Science and society halting biodiversity loss

- a framework for Germany -

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1 Overview

Society's wellbeing depends on biodiversity, the natural wealth of plants, animals and micro-organisms, which are the basis and driving forces providing ecosystem services to mankind. These essential ecosystem services are jeopardized by loss of species and loss of ecosystem functioning. Society is both the main driver of, and suffers the consequences of biodiversity change. We therefore believe that an improved national program of scientific excellence aimed at finding solutions to the harmful consequences of biodiversity change needs to involve societal actors and assign a leading role to social scientists from the very beginning.

Here we propose a framework that aims at developing a generic workflow involving natural scientists, social scientists and society to find solutions to prevent harmful biodiversity change for the major ecological systems in Germany. The essential components ('operators' identified by capital letters) of this workflow are depicted in Figure 1 and described below

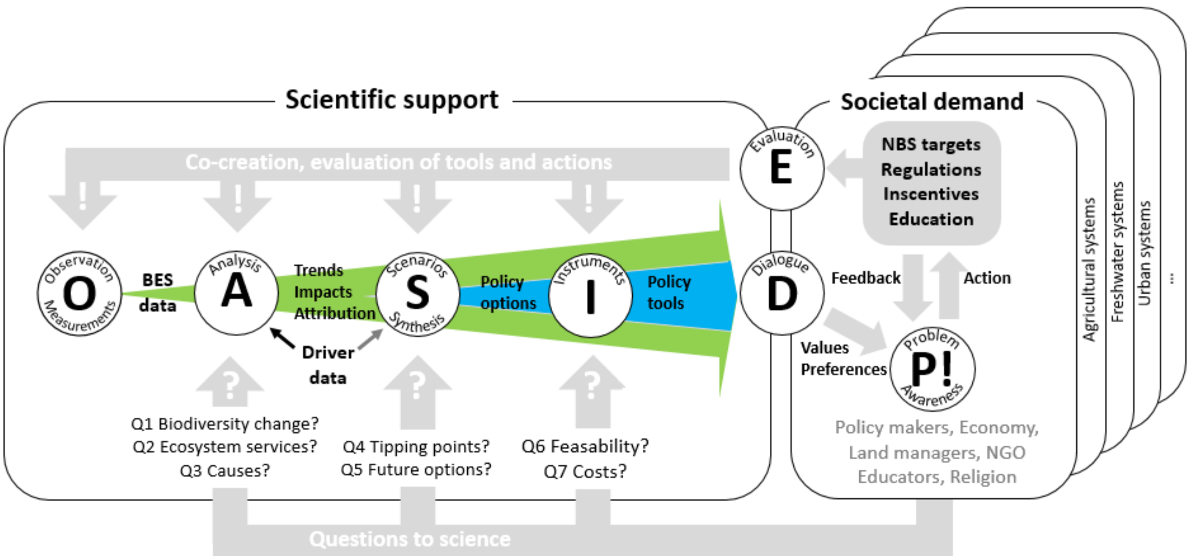

Figure 1: *Key components of a science program to support decision making and society in addressing biodiversity loss. We suggest seven guiding questions. The workflow is meant to represent a generic approach to be adjusted to different socio-ecological systems (agriculture, freshwater etc.) shown as different layers. Green = natural systems knowledge, blue = social systems knowledge, BES = Biodiversity-Ecosystem Services*

We believe that solutions for the biodiversity problem (**P!**) can also be societal and economic opportunities and that they require the awareness of the existence and the severity of the problem. This requires an efficient dialogue between scientists and society (**D**) about science facts, values and targets. Without this dialogue and awareness scientific knowledge will not be translated into action. Reaching it requires that scientists address questions of societal relevance (co-development) and actively inform society about their findings (risks, uncertainties, opportunities).

The scientific workflow addresses seven questions.

