

# Monitoring of Biological Diversity: a Common-Ground Approach

TIIT TEDER,\* MARI MOORA, ELLE ROOSALUSTE, KRISTJAN ZOBEL, MEELIS PÄRTEL,  
URMAS KÕLJALG, AND MARTIN ZOBEL

Institute of Botany and Ecology, University of Tartu, Lai 40, 51005 Tartu, Estonia

**Abstract:** *Practical approaches to monitoring biological diversity vary widely among countries, and the accumulating data are frequently not generalizable at the international scale. Although many present monitoring schemes, especially in developed countries, produce highly complex data, there is often a lack of basic data about the level and spatial distribution of biodiversity. We augmented the general framework for improving biomonitoring, proposed by Green et al. (2005), and identified its core tasks and attributes. The first priority for a more unified biodiversity monitoring is to agree on a minimum set of core tasks and attributes, which will make it possible to build a standardized biomonitoring system even in countries with few resources. Our scheme has two main organizational levels—taxa and ecosystems. The basic elements of the biomonitoring system proposed are recording of presence and absence of taxa and ecosystems in a target area, mapping of their distribution in space, and assessment of their status. All the elements have to be repeated over time. Although these tasks are fundamental, they are frequently not considered in currently functioning biomonitoring programs. The whole system has to be hierarchical and additive: if more resources are available, new activities may be added to the basic routine. Agreeing on a common standard will facilitate aggregating measures of biodiversity status and trends into regional and global indices. This information will relate directly to several Convention on Biological Diversity indicators for assessing progress toward the 2010 Biodiversity Target.*

**Keywords:** biodiversity, biomonitoring, distribution maps, indicators, species lists

Monitoreo de la Diversidad Biológica: un Método con Denominador Común

**Resumen:** *Los métodos prácticos para el monitoreo de la diversidad biológica varían ampliamente entre países, y los datos acumulados frecuentemente no son generalizables a escala internacional. Aunque muchos programas de monitoreo, especialmente en los países desarrollados, producen datos muy complejos, a menudo hay una carencia de datos básicos sobre el nivel y la distribución espacial de la biodiversidad. Aumentamos el marco de referencia general para mejorar el biomonitoreo, propuesto por Green et al. (2005), e identificamos sus atributos y cometidos centrales. La primera prioridad para un monitoreo de biodiversidad más unificado es estar de acuerdo en un conjunto mínimo de atributos y cometidos centrales, que harán posible la construcción de un sistema de monitoreo estandarizado aun en países con recursos escasos. Nuestro esquema tiene dos principales niveles organizacionales—taxa y ecosistemas. Los elementos básicos del sistema de monitoreo que proponemos son los registros de presencia y ausencia de los taxa y ecosistemas en un área determinada, los mapas de su distribución espacial y la evaluación de su estatus. Todos los elementos deberán ser repetidos en el tiempo. Aunque estas tareas son fundamentales, frecuentemente no son consideradas en los programas de biomonitoreo actualmente en operación. Todo el sistema debe ser jerárquico y aditivo: si hay más recursos disponibles, se pueden agregar más actividades a la rutina básica. El consenso sobre un estándar común facilitará la adición de medidas del estatus y tendencias de la biodiversidad a los índices regionales y globales.*

\*email tiit.teder@ut.ee

Paper submitted November 16, 2005; revised manuscript accepted July 13, 2006.

*Esta información se relacionará directamente con varios indicadores de la Convención sobre Diversidad Biológica para la evaluación del progreso hacia el Objetivo Biodiversidad 2010.*

**Palabras Clave:** biodiversidad, biomonitoreo, indicadores, listas de especies, mapas de distribución

---

## Introduction

The monitoring of biological diversity is regarded as essential to carrying out the directives of Articles 8, 9, and 10 of the Convention on Biological Diversity (CBD) (Glowka et al. 1994). Based on the CBD, Stork and Samways (1995) outline an extensive set of tasks for inventorying and monitoring biodiversity but do not specify priorities. Currently, there are no firmly established methodological approaches to achieve its goals (Royal Society 2003).

