materials such as photographs, alcohol samples, faeces, feathers, tissue samples, etc.
- ★ For “detailed biodiversity survey sites”: The monitoring program should include systematic storage of vouchers of the biodiversity monitoring series, i.e. not only data are stored but also raw materials such as photographs, alcohol samples, faeces, feathers, tissue samples, etc.).

With regard to individual monitoring methods for different biodiversity elements in different habitats, innumerable documents and method descriptions exist. Hence, it cannot be the aim of such a report to give an exhaustive bibliographic summary. Some key publications that allow a good first overview of standard monitoring methods are provided in the appendix 5.3.

As the integration of monitoring data across monitoring networks depends on the direct comparability of data, a number of initiatives aim at method harmonisation between different monitoring sites.

To decide on a common methodology is easy if networks are designed from scratch. However, most such networks are formed as a consortium of partners with common interests and already running monitoring activities that want to create added value from existing fragmented monitoring data and see a more complete, large-scale picture. Therefore, a post-hoc strategy to match data that is gathered with different sampling methods is common. Nevertheless, there are opportunities, especially as sampling technologies advances, to homogenize sampling methods.

A useful tool to keep track of state-of-the-art monitoring techniques and exchange opinions on different methods with other experts is the ECOPAR tool of LTER community (http://www.ufz.de/lter-d/index.php?en=32141&contentonly=1). ECOPAR is an online tool connected to a database that provides a description of different methods used in environmental monitoring. Biodiversity is one important part of this set of environmental variables. Additional methods for the monitoring of other elements of ecosystem integrity (see Burkhard *et al.* 2009) are available as well. Being a online wiki, ECOPAR is interactive and allows users to add more methods and to discuss their advantages and disadvantages.

Recommendation 9 (Sampling standards):

- ★ For "regular biodiversity survey sites": The methods applied in the monitoring program should be standardised, at the state-of-art and full metadata including detailed method descriptions are available, preferably online.
- ★ For "detailed biodiversity survey sites": The methods applied in the monitoring program should be at the state-of-art and besides the requirements for regular biodiversity survey sites, the methods that are applied should be harmonised, consistent and fully comparable within the networks that a site is associated with.

3.4 Data management plan

During the design and operation of EU BON test sites, it is important to review the planned or current data lifecycle (creating, processing, analysing, preserving, giving access and re-using data) in order to develop or refine a data management plan which supports the overall functioning of the site. This plan should cover all steps of the data lifecycle and foresee open-access data publication up front. The development of such a data management plan, keeping in mind future (re)use and on-line publication of collated data, should ensure that any intellectual property right issues and attribution of the different parties involved in the data generation are addressed.

Crucial components of the data management plan include 1) documenting protocols used for collecting, processing and analysing samples and measurements, and information on the datasets in which the data are collected (metadata), 2) the use of data and metadata standards and control vocabulary, 3) documenting quality control steps included at each processing step, 4) documenting the workflow for (short-term) storage of raw and processed data, while 5) ensuring redundancy of data storage according to the "lots of copies keep stuff safe" (LOCKSS) principle and 6) planning of public archiving and on-line data publication. Typically the data management plan addresses questions such as: Who will store data, what to store, where to store, how to store and retrieve it, or to whom should it be available (e.g. Jones 2011, Magnusson *et al.* 2013). These topics are the subject of the following subsections. The topics discussed under these section need to be further elaborated throughout the EU BON project, building on the experience gained by the test sites and through the exchange of expertise among them. The Doñana Biological Station could for instance report on its experience with implementing specific data sharing tools, whereas the Brazilian PPBio could present and refine its workflow for quality control and the upload of data associated with metadata documented using the Metacat system.

Recommendation 10 (Data management plan):

★ All sites should implement and regularly review a data management plan, which (minimally) covers the digital storage of all generated data, digitization of legacy data, and its quality checking.

3.4.1 Metadata on data generation and storage

The documentation on data collection and storage should include information on the standard naming convention(s) and metadata standards used. Any dataset generated during the data lifecycle must be properly documented, using those metadata standards best suited to each kind of information (see section 2 in EU BON deliverable 2.1). For monitoring sites, EML and Darwin Core are advised (see Metadata and data sharing tools).

All phases of the data collection, from the place where original data are recorded to the final storage, must be clearly indicated. It is important to have the metadata recorded within a short interval after the data collection, as the researchers who conducted the survey tend to forget details about the adopted procedures that are relevant to their interpretation, or even the abbreviations used (Magnusson *et al.* 2013). Following the recommendations of the GBIF metadata implementation framework task group (Jones *et al.* 2010) minimal metadata for datasets consisting of an identifier, title, creator, contact details, publisher and abstract are deemed acceptable but data providers should be strongly encouraged to provide more complete metadata including "geographic coverage, temporal coverage, taxonomic concepts, methods, data quality (linked to domain specific controlled vocabularies), provenance, thematic keywords, structured entity and attribute descriptions, measurement units using a controlled vocabulary, physical format of the data, distribution information, access control and intellectual property rights".

Data managers should implement practices for preventing erroneous data entry, for quality checking and correcting typing mistakes and validation (detecting gaps or inconsistencies) and document these procedures. This documentation on the procedures should address what has been done, where and by whom, but it should also include information on whether any material must be handled confidentially, terms of use and licensing. The recommended metadata editors (e.g. Morpho, DEIMS, GBIF-IPT) include all these terms.

Information platforms are advised to maintain a dynamic registry and metadata catalogue that would promote synergies with other initiatives. Data and meta-data will be stored in conveniently designed databases. In addition to information on the methods used for generating the data and performing quality control, it is important to document practical and technical details on how and where the data are stored (e.g. URL, filename, field definitions, etc.) Furthermore, it is also important to indicate how the data will be selected for data publication and/or archiving and how long the data need to be kept. Whether the costs of archiving in a data archive or repository have been included in the budget of the data collection project should be also considered. Conditions for re-use and recommended citation should also be recorded, especially for data for which public release is foreseen.

3.4.2 Data storage

Each EU BON test site must use protocols aimed at guaranteeing the safe, long-term storage of data (e.g. ISO/IEC 20000, ITIL 2011). Typically, storage protocols advise to use two or more copies of the data housed on different servers; in addition to enforcing a hierarchical system of access privileges. This should be properly documented with protocols for file recovery (ISO/IEC 20000, ITIL 2011). Similarly, the method used to keep copies up-to-date and/or synchronized should be detailed. If version management is applicable to the data, the arrangements made with regard to version management should be specified.

Depending on the volume of data collected it is advised that each site has either a dedicated member of staff or a service responsible for these tasks.

Recommendation 11 (Data-sets & metadata):

All sites should store their data to international standards of data security and dedicate staff are assigned to data management.

- ★ "Regular biodiversity survey sites" should make all metadata for the datasets held available online, using a well-known metadata format, including contact details for the person to address for further information and requests for access to the data.
- ★ "Detailed biodiversity survey sites" should, in addition, have all metadata for the datasets held available online (e.g. OAI-PMH or OGC CSW) and provide functioning (i.e. regularly checked or permanent) links to data which are available online.

