Connectivity of nature in the Nordic countries (CONNOR)

Assessing landscape structure in habitat monitoring in
the Nordic countries - potential approaches, methods
and data

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hunen & Bernd Münier*

Proceedings from the workshop at Roskilde
Vandrehjem, Denmark, 14–15 May 2008

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Preface

The way people are thinking about biodiversity is changing. For a long time the main arguments made for the conservation of species and habitats were based on issues such as their evolutionary uniqueness, their rarity, or on the extinction threat they may face. Today, the argument that we need to maintain biodiversity is also being made in terms of how it directly benefits people – that is how biodiversity contributes to their well-being or quality of life. One way of looking at the relationships between biodiversity and the benefits that people gain from ecological systems is in terms of what is known as *ecosystem services*. These are services which fundamentally depend on the properties of living systems, ranging from individual species to habitats. Thus biodiversity loss does not only mean the loss of species, but also the loss of ecosystem services through changes in ecosystem functions.

Understanding the implications of biodiversity loss is as much about tracking the way in which ecosystems change over time, as describing in scientific terms the links between living organisms and their organisation and the services they provide.

Assessing landscape structure is an interesting area of scientific work that might be leading us to new ways of collecting and evaluating information on biodiversity, perhaps one step further also in identifying changes in ecosystem functions supported by living organisms at different levels.

This report brings together approaches and methods to measure landscape structure and habitat fragmentation and sets a basis for further work in this area. This is an issue not only of Nordic, but of European and global importance.

Rania S. Spyropoulou,
European Environment Agency, June 2008

Summary

Changes in the spatial structure of habitats, such as declining habitat areas and the spatial fragmentation of habitats are, together with a decreasing habitat quality, a major pressure on biological diversity. Spatial indicators can function as a suitable tool for the assessment of habitat structure and its effects on biological diversity.

In May 2008 the Nordic Workshop *Connectivity of nature in the Nordic countries (CONNOR)* was held. The aim of the workshop was to gather scientists and stakeholders from the Nordic and other European countries to discuss opportunities, limitations and needed research for the integration of spatial indicators in nature monitoring in the Nordic countries. This report sums up the workshop results.

Presentations given throughout the workshop clearly indicate the relevance of spatial structure of habitats for biological diversity. Furthermore, a variety of approaches exist, where spatial indicators have been successfully applied to describe state and change in biological diversity. In order to reasonably describe biological diversity, spatial indicators must be based on specific knowledge on species' requirements for quality and spatial structure of habitats. Applied data must contain information reflecting these requirements. Although there is a lack of data, which encompass this information, within the Nordic countries there do exist different spatial datasets, which are enough detailed for a biologically meaningful application of spatial indicators.

Recommendations from the workshop suggest the necessity to establish a research platform including experts with a biological, species based approach and experts with a spatial and geographical approach. Specific research needs include the establishment of a knowledge base of existing theories and methodologies. Furthermore, available spatial data need to be critically examined. Finally, in order to practically evaluate opportunities, limitations and needed actions for the application of spatial indicators in the Nordic countries, specific example studies need to be conducted. These research activities are crucial for scientifically qualified and sound recommendations for the future exploitation of existing map data and for the design of nature monitoring programmes in the Nordic countries.

Gregor Levin, Bernd Münier, Wendy Fjelstad, Antti Rehunen and Marcus Hedblom, June 2008

1. Introduction

1.1 Background

Changes in landscape structure, including both the loss and fragmentation of habitats, are widely recognised as major causes of the loss of biodiversity. Habitat fragmentation can be described as the spatial splitting of a habitat as a consequence of changes in land-use and land-cover. Human-induced changes in landscape structure generally involve direct habitat destruction through e.g. urbanisation, infrastructure development and intensification of agricultural land use. In addition to the obvious loss of habitat, these processes also fragment and isolate remaining habitat patches. Based on the theories of island biogeography (McArthur and Wilson 1967) and metapopulations (Levins 1969), research has shown that landscape structure significantly affects biodiversity (Bogaert 2003; Fisher and Lindenmayer 2007; Jaeger and Holderegger 2005; Seiler and Folkeson 2006). The negative impacts of reduced habitat area can be exacerbated by the fact that remaining habitats become separated by distances exceeding the natural dispersal distance for key species and/or endangered species. Furthermore, reduced patch sizes and changed patch structures may lead to increased edge-effects and thus increased disturbance from surrounding land-use. Whilst direct loss of habitat has to be taken into account when planning landscape changes, the wider effects of habitat fragmentation may be neglected because their impacts are less obvious and less easily measured.

