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Biodiversity monitoring for decision-making

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Biodiversity monitoring provides guidelines for decisions on how to manage biological diversity in terms of production and conservation. Monitoring determines the status of biological diversity at one or more ecological levels and assesses changes over time and space. Monitoring at the global level is needed to compare trends caused by the increasing homogenisation of the world's landscapes. Bioindicators are routinely used, but each indicator's potential to determine changes in the overall biodiversity should be rigorously tested. Monitoring is a vital feedback link between human actions and the environment, but incorporation of monitoring results into decision making is hampered by poor communication between ecologists and decision-makers. A global network for assessing biodiversity changes (GLOBENET) is described as an example of an initiative that attempts to address the above issues by using a simple field protocol with the aim to develop tools for assessment and prediction of the ecological effects of human-caused changes in the landscape.

Introduction

Monitoring is an integral part of efforts to stop the loss of biodiversity (Dallmeier 1996). However, monitoring should not be an end in itself, but a means to an end. The aim of biodiversity monitoring should be to provide guidelines for making decisions on how to best manage the landscape for the production of resources for the human population, and at the same time, to maintain biological diversity. The specific purpose of a monitoring programme can include: identifying key issues for policy and management goals, assessing priorities for conservation, or informing policy-makers and the general public on the state of biodiversity (Stork & Samways 1995).

Humans affect landscapes in two basic ways: by fragmenting and homogenising. This process was labelled 'Europeanisation' by Elton (1958), who correctly predicted that the world's biota would become increasingly similar through a two-step process that included homogenisation of landscapes, and introduction of exotic species. Introduced species are an increasing problem in many parts of the world. For instance, nearly 2 000 insect species of European origin were established in North America after its settlement by Europeans (Niemelä & Mattson 1996). Many of these insects, including ground-beetles (Coleoptera, Carabidae), have become established through human transport far from their original ranges (Spence & Spence 1988, Spence 1990, Niemelä & Spence 1991). Comparisons of sites newly colonized by introduced species with those in the original distribution area of the species can yield valuable understanding of why certain species become successful invaders and how to mitigate any adverse effects on native biota in the invaded areas.

Programmes established to monitor changes in populations of single species abound. For instance, by the mid 1980s about 170 programmes for monitoring rare plants were in operation in the USA. Some of the programmes used different methods to monitor different populations of the same species (Spellerberg 1993). These programmes, if coordinated properly, are useful for monitoring single species. However, on the global scale, single species monitoring is rarely possible because of the restricted distribution of most species. Thus, global monitoring needs to focus on equivalent species assemblages, but using similar methods for comparable inferences.

The aim of this paper is to examine procedures for biodiversity monitoring, with special focus on the categories of and criteria for the selection of indicators. I discuss the link between monitoring and decision making, and describe an example of global monitoring: the GLOBENET initiative, which attempts to address the above issues by using a simple field protocol with the aim of developing tools for assessment and prediction of the ecological effects of human-caused changes in the landscape.

What is biodiversity monitoring?

Monitoring is defined as 'intermittent (regular or irregular) surveillance carried out to ascertain the extent of compliance with a predetermined standard or the degree of deviation from an expected norm' (Hellawell 1991). Therefore, a standard or norm has to be defined before the programme can be implemented. The formulation of this standard requires information on the baseline structure of and variation in the system to be monitored (Karr 1987). However, establishment of the natural baseline may be difficult for two reasons. First, long term data sets on most taxonomic groups from undisturbed sites are not available to provide information about natural variation in species assemblages. Second, as humans have affected most of the world's ecosystems it may be difficult to find truly undisturbed sites that can provide baseline information about natural variation (Arcese & Sinclair 1997). Such areas still exist for some habitat types (e.g. northern boreal forest in Canada and Russia), and large parts of them should be urgently set aside to function as ecological baselines (Angelstam *et al.* 1997).

Fairly natural areas still exist in the surroundings of many urban centers, and an urban-to-rural gradient of decreasing human influence could be used to assess the effect of human-caused landscape changes (urbanisation) on biota (McDonnell & Pickett 1990). These gradients can provide a framework in which ecologists can examine human-induced landscape changes and compare the findings throughout the world to unravel generalities in community structure that relate to the disturbance. Through consistent monitoring efforts, these landscapes can be treated as field experiments for addressing basic ecological questions as well as issues related to the impact of humans on their environment (Niemelä *et al.* 2000).

The Convention on Biological Diversity defines biodiversity as follows: 'biological diversity means the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (Stork & Samways 1995). Thus, biodiversity monitoring can encompass a variety of biological entities and levels. Generally, the monitoring of biodiversity uses the distribution and abundance of organisms (e.g. species, genera, families), and their associations with the physical environment to determine the status of biodiversity or changes, over time and space.