3.4.3 Data publication

While data sharing and publication have not been universally adopted among scientists, we consider it to be part of standard scientific practice together with reporting, publication of results and archiving. As a European contribution to GEO BON, EU BON and participating test sites are encouraged to adopt these GEOSS Data Sharing Principles taken from Uhlir *et al*. (2009).

- ⇨ There will be full and open exchange of data, metadata and products shared within GEOSS, recognising relevant international instruments and national policies and legislation.
- ⇨ All shared data, metadata and products will be made available with minimum time delay and at minimum cost.
- ⇨ All shared data, metadata and products being free of charge or no more than cost of reproduction will be encouraged for research and education.

A number of institutions, funding and publishing agencies have policies regarding data sharing. While data sharing for some is about validating results, for others, publishing data is about enabling big-data solutions and approaches. But shared data are useful only if they are searchable and usable. For both characteristics data must be formatted in a standard way, conform to standard structure and semantics and have appropriate metadata attached. Detailed recommendations on data publication/sharing tools and practices can be found for example in the EU BON milestone MS 231.

Recommendation 12 (Data publication policy):

- ★ "Regular biodiversity survey sites" do not require a systematic data publication policy and can adopt a case-by-case approach in dealing with data release, which may include restrictions on the usage of data.
- ★ "Detailed biodiversity survey sites" have specific data sharing principles implemented and details are easily accessible. Through the adoption of a systematic data publication policy they strive to make data publicly and openly available as a rule. Restricted access to data is only envisaged in exceptional cases for sensitive data.

3.5 Synthesis of recommendations

In sections 3.1 to 3.4, we developed twelve specific recommendations for principles and guidelines that EU BON test sites should use (Table 4). These recommendations are concerned with the questions, what to measure, where to measure, how to measure and how to manage the data that are being gathered. For most of these recommendation two levels of have been developed for different degrees of maturity of a monitoring site. These recommendations, with their specific criteria, are suggested to be used by biodiversity monitoring sites to self-assess their level within the network. They can also be used to guide sites who are interested in becoming a node in EU BON. The two tiered structure of the recommendations is not intended to devalue the important contribution of small-scale monitoring programs that do not reach the status of a "Detailed Biodiversity Monitoring Site" or even a "Regular Biodiversity Monitoring Site". However, with this recommendation, we guide each monitoring site to develop strategically in order to make data more comparable and easier to locate, such that these data can be placed in a wider, often spatially larger, context.

Harmonised and systematically integrated data are key to provide scientifically sound and useful knowledge on the status and development of biodiversity for different stakeholders, including decision-makers. Compliance with our recommendations and active co-operation in the biodiversity observation network will enhance the visibility and availability of data. Ultimately, this will increase the chances of the network attracting long-term funding, which is the greatest challenge in the biodiversity monitoring sites that have joined EU BON so far.

All EU BON sites were asked to self-evaluate whether they follow the recommendations for "regular sites" or the ones for "detailed sites" (see Table 5). A total of 100% of "detailed sites" was not achieved for any recommendation. However, 83% of the sites follow the recommendations concerning "where to measure" and for the "data management plan". Thus there is only little need for improvement in this respect. More improvements are certainly necessary in other aspects. Only few sites follow the recommendations for the "temporal resolution of sampling", on the "length of time series" and "documentation of data collection".

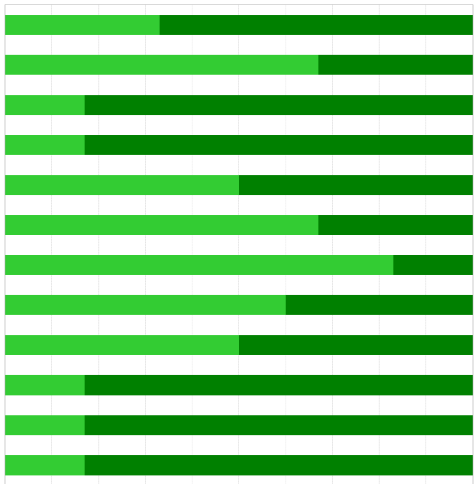
It is important to note that all principles and guidelines only provide snapshots of the current state. New insights and new methods appear constantly and change the previous recommendations. To avoid such a static state new "dynamic publication forms" are required, e.g. ECOPAR which is an online database were the community is constantly exchanging experiences and improving the ways to standardise and harmonise their efforts.

Table 4: Summary of the twelve recommendations for biodiversity monitoring sites. Two levels of compliance with these recommendations (abbreviated as rec.), differentiating "regular biodiversity survey sites" and "detailed biodiversity survey sites", are described The aim of these recommendations is to enhance network integration and promote harmonisation and orchestration of monitoring sites.

Rec. No.	Section	Brief description of recommendation	Regular sites	Detailed sites
1	3.1 What to measure	Minimum sampling effort for: EBVs	Min. 6 EBVs from min. 2 EBV classes	Min. 9 EBVs from min. 3 EBV classes
2		Minimum sampling effort for: associated relevant environmental pressures	Min. 5 data series	Min. 10 data series
3	3.2 Where to measure	Spatial context of sites	Associated to a network	
4		Provision of contextual spatial information	Min. 5 types of "simple" information	Min. 5 types of "simple" information + min. 2 types of "complex" information
5	3.3 How to measure	Use of consistent methodology	Full spatial and temporal comparability of samples within site	Spatial and temporal comparability of samples within network
6		Temporal resolution of sampling	Annual sampling	Intra-annual variability covered
7		Length of time series	Min. 5 consecutive years	Min. 10 consecutive years
8		Documentation of data collection	Occasional collection of vouchers	Systematic & extensive collection of vouchers
9		Sampling standards for methods	Methods are standardised	Methods are harmonised
10	3.4 Data management plan	Existence of data management plan	Covers digital storage of data and quality checks	
11		Provision of data-sets and corresponding metadata	Metadata available online + contact person for data-sets	Metadata available online data-sets available online
12		Data publication policy	Case-by-case decisions	Specific data sharing principles available, goal: open access to data

Table 5: Summary of the self-evaluation of the current EU BON sites. The two different levels of compliance with the recommendations, "regular biodiversity survey sites" (R) and "detailed biodiversity survey sites" (D) are described in sections 3.1 to 3.4. A summary of the recommendations is provided in Table 4. Percentages are provided in the right column.