1.2 Policy relevance

Limiting habitat fragmentation and improving connectivity between habitats is broadly being recognised as an important measure to sustain biodiversity. All Nordic countries have signed The Convention on Biological Diversity (CBD 2010), with the aim to significantly reduce the decline of biodiversity by 2010. As part of The Nordic Environmental Action Plan 2005–2008 chapter 3.2, all Nordic countries have joined EU's target to halt the loss of biodiversity by 2010. Measures of connectivity and fragmentation of ecosystems are proposed as indicators for assessing progress towards the 2010 target. At EU scale, Streamlining European Biodiversity Indicators 2010 (SEBI2010) defines fragmentation of natural and semi-natural areas as a key pressure indicator to assess and inform about progress towards the European 2010 targets. Also within the EU Habitat Directive the importance of enhancing habitat connectivity has been

stressed. In Denmark, the National Monitoring and Assessment Programme for the Aquatic and Terrestrial (NOVANA) (Svendsen et al. 2005) mentions fragmentation as one of the 5 most important pressures for the quality of natural and semi-natural habitats. In Norway, the preparatory document for a new Biodiversity Act (Miljøverndepartementet 2004) recognises fragmentation as an important factor influencing biodiversity and points to the need for more knowledge about the effects of fragmentation. The importance of fragmentation is mentioned in general terms within many of the Swedish environmental objectives (Miljömålen 2008). Moreover, within a memo from the Swedish environmental protection agency, concerning the objective of a rich diversity of plant and animal life, the importance of fragmentation is mentioned in more specific terms (Massarink 2007).

2. Objectives

The scientific and political recognition of the importance of habitat fragmentation shows that fragmentation, its effects on habitat structure and its consequences for biodiversity should be integrated in monitoring programmes. Over recent years many methods to measure habitat fragmentation have been developed. However, approaches to integrate such measures within monitoring programmes are scarce. One reason is that state and development of biodiversity depend on a variety of parameters, which affect habitat quality and thus biodiversity. Habitat structure is but one parameter of a larger number, and it can therefore be difficult to determine relationships between habitat structure and biodiversity isolated from other parameters and pressures. Furthermore, relationships between habitat structure and biodiversity highly depend on species' specific characteristics. E.g. dispersal distances and consequently responses to changes in habitat structure differ substantially between different species. Finally, map data for habitat structure have often not been adequate to reasonably assess fragmentation.

Based on these findings, the main objective of this workshop was to gather scientists and nature managers from the Nordic countries, together with experts from other European countries and the European Environmental Agency. The task of the workshop was to clarify opportunities and limitations to integrate assessments of the spatial structure of habitats in nature monitoring, with special emphasis on a Nordic context. Specific objectives were to:

- discuss the relative importance of habitat structure and more general habitat quality for biodiversity
- provide an overview of state-of-the-art approaches to measure habitat structure within the Nordic countries and Europe
- discuss particular aspects of habitat structure and fragmentation in relation to different main habitat types (e.g. agricultural landscapes, forests, alpine areas) and in relation to different pressures (e.g. forest management, agricultural change, urbanisation, infrastructure development and transport)
- examine methods to integrate measures of habitat structure and fragmentation with other measures of habitat quality
- discuss data-availability for the assessment of habitat structure at the Nordic scale and within the different national monitoring programmes
- define issues and cooperation platforms for further research in assessment of habitat fragmentation and structure

This report sums up discussions and conclusions of the workshop and recommendations for further work. The report has been produced by a project group consisting of the project leader and one researcher from each Nordic country (except Iceland). The report forms the main scientific input to a project application to the Nordic Council by mid 2008.

The report is structured so that first, in chapter 3, theories and approaches to assess habitat structure and effects on biodiversity are examined as a background for workshop discussions. Chapter 4 contains the abstracts provided by the authors with some illustrations from their presentations. An overview of data available for the assessment of habitat structure in the Nordic countries is presented in chapter 5. Discussions and the main conclusions of the workshop are summed up in chapter 6 followed by recommendations for further actions and research in chapter 7.