The many goals of monitoring, including biodiversity monitoring, may be classified into three, not mutually exclusive categories (Hellawell 1991): (1) assessing the effectiveness of policy or legislation, (2) regulatory, i.e. a performance or audit function, and (3) detecting incipient change, i.e. providing an early warning. The aim may also be to develop a strategic framework for policy making, i. e. predicting the behaviour of key variables to improve management and increase management options (Stork & Samways 1995). To achieve these goals biodiversity monitoring may be conducted on a range of ecological scales using a variety of techniques, including surveying, cataloguing, quantifying and mapping entities such as genes, individuals, populations, species, habitats, and ecosystems; synthesising of the resulting information (Stork & Samways 1995). For instance, at the population level the aim may be to compare and monitor the genetic structure of various populations. At the species level the goal may be to monitor changes in individual species or species assemblages.

As monitoring is such a complex task, any monitoring programme has to be well planned. Before monitoring begins, the following basic questions must be addressed (Usher 1991):

1. What is the goal of the monitoring to be undertaken?
2. What are the indicators and methods to be used to achieve the goals?
3. How are the data going to be analysed?
4. How are the results going to be interpreted in terms of biological and socio-economic implications?
5. How are the results and interpretations going to be communicated to managers, decision makers and the public?

Questions 1–4 basically deal with monitoring itself, while question number 5 puts the programme into a larger, societal context. The purpose of a monitoring programme determines to a great extent the kinds of field methods, indicators and data analysis used, and the ways of synthesising and communicating the results. Communication is important, because the results of any monitoring exercise need to be communicated to the planners, managers and decision-makers. As these individuals do not necessarily have academic training, communication of results must be done in a way and language familiar to them. Examples to this effect are given by Norton (1998).

Indicators of change

Definitions and types of indicators

Biological indicators can be classified as environmental indicators, ecological indicators, biodiversity indicators and impact indicators (Kremen *et al.* 1994, McGeoch 1998). The first three are bioindicators (i.e., biological entities), whereas the fourth is a broader one combining biological, physical and/or geographical indicators. For instance, habitat fragmentation and its effects could be an impact indicator. The categories of indicators are broadly overlapping, and some indicators fall between the categories while others may belong to several categories. For instance, introduced species are biological entities, i.e. bioindicators, but at the same time they are impact indicators being introduced by humans to new areas (Fig. 1).

Environmental indicators are taxa that demonstrate a predictable response to environmental disturbance or change (e.g. pollutants, habitat alteration, vegetation successional stage), thereby indicating the presence and extent of a disturbance (McGeoch 1998). The responses can be many, such as behavioural or biophysical ones. Canaries indicating air quality in coal mines is an example of an environmental indicator. More recently, Dallinger *et al.* (1992) used levels of lead and cadmium in the isopod species *Porcellio scaber* as an environmental indicator to assess variation in levels of heavy metals in the city of Innsbruck, Austria.

Ecological indicators are taxa or taxonomic assemblages that are sensitive to environmental stress factors, and demonstrate the effect of these factors (e.g. habitat alteration, climate change) on biota (communities, habitats, ecosystems), and whose response is representative of the response of at least a subset of other taxa present in the habitat (McGeoch 1998). The difference between environmental indicators and ecological indicators is that the former are used primarily to detect changes in the stressor (e.g. air pollution), while effects on the indicator itself are of secondary importance. Ecological indicators, on the other hand, are used to detect changes in the indicator itself, and the ecological systems repre-

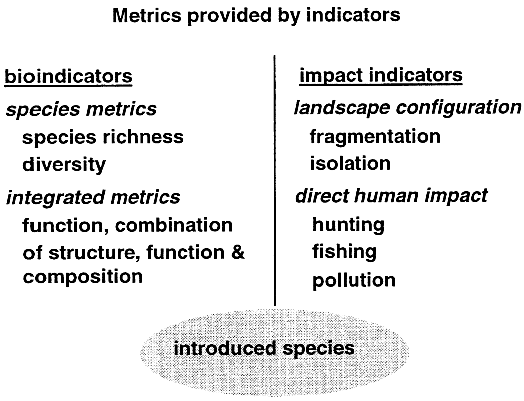

Fig. 1. Bioindicators and impact indicators, and the types of measures they provide. Introduced species is an example of indicators falling between the two types of indicators.

sented by the indicator are of primary interest.

A biodiversity indicator is a group of taxa (e.g. species, genera) or a functional group the diversity of which reflects some measure of the diversity of other taxa in a habitat or set of habitats (Kremen *et al.* 1994, McGeoch 1998). Usually, the species richness of a particular indicator taxon is used to estimate the species richness of other taxa (Noss 1990, McGeoch 1998). For instance, guilds have been proposed as useful indicators (Landres 1983), but not without criticism (Szaro 1986).