Recommendation Number	Doñana Biological Station	Rhine-Main-Observatory	Amvrakikos wetland	Brazilian Research Program	Sierra Nevada Observatory	Israel's National Biodiversity Monitoring Program	Percentages
1	D	D	D	R	R	D	
2	R	D	R	R	R	D	
3	D	D	D	D	R	D	
4	D	D	D	D	R	D	
5	R	R	R	D	D	D	
6	D	D	D	R	D	R	
7	R	D	R	R	R	R	
8	R	D	R	D	R	-	
9	R	R	D	R	D	D	
10	R	D	D	D	D	D	
11	R	D	D	D	D	D	
12	R	D	D	D	D	D	



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5 Appendix

5.1 List of acronyms

Acronym	Full name	URL (retrieved 29-01-2015)
ALTER-Net	A Long-Term Biodiversity Research Network	http://www.alter-net.info/
AP BON	Asia Pacific Biodiversity Observation Network	http://www.esabii.biodic.go.jp/ap-bon/index.html
Arctic BON	Arctic Biodiversity Observation Network	
BD	Birds Directive	http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
BiK-F	Biodiversität und Klima Forschungszentrum	http://www.bik-f.de/
BIOMARE	Implementation and networking of large-scale long-term marine biodiversity research in Europe	http://cordis.europa.eu/result/rcn/27858_en.html
BioMAT	EuMon integrated Biodiversity Monitoring and Assessment Tool	http://eumon.ckff.si/biomat/
CBD	Convention on Biological Diversity	http://www.cbd.int/
CBMP	Circumpolar Biodiversity Monitoring Program	http://www.caff.is/monitoring/
COST	(European) Cooperation in Science and Technology	http://www.cost.eu/
CSIC	Consejo Superior de Investigaciones Científicas	http://www.ebd.csic.es/inicio
CTFS	Center for Tropical Forest Science	http://www.ctfs.si.edu/
DataONE	Data Observation Network on Earth	https://www.dataone.org/
DEIMS	Drupal Ecological Information System	http://data.lter-europe.net/deims/
DMEER	Digital Map of European Ecological Regions	http://www.eea.europa.eu/data-and-maps/data/digital-map-of-european-ecological-regions
DPSIR	Driver Pressure State Impact Response	
DwC	Darwin Core	http://rs.tdwg.org/dwc/
EBONE	European Biodiversity Observation Network	http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra/Projects/EBONE-2.htm
EBV	Essential Biodiversity Variables	https://www.earthobservations.org/geobon_ebv.shtml
ECOPAR	Parameters and methods for ecosystem research and monitoring	http://www.ufz.de/lter-d/index.php?en=32141&contentonly=1
ECOSCOPE	Réseau Des Observatoires De Recherche Sur La Biodiversité	http://www.fondationbiodiversite.fr/programmes-phares/ecoscope-presentation

EEA	European Environment Agency	http://www.eea.europa.eu/
EMBOS	Development and implementation of a pan-European Marine Biodiversity Observatory System (EMBOS)	http://www.cost.eu/COST_Actions/essem/Actions/ES1003
EML	Ecological Metadata Language	http://knb.ecoinformatics.org/software/eml/
EnvEurope	Environmental quality and pressures assessment across Europe	http://www.enveurope.eu/
EnvThes	Environmental Thesaurus	http://vocabs.lter-europe.net/EnvThes3.html
EU BON	European Biodiversity Observation Network	http://www.eubon.eu/
EuMon	EU-wide monitoring methods and systems of surveillance for species and habitats of community interest	http://eumon.ckff.si/index1.php
EUNIS	European Nature Information System	http://eunis.eea.europa.eu/
EurOBIS	European Ocean Biogeographic Information System	http://www.eurobis.org/
ERA	European Research Area	http://www.cost.eu/service/glossary/ERA
GBIF	Global Biodiversity Information Facility	http://www.gbif.org
GEO BON	Group on Earth Observations Biodiversity Observation Network	https://www.earthobservations.org/geobon.shtml
GEOSS	Global Earth Observation System of Systems	http://www.earthobservations.org/geoss.shtml
GLOCHAMORE	Global Change in Mountain Regions	http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/specific-ecosystems/mountains/glochamore/
HCMR	Hellenic Centre for Marine Research	http://www.hcmr.gr/en/
HD	Habitat Directive	http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm
ICZM	Integrated Coastal Zone Management	http://ec.europa.eu/environment/iczm/home.htm
ILTER	International Long Term Ecological Research network	http://www.ilternet.edu/
INPA	Instituto Nacional de Pesquisas da Amazonia	https://www.inpa.gov.br/index.php
INSPIRE	Infrastructure for Spatial Information in Europe	http://inspire.ec.europa.eu/
IPT	Integrated Publishing Toolkit	http://www.gbif.org/ipt
ISO	International Organisation for Standardization	http://www.iso.org/iso/home.html
ITIL	Information Technology Infrastructure Library	
LifeWatch		http://www.lifewatch.eu/web/guest/home

LOCKSS	Lots of copies keep stuff safe	http://www.lockss.org/
LTER Europe	Long Term Ecological Research network	http://www.lter-europe.net/
MarBEF	Marine Biodiversity and Ecosystem Functioning	http://www.marbef.org/
MARS	The European Network of Marine Research Institutes and Stations	http://www.marsnetwork.org/
MCPFE.	Ministerial Conference on the protection of Forests in Europe	http://www.foresteurope.org/
MfN	Museum für Naturkunde, Berlin	http://www.naturkundemuseum-berlin.de/
MSFD	Marine Strategy Framework Directive	http://www.msfd.eu/
Natura 2000		http://ec.europa.eu/environment/nature/natura2000/index_en.htm
NEON	National Ecological Observatory Network	http://www.neoninc.org/
OBI	Ocean Biodiversity Informatics	
OSPAR.	Convention for the protection of the marine environment of the North-East Atlantic	http://www.ospar.org/welcome.asp?menu=0
PPBio	Program for Planned Biodiversity Research	http://ppbio.inpa.gov.br/
SEBI	Streamlining European Biodiversity Indicators	http://ec.europa.eu/environment/nature/knowledge/eu2010_indicators/index_en.htm http://www.eea.europa.eu/publications/streamlining-european-biodiversity-indicators-2020
SGN	Senckenberg Gesellschaft für Naturforschung	http://www.senckenberg.de/
STAR	Standardisation of River Classifications	http://www.eu-star.at/frameset.htm
TEAM	Tropical Ecology Assessment & Monitoring Network	http://www.teamnetwork.org/
UNCLOS	United Nations Convention on the Law of the Sea	http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm
UNEP	United Nations Environmental Programme	http://www.unep.org/
WCS	Wildlife Conservation Society	http://www.wcs.org/
WFD	Water Framework Directive	http://ec.europa.eu/environment/water/water-framework/index_en.html
WWF	World Wide Fund for Nature	http://panda.org/

5.2 Description of EU BON sites

5.2.1 Doñana Biological Station

Protected since 1968, Doñana National Park (537 km2) is a UNESCO Biosphere Reserve, a Ramsar Site, a Natural World Heritage Site and it is integrated in the Natura 2000 network. It contains the largest wetland in Western Europe (García and Marín 2005), an intricate matrix of marshlands (270 km2), phreatic lagoons, and a 25 km-long dune ecosystem with its respective shoreline and representative Mediterranean terrestrial plant communities (around 100 km2; Diaz-Delgado 2010). Environmental monitoring in Doñana started in the mid 60's, with a very local perspective of monitoring that mainly focused on the surroundings of the main field station where the high density of heronries, breeding water birds and raptors impressed the visitors. At that time, the main goal was to make the high species richness of the site visible to the world to help preserving the area and finally declare it as National Park. Afterwards, different monitoring protocols started being conducted under the helm of the Spanish Council for Scientific Research. In 2006, Doñana joined ALTERNet (A Long-Term Biodiversity, Ecosystem and Awareness Research Network) that aims to establish a lasting infrastructure for integrated ecosystem research and since 2007 it is LTER site. This change from local naturalism and management to international long-term monitoring imposes the reorganisation of monitoring activities into a proper Environmental Monitoring Program aiming to gather reliable information supporting management actions in the National Park. Its objectives, as detailed in Diaz-Delgado 2010 are:

A. To achieve an exhaustive bibliographical review of available, up-to-date and standard protocols for the selected features to be monitored.
B. To designate scientific supervisors with recognised expertise in the ecological monitoring targets.
C. To propose feasible monitoring protocols and test their validity and adequacy for monitoring the proposed targets.
D. Final adoption/rejection of the tested methodological protocols and the features proposed for monitoring.

