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Securing the Conservation of biodiversity across Administrative Levels and spatial, temporal, and Ecological Scales

SCALES (2009–2014) is a European research project financed by the seventh EU framework programme for research and development (FP7). SCALES seeks ways to better integrate the issue of scale into policy and decision-making and biodiversity management in the EU. For more information please see: www.scales-project.net

SCALES briefs 1
A primer for biodiversity monitoring across SCALES

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Ornithologists contribute most but mainly descriptively to monitoring schemes in Europe.
(Photo: André Künzelmann, © Helmholtz Center for Environmental Research)

(1) Basic principles of designing and evaluating monitoring schemes

Figure 1 illustrates the basic principles that need to be considered in the design or evaluation of monitoring schemes. The aim of a monitoring scheme is to answer specific questions, originating from external needs. Sampling designs and field methods (determining field data) are chosen according to objectives. Inferences that can be extracted from the monitoring scheme to answer the general questions of the scheme are directly dependent on the chosen sampling design; the same is true for the biological parameters that can be estimated from the collected data. Then, ideally, a monitoring scheme should be adaptive: monitoring methods are revised according to weaknesses identified during data analysis, and monitoring goals are revised according to new needs or more precisely defined questions

policy support, which management problem, or which scientific issue. These questions will constrain all the following characteristics of the monitoring: What to monitor at what scale? Which field methods to use, how to design the scheme, and how to analyse the data?

For the long-term, multi-purpose surveillance can be advantageous to address general questions, such as the status and trend of distribution and abundance of a set of species, and the causes for their changes. With such generalist scheme, many questions could be addressed using appropriate post-stratification, taking advantage of the many sites sampled. Narrowly targeted monitoring schemes may die once the original goals have been achieved.

Useful references: Elzinga et al. 2001; Yoccoz et al. 2001; Parr et al. 2002; Green et al. 2005; Teder et al. 2007; see also Nichols and Williams 2006.