Although Noss (1990) proposed a hierarchical, top-down approach to biodiversity monitoring more than 15 years ago, this approach is still rarely implemented. Perhaps the most comprehensive monitoring system has been implemented in the United Kingdom, where a large body of volunteers has been strongly supported by top-down provision of common monitoring standards, guidelines, information collecting, and handling systems (e.g., Davies et al. 2001; Hurford et al. 2001; JNCC 2004). Nevertheless, even in countries with well-established monitoring systems, there is a huge variation with respect to biomonitoring ideology, priorities, and methodologies. Not surprisingly, reviews of biomonitoring programs have therefore been critical, highlighting their lack of well-articulated objectives (Yoccoz et al. 2001), use of very different monitoring standards, and lack of utility for decision makers (Delbaere 2002; Watson & Novelty 2004).

Recently, the representatives of most countries at the 2002 World Summit on Sustainable Development committed themselves to achieve a significant reduction of the current rate of biodiversity loss (Balmford et al. 2005). In response to this goal Green et al. (2005) proposed a general framework to improve monitoring of biodiversity. They argue there is a shortage of standardized, regularly repeated measurements of the state of biomes and their biota that could be used to monitor progress toward this goal. Green et al.'s (2005) framework consists of scoping, design, and implementation stages and is general enough to provide a flexible tool that can be applied across a broad range of biodiversity attributes and scales. The implementation of the framework in any particular country, however, depends much on the scoping stage and on identifying valued tasks and attributes in particular.

In principle, there are two possible scenarios. The first includes uncoordinated divergent development. The identification phase is extremely important in order to meet the needs of end users acting on different levels, but these needs differ across countries. As a consequence the identification phase may result in high diversity of approaches in different countries or regions. Another

scenario is convergent coordinated development. This means different countries have to agree on a minimum set of very robust objectives and approaches, which might be applicable even in the regions with few resources for conservation.

Biodiversity monitoring is expected to fulfill a multiplicity of tasks (Smyth & James 2004; Green et al. 2005). We emphasize, however, the importance of agreeing upon some national-level minimum standard. Such core common ground will facilitate aggregating measures of biodiversity status and trends into regional and global indices. Moreover, by making biodiversity trends comparable across different countries, regions undergoing the most severe negative changes can be identified. Regional differences may also hint at possible causes underlying undesired changes. In the following we propose a minimum set of core tasks and attributes in national biomonitoring programs.

## Unified Aims and Attributes of Biodiversity Monitoring

Several existing sources describing the methods of biodiversity monitoring offer intensive approaches that are distinguished by high scientific quality and, accordingly, by a requirement for a large amount of highly qualified labor (e.g., Larsson 2001; Rempel et al. 2005). Green et al.'s (2005) approach is more extensive, suggesting that necessary measurements must capture information on biome area; the diversity, distribution, and abundance of species; and the provision of ecosystem goods and services. To meet these tasks one may skip detailed descriptions of populations and ecosystems at the first stage and instead start with a basic and simple approach that provides data that are easily converted into information needed for practical nature conservation and land-use planning and that supply ecologists and taxonomists with basic background information.

In their recent paper Pereira and Cooper (2006) introduce the principles for global biodiversity monitoring network and suggest focusing on two levels—species and ecosystems—and repeating the collection of basic data over time to reveal trends. Earlier, Menges and Gordon (1996) suggested a three-level hierarchical approach for monitoring plant species, focusing either on species occurrence, quantitative assessment of abundance and condition, or detailed demographic monitoring. These two approaches are complementary and we argue that

an analogous hierarchical approach may be extended to constitute a core common ground for all biomonitoring programs at the ecosystem and species level. At both levels the occurrence (list) and spatial distribution of species are described and the description is redone over time to reveal temporal trends. If more resources are available, qualitative and quantitative assessments of abundance and condition are added to the scheme.

Because it is not always clear whether the target units are really species, or represent other taxonomic entities (e.g., subspecies, collective species, DNA sequence types), we use the neutral term *taxa*. Similarly, the classification of ecosystems is based on either vegetation, habitat, or land-use classification units. We use the term *ecosystem* in a broad sense in an attempt to cover all possible related concepts and terms. In particular we propose that the primary attributes of common-ground biomonitoring could include the activities listed below.

### Create the General List of Taxa and Ecosystems within the Target Area

A valid list of taxa for a particular country is an elementary requirement for every kind of biomonitoring. Currently, there are few countries without any kind of species list for at least the better-known taxonomic groups such as vascular plants and vertebrates. But, in most countries, these lists have not been used in biomonitoring programs. These lists are being compiled by enthusiastic individual scientists and therefore often lack regular updating and a uniform format. From a biodiversity conservation point of view, it is evidently unavoidable that standardized lists of species, including on line global synonymic checklists, have to be agreed upon. Several global initiatives (electronic lists of scientific names of taxa: Species 2000 [<http://www.sp2000.org/>], Integrated Taxonomic Information System [<http://www.itis.usda.gov/>], Global Biodiversity Information Facility [<http://www.gbif.org/>], Fauna Europaea [<http://www.faunaeur.org/>], Index Fungorum [<http://www.indexfungorum.org/>]) that aim to compile or support the development of lists of scientific names are likely to fulfill this precondition in the future.