The human resources associated to monitoring is one of the strengths of the site, despite the economic crisis has slimmed down the monitoring team, limiting their capacities over the last three years and forcing them to modify and even abandon some of the monitoring protocols. Still, they keep a sufficient number of highly specialized technicians that warranties the high quality of data coming from monitoring. On the opposite, a proper structure and managing of the monitoring activities has been achieved only recently, slowing down the process of data validation, harmonisation and integration, which constitute the biggest challenge currently and where more efforts are being concentrated.

5.2.2 Rhine-Main-Observatory

The Rhine-Main-Observatory comprises the catchment of the river Kinzig (~1000km²), situated on the Eastern boundary of the Rhine-Main agglomeration area in Central Germany, between the Vogelsberg and the Spessart mountains (see Figure 9). At the Rhine-Main-Observatory, the long-term impacts of changes in land use, climate and other environmental variables on animal and plant communities in anthropogenically used habitats are investigated. The monitoring program focuses on habitats in streams and their floodplains, including areas with natural vegetation, agricultural and settlement areas. Especially the latter are underrepresented in existing long-term ecological research facilities. Taxonomic groups that are regularly monitored comprise stream benthic invertebrates, riparian vegetation, carabid beetles and spiders; a range of additional taxonomic groups are studied on project base and we receive floristic and faunistic data from databases in regional environmental administration.

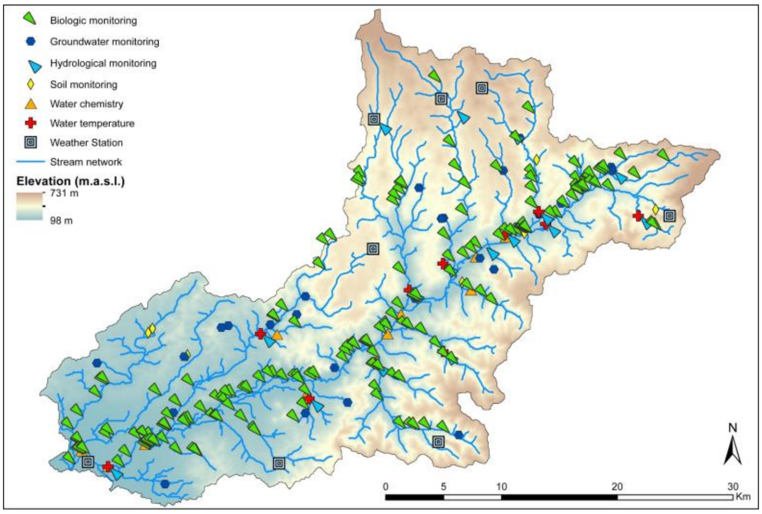

Figure 9. Design of the monitoring activities carried out at the Rhine-Main-Observatory (RMO). The research focus at this LTER site is on river and floodplain ecology. Rivers and floodplains are biodiversity hotspots in Central Europe and communities are strongly shaped by flooding dynamics. At the same time, such flat and productive areas close to water face the highest pressure from anthropogenic use.

The Rhine-Main-Observatory is organised in the Long-Term Ecological Research network and currently is a partner in the EU Life-Project EnvEurope. Senckenberg Research Institute (SGN) and the Biodiversity and Climate Research Centre Frankfurt (BiK-F) carry out a range of biodiversity research projects at the Rhine-Main-Observatory.

One focus of the work at the Rhine-Main observatory is on stream benthic invertebrates. This group is highly diverse, including aquatic insects, crustaceans, mollusks, worms, sponges, etc. Monitoring of stream benthic invertebrates is required in Europe as this group was defined as a main indicator of habitat quality in the European Union Water Framework Directive. It is a challenge that sampling methodologies and taxonomic resolution of stream benthic invertebrates assessments greatly vary across Europe. This impedes integration and common analyses of the data. Attempts are being made to homogenize these diverging approaches. In the STAR project, SGN contributed to compare the variation between different approaches used in Europe and subsequently a shared operational taxa list has been developed (by now adopted in a range of Central European countries). This operational taxa list defines a common minimum taxonomic depth for monitoring. This is a trade-off between taxonomic precision (all taxa on species level) and workload for species determination, as in some groups, e.g. chironomids, taxonomic specialist are rare and species-specific determination is highly time-consuming and requires elaborate histological preparations.

A further challenge encountered when analysing biodiversity time series is that taxonomy is a dynamic field of science. Species names change, species are divided and re-joint. Thus, what is labelled with one name might not be at all the same biological entity. It is thus important to keep and store the original sampling material to be able to re-determine individuals with new taxonomic keys and methods if necessary. We store all samples, so if taxonomy changes, we are able to update species identities.

Also, timing of sampling is crucial to ensure the comparability of data. Species have circadian rhythms; perform seasonal migrations or life cycles. Sampling methods and timing need to be harmonised to obtain comparable quantitative biodiversity data. We participated in a number of projects aiming at method standardisation and harmonisation. In the European Commission Framework V project "STAR" (EVK1-CT-2001-00089), for instance, provided practical advice and solutions with regard to many of the issues associated with biodiversity assessment in the context of the European Water Framework Direction (Furse *et al.* 2006). The European Life Environment Project "EnvEurope" (LIFE08 ENV/IT/000399) aimed at harmonising methods to assess ecosystem integrity in the major European biomes. Central outputs of this project are the online interactive web tool and database on monitoring methods ECOPAR (http://www.ufz.de/lter-d/index.php?en=32141&contentonly=1), the metadatabase for all ongoing long-term monitoring activities in the LTER community DEIMS (http://data.lter-europe.net/deims) and the associated thesaurus EnvThes (http://vocabs.lter-europe.net/EnvThes3.html).

5.2.3 Amvrakikos Wetland

Amvrakikos Wetlands site (West Greece) has been characterized as a National Park since 2008 and is protected through several Conventions (Ramsar, Barcelona, Bern and Bonn Conventions). Amvrakikos is also a Natura 2000 SCI and SPA site. The National Park of Amvrakikos Wetlands was established in order to protect, conserve and manage the nature and the landscape of the Amvrakikos terrestrial and aquatic areas, since they officially consist of a significant natural heritage and are distinguished for their high biological, ecological, aesthetical, scientific, geomorphological and educational value. The National Park is divided in four protection zones: a) red zone A: Area of Protection of Nature, b) blue zone A1: Area of Special Water Management, c) yellow zone B: Area of Special Regulations, d) orange zone: Area of Environmental Control.