Impact indicators focus on both resources and ecological processes that are directly affected by human actions (Fig. 1). These indicators include, for instance, the level and effect of habitat fragmentation and edge effects on ecosystems, degree of regeneration of ecosystems, and degree of soil production (Kremen *et al.* 1994). Impact indicators also include human patterns of resource use, such as the effects of hunting and fishing on ecosystems. Impact indicators would correspond to the regional-landscape level variable in Noss's (1990) scheme.

Bioindicators provide two kinds of measures: species metrics and integrated metrics (Jones & Riddle 1996) (Fig. 1). Species metrics are measures that describe status and trends related to species, such as species richness and diversity. Integrated metrics are measures that evaluate composition, structure and function of biodiversity or its indicators. For instance, nutrient release from litter showed responses to air pollution along an urban-to-rural gradient in Helsinki, Finland (Fritze 1988), implying that functional biodiversity (nutrient release) is affected by human activities. In addition to this division, other classifications of bioindicator measures have been proposed. For instance, Noss (1990) used four levels (regional landscape, community-ecosystem, population-species, genetic) and three attributes of biodiversity (composition, structure, function) to create a 4×3 table of indicator variables.

The use of bioindicators combined with the two types of metrics (species metrics and integrated metrics) is analogous to the Index of Biotic Integrity (IBI), which incorporates various attributes of biotic communities to evaluate human effects on aquatic systems (Karr 1987). These attributes can be divided into three groups: species richness and composition, trophic composition, and abundance and condition of the focal organisms (Karr 1991). A useful metrics for monitoring biotic integrity should include multiple parameters because no single index (e.g. species richness) can be expected to detect the various changes in biodiversity caused by human actions (Karr 1991). In a global monitoring programme (such as GLOBENET described below) it is important to use the same combination of metrics in various parts of the world in order to gain comparable inferences.

Selection of bioindicators

Although exhaustive surveys of all taxa and habitats might be attempted on a local scale, this is not feasible for monitoring that encompasses several countries and biogeographical regions, for reasons such as high species richness and poor taxonomy (Kremen 1992, Pearson & Cassola 1992, Wheeler & Cracraft 1997, Lawton *et al.* 1998). Therefore, it is necessary to select a set of taxa as indicators of the overall changes in biodiversity. However, the selection has to be done with care. A series of tests and evaluations should be conducted to assess each indicator's potential to detect and reflect changes (Kremen *et al.* 1994, Jones & Riddle 1996).

McGeoch (1998) presents a procedure by

which bioindicators can be selected, and their usefulness tested. The first step is to determine the objectives of indication. Once this is done, potential indicators can be selected based on a set of *a priori* suitability criteria. Several kinds of suitability lists have been produced, and one is presented in Table 1. The aim of such lists is to minimise the chance of proceeding with a taxon that might be rejected subsequent to a large investment of research resources.

After a preliminary selection of the indicator group, its suitability needs to be tested. According to the step-wise testing procedure, the first task is to accumulate quantitative data both on the indicator group and on the disturbance to be evaluated (McGeoch 1998). Thereafter, relationships between the indicator and the environmental or ecological state (e.g. habitat fragmentation or occurrence of some other taxa) need to be established. The critical step is to find out whether there are significant, strong correlations between this state and measured qualities of the indicator. If these do not exist, the tentatively selected group should be rejected as a bioindicator. If correlations exist, the procedure continues to establish the robustness of the indicator by developing and testing appropriate hypotheses under different conditions (McGeoch 1998).

For a global monitoring programme it is important to select an indicator group that fulfills the above requirements, and also occurs and is well-known around the world. Carabid beetles is one such group, although its biology is less well-known in some parts of the world, such Australia (New 1998) than in others, such as Europe (Niemelä 1996). The advantages that carabids have as bioindicators are discussed below.

Monitoring, communication and decision making

After a bioindicator has been selected and the monitoring work done, the final question to be answered according to Usher's (1991) list (*see* above) is how are the results of monitoring going to be communicated to managers, decision makers and the public. Dissemination of research results is vital because biodiversity monitoring is an important feedback link between human actions and the environment (Keddy 1991). For this feedback loop to be efficient, however, results of biodiversity monitoring must first be efficiently communicated to decision-makers.

Adaptive management is a useful framework for linking monitoring, communication and decision making (Hillborn *et al.* 1995). According to the procedure of adaptive management, monitoring must feed back to the knowledge base, identification of goals and definition of management actions, i.e. decision making (Fig. 2). In theory, this scheme very effectively combines the public, decision makers and scientists in a management process based on research and monitoring (Stanford & Poole 1996). However, one of the major problems is poor communication between ecolo-

Table 1. Potential criteria for selection of bioindicators (adapted from Jones & Riddle 1996). Symbols indicate the estimated fit of carabids with each of the attributes (☺ carabids fulfill this requirement, 😐 not known for carabids).