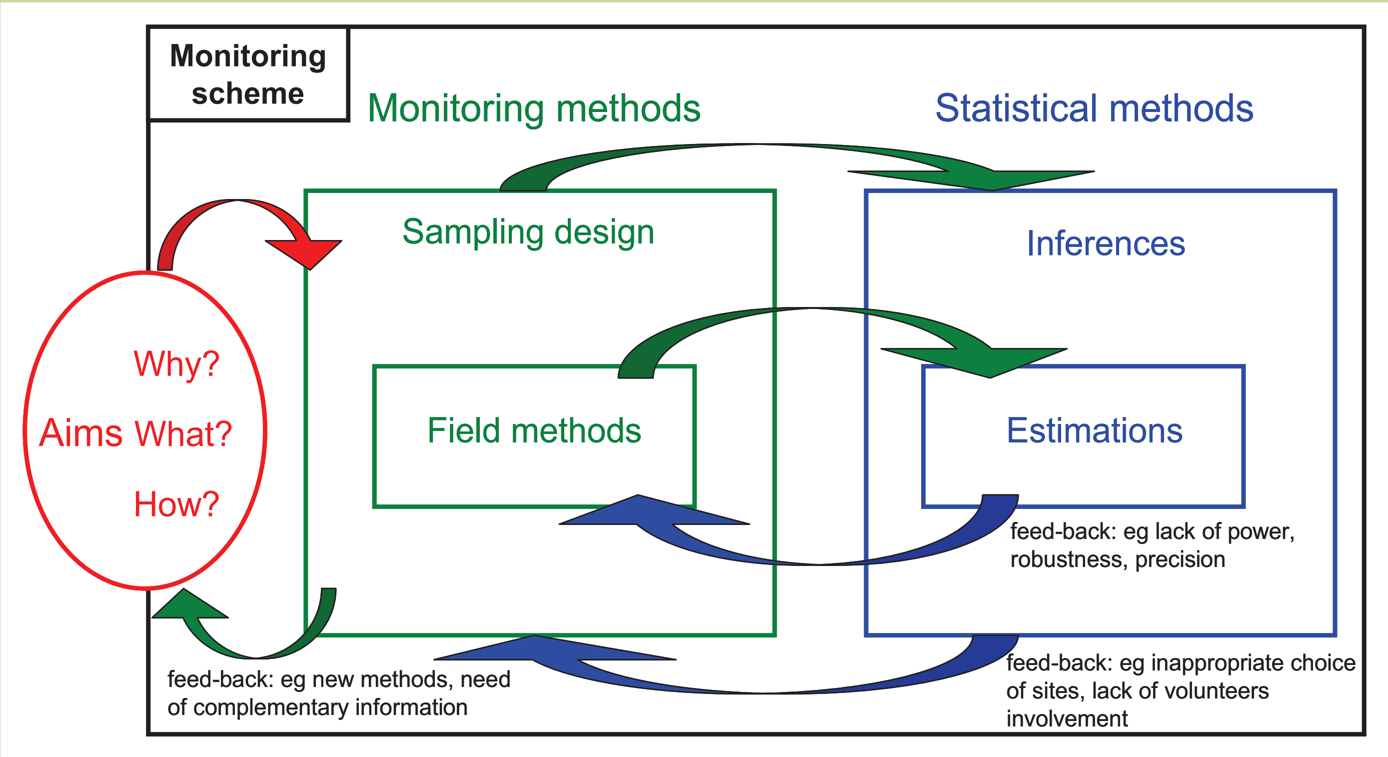


Figure 1: Basic principles of a monitoring scheme.

(2) Why monitor biodiversity?

The very first step when launching, evaluating, or analysing a biodiversity monitoring scheme is to clearly define the questions that need to be answered (Figure 1). Usually, the questions will fall into one of the following three categories: which

(3) Choice of the biodiversity components to be monitored

The hierarchical decomposition by Noss (1990) of biodiversity into biodiversity components is useful for defining what measures of biodiversity may be monitored. For many management and policy issues species and habitats are among the most important components. *Presence/absence, distribution, abundance, quality criteria for habitats*, and to a lesser extend *demographic processes* are important parameters to monitor for species and habitats. The Appendix provides guidance on which general data type is particularly appropriate for which of these components. *Community processes*, such as changes in species number or composition, may also be important measures. However, they do not need special schemes. It is rather a way to analyze multi-species abundance data.

(4) Use of biodiversity indicators

Biodiversity usually cannot be measured in its full complexity. Therefore, a range of biodiversity indicators has been proposed. They serve as a common currency to facilitate comparison. Besides species and habitats targeted by national and international legislations and agreements (e.g., Annexes of the Birds and Habitats Directives), birds and butterflies have emerged as the only taxonomic groups broadly used for large-scale state and trend assessments. The BioMAT tool of the EU FP6 project EuMon (eumon.ckff.si/biomat), which will become part of the SCALESTOOL, allows an evaluation of current monitoring practices for other candidate groups. Useful references: Balmford et al. 2005a,b; European Environment Agency 2007 and references therein.

(5) Which field methods?

Textbooks and reviews provide practical introductions to standard field methods. Useful references: Cooperrider et al. 1986; Noss 1990; Bookhout et al. 1994; Elzinga et al. 2001; Vořišek et al. 2008.

(6) How to distribute samples in time and space?

This is the crucial step of sampling design and is essential if we want to make reliable inferences

Butterflies are easy to observe and monitor. Voluntary people provide most of the monitoring data
(Photo: Walter Müller, © Helmholtz Center for Environmental Research)

from the collected data. It is fundamental for any data collection, including monitoring, but is often neglected in many monitoring schemes (Nichols and Williams 2006; Henry et al. 2008. Distribution of efforts will depend first of all on available manpower, which therefore needs to be evaluated first. The most important components of sampling design choice are:

a. **Where to monitor?** Site selection methods yielding unbiased data are random sampling, exhaustive sampling, or systematic sampling; stratification may help to reduce the number of samples needed. The absence of representative site selection is a serious weakness even in some long-term large-scale monitoring schemes (Buckland et al. 2005). It imposes that monitoring data must be post-stratified to achieve unbiased conclusions. An other approach is to take advantages of existing variation among sample sites to test some hypothesis about biodiversity distribution and environmental gradients, when sampling was not initially designed for that gradient.