Several diverse habitats are present in the Amvrakikos wetlands site, such as coastal lagoons, estuaries, salt meadows, marshlands, halophilus scrubs, sandbanks and mudflats, swamps and delta formations, whereas many of them are defined as priority habitats according to the Habitats Directive. Amvrakikos Gulf is one of the most important routes of migratory birds with more than 254 bird species. Additionally, a great number of threatened - protected species is allocated in the Amvrakikos site: 7 amphibians/reptiles, 192 birds, 2 fishes, 1 invertebrate, 3 mammals.

The Managing Body of Amvrakikos Wetlands is currently running a seasonal monitoring protocol for birds which includes timing and location of recordings, weather conditions, species and abundance (plus ethology, sex and age in some cases). They also collect data from fish species and abundance (records by fishermen), which are officially provided by the local fisheries departments (Preveza and Arta). The Hellenic Centre for Marine Research (HCMR) is a public research centre that collaborates with the Managing Body of Amvrakikos Wetlands since several years now and has participated in many research projects in the area, during which the macrobenthic communities, the sediment microbial diversity and the polychaete genetic diversity have been described. Over the years, the sampling methods and the sampling stations have been standardised and fixed in a gradient along the sea-land axes, mainly focused at lagoons receiving multiple anthropogenic pressures on top of their physical disturbance. The teams working in the area developed and implemented methods to sample, process, analyse and interpret the trends coming from multiple levels of the biological organisation: from genes all the way up to the communities. Their interrelationships as well as their association with the environmental variables worked pretty well, especially over the last five years.

Some preliminary results show that the bacterial communities are very promising in the exploration of the biodiversity trends along the lagoonal gradients and can describe the system more clearly than the higher components (e.g. macrofauna, fish).

These data are of high scientific value but they are characterized by some gaps within the years (i.e. the monitoring is not strictly regular). Macrofauna is best sampled over the last twenty years, although even in that case temporal gaps appear here and there. This was partly due to the lack of a management authority. However, even in the last five years over which the management authority was established, monitoring funding was never made available by the state. The very extensive area of Amvrakikos site and the limited personnel of the Managing Body make supervision of the area and the accurate control of illegal activities (e.g. hunting) difficult. Therefore, the sampling effort still largely depends on the research teams activated in the area, which come from the national Research Centres and Universities. The economic crisis has aggravated the picture over the last three years. It is anticipated that this trend will be reversed in the next years because of the few projects starting in the area, as well as of the implementation of the Marine Strategy Framework Directive, in the context of which the state has been committed to perform continuous sampling in the Amvrakikos lagoons.

Further work could aim to long-term data series and to the investigation of additional ecosystem components (e.g. phyto-zooplankton).

Another big challenge in the Amvrakikos lagoons is the production of big data on community structure and function. The implementation of recent approaches such as community genomics and functional genomics will shed more light to the processes taking place in the lagoonal environment. Also, there is a sheer need for manipulation experiments in order to acquire a better knowledge of the interplay between biodiversity and ecosystem functioning at all levels of the biological organisation and all scales of observation. Big data are believed to bring more evidence in order to clarify these issues and successfully test the current relevant scientific hypotheses.

In addition, the dynamic nature of Amvrakikos site introduces specific constraints in its regular monitoring and management plans. Its coastal lagoons are considered as naturally stressed environments (extreme temperature and salinity values) and they are hosting a low number of tolerant species. For this reason pollution or eutrophication events may cause seasonal trophic crises or anoxic conditions which might be responsible for extreme community fluctuations. Last, but not least, more work needs to be done at the lower ecosystem components, notably bacteria and meiofauna. This is a laborious task and requires expertise on multiple subjects and a number of research teams that would be specialized on different methodological approaches.

5.2.4 Brazilian Research Program in Biodiversity

Brazilian Research Program in Biodiversity - PPBio was developed in line with the Convention on Biological Diversity and the Brazilian National Biodiversity Policy. Created in 2004, it has the mission to articulate regional and national competence to expand and disseminate biodiversity information in a planned and coordinated form. To achieve this, PPBio adopted a model of decentralized logistic management associated with a system of standardised sampling design and a centralized data management. The decentralized logistic management facilitated the implementation of actions in conjunction with local researchers and funding agencies to attend local needs. Conversely, the data management is centralized and uses the Metacat system that is used by the International Long-Term Ecological Research (ILTER) sites throughout the world. The system is based on the Ecological Metadata Language (EML <http://knb.ecoinformatics.org/software/eml/>), but we augmented the EML with extra metadata tables to allow evaluation of sampling effort <http://ppbio.inpa.gov.br/repositorio/dados>. The system does not allow automatic upload of data by individual researchers, because we, and many other programs, found that it was not possible to guarantee adequate quality control, and all data are verified by a full-time staff member before being made available in the repository.

The PPBio program is now functioning in all of Brazil, with regional hubs in Amazônia, the northeastern semi-arid, the Atlantic forest, the Pantanal, the central savannahs and the southern grasslands. However, only the Amazon (5 million square kilometres) presently has a large number of sites and they are not evenly distributed (see Figure 10).

Presently, PPBio counts on a basic standardised field infrastructure in 17 sites across Amazon basin, 2 sites in the Brazilian Patanal wetlands and 5 sites in the Atlantic forest. The field sites cover a wide range of ecosystems, from open savannahs and periodically flooded forests (várzea and igapó) to tropical terra-firme and submontane forests. The same system has been replicated in sites in Eucalypt forests and deserts in Australia and in woodlands and grasslands in Nepal´s Chitwan National Park <http://ppbio.inpa.gov.br/ppbiointer>. The basic sampling design follows the RAPELD, which allows rapid inventories (RAPs) to assess the biotic complementarity keeping the data fully integrated among areas with more detailed information (LTER sites).

The system is working well because it is growing from the bottom up and is sufficiently flexible to attend to local demands, while following minimum spatial standards that allow integration of data generated in all sites. This allows both academic studies and provides data for state and continent-wide environmental evaluations. The system has been adopted as standard by many environmental agencies and is the default for the Rainforest Standard for REDD++ projects. As each hub elects their priorities, it was not possible to collect data on all aspects of biodiversity simultaneously in all sites due to lack of trained personnel and funding limitations. However, many publications on a wide variety of taxa have been published in the scientific literature, and most of these can be downloaded from the PPBio site <http://ppbio.inpa.gov.br/>.