Attribute	Description
Biologically relevant ☺	Related to structure, function etc. of biodiversity
Sensitive ☺	Responsive to stressors of concern
Geographic coverage ☺	Occurrence and response cover large area
Diagnostic ☺	Helps uncover potential source of the problem
Interpretable 😐	Unambiguously distinguishes between conditions
Cost-effective ☺	Inexpensive to measure, maximum data/effort ratio
Integrative 😐	Represents a few to many processes of biodiversity
Historical databases ☺	Historical data allows comparisons with observed trends
Anticipatory ☺	Provides an early warning
Capable of scaling ☺	Possible to aggregate through temporal and spatial scales
Synergistic 😐	Adds value to other measurements, yet provides unique information

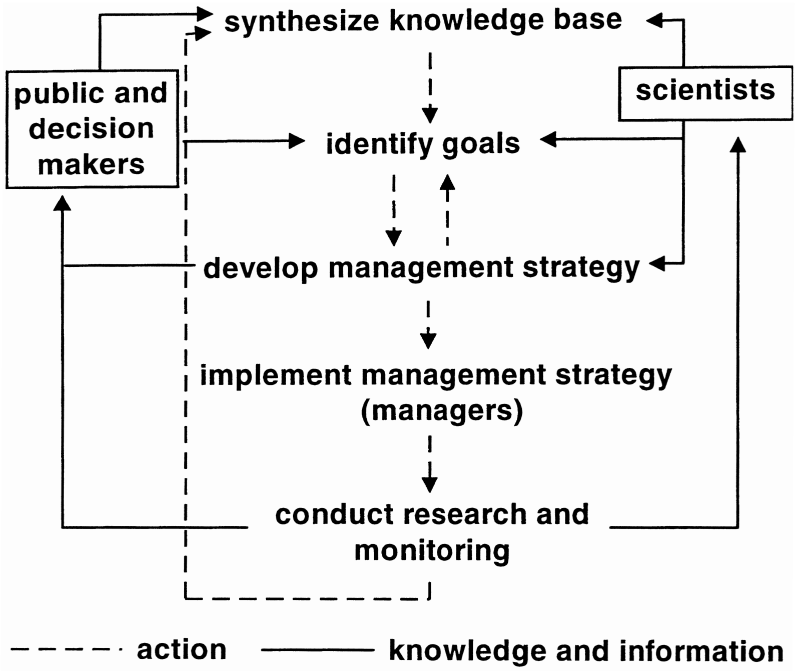

Fig. 2. A scheme of adaptive management with flows of action and management indicated (adapted from Stanford & Poole 1996).

gists on the one side, and the public and decision makers on the other side.

Examples of the problems related to 'ecological communication' are given by Norton (1998). He feels that 'ecologists are reluctant to mix value issues with scientific study', and 'ecologists are slow to pick up on signals flowing from policy discourse to ecological science'. Furthermore, 'ecologists often fail to study nature on a scale that would provide guidance to decision makers'. To some extent these statements are true, and fortunately Norton (1998) provides guidelines for improved communication according to which ecologists should use the adaptive management approach, have perspective and be place-based, consider multiple scales (larger space around the focal place), use measurable indicators, express normative content, and aim at enhancing communication. Although ecologists are not the only ones to be blamed for poor communication, improved communication is in the best interest of ecologists themselves, as well as decision-makers and the public.

GLOBENET: global biodiversity monitoring for landscape change

Theory and rationale

This chapter describes a newly established global monitoring programme that uses the above outlined approaches of biodiversity monitoring. GLOBENET is simple, repeatable, uses tested bioindicators, and is designed to enhance communication between scientists, managers, decision-makers and the public.

The background of GLOBENET is that anthropogenic activities homogenise natural landscapes and create patchworks of modified land types that exhibit similar patterns throughout the world. However, it is not known whether these changes affect biodiversity in similar ways around the globe, or depend on the unique aspects of local conditions (Samways 1992). Thus, there is a need to develop 'simple' protocols to assess and monitor the effects of these activities on biodiversity. This knowledge could help researchers and managers collaborate in finding ways of mitigating the adverse effects of human-caused landscape changes.

To assess changes in anthropogenic landscapes a global programme entitled GLOBENET is being developed. It uses a common field methodology (pitfall trapping), the same bioindicator (carabid beetles, which form definable assemblages) and the same impact indicator (urban-to-rural gradient) in different parts of the world (Niemelä *et al.* 2000). The same species metrics will be used to evaluate responses of carabid assemblages to landscape change (e.g. species richness, diversity, community similarity, and species characteristics, such as body size).

Preliminary studies indicate similarities in carabid responses to human-caused landscape changes around the world (Niemelä *et al.* 1999). For example, as predicted by Gray (1989) for stressed environments, small sized carabid species survive frequent disturbances better than large-sized species both in Europe (Blake *et al.* 1996) and in South Africa (Jaganyi 1998). This observation suggests that similar management and conservation practices could be applicable in various parts of the world. Of course, general prescriptions about assemblage features would not automatically contain all the specific natural history information required to manage systems to conserve particular species on any continent. However, initiatives like GLOBENET can determine the extent to which classifications and metrics, such as outlined below (*see* 'Use of carabids as indicators: why and how?'), may be effectively substituted for complete information about the species involved.