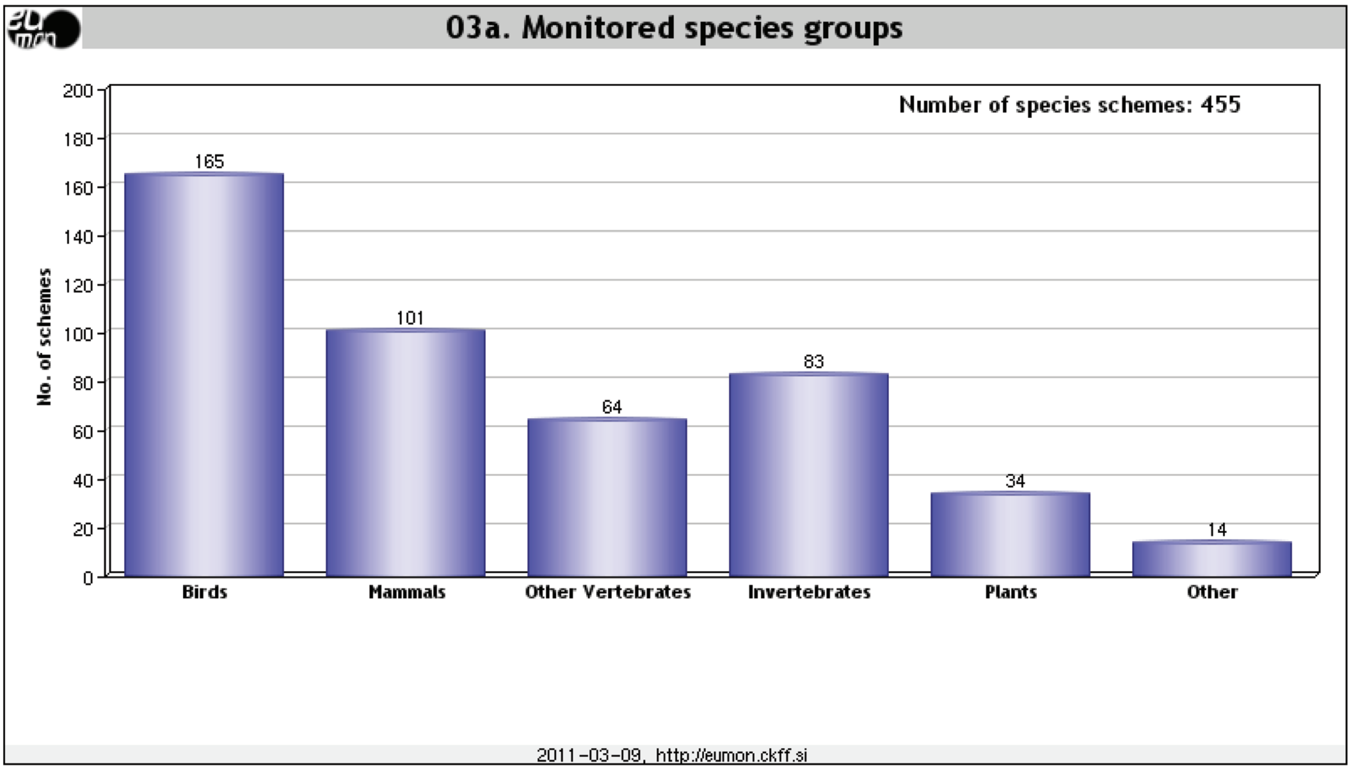
b. **At which scale to monitor?** Sites to be monitored must be representative at the spatial scales relevant for the monitoring targets and should spatially cover variation in processes that may drive changes. Much can be gained from nested spatial designs (with e.g. one or two nested levels). Small-scale designs can be used to address local concerns (e.g. effectiveness of protected areas). However they should always be coupled with monitoring over broader scales (national to European scales), which can be used as benchmarks to discriminate the role of local vs. large-scale drivers of biodiversity. Ideally, the same monitoring protocols are used for data collection s this facilitates the integration across scales.

c. **When to monitor?** The designing of monitoring can be as refined in time as in space. Nonetheless, the common practice is to monitor every year (or every 2nd or 5th year for long-lived organisms or habitats, or several times a year for species with several generations per year). Temporal repetition should be designed to allow accounting for variation in detectability (typically within year repetition) and change in trend (typically among year variation). For monitoring changes in phenology, in particular, repeated sampling within a year is required.