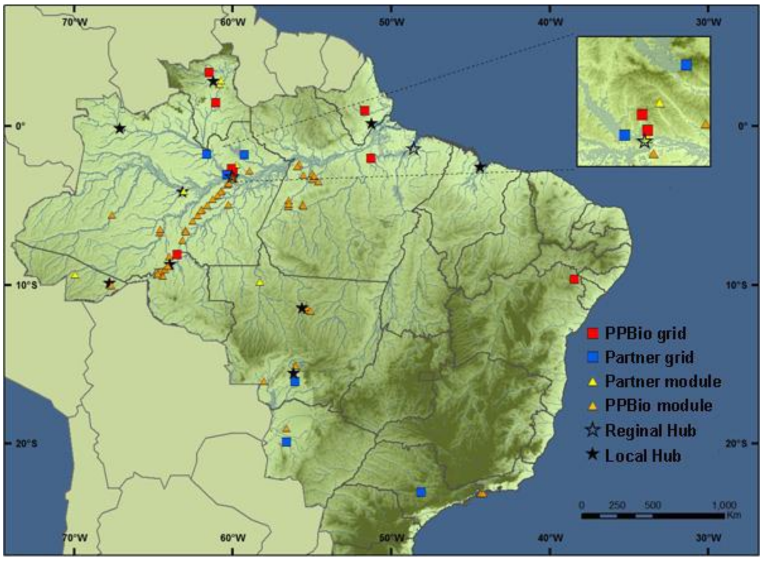

Figure 10. Design of the Brazilian Research Program in Biodiversity (PPBio).

There is a need to train personnel in matters relating to field collection, identification, data management and analysis, collection of auxiliary data on biochemistry and genetics by taxonomists and ecologists, and implementation of automatic recording devices for environmental data in many sites. There is need for training of participants in integrated analyses to link the physical environment, micro-organisms, invertebrates, vertebrates and plants in functioning systems.

The biggest challenge is to convince participants of the need for strict spatial standardisation and the need to make data, together with appropriate metadata, available shortly after it is collected. It can be difficult to find leaders interested in both advancing scientific questions and promoting capacity building in local institutions. It is sometimes difficult to find financing for integrated studies that transcend state and national boundaries.

5.2.5 Sierra Nevada Observatory

The Sierra Nevada Global-Change Observatory is intended to put together useful and relevant information regarding the ecological systems and the socioeconomics of Sierra Nevada. The project has four fundamental parts to fulfil its overall objectives: 1) a monitoring programme to collect biophysical, ecological and socioeconomic data; 2) an information system for appropriate data management; 3) a series of mechanisms that enable the effective transfer of the results on adaptive management; and 4) an outreach and reporting system. Dissemination is indeed one of the hallmarks of the project, since the design of management systems is considered vital to reinforce the resistance and resilience ability of the natural systems confronted with the new hypothetical scenarios.

The design of the Global-Change Monitoring Programme in the Sierra Nevada is based on the conceptual and thematic frameworks proposed by the GLOCHAMORE strategy (GLObal CHAnge in MOuntain REgions http://mri.scnatweb.ch/ projects/glochamore), sponsored by UNESCO, in which hundreds of experts (scientists, managers, technicians) have participated. Thus our monitoring programme in the Sierra Nevada can be considered an implementation of the GLOCHAMORE conceptual framework. The local implementation of the global initiative first required the exhaustive compilation of monitoring protocols that were previously used in the Sierra Nevada. Thus, many of the monitoring protocols for wild fauna (Spanish ibex and wild boar) and flora (threatened species endemic to the high peaks) have been incorporated into the current programme. The result provides 48 methodologies related to data collection on various aspects of the composition, structure, and function of the Sierra Nevada ecological system. This set of protocols is the result of including existing methodologies (after a review process) and the specifically designed philosophy of the GLOCHAMORE project. These protocols were designed under the supervision of scientific experts in each field.

For each of the thematic areas proposed by GLOCHAMORE, monitoring methodologies are defined in order to assess both the status of key ecological functions, such as the processes of the main Sierra Nevada ecosystem as well as possible global-change impact on Sierra Nevada. It also defines monitoring methods to characterize human activity in Sierra Nevada. The scheme allows us to cover many of the aspects considered to be crucial by the scientific community in evaluating the effects of global change in ecosystems processes of mountain regions. Therefore, the characterization of GLOCHAMORE thematic areas and the methodology design associated with each of them is based on scientific hypotheses to be addressed by the monitoring programme. In addition, each monitoring procedure is included into a consistent conceptual model based on the ecosystem, our monitoring programme can be considered to be “monitoring based on questions”. Each protocol provides information on a number of environmental variables related to the thematic sphere covered. The data are gathered from a total of 130 different variables.

In addition, our programme is designed to take into account the great spatial heterogeneity and ecological diversity of the massif. Consequently, the programme follows a hierarchy of spatial scales of the data gathering. Thus, the scale or spatial resolution of the data compiled for all methodologies covers a large part of the spatial heterogeneity of the Sierra Nevada. As a result, we have procedures that gather data on a finer scale (points and transects), on a somewhat coarser scale but covering the entire space (pixels of satellite images or polygons of a vegetation map, for example), and finally on an administrative-boundary scale (public mountain, municipal area, or catchment basin). In addition, many of the sampling points that take more detail (points and transects) are spatially aggregated in places with high density and have a multi-parameter weather station. These sites are known as Intensive Monitoring Stations. Each of these protocols not only collects data on a spatial scale but may also apply them in other different spatial fields. For example, data from a weather station (collection-point scale) can be extrapolated using various techniques in all territories (the entire area). This interpolation process cannot be applied to other ecological sampling such as the monitoring of raptors. Thus, each procedure can also be characterized by the extent of the application of data captured therein. Some protocols have an extension point, while others may extrapolate their values to municipal scales or to the entire protected area.

Finally, our monitoring programme incorporates the temporal dimension from two different perspectives. On the one hand, we consider it essential to gather historical information on the structure and dynamics of the Sierra Nevada ecosystems. The purpose of this historical reconstruction is to ascertain the past in order to understand the present and thereby try to predict future scenarios. In this regard, it is important to consider the length of the series available for each subject monitored. Highlights include the vegetation and climatic data for those with a longer series. On the other hand, it is vital to consider the frequency of the data collection in each protocol. In this sense, we use the methodologies, which take information periodicities of less than a day (weather stations) to others by which inventories are conducted annually or every several years (e.g. reptile monitoring).

In short, the monitoring programme to assess the effects of global change in Sierra Nevada is comprised of a multidisciplinar array of protocols that can be described based on a number of attributes, thematic (according to GLOCHAMORE approach), spatial (data-collection scale and the extent of data application), and temporal (length of time series and data-collection periodicity). The protected areas of the Sierra Nevada region cover 171.000 hectares, where sampling is carried out (see Figure 11).