A programme for monitoring field assemblages must be related to a 'baseline' or predefined standard, usually measured by establishing distributional patterns and ecological needs of focal taxa (Karr 1987, Kremen *et al.* 1994). Establishing these baseline data is therefore critical, and one of the important initial outcomes of the GLOBENET scheme.

Monitoring is an integral part of any sound management system, be it at the species, assemblage or community level (Karr 1987). Under the concept of adaptive management, GLOBENET seeks to ensure that long-term management goals are met by determining the effects of management and, when departures from the goals are detected, the system must be refined in the light of the new knowledge (Fig. 2). Monitoring biodiversity depends on our ability to capture or evaluate members of focal indicator taxa in ways which are sufficiently standardised and replicable to produce valid comparative data on changes in species richness, incidence and relative abundance.

Urban landscapes, with densely built cores and increasingly rural surroundings reflecting diminishing intensities of human intervention, are rather easily characterised and fairly similar throughout the world. Thus, GLOBENET will compare, estimate and monitor human effects on biodiversity along urban-rural gradients (Niemelä *et al.* 2000).

The initial GLOBENET programme will provide an inventory and description of biological communities in an attempt to better understand biological diversity at landscape or larger scales (Dennis & Ruggiero 1996). One of the primary goals of GLOBENET is the development of appropriate tools and metrics to be used for biodiversity monitoring using carabids. The set of metrics used should be a combination of a variety of indices along the lines outlined above for Index of Biotic Integrity (IBI), developed for assessing the quality of aquatic ecosystems (Karr 1991). Species richness, composition and abundance are useful metrics for carabids, and trophic composition could be added using Sharova's (1981) carabid life forms.

GLOBENET also provides an opportunity to test specific ecological hypotheses worldwide: (1) does the intermediate-disturbance hypothesis (Connell 1978) apply to urban-rural gradients? (2) does habitat homogenisation through urbanisation always lead to faunal similarities, and if so, which aspects of species life history traits are most useful? (3) do habitat homogenisation and species introductions lead to more convergence than homogenisation alone? (4) is there a temporal dimension, i.e. do older cities show more faunal effects? and (5) is there a spatial dimension, i.e. do cities with more and connected green areas show less faunal effects?

Use of carabids as indicators: why and how?

The GLOBENET programme uses ground-beetles (Carabidae) to assess human-induced changes along urban-to-rural gradients. Several studies indicate that carabids can be considered useful bioindicators. Carabids have several advantages in signaling the relative qualities of the land mosaic, and they fulfill many criteria for selecting bioindicators (Table 1):

These beetles are speciose and varied (morphologically, taxonomically, behaviourally and ecologically), and abundant in many parts of the world (Lövei & Sunderland 1996).

Carabids can be collected by an easily standardisable field method, pitfall trapping (Spence & Niemelä 1994).

Most carabid species can be relied upon to provide consistent habitat-related information (Thiele 1977, Niemelä *et al.* 1994, Samways *et al.* 1996, Desender 1996, Dufrêne & Legendre 1997), and many species are sensitive to environmental changes and will thus signal human-caused disturbances (Desender *et al.* 1991, Heijerman & Turin 1994, Blake *et al.* 1994, Eyre *et al.* 1996, Luff 1996). Whether the responses are comparable in various part of the world will be tested by the GLOBENET programme.

There is a long history of success using carabids to study environmental change (Lindroth 1949, Thiele 1977, Stork 1990, Desender *et al.* 1994), such as fragmentation (Burel & Baudry 1995), urbanisation (Czechowski 1982, Klausnitzer 1983), and forest management (Niemelä *et al.* 1994, Spence *et al.* 1996). Moreover, carabids have been used as indicators of large-scale environmental changes (Penev 1996), and predictors of future landscape changes (Müller-Moetzfeld 1989).

Carabids appear to be one of the few groups that have passed the test designed by McGeoch (1998) for selection of bioindicators (for the steps of this procedure *see* above). Distributional patterns of carabids appear to reflect those of other epigaeic arthropod taxa (e.g. spiders, Niemelä *et al.* 1996), although some studies have shown a poor correlation between carabids and other arthropod taxa (Duelli & Obrist 1998). Thus, further research is needed to find out about the generality of relationships between carabids and other taxa.