3. Theories and approaches to assess habitat structure and effects on biodiversity

3.1 Theoretical concepts linking habitat structure to biodiversity

Island biogeography

The theory of island biogeography by McArthur and Wilson (1967) has had essential influence on approaches to link spatial characteristics of habitats to conditions for biological diversity. The theory holds that the number of species found on an island (the equilibrium number) is determined by the island size and the distance from the mainland. As the chance of extinction is larger on small islands than on large ones, larger islands can hold more species. Furthermore, islands closer to the mainland are more likely to receive immigrants from the mainland than islands further away from the mainland. Consequently, island size and distance to the mainland affect rates of extinction and immigration. The interplay between species extinction and immigration can thus be used to establish how many species an island can hold at equilibrium (see Figure 1).

Any area or patch of habitat can be compared to an island, being surrounded by a “sea” of non-habitat that is unsuitable for the species dependent upon that particular habitat. Consequently, the theory of island biogeography can be applied to study effects of human-induced fragmentation of habitats. The number or abundance of species in a habitat patch is thus determined by the distance to other habitats and the size of the habitat patch.

Figure 1. Equilibrium model of a species on a single island. The equilibrium species number is reached at the intersection point s , where immigration and extinction rates cross (after McArthur and Wilson 1967).

Metapopulation theory

An important assumption of the theory of metapopulations (Levins 1969) is that individual and spatially separated populations of a species interact with each other and thus form a larger (meta-) population. Due to external disturbances, the individual populations can have finite life-spans and go extinct. However, due to re-colonization from other populations, the whole metapopulation can remain stable. Fragmentation can result in increased distances between habitat patches and thus between individual populations dependent upon these habitats. If habitats become separated by distances exceeding the natural dispersal distance of the species, chances for re-colonisation of habitats, where individual populations have gone extinct, are reduced and the total metapopulation can be endangered.

Edge effects

An edge effect is the effect of the juxtaposition of contrasting environments on an ecosystem or habitat. The term is commonly used in conjunction with the boundary between habitats and disturbed or developed land. An edge or a boundary between a habitat and disturbed or developed land can seriously affect the habitat for some distance from the edge. E.g. in the case of forest, where the adjacent land has been cut, creating an open forest boundary, sunlight and wind penetrate, drying out the forest close to the edge and encouraging growth of opportunistic species. Air temperature, vapour pressure deficit, soil moisture and light intensity all change at edges. For natural and semi-natural habitats in

agricultural landscapes, edge effects can include increased nutrient deposition from surrounding, intensively managed land.

Figure 2. Relationships between patch area and edge effects

As illustrated in Figure 2, edge effects increase with decreasing patch area. Although the edge length decreases with decreasing patch size, the relative effect of the edge, calculated as the ratio between the edge length and the patch area, increases. As a consequence, the core area of the patch, where edge influences are relatively low, decreases. For this example the core area is defined as the area that is located at least 50 metres from the edge of the patch. (The distance limit of 50 metres was chosen arbitrarily). Similarly, a long, thin patch will have less core area than a round patch of the same area.

The patch-corridor-matrix landscape model

The theories of island biogeography, metapopulations and edge effects imply a number of spatial parameters, which are of importance for the linkage between landscape spatial structure and biodiversity. These parameters are: a) habitat size; b) distance between habitats; and c) the influence of the habitat edge (related especially to patch shape).

Figure 3. The patch-corridor-matrix landscape model. The landscape consists of habitat patches, corridors connecting habitat patches and a surrounding matrix, which is unsuitable for the species in the habitats (from Levin 2006).

In order to assess these spatial parameters the patch-corridor-matrix landscape model, as illustrated in Figure 3, is useful. In this simplified conceptual model, the landscape or spatial unit of interest is broken up into units, which have different functions in relation to biodiversity. Patches function as habitats for specific species or species groups. Habitat patches are surrounded by a matrix, which is unsuitable or at least less suitable to the species in the habitat patches. Furthermore, corridors connect the habitat patches and thus favour the dispersal of species between habitats.

The applicability of this landscape model highly depends on types of habitat and species, and the type of landscape being studied. E.g. for agricultural landscapes, patches would typically be isolated biotopes surrounded by a matrix of intensively managed agricultural land. Hedgerows, field divides and ditches would function as corridors between these biotopes. In a forest landscape, patches could be isolated areas of old growth forest, which are important habitats for several rare forest species, surrounded by a matrix of younger, more intensively managed forest.