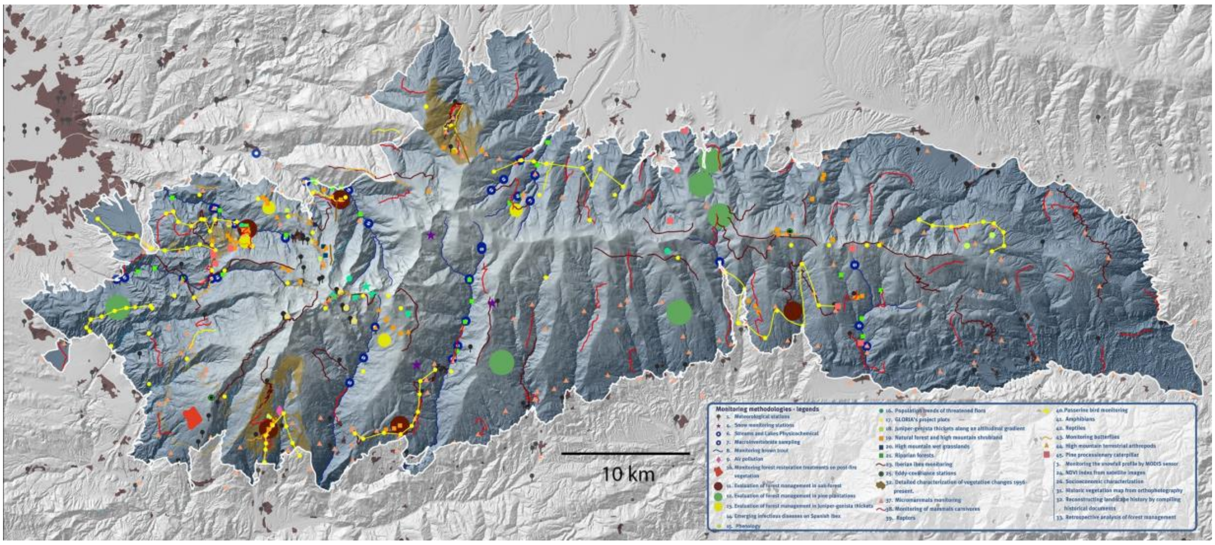

Figure 11. Design of the monitoring programme in the Sierra Nevada Observatory.

The Ecosystems surveyed are:

A. High mountains wet grasslands.
B. High mountains grasslands.
C. Olm oak forests and Pyrenean oak forests (Quercus ilex and Quercus pyrenaica)
D. High mountain shrubland (Juniper, Genista, Cytisus, etc.)
E. Mid mountain shrubland (Rosmarinus, Thymus, Stipa)
F. Pine plantations
G. Rivers and alpine lakes

The Sierra Nevada Observatory was able to successfully design a comprehensive monitoring program able to collect information from 100 biophysical variables. They also created a modular information system able to store, document, analyse and visualize all the information collected by the monitoring program. Because the observatory has been designed and is being implemented by a team composed by managers and scientists it bridges the gap between scientists and managers, and creates knowledge useful for decision-making. It also establishes relationships with other international networks and projects (LTER, NEON, etc.). It was however difficult to harmonise their monitoring protocols with other similar ones carried out in other LTER sites as well as applying the knowledge obtained by the monitoring program to the decision-making process. They are still working in analysing the data obtained by the monitoring program and promoting the implementation of citizen science projects to obtain information about the impacts of global change in Sierra Nevada. Their biggest challenges are to make their Observatory sustainable under a financial point of view, to use the knowledge created by the Observatory in the decision-making process via real long-time management projects and reinforce the relationships of the Observatory with major projects (EU BON, LifeWatch, NEON, LTER, etc.).

5.2.6 Israel's National Biodiversity Monitoring Program

The objective of the monitoring program is to conduct a quantitative and qualitative evaluation of key ecosystems in Israel, in a systematic manner over time, enabling an assessment of the state of nature in the country and identification of significant changes, mainly those that reflect deterioration of and damage to ecosystems and to the biological diversity and functioning of their populations. Based on these insights, it will be possible to propose ways of halting this decline

The monitoring program included 4 major stages:

A. Defining the monitoring units- Geographical definition of the monitoring units – for each of the tenth ecological system/region.
B. Defining threats and processes- definition of key factors/threats affecting the condition, functionality and biodiversity of a specific system (ranking them by importance). The assumption is that these factors/threats are the most important for long-term monitoring and tracking, and accordingly they form the basis for the program. An example for threat or process- climate change, grazing, settlements, Succession, fires etc.
C. Selection of indicators/indices- that need to be monitored in order to track changes in the above factors/threats. These indicators should tell us, in a reliable and accurate manner, without monitoring too many variables, about the trend of a given process or about the functionality and health of a specific ecosystem in light of a certain threat or process occurring.
D. Selection of methods- The monitoring methods and protocols were formulated by the specialists in the different fields (remote sensing, plants, birds and mammals) during a number of meetings dedicated to this subject.

5.2.7 European Natural Park Mercantour/Alpi Marittime

Located at the western end of the Alps, overlapping France and Italy, the Argentera-Mercantour massif is comprised of nearly 250,000 hectares. At the border with the Italian Piedmont, the Mercantour massif is the lowest southern promontory of the Alps, before its chain dips sharply into the Mediterranean Sea: the top of Gelas, which stands 3143 meters above sea level, is the highest in the Mercantour and it is just 50 km in a line from the sea. Among the Colle di Tenda and the Colle della Maddalena rises the last great castle of crystalline rock in the Alps: these are the Maritime Alps. There are three valleys within the Alpi Marittime Natural Park (Valle Vermenagna, Valle Gesso and Valle Stura).

This Massif is protected on the French side by the Parc national du Mercantour, created in 1979, and on the Italian side by the Parco Naturale Alpi Marittime, created in 1995. Together, these two parks are home to a unique natural and cultural heritage of Europe (see Figure 12). To protect this common heritage, both natural areas have been twinned since 1987, with the common ambition of enhancing territorial continuity that ignores any border. This strong collaboration, probably one of the most successful among European contiguous parks, has allowed them to become, in 2011, the first real European Park.

<u>A wide variety of flora and fauna</u>

By the presence of a single territory of Alpine influences – Provençal, Mediterranean and Ligurian – are born a great diversity of plant and animal species. It is not uncommon, just a few hundred meters apart, to have alpine species with typically Mediterranean species. In this region, high peaks and rugged rocks are mirrored in the lakes among the eternal snows, and down into the valleys grow olive trees!

There are about a dozen of the most interesting habitats, including the related Sites of Community Interest (Siti d'interesse comunitario or SIC). Added to that, are many other areas collected by the Habitat Directive.

The two parks are home to numerous endemic plants, which live only in a very narrow zone, such as the famous Saxiraga florulenta, a species that specific to the border crystalline massif. More than 2 000 plant species (half the species found in France) are listed, 220 considered very rare, and 400 cannot be found anywhere else in the world. Chamois, ibex, wolfes, marmots, stoats…but also numerous and rare bat species are just a few examples of the 58 mammals that inhabit the two parks. On the other hand, more than 150 species of birds have been recorded. But the most part of our biodiversity is obviously composed by invertebrates: more than 8.000 species of insects, molluscs, arachnids have been inventoried on our territory!