Several classifications of carabids are potentially useful for global comparisons in GLOBENET. Sharova (1981) introduced a classification of carabid 'life forms' based on morphological and ecological criteria (e.g. feeding type, body size, body shape and habitat preference). As taxonomic relations are not considered, species from phylogenetically distant taxa can be grouped into the same 'life-form' group or 'guild'. A number of studies show that the 'life-form spectrum' of carabid assemblages can vary in a meaningful way in relation to several environmental factors (Šustek 1992). The approach supports comparisons of communities consisting of taxonomically distinct species, and is analogous to the guild concept advocated by Karr (1987, 1991). Indices based on 'rarity' and body size changes of species are another promising approach for global application as they are independent of species identity (Blake *et al.* 1994, 1996, Eyre *et al.* 1996).

More information on GLOBENET including a description of trapping schemes, results and further GLOBENET developments are available at our website: http://www.helsinki.fi/science/globenet/.

Conclusions: the challenge of biodiversity monitoring

Monitoring is a challenging but important undertaking, which requires careful preparations. Before launching a monitoring programme one has to ask what the goals are, what kind of data are to be collected, and how the data are to be analysed. Furthermore, communication with decision makers, managers and the public is vital for the success of monitoring.

Perhaps the most difficult question for ecologists has been communication: should results be disseminated and made available to non-scientists (Norton 1998)? It appears that the application of the adaptive management concept is a useful framework (Fig. 2) for improving communication. This framework 'forces' ecologists to communicate with the society at large and enhances the acceptability of our work among the public and the end-users of research results.

GLOBENET is an attempt to design a simple, global biodiversity monitoring scheme with the aim of developing tools for assessment and prediction of the ecological effects of human caused changes in the landscape. The basic idea of GLOBENET in a nutshell is that community inventories and descriptions in different parts of the world are compared to gain a worldwide picture of human-caused landscape changes along urban-to-rural gradients. These comparisons may seem simple, but 'When done with quality and consistency, and when repeated over a broad geographic range, however, they can become an extremely important contribution to understanding biological diversity at landscape or larger scales' (Dennis & Ruggierro 1996). The ultimate goal of GLOBENET is the insightful use of results of biodiversity monitoring for making reliable predictions about the effects of human actions rather than only after-the-fact judgements.

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References

Angelstam, P. K., Anufriev, V. M., Balciauskas, L., Blagovidov, A. K., Borgegård, S.-O., Hodge, S. J., Majewski, P., Ponomarenko, S. V., Shvarts, E. A., Tishkov, A. A., Tomialojc, L. & Wesolowski, T. 1997: Biodiversity and sustainable forestry in European forests: how East and West can learn from each other. — *Wildlife Society Bulletin* 25: 38–48.

Arcese, P. & Sinclair, A. R. E. 1997: The role of protected areas as ecological baselines. — *J. Wildl. Manage*. 61: 587–602.

Blake, S., Foster, G. N., Eyre, M. D. & Luff, M. L. 1994: Effects of habitat type and grassland management practices on the body size distribution of carabid beetles. — *Pedobiologia* 38: 502–512.

Blake, S., Foster, G. N., Fischer, G. E. J. & Ligertwood, G. L. 1996: Effects of management practices on the carabid fauna of newly established wildflower meadows in southern Scotland. — *Ann. Zool. Fennici* 33: 139–147.

Burel, F. & Baudry, J. 1995: Species biodiversity in changing agricultural landscapes: a case study in the Pays d'Auge, France. — *Agric. Ecosyst. & Environ*. 55: 193–200.

Czechowski, W. 1982: Occurrence of carabids (Coleoptera, Carabidae) in the urban greenery of Warsaw according to the land utilization and cultivation. — *Memorabilia Zool*. 39: 3–108.

Connell, J. H. 1978: Diversity in tropical rainforests and coral reefs. — *Science* 199: 1302–1310.

Dallinger, R., Berger, B. & Birkel, S. 1992: Terrestrial isopods: useful biological indicators of urban metal pollution. — *Oecologia* 89: 32–41.

Dallmeier, F. 1996: Biodiversity inventories and monitoring: essential elements for integrating conservation principles with resource development projects. — In: Szaro, R. C. & Johnston, D. W. (eds), *Biodiversity in managed landscapes: theory and practice*: 221–236. Oxford University Press, New York.

Dennis, J. G. & Ruggiero, M. A. 1996: Biodiversity inventory: building an inventory at scales from local to global. — In: Szaro, R. C. & Johnston, D. W. (eds.), *Biodiversity in managed landscapes: theory and practice*: 149–156. Oxford University Press, New York.

Desender, K. 1996: Diversity and dynamics of coastal dune carabids. — *Ann. Zool. Fennici* 33: 65–76.

Desender, K., Maelfait, J.-P. & Baert, L. 1991: Carabid beetles as ecological indicators in dune management. — *Elytron*, *Suppl*. 5: 239–247.

Desender, K., Dufrêne, M., Loreau, M., Luff, M. L. & Maelfait, J.-P. (eds.) 1994: *Carabid beetles: ecology and evolution*. — Kluwer Academic Publishers, Dordrecht.