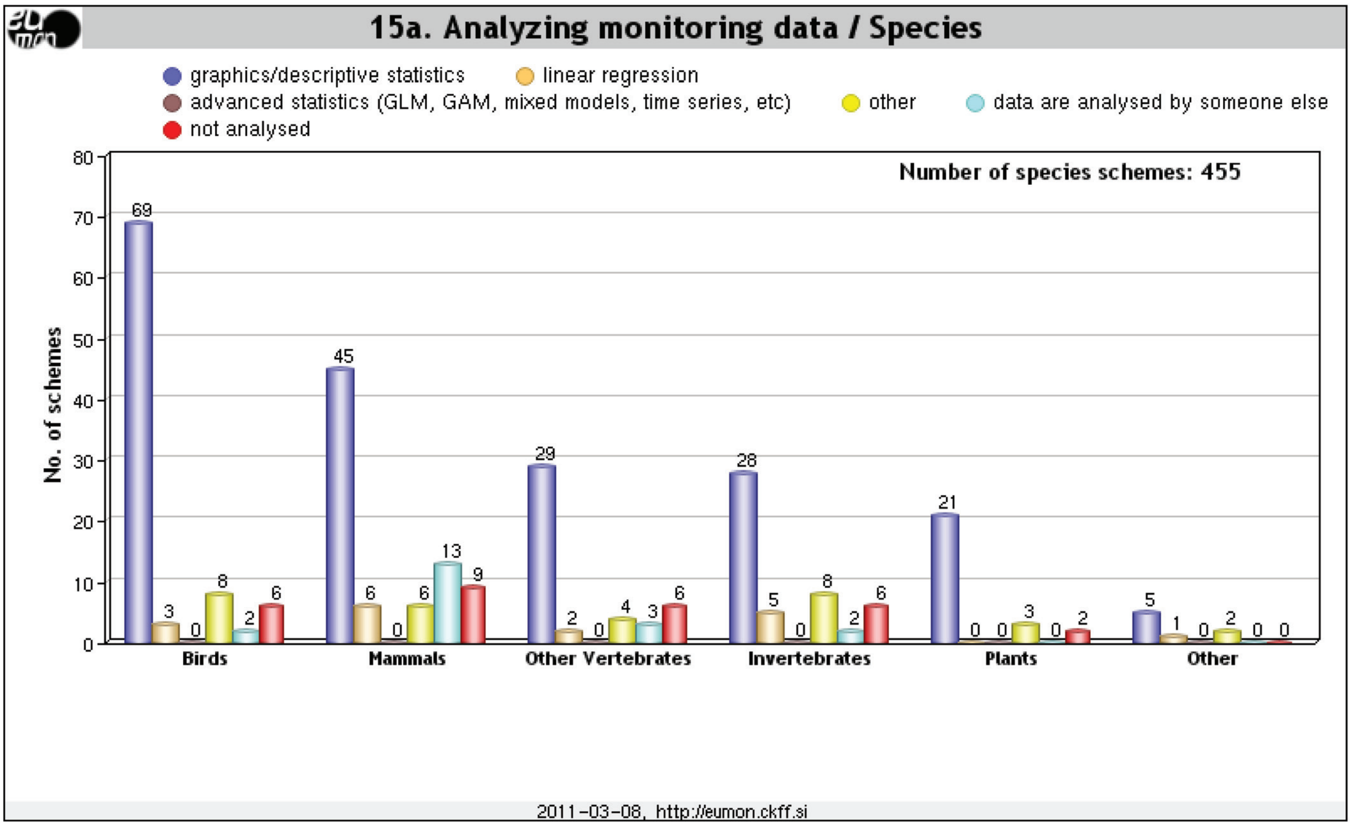
d. If the impact of a given **cause of biodiversity change** is to be demonstrated, an experimental design is needed (ideally, a control treatment, or at least before-after comparisons). At large scale, setting-up a true experimental design due to the difficulties of accounting for all environmental variation. is often impossible. On the other hand, much can be achieved with a stratified design, or with post-stratification with a generalist sampling design, if data on potential drivers of change are also collected.

e. Accounting for **error in the measures**. The key issue here is whether detection probability varies spatially and/or temporally. Otherwise changes in the recorded value may not reflect the true changes in the parameter but, instead, variations in detection probability. Although detection probability may require considerable field effort, it should be accounted for whenever its variations are expected to confound temporal or spatial changes in the parameter of interest. The best approach is replicated sampling (i.e., several samples at the same sites) as it allows estimating detection probability. An alternative approach may be to use covariables, such as habitat type or observer identity, in the data analyses to account for potential variation in detection probability.

Useful references: BioMAT modules 2 and 3 (eumon.ckff.si/biomat); Caughley 1980; Olsen et al. 1999; Parr et al. 2002; Yoccoz et al. 2001; Margurran 2004; Buckland et al. 2000, 2005; Nichols & Williams 2006; Henry et al. 2008.



Number of monitoring schemes by species group. The species monitored were divided into six organism groups – birds, mammals, other vertebrates, invertebrates, plants, and other (Source: EUMON at http://eumon.ckff.si).