Another necessary precondition of creating lists of taxa and implementing other biomonitoring tasks is the rapid and accurate identification of species. Identification of vertebrates and higher plants is in most cases straightforward except in some less-studied regions. Nevertheless, the accurate identification of, for example, invertebrates, protists, and fungi are often constrained by lack of keys, specialists, or even by lack of taxonomy. It is plausible that most species of the aforementioned taxa are still undescribed. Currently, the ambitious Barcode of Life Initiative aims to build up an identification system based on species-specific sequences of DNA (cf Savolainen et al. 2005). Successful barcoding of the species may sig-

nificantly contribute in near future to the biomonitoring scheme we propose here.

A useful list of ecosystems means there is a functioning, broad-scale ecosystem classification scheme (e.g., habitats, vegetation) that as far as possible is uniform across different countries, easily applicable, and biologically meaningful. There have been several attempts to establish global classification units for ecosystems (e.g., Walter & Box 1976; Nemani & Running 1996; Olson et al. 2001) and to develop a common standard for vegetation surveys (Mucina et al. 2000). Although the common worldwide standard is not yet agreed upon, there is a continuing effort to unify local vegetation, habitat, and ecosystem types into broad land cover types.

### Obtaining Information about the Spatial Distribution of Taxa and Ecosystems

Besides the work with species lists, the need for more systematic monitoring of populations and habitats has been emphasized (Balmford et al. 2003). The focus here has to be on spatial distribution of taxa and ecosystems.

Updated distribution atlases of taxa is an obligatory part of any biomonitoring scheme. One may start from better-known taxonomic groups that have been shown to be ecologically indicative. For example, Pereira and Cooper (2006) suggested focusing on birds and vascular plants as indicator taxa. At least in the case of taxa of special interest (e.g., taxa protected by law, red-listed taxa), all finds of specimens have to be recorded together with geographic coordinates. For abundant taxa presence or absence may be documented in a representative sample of well-defined areas of a particular country.

Similarly, there is a need for data about the distribution of particular ecosystem types within a target area (e.g., a country). With regard to broad-scale types, there would be an ecosystem (vegetation, habitat) map for the whole target territory. As detailed mapping is resource consuming, a priority should be given to the mapping of ecosystems of special interest (e.g., ecosystems unique or valuable from the point of view of nature conservation). In Europe a great step toward this task has been made through inventorying of Natura 2000 habitats (Habitat Directive [92/43/EEC]).

### Characterization of the Status of Taxa and Ecosystems

Qualitative and quantitative information on the status of taxa may be gathered on several scales (Menges & Gordon 1996; Pärtel et al. 2005). It is reasonable to give a general estimation of status based on the IUCN Red List categories (Hilton-Taylor 2000). Butchart et al. (2004) demonstrated the usefulness of such robust data in measuring the global

trends in the status of bird biodiversity and in proposing a red list index. Given the resources the primary monitoring activities may easily be extended to, for example, collection of more detailed density estimates and information on the age, stage, or sexual structure of populations and measures of fecundity, depending on specific goals.

The obligatory evaluation of the status of ecosystems has to characterize the dynamic status of the particular ecosystem on the basis of structural and compositional parameters. For example, natural forest ecosystems can be classified into broad categories such as primeval stands, old growth, intermediate age, young, and clearcut. Similarly, seminatural grassland ecosystems may be divided into different categories along a successional gradient from permanently managed traditional grasslands to secondary woods. Given greater resources one may use more detailed descriptions of the structure and composition of stands and elaborate appropriate biodiversity indicators for each dynamic stage (cf Larsson 2001). If information exists on species composition and structure of an undisturbed reference system, the dynamic status of any particular ecosystem may be estimated as the deviation from the undisturbed state (Ejrnæs et al. 2002).