- **Q1: What is the extent and meaning of current biodiversity change?**
- **Q2: How are ecosystem services relevant for society impacted by biodiversity change?**
- **Q3: What are the main drivers of biodiversity change?**

Answering the first three questions requires observations on biodiversity change and measurements of ecosystem services, from either existing or newly tailored observations and observational experiments (**O**). These data have to be analyzed in the light of the three questions (**A**), which for Q3 requires additional data on environmental and societal drivers. In the next step, teams of natural and social scientists and actors from society synthesize new and existing knowledge of socio-ecological systems and develop scenario models (target seeking and policy screening scenarios) to explore two important additional questions:

- **Q4: What are the tipping points of systems in the light of environmental or societal change?**
- **Q5: Which (management) options exist to restore biodiversity and prevent its loss?**

Answering these two questions reveals policy options as targets to develop socio-economic instruments (**I**) capable of triggering a change in societal behavior, with two key questions:

- **Q6: How will instruments need to be designed given political and cultural constraints and the need to balance conflicting interests?**
- **Q7: What are the socio-economic costs of these instruments?**

In order to develop effective biodiversity research for society the dialogue between science and society is central to the whole circle. The dialogue leads to decisions on problem solutions in the form of programs (e.g. the 'Nationale Biodiversitätsstrategie'), regulations and incentives (including implementation of SDGs as well as cross-sectoral regulations for water, agriculture, energy, e.g. WFD, CAP, EEG). These instruments 'in action' require regular evaluation (**E**) of all parts of the workflow. This evaluation and the development of the components O, A, S and I are based on of co-design with society.

All "operators" are distinct elements of the workflow and can thus also be used as **project modules** organizing the program. We suggest also to include a careful discussion on the **governance** of the program considering elements allowing for engaging societal actors, research organizations and media.

2 The individual 'operators'

2.1 P! = Problem awareness

Nothing changes if the major players of the society are not aware of the problem of the biodiversity crisis. The sequence of operators discussed below has to answer questions posed by the society and to provide knowledge that raises awareness and that helps societies to act. For this to work, stakeholders and decision makers should be involved in designing scientific programs (co-design). Finding the right partners in society is key to success.

2.2 O = Observation

Addressing the questions (Q1-Q3) requires empirical data. Two types of data are needed, (i) existing long-term data, (ii) data from newly designed observation schemes.

Existing biodiversity data arise from a range of sources such as e.g. regional/FFH monitoring programs, impact assessments, taxonomic mapping schemes, ecological studies, and citizen science organized e.g. by NGOs and natural history societies. Up to now these data form the basis of red lists and higher level indicators such as the common farmland bird indicator, and have been used for a number of important analyses. For example, the recent discussion about dramatic insect declines in German natural areas comes from data collected in this manner. Currently 80-90% of all these data are derived from volunteered information that will increase in value with increased digitization and mobilization. Indeed, **citizen-science** data composes the backbone of the data sources that can be used to carry out a historical reconstruction of diversity trends and driver analyses in Germany, or support new programmes (e.g. sMon project, Living Atlas concept). Many of these data in combination with data from agencies are heterogeneous, fragmented and, at times of unknown quality. As a result, the analysis of these data requires significant post-collection harmonization efforts, taxonomic verification (via **taxonomy experts** and next generation molecular tools) and advanced statistical methods (see 'Analysis').

New designs of observation schemes: Existing data are typically restricted to taxonomic data of few conspicuous species groups (e.g. birds, butterflies, vascular plant species) only observable aboveground, and often have limited temporal coverage and resolution. Rarely do they provide information on other essential facets of diversity (e.g. ***Essential Biodiversity Variables*** EBV in the sense of GEO BON) or can they be linked to drivers and different spatio-temporal scales. New observations schemes – if possible representative for major land units – are required that:

- Allow quantification of biodiversity change at sufficient temporal resolution for representative groups of organisms (above- and belowground, terrestrial and aquatic, etc.)
- assess trends on genetic and functional diversity of relevant keystone taxa and important crops and breeds
- quantify functionally relevant species interactions and selected ecosystem processes and services

Operationally, these new observational schemes should achieve the following:

- systematically span gradients of important drivers (e.g. climatic gradients, landscape fragmentation, land use intensity, land management schemes, fertilization, pesticides, etc.) and quantify these on-site.
- account for scale-sensitivity (space and time) from plot to landscape of any diversity quantity observed
- include information on species interactions and in situ traits and behaviors, rather than just numbers
- include citizen science approaches
- apply new and automated monitoring and measurement techniques (barcoding, computer vision, soundscape analysis, remote sensing etc.) and involve taxonomic experts for calibration.
- link with international initiatives, most importantly GEO BON and eLTER