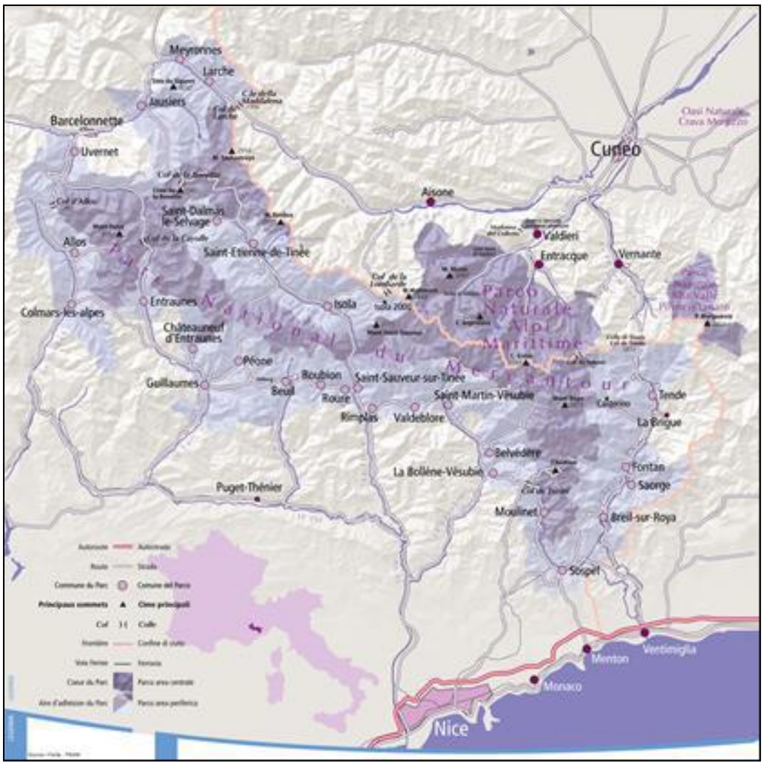

Figure 12. Location of the Parc national du Mercantour (France) and the Parco naturale Alpi Marittime (Italy).

<u>Nature and Research</u>

The protection and conservation of the exceptional natural heritage of the Maritime Mercantour area are coming the institutional aims of the two parks. But, to protect and better manage a territory, you must know its every aspect: from geology to zoology, from botany to meteorology. This is why research is essential: in fact, only field work and laboratory work can tell us what there is (such as habitat and species) in the Parks and how it works (relationship between habitats and species, dynamic intra- and inter-specific structure, and evolution of ecosystems). It is for this project that expert researchers and students, geologists, biologists, naturalists, and veterinarians, all coordinated by the staff of protected areas, alternating years in the study of the environment of the two parks with passion and dedication.

The two Maritime and Mercantour Parks have numerous collaborations in the scientific world with universities and scientific research institutes both domestic and international, all of which result in long-term ecological surveys of species of conservation interest. All scientific activities and monitoring are carried out in close collaboration with the rangers, who provide essential technical and operational support, without which a lot of research would be impossible.

The territory of the Maritime and Mercantour Alps has the privilege of being selected as a pilot area for the first All Taxa Biodiversity Inventory + Monitoring (ATBI+M) in Europe. Two prestigious scientific museums have consolidated their involvement in the project over the years, so that they can keep and display their many findings from the Inventario Biologico: the Muséum national d'Histoire naturelle in Paris and the Museo Regionale di Scienze Naturali in Turin.

Today, more than 12.000 species are inventoried, and around 100.000 data have already been acquired on this territory! Some monitoring protocols have also been implemented, in particular on the most well-known or patrimonial species (bats, galliforms, ungulates, , wolves, protected flora, …), some of them from more than 20 years.

However, some analysis and interpretation of this big amount of data are still missing. Therefore, Mercantour Alpi Marittime European Park encourage scientists to work on their dataset, in order to better understand the functioning of their ecosystem and to better manage and protect their fauna and flora populations.

5.3 List of selected handbooks on biodiversity and monitoring

General handbooks

- ⇨ Brazilian Research Program in Biodiversity (PPBio): Series of manuals and handbooks: http://ppbio.inpa.gov.br/metodos
- ⇨ Bunce, R.G.H., Bogers, M.M.B., Roche, P., Walczak, M., Geijzendorffer, I.R. & Jongman, R.H.G. (2011) Manual for Habitat and Vegetation Surveillance and Monitoring: Temperate, Mediterranean and Desert Biomes. Alterra report 2154, WUR, Wageningen, The Netherlands.
- ⇨ Caryl, L. Elzinga, Daniel W. Salzer, John W. Willoughby, James P. Gibbs. 2001. Monitoring Plant and Animal Populations: A Handbook for Field Biologists. Wiley-Blackwell.
- ⇨ Clait, Braun (Ed). 2005. Techniques for Wildlife Investigation and Management. The Wildlife Society Press
- ⇨ Costello, M.J. 2000. Developing species information systems: The European Register of Marine Species (ERMS). Oceanography 13(3):48–55, http://dx.doi.org/10.5670/oceanog.2000.09.
- ⇨ Dennis, P., Bogers, M.M.B., Bunce, R.G.H., Herzog, F., & Jeanneret, P. (Editors); Contributing authors: Dennis, P., Herzog, F., Jeanneret, P., Arndorfer, M., Bailey, D., Bogers, M.M.B., Bunce, R.G.H., Choisis, J.-P., Choisis, N., Cuming, D., Ehrmann, O., Fjellstad, W., Franck, T., Fraser, M.D., Friedel, J.K., Geijzendorffer, I., Gomiero, T., Jongman, R., Kainz, M., Kölliker, R., Last, L., Lüscher, G., Moreno, G., Nicholas, P., Paoletti, M.G., Papaja-Hülsbergen, S., Pelosi, C., Pointereau, P., Sarthou, J.-P., Schneider, M., Siebrecht, N, Targetti, S., Viaggi, D., Wilkes, J. & Wolfrum, S. (2012) Biodiversity in organic and low-input farming systems. Alterra report 2038, WUR, Wageningen, The Netherlands. http://www.biobio-indicator.org/deliverables/D22.pdf
- ⇨ Eleftheriou A (2013) Methods for the study of Marine Benthos. Fourth Edition, Wiley
- ⇨ Eymann J, Degreef J, Häuser C, Monje JC, Samyn Y, VandenSpiegel D (2010) Manual on field recording techniques and protocols for All Taxa Biodiversity Inventories and Monitoring (ATBIs). Abc Taxa Volume 8, part 1 & 2. 653pp.
- ⇨ Feral J-P (2002) How useful are the genetic markers in attempts to understand and manage marine biodiversity? Journal of Experimental Marine Biology and Ecology268:121–145
- ⇨ Féral, J.-P., M. Fourt, T. Perez, R. Warwick, C. Emblow, C. Heip, P. van Avesaath, H. Hummel, 2003. European Marine Biodiversity Indicators. ISBN 90-74638-14-7
- ⇨ HELCOM, 2013. HELCOM core indicators: Final report of the HELCOM CORESET project. Balt. Sea Environ. Proc. No. 136
- ⇨ Hill, David, ed. Handbook of biodiversity methods: survey, evaluation and monitoring. Cambridge University Press, 2005.
- ⇨ Gitzen, Robert A., Joshua J. Millspaugh, Andrew B. Cooper, Daniel S. Licht (Eds). 2012: Design and Analysis of Long-term Ecological Monitoring Studies. Cambridge University Press
- ⇨ Goldsmith, Frank Barrie. 1990. Monitoring for conservation and ecology. Chapman and Hall
- ⇨ Heyer, W. Ronald, Maureen A. Donelly, Roy W. McDiarmid, Lee-Ann C. Hayek, and Mercedes S. Foster (Eds). 1994. Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians. Smithsonian Institution Press
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