### **Recording the Dynamics of the Number, Distribution, and Status of Taxa and Ecosystems**

Ultimately, biodiversity monitoring has to mirror changes in the state of biomes and biota (Watson & Novelly 2004). Repeated mapping of species distribution has made it possible to trace changes in their status in particular areas (Thomas et al. 2004). Similarly, repeated monitoring of priority ecosystem types (Critchley et al. 2003) or broad habitat types (Howard et al. 2003) has made it possible to trace changes in their status in particular areas. Repeated mapping of ecosystems may also predict possible future loss of species (Helm et al. 2006). On a global scale Hoekstra et al. (2005) has attempted to estimate habitat conversion within biomes. Remote sensing follows changes in the distribution of ecosystems cost effectively and its common standards make it easily applicable across different countries (e.g., Achard et al. 2002).

Pereira & Cooper (2006) suggest an optimal time interval between surveys. In reality the interval used should take into account the amount of available resources. For species that are difficult to observe (e.g., many groups of insects), a cost-effective assessment of the status and trends may require continuous monitoring. A longer time interval should then be the basis of summaries.

### **Conclusions**

A common-ground biomonitoring scheme has to consist of three main elements: recording the occurrence of taxa and ecosystems in a target area, mapping their distribu-

tion in space, and assessing their status. All three elements have to be repeated over time. The sequence followed above is the sequence of priorities—it is essential to start with simple and basic activities and add other elements when resources become available.

Well-conceived, robust, and understandable biodiversity indicators are needed for communication with the public and governments (Balmford et al. 2005). Our framework aims to fulfill only the basic requirements of good communication between biodiversity conservationists and society. The information that can be obtained through such a scheme could directly apply to several CBD indicators for assessing progress toward the 2010 Biodiversity Target (COP decision VII/30).

The elements of biomonitoring we propose are fundamental, and the fact that they are frequently not the key elements of currently functioning biomonitoring programs is surprising. The generation of basic background data on the level of biodiversity (species lists and distribution maps, ecosystem maps) frequently remains in the financial gray zone—granting bodies avoid financing routine work and prefer novel approaches. Arguably, nature conservation agencies may believe novel, academic research on biodiversity is often “too scientific” and does not have clear policy relevance. If we agree that biomonitoring should primarily provide uniform, basic data about the composition, spatial distribution, and status of taxa and ecosystem types and should repeat these descriptions over time, this will considerably improve the understanding of the forces behind biodiversity patterns and the probability of optimizing biodiversity conservation and management and land-use planning at both the national and international levels.

### **Acknowledgments**

U.N. Environment Programme and the Estonian Ministry of Environmental Protection (GF/2716-01-4354), EU Integrated Project ALARM (GOCE-CT-2003-506675), University of Tartu (TBGBO0553), and Estonian Science Foundation (grants 6619 and 6614) financed this work. We thank the participants of the Nordic Workshop in Aarhus (2002). L. Klein, L. Eek, Ü. Kukk, N. Ingerpuu, R. Mänd, T. Tammaru, I. Part, and three anonymous referees kindly commented on the first draft of the manuscript.

### **Literature Cited**

- Achard, F., H. D. Eva, H.-J. Stibig, P. Mayaux, J. Gallego, T. Richards, and J.-P. Malingreau. 2002. Determination of deforestation rates of the world's humid tropical forests. *Science* 297:999–1002.
- Balmford, A., R. E. Green, and M. Jenkins. 2003. Measuring the changing state of nature. *Trends in Ecology & Evolution* 18:326–330.
- Balmford, A., et al. 2005. The Convention on Biological Diversity's 2010 target. *Science* 307:212–213.