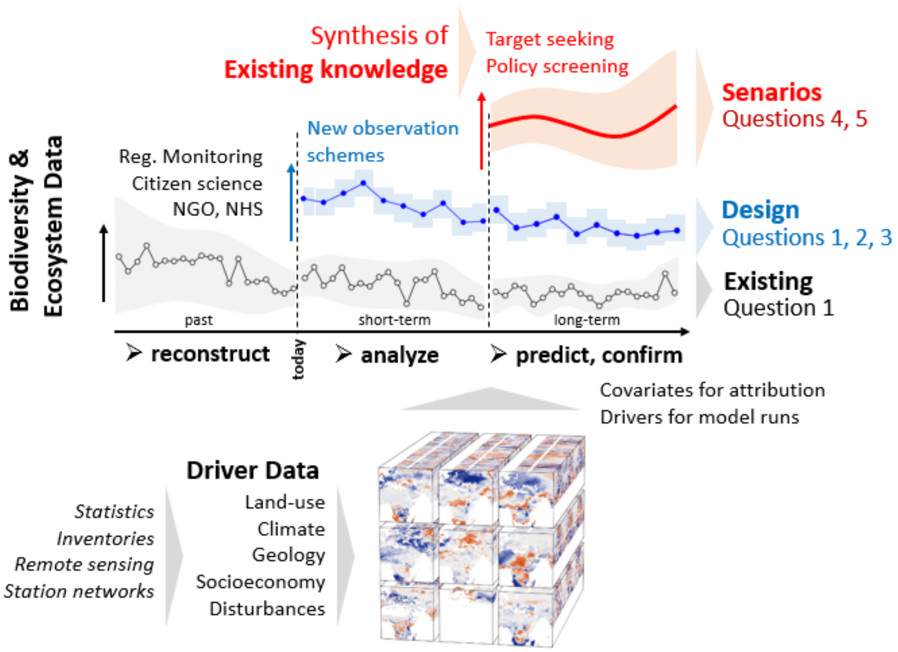

Figure 2: *An overview of the interplay of 'observations' (O) generating existing and newly designed data from new observation schemes, 'analysis' (A) processing these date partly assimilating additional data on drivers. Synthesis of existing knowledge and mechanisms revealed by analysis informs scenario modeling concrete action (S). Data cube by M. Mahecha et al. from MPI Biogeochemistry, Jena. (http://earthsystemdatacube.net/)*

2.3 A = Analysis

It is the analysis step that answers the questions 1 to 3. Depending on the data used extracting trends (Q1) can be anything from straight-forward to very complex. Especially, working with existing opportunistic and thus heterogeneous data requires besides clear communication with data holders often also **biodiversity informatics** tools to find and access the data, **advanced statistics** and high **computing power** (e.g. www.idiv.de/smon). Quantifying trends is important but does not inform to the nature of necessary political action preventing diversity change. Only if the causes underlying biodiversity change are known (Q2) can appropriate measures be devised (Q6, Q7). In order to attribute diversity loss to drivers, respective data need to be assimilated to enable causal analyses. Data on land-use (e.g. management, pesticide use, fertilization), climate, edaphic conditions, disturbances, socioeconomic dynamics acquired by a range of methods such as regional statistics, inventories and surveys, remote sensing, interpolated data from station networks etc. Many such data are available thanks to recent advances in eco-informatics. The **data cube of drivers** developed by MPI Biogeochemistry, Jena or the databases compiled by the GLUES projects (http://www.ufz.de/glues/) are examples of such databases. Driver data enter as predictors in statistical models (frequentist, Bayesian or machine-learning) and are needed input for scenario runs. Jointly, these analyses produce quantifications of trends, impacts and likely causal attribution used in the next step. The development of **indicators** for operationalization is another output of biodiversity analysis. In addition, spatial and temporal data gaps must be filled by using (imputation) models and by combining in situ and remote sensing data.

2.4 S = Synthesis and Scenarios

A key component of decision-support is the evaluation of future scenarios. Two relevant categories of future scenarios are **target-seeking** scenarios and **policy-screening** scenarios. In target-seeking scenarios, pathways to reach policy targets for biodiversity are assessed. For instance, in the context of the post-2020 national biodiversity strategy, an explicit target for an increase in insect biomass or a target for an improvement in status of endangered species may be set.