The patch-corridor-matrix model fits best to areas that are characterised by a strong influence of human land use, such as intensive agriculture, forestry or urban uses. In landscapes with larger areas of limited human influence (e.g. mountain areas of northern Scandinavia or Iceland), the model might even be turned around. In such situations, human land uses will form patches imbedded in a matrix of natural areas.

For landscapes with less clearly defined patches, where there is little contrast between “patch” and “matrix” or where these are closely intermingled, a mosaic landscape model may be more appropriate (Duelli

1992). A typical example might be the early stages of abandonment of extensive pasture, where grassland, scrub and trees are inter-dispersed.

The process of habitat fragmentation through land-cover change

Spatial fragmentation of habitats is a consequence of changes in land cover. Figure 4 gives an example of changes in the extent and distribution of freshwater meadows in a small river valley in western Denmark. Over a period of 50 years, the total area of meadows decreased substantially. This decrease was mainly caused by intensification of agricultural land use and conversion of meadows into cropland. The decrease in the total area of meadows was accompanied by a spatial fragmentation. The number of patches of meadows increased from 5 to 24 while the mean patch size decreased significantly from 0.28 to 0.02 km². Meanwhile meadows became increasingly isolated, the mean distance between meadow patches increased from 2.9 to 23.4 metres. Also as a consequence of spatial fragmentation, edge effects increased considerably. The edge-area ratio increased from 0.02 to 0.04, due to increasingly complex patch shapes. The total core area, where effects from surrounding land use are limited (here calculated as the area of meadow located at a distance of at least 50 metres from the patch boundary) decreased from 0.55 to 0.04 km². The proportion of the core area of the total habitat area decreased from 28.8% to 12.0%.

Figure 4. Change in spatial characteristics of wet meadows from 1954 – 2002 in a sample area in western Denmark. Based on interpretation of aerial photos. From Levin (2006).

Based on theories and concepts of island biogeography, metapopulations and edge effects, change in land cover and increasing spatial fragmentation has a number of consequences for spatial characteristics of habitats, which are important to biodiversity: *Decreasing total habitat area* reduces species' total living space. *Declining sizes of habitat patches* increases the probability of species extinction, particularly if patch sizes become smaller than specific species' area requirements. *Increasing spatial isolation of habitats* hampers movement of species between habitat patches and thus reduces chances for re-colonisation of patches where individual populations have gone extinct. *Increasing edge effects* increase harmful influences from surrounding land uses.

3.2 Assessing habitat structure by means of spatial metrics

Spatial metrics (also called landscape metrics or landscape indices) are mathematical calculations based on spatial data (maps). Spatial metrics can describe the spatial characteristics of a landscape at different scales (Figure 5). At the patch scale, calculations are made for individual patches or landscape elements. At the class level, metrics are calculated for a whole land cover type or habitat class (e.g. forest), where a class is usually composed of several individual patches. Finally, at the landscape scale, metrics are calculated for the whole landscape area.

Figure 5. Different spatial scales for application of spatial metrics.

Based on theories and empirical studies, spatial metrics can be used as surrogates or indicators for biological diversity in terms of species abundance and richness and for species dynamics and interactions. Spatial metrics are also used in relation to other processes and issues, such as flows of e.g. nutrients or water, landscape changes and for aesthetical and recreational issues. Furthermore, metrics can be applied within monitoring, planning and management.

The Fragstats software (McGarigal and Marks 2007), which aims at gathering existing metrics and making them easily accessible, currently

embraces more than 100 different spatial metrics. These metrics can be grouped according to the spatial level of calculation or according to the type of characteristics that are measured (Table 1).

Table 1. Groups of spatial metrics and spatial level of measurement

	Spatial level of measurement		
	Patch	Class	Landscape
Measured characteristics			
Area / Density / Edge	X	X	X
Shape	X	X	X
Core area	X	X	X
Isolation / Proximity	X	X	X
Contagion / Interspersion		X	X
Diversity			X

Area / density / edge metrics

This group of metrics deals with the number and size of patches and the amount of edge created by these patches. Although these metrics are very simple, they are extremely important and useful pieces of information describing the landscape. Furthermore area, density and edge metrics form the basis for more complex groups of indicators. Values for area and edge metrics are calculated at patch level and applied as sums, means, densities and distributions at class and at landscape levels.