- Butchart, S. H. M., A. J. Stattersfield, L. A. Bennun, S. M. Shutes, R. Akcakaya, J. E. M. Baillie, S. N. Stuart, C. Hilton-Taylor, and G. M. Mace. 2004. Measuring global trends in the status of biodiversity: red lists indices for birds. *PLOS Biology* **2**:e383.
- Critchley, C. N. R., M. J. W. Burke, and D. P. Stevens. 2003. Conservation of lowland semi-natural grasslands in the U.K.: a review of botanical monitoring results from agri-environmental schemes. *Biological Conservation* **115**:263–278.
- Davies, J., J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull, and M. Vincent. 2001. Marine monitoring handbook. Joint Nature Conservation Committee, Peterborough, United Kingdom.
- Delbaere, B. 2002. Biodiversity indicators and monitoring: moving towards implementation. Proceedings of a side event held at CBD/COP6. European Centre for Nature Conservation, Tilburg, The Netherlands.
- Ejrnaes, R., E. Aude, B. Nygaard, and B. Münier. 2002. Prediction of habitat quality using ordination and neural networks. *Ecological Applications* **12**:1180–1187.
- Glowka, L., F. Berhenne-Guilmin, and H. Synge. 1994. A guide to the Convention on Biological Diversity. World Conservation Union, Gland, Switzerland.
- Green, R. E., A. Balmford, P. R. Crane, G. M. Mace, J. D. Reynolds, and R. K. Turner. 2005. A framework for improved monitoring of biodiversity: responses to the World Summit of Sustainable Development. *Conservation Biology* **19**:56–65.
- Helm, A., I. Hanski, and M. Pärtel. 2006. Slow response of plant species richness to habitat loss and fragmentation. *Ecology Letters* **9**:72–77.
- Hilton-Taylor, C. 2000. 2000 IUCN red list of threatened species. World Conservation Union, Cambridge, United Kingdom.
- Hoekstra, J. M., T. M. Boucher, T. H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters* **8**:23–29.
- Howard, D. C., J. W. Watkins, R. T. Clarke, C. L. Barnett, and G. J. Stark. 2003. Estimating the extent and change in broad habitats in Great Britain. *Journal of Environmental Management* **67**:219–227.
- Hurford, C., M. R. Jones, and A. Brown. 2001. Habitat monitoring for conservation management and reporting. 2. Field methods. Countryside Council for Wales, Bangor, United Kingdom.
- JNCC (Joint Nature Conservation Committee). 2004. Common standards monitoring: introduction to the guidance manual. JNCC, Peterborough, United Kingdom.
- Larsson, T. B. 2001. Biodiversity evaluation tools for European forests. *Ecological Bulletins* **50**:1–236.
- Menges, E. S., and D. R. Gordon. 1996. Three levels of monitoring intensity for rare plants species. *Natural Areas Journal* **16**:227–237.
- Mucina, L., J. H. J. Schaminee, and J. S. Rodwell. 2000. Common data standards for recording relevés in field survey for vegetation classification. *Journal of Vegetation Science* **11**:769–772.
- Nemani, R., and S. W. Running. 1996. Implementation of a hierarchical global vegetation classification in ecosystem function models. *Journal of Vegetation Science* **7**:337–346.
- Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* **4**:355–364.
- Olson, D. M., et al. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. *BioScience* **51**:933–938.
- Pereira, H. M., and H. D. Cooper. 2006. Towards the global monitoring of biodiversity change. *Trends in Ecology & Evolution* **21**:123–129.
- Pärtel, M., R. Kalamees, Ü. Reier, E.-L. Tuvi, E. Roosaluuste, A. Vellak, and M. Zobel. 2005. Grouping and prioritization of vascular plant species for conservation: combining natural rarity and management need. *Biological Conservation* **123**:271–278.
- Rempel, R. S., K. A. Hobson, G. Holborn, S. L. Van Wilgenburg, and J. Elliott. 2005. Bioacoustic monitoring of forest songbirds: interpreter variability and effects of configuration and digital processing methods in the laboratory. *Journal of Field Ornithology* **76**:1–11.
- Royal Society. 2003. Measuring biodiversity for conservation. The Royal Society, London.
- Savolainen, V., R. S. Cowan, A. P. Vogler, G. K. Roderick, and R. Lane. 2005. Towards writing the encyclopaedia of life: an introduction to DNA barcoding. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **360**:1805–1811.
- Smyth, A. K., and C. D. James. 2004. Characteristics of Australia's rangelands and key design issues for monitoring biodiversity. *Austral Ecology* **29**:3–15.
- Stork, N. E., and M. J. Samways. 1995. Inventorying and monitoring. Pages 453–543 in V. H. Heywood and R. T. Watson, editors. *Global biodiversity assessment*. Cambridge University Press, Cambridge, United Kingdom.
- Thomas, J. A., M. G. Telfer, D. B. Roy, C. D. Preston, J. J. D. Greenwood, J. Asher, R. Fox, R. T. Clarke, and J. H. Lawton. 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* **303**:1879–1881.
- Walter, H., and E. Box. 1976. Global classification of natural terrestrial ecosystems. *Vegetatio* **32**:75–81.
- Watson, I., and P. Novelly. 2004. Making the biodiversity monitoring system sustainable: design issues for large-scale monitoring systems. *Austral Ecology* **29**:16–30.
- Yoccoz, N. G., J. D. Nichols, and T. Boulinier. 2001. Monitoring of biological diversity in space and time. *Trends in Ecology & Evolution* **16**:446–453.