These targets can be informed by past trends from existing data, and progress can be monitored by continuing existing monitoring programs and designing new monitoring schemes as appropriate. At the same time, models can be used to try to project the future evolution of indicators relevant for these targets, under for instance combinations of particular land protection and agri-environmental policies. The models used to make these projections are often based on the models that are used to fill spatial and temporal gaps in data to produce essential biodiversity variables. Similarly, in policy screening scenarios, the future evolution of biodiversity indicators is projected using models for particular policies that can be implemented (including cross-sectoral policies for energy, water, food production etc).

For the mid-term future, it is conceivable and desirable that 'data assimilation schemes' are developed based on high-resolution automated observations similar to the inverse modeling frameworks used in the weather forecast.

2.5 I = Instruments

Governing biodiversity requires designing and implementing **policy instruments** in multi-level governance structures. A broad set of policy instruments has been discussed for governing biodiversity over the last years. However, most of these instruments have been ineffective so far, either because they have not or only poorly been implemented, or because other factors that drive biodiversity loss have become more prominent. One reason is that biodiversity protection targets and other policy targets only rarely lead to synergies. In most cases trade-offs between different policy fields are predominant (e.g., between agricultural production and species richness). In this field it is of utmost importance to develop **scenario-based policy tools**, and study their impacts against diverse policy mixes, unintended side-effects multiple political targets in different sectors, and bottlenecks and barriers of implementation. As biodiversity loss is mainly caused by sectors beyond environmental and nature protection, these sectors and there specific governance structures and institutional organization have to be particularly addressed.

2.6 D = Dialogue

Valuing biodiversity – from economic valuation to nature for the people. Biodiversity is important for society for two reasons: Firstly, humans hold **values for biodiversity** and nature as such – in this perspective biodiversity means diversity, beauty, as well as means for mental and physical health and wellbeing. Here, biodiversity protection is considered a target in itself. Secondly, biodiversity is generating ecosystem functions and services that nature provides for humans. In this perspective biodiversity is a means, it has an instrumental function. Integrative valuation approaches are required at the interfaces between natural sciences that deliver knowledge about ecological processes, functions and services, and socio-economic approaches that seek to capture biodiversity's values for humans, addressing different aspects like option values, insurance values, but also social and "relational" values resulting from the specific character of nature-human-relationships. Approaches and methods in these fields have been addressed recently (e.g. by TEEB or IPBES), but have to be researched in an integrative manner. **Awareness** of and solutions to the problem dimension (P!) can only arise from checking reality against values and preferences as well as joint approaches of conducting research. Only if a mismatch is uncovered will societies be willing to take action in the form of legislation or programs.

2.7 E = Evaluation

Evaluation of the scientific activities should be carried out jointly by representatives of science and society. Observational experiments, monitoring schemes, economic instruments need to be evaluated, i.e. tested and if necessary improved. The goal of evaluation is a continuous improvement of methods and tools but also to check whether the measures devised by society in response to problems work. This requires that observation schemes, analyses, and scenario models also include and **evaluate real-world programs** (existing ones and progressively those that are still developed). This typically requires simple ecological and societal **indicator** schemes providing an easy and fast method to quantify success. It is an important component of the scientific workflow to develop efficient test systems.

3 Ten statements

In addition to presenting a framework for structuring a comprehensive program we also want to share ten – not necessarily consensual or representative – statements that emerged in our discussions and that are cross-cutting and potentially worth considering in the discussion:

1. Science should not be abused to delay action that can and has to be taken now
2. A thorough synthesis of existing knowledge (we know a lot!) needs to be a central pillar of the program; science developing instrument based on this knowledge has priority
3. Existing data present the most valuable source of knowledge we currently have. Science harnessing this resource has priority.
4. Biodiversity scenario modeling is an important but underused tool for Germany.
5. Science should contribute to evaluating programs and measures that already exist (e.g. regional AUKM within pillar 2 of CAP).
6. A new monitoring scheme addressing essential biodiversity variables needs to be developed, but first results can only be expected 10-20 years from now
7. A new monitoring scheme cannot be representative for organism and eco-regions and at the same time detect the causes of biodiversity change. Extra effort and observational experiments is needed for the latter
8. Co-design: Scientists cannot involve everyone but instead need to invest in finding the right partners in society to make real progress
9. Science providing solutions to improve information flow to key players and raise their awareness is needed.
10. Belowground biodiversity change has been completely neglected so far, although it drives element cycles and is likely strongly affected by pesticides, land management practices and climate change.