Duelli, P. & Obrist, M. K. 1998: In search of the best correlates for local organismal biodiversity in cultivated areas. — *Biod. and Conserv*. 7: 297–309.

Dufrêne, M. & Legendre, P. 1997: Species assemblages and indicator species: the need for a flexible asymmetrical approach. — *Ecol. Monogr*. 67: 345–366.

Elton, C. S. 1958: *The ecology of invasions by animals and plants*. — Methuen, London.

Eyre, M. D., Lott, D. A. & Garside, A. 1996: Assessing the potential for environmental monitoring using ground beetles (Coleoptera, Carabidae) with riverside and Scottish data. — *Ann. Zool. Fennici* 33: 157–164.

Fritze, H. 1988: Influence of urban air pollution on needle litter decomposition and nutrient release. — *Scand. J. For. Res*. 3: 291–297.

Gray, J. S. 1989: Effects of environmental stress on species rich assemblages. — *Biol. J. Linn. Soc.* 37: 19–32.

Heijerman, T. & Turin, H. 1994: Towards a method for biological assessment of habitat quality using carabid samples (Coleoptera, Carabidae). — In: Desender, K., Dufrêne, M., Loreau, M., Luff, M. L. & Maelfait, J.-P. (eds.), *Carabid beetles, ecology and evolution*: 305–312. Kluwer Academic Press, Dordrecht.

Hellawell, J. M. 1991: Development of a rationale for monitoring. — In: Goldsmith, F. B. (ed.), *Monitoring for conservation and ecology*: 1–14. Chapman and Hall, London.

Hillborn, R., Walters, C. J. & Ludwig, D. 1995: Sustainable exploitation of renewable resources. — *Annu. Rev. Ecol. Syst*. 26: 45–67.

Jaganyi, J. 1998: *Response of carabid and cicindelid beetles to various types of landscape disturbance*. — Ph.D. dissertation, University of Natal, Pietermaritzburg.

Jones, K. B., & Riddle, B. R. 1996: Regional scale monitoring of biodiversity. — In: Szaro, R. C. & Johnston, D. W. (eds.), *Biodiversity in managed landscapes: theory and practice*: 193–209. Oxford University Press, New York.

Karr, J. R. 1987: *Biological monitoring and environmental assessment: a conceptual framework*. — Environ. Man. 11: 249–256.

Karr, J. R. 1991: Biological integrity: a long-neglected aspect of water resource management. — *Ecol. Appl.* 1: 66–84.

Keddy, P. A. 1991: Biological monitoring and ecological prediction: from nature reserve management to national state of the environment indicators. — In: Goldsmith, F. B. (ed.), *Monitoring for conservation and ecology*: 249–267. Chapman and Hall, London.

Klausnitzer, B. 1983: Faunistisch-ökologische Untersuchungen über die Laufkäfer (Col., Carabidae) des Stadtgebietes von Leipzig. — *Entomol. Nachr. Ber.* 27: 241–261.

Kremen, C. 1992: Assessing the indicator properties of species assemblages for natural areas monitoring. — *Ecol. Appl.* 2: 203–217.

Kremen, C., Merenlender, A. M. & Murphy, D. D. 1994: Ecological monitoring: a vital need for integrated conservation and development programs in the tropics. — *Conserv. Biol*. 8: 388–397.

Landres, P. B. 1983: Use of the guild concept in environmental impact assessment. — *Environ. Man.* 7: 393–398.

Lawton, J. H., Bignell, D. E., Bolton, B., Bloemers, G. F., Eggleton, P., Hammond, P. M., Hodda, M., Holt, R. D., Larsen, T. B., Mawdsley, N. A., Stork, N. E., Srivastava, D. S. & Watt, A. D. 1998: Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. — *Nature* 391: 72–76.

Lindroth, C. H. 1949: Die Fennoskandischen Carabidae, I. — *Göteb. K. Vetensk. Vitterhetssamh. Handl.* B4(3): 1–911.

Luff, M. L. 1996: Use of carabids as environmental indicators in grasslands and cereals. — *Ann. Zool. Fennici* 33: 185–195.

Lövei, G. L. & Sunderland, K. D. 1996: Ecology and behavior of ground beetles (Coleoptera: Carabidae). — *Annu. Rev. Entomol*. 41: 231–256.

McDonnell, M. J. & Pickett, S. T. A. 1990: Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. — *Ecology* 74: 1232–1237.

McGeoch, M. A. 1998: The selection, testing and application of terrestrial insects as bioindicators. — *Biol. Rev*. 73: 181–201.

Müller-Moetzfeld, G. 1989: Laufkäfer (Coleoptera, Carabidae) als pedobiologische Indikatoren. — *Pedobiologia* 33: 145–153.

New, T. R. 1998: The role of ground beetles (Coleoptera: Carabidae) in monitoring programmes in Australia. — *Ann. Zool. Fennici* 35: 163–171.