The number of monitoring schemes employing various statistical or other techniques to analyse monitoring data for various species groups (Source: EUMON at http://eumon.ckff.si)

(7) How to analyse monitoring data?

Key messages are:

a. Use of **generalised linear models**. It allows testing and accounting for temporal trends with incomplete time series (missing data). Including the effect of site identity as a random effect partly compensates for among-site variations (e.g., observer effect, detection probability variations) without introducing biases, and only lowering the precision of the estimate.

b. Use of **spatial interpolation**: it allows production of biodiversity estimates even for areas not monitored.

c. Use of statistical models that account for **measurement error** (i.e., detection probability).

d. Considering spatial variation in the temporal trend of the biodiversity indicator. An average value of the indicator can always be computed, but major spatial variations in the trend should not be neglected because of their major implications in terms of environmental policy and the understanding of the monitored system.

e. Up-scaling information is becoming possible due to advances in analytic methods. Thus, a well-chosen set of local biodiversity surveys can potentially be used to allow assessing diversity change at regional or national scale. The SCALES project is involved in developing and testing such methods.

f. Integration across schemes. Complementarity in monitoring targets across schemes enables the description of complex patterns of biodiversity dynamics. The integration of information across schemes is still poorly developed. There are four avenues for integration along the four dimensions that characterize a monitoring design: sample size, biological coverage, spatial coverage, and temporal coverage. Integration may be possible at the level of raw data, parameter estimates, or estimates of effect sizes. See Henry et al. (2008) and Lengyel et al. (2008) for further guidelines for integration across species respectively habitat monitoring schemes.

Recommendations of suitable statistical methods for monitoring data are integrated in BioMAT module 2. Further useful references: Olsen et al. 1999; Parr et al. 2002; Yoccoz et al. 2001; Margurran 2004; Buckland et al. 2000, 2005; Nichols & Williams 2006; Hengl et al. 2009).

Popular programs:

● for abundance trend analyses with count data: TRIM (www.cbs.nl/nl-NL/menu/themas/natuur-milieu/methoden/**trim**/manual-**trim**.html)

● for demographic and abundance trend analysis with capture-mark-recapture data: MARK (http://www.cnr.colostate.edu/~gwhite/software.html)

R Development Core Team 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org.

(8) Need for more integration of monitoring output across monitoring schemes.

Meta-analysis tools are particularly suitable for data integration, but they remain under-used in the context of biodiversity assessment. Avenues and methods for integration are presented in Henry et al. 2008. BioMAT module 2 further provides web-based guidelines for integration of output across monitoring schemes (available at eumon.ckff.si/biomat).

(9) How to evaluate a monitoring scheme?

To assess the reliability of monitoring results, the underlying monitoring scheme should be evaluated in terms of the criteria listed above under items (5) and (6). A framework for such an evaluation of monitoring schemes will be implemented in BioMAT module 3. This framework additionally considers criteria for time- and cost-effectiveness (available at eumon.ckff.si/biomat).

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Appendix. Link between functional parameters to be monitored (rows) and measures to be taken (columns).

	Presence/absence	Counts of individuals	Age or size-structure	Individual follow-up (cf. Capture-Mark-Recapture)	Advantages	Disadvantages
Distribution	**Optimal**	Not used	Not used	Not used	Basic information required for status identification	Trends are detected late, after local extinction or colonisation only
Abundance	Appropriate but lower power to detect trends than counts of individuals	**Optimal**	Not used	Ideal but field intensive	Trends detected early, before local extinction or colonisation	No cues on demographic processes driving changes if only count data are available; if complementary information is available, inferences on demographic processes may be possible
Demographic processes	Appropriate for estimation of population growth rate inducing range extension / restriction only	Appropriate for population growth rate estimation only	Appropriate	**Optimal**	Detailed understanding of processes driving trends	Data consuming
Community dynamics	Suboptimal but still allows assessing species turn-over	**Optimal**	To be developed	To be developed	Understanding of changes in biodiversity components across broad taxonomic groups	Community dynamics theory under development
Advantages	Large coverage because easy to implement	Large coverage because easy to implement	Intermediary level of detail	Highest level of detail		
Disadvantages	Poor precision	Limited information	Usually involves unrealistic simplifications for parameter estimation; Intermediary coverage	Restricted coverage due to intensity of field work		
Spatial scale at which suitable	Large scale; international, national scale	Large scale; international, national scale	Intermediate scale; regional scale	Small scale; local scale		

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