Niemelä, J., Haila, Y. & Punttila, P. 1996: The importance of small-scale heterogeneity in boreal forests: variation in diversity in forest-floor invertebrates across the succession gradient. — *Ecography* 19: 352–368.

Niemelä, J. 1996: From systematics to conservation — carabidologists do it all. Preface. — *Ann. Zool. Fennici* 33: 1–4.

Niemelä, J., Kotze, J., Ashworth, A., Brandmayr, P., Desender, K., New, T. Penev, L. Samways, M. & Spence, J. 2000: The search for common anthropogenic impacts on biodiversity: a global network. — *J. Insect Conserv*. 4: 3–9.

Niemelä, J., & Spence, J. R. 1991: Distribution and abundance of an exotic ground-beetle (Carabidae): a test of community impact. — *Oikos* 62: 351–359.

Niemelä, J., Spence, J. R. Langor, D. Haila, Y. & Tukia, H. 1994: Logging and boreal ground-beetle assemblages on two continents: implications for conservation. — In: Gaston, K. J., New, T. R. & Samways, M. J. (eds.), *Perspectives on insect conservation*: 29–50. Intercept Publications, Andover.

Niemelä, P. & Mattson, W. J. 1996: Invasion of North American forests by European phytophagous insects. — *BioScience* 46: 741–753.

Norton, B. G. 1998: Improving ecological communication: the role of ecologists in environmental policy formation. — *Ecol. Appl*. 8: 350–364.

Noss, R. F. 1990: Indicators for monitoring biodiversity: a hierarchical approach. — *Conserv. Biol*. 4: 355–364.

Pearson, D. L. & Cassola, F. 1992: World-wide species richness patterns of tiger beetles (Coleoptera: Cicindelidae): indicator taxon for biodiversity and conservation studies. — *Conserv. Biol*. 6: 376–391.

Penev, L. 1996: Large-scale variation in carabid assemblages, with special references to the local fauna concept. — *Ann. Zool. Fennici* 33: 49–64.

Samways, M. J. 1992: Some comparative insect conservation issues of north temperate, tropical, and south temperate landscapes. — *Agric. Ecosyst. & Environ*. 40: 137–154.

Samways, M. J., Caldwell, P. M. & Osborn, R. 1996: Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. — *Agric. Ecosyst. & Environ*. 59: 19–32.

Sharova, I. Ch. [Шарова, И. Х.] 1981: *Жизненные формы жужелиц (Coleoptera, Carabidae)* [*Life forms of carabids (Coleoptera, Carabidae)*]. — Nauka, Moscow.

Spence, J. R. 1990: Success of European carabid species: preadaptation for synanthropy? — In: Stork, N. (ed.), *The role of ground beetles in ecological and environmental studies*: 129–141. Intercept, Andover.

Spence, J. R., Langor, D. W., Niemelä, J., Cárcamo, H. & Currie, C. R. 1996: Northern forestry and carabids: The case for concern about old-growth species. — *Ann. Zool. Fennici* 33: 173–184.

Spence, J. R. & Niemelä, J. 1994: Sampling carabid assemblages with pitfall traps: the madness and the method. — *Can. Entomol*. 126: 881–894.

Spence, J. R. & Spence, D. H. 1988: Of ground-beetles and man: introduced species and the synanthropic fauna of western Canada. — *Mem. Entomol. Soc. Can*. 144: 151–168.

Stork, N. (ed.) 1990: *The role of ground beetles in ecological and environmental studies*. — Intercept, Andover.

Spellerberg, I. F. 1993: *Monitoring ecological change*. — Cambridge University Press Cambridge.

Stanford, J. A. & Poole, G. C. 1996: A protocol for ecosystem management. — *Ecol. Appl*. 6: 741–744.

Stork, N. E. & Samways, M. J. 1995: Inventorying and monitoring. — In: Heywood, V. H. (ed.), *Global biodiversity assessment*: 453–543. Cambridge University Press, Cambridge.

Šustek, Z. 1992: Changes in the representation of carabid life forms along an urbanisation gradient (Coleoptera, Carabidae). — *Biológia (Bratislava)* 47: 417–430.

Szaro, R. C. 1986: Guild management: an evaluation of avian guilds as predictive tool. — *Environ. Man*. 10: 681–688.

Thiele, H.-U. 1977: *Carabid beetles in their environments*. — Springer Verlag, Berlin.

Usher, M. B. 1991: Scientific requirements of a monitoring programme. — In: Goldsmith, F. B. (ed.), *Monitoring for conservation and ecology*: 15–32. Chapman and Hall, London.

Wheeler, Q. D. & Cracraft, J. 1997: Taxonomic preparedness: are we ready to meet the biodiversity challenge? — In: Reaka-Kudla, M. L., Wilson, D. E. & Wilson E. O. (eds.), *Biodiversity II:* 435–446. Joseph Henry Press, Washington D.C.