Shape metrics

On the basis of the ratio between patch area and patch perimeter, this group deals with the shape of patches. Similar to area, density and edge metrics, shape metrics are calculated at the patch level and applied as sums, means, densities and distributions at class and at landscape levels.

Core area metrics

Core area is defined as the area within a patch beyond some specified influence (i.e. distance from the edge) or buffer width. The specification of distance or width depends on the studied species or phenomena. Unlike patch area, core area is affected by patch shape. Thus, while a patch may be large enough to support a given species or process, it still may not contain enough suitable core area to support the species or process. Also values for core area metrics are calculated at patch level and applied as sums, means, densities and distributions at class and at landscape levels.

Isolation / proximity metrics

This group of metrics deals with the spatial context of habitat patches. Spatial context of a patch is measured in terms of the distance to neighbouring patches and in terms of the similarity (e.g. habitat type) with neighbouring patches. Distance is measured either as the Euclidean distance (shortest edge-to-edge distance) or as the functional distance (least cost path edge-to-edge). Least cost path necessitates information on what kind of land cover is located between two neighbouring patches. E.g. opportunities for movement of species would often be larger across natural or semi-natural land cover compared to intensive agriculture or urban land cover. Isolation and proximity metrics are calculated at patch level and applied as sums, means, densities and distributions at class and at landscape levels.

Contagion / interspersion metrics

This group of metrics deals with aspects of landscape texture, i.e. they reflect the adjacency of patch types. Contagion refers to the tendency of patch types to be spatially aggregated; that is, to occur in large, aggregated or “contagious” distributions. Interspersion, on the other hand, refers to the intermixing of patches of different types and is based solely on patch (as opposed to cell) adjacencies. Necessitating information on adjacencies between several patches or patch types, calculations for this group of metrics can only be made at class or landscape level.

Diversity metrics

Diversity measures, such as the Shannon’s Diversity Index and Simpson’s Evenness Index, originally gained popularity as measures of plant and animal species diversity but in recent years have been applied to the diversity of habitats in a landscape. Metrics for diversity are influenced by two components: richness and evenness. Richness refers to the number of patch types present; evenness refers to the distribution of area among different types. Richness and evenness are generally referred to as the compositional and structural components of diversity, respectively. Depending on information on richness and area distribution of different patch types, diversity metrics are exclusively calculated at the landscape level.

3.4 Spatial metrics as indicators for biodiversity

Relating habitat structure to biodiversity

Numerous investigations have found empirical evidence of relations between spatial characteristics of habitats and biodiversity in terms of abundance and richness of different species groups. E.g. for birds (Laube et. al. 2008; Tworek 2007; Atauri & de Lucio 2001); for mammals (Tews et. al. 2004; Perault & Lomolino 2000); for spiders and insects (Hendrickx et. al. 2007; Stefanescu et al. 2004); for amphibians and reptiles (Bell & Donnelly 2006; Loehle et. al. 2005) and for plants (Pacha et. al. 2008; Gardner & Engelhardt 2008; Kruess 2003). Consequently, both theoretical concepts and empirical studies clearly indicate that the spatial characteristics of habitats in terms of habitat area, spatial configuration and shape do affect biodiversity.

Although there exist clear indications that spatial habitat structure affects biodiversity, three factors can limit opportunities to apply spatial metrics as indicators of biodiversity. First, empirical studies are usually limited to specific species within a specific area or region. Proven relationships between habitat structure and biodiversity can therefore be difficult to transfer to other areas or regions or to other species. Furthermore, spatial characteristics of habitats, which are beneficial to one species, can have a negative influence on other species. Second, spatial structure of habitats is one of a variety of different parameters that influence biodiversity. Spatial structure as an explanation for biodiversity can thus be difficult to separate from parameters such as habitat quality, human pressures and management, or interactions with other species. Third, a reliable application of spatial metrics as indicators of biodiversity necessitates spatial data (maps) that embrace information on different criteria (e.g. habitat type and quality) at a spatial scale or resolution that is appropriate for the studied processes, species or group of species. The availability of such detailed spatial information is limited.

Critical issues for the application of spatial metrics as indicators of biodiversity

In spite of these limitations, advantages of spatial metrics are obvious. Compared to empirical investigations of species abundance or richness, spatial metrics can be calculated relatively quickly and require fewer resources. Furthermore, spatial metrics can be applied to assess change in spatial structure of habitats over time (e.g. Figure 6) or even to assess scenarios of future changes and thus be used to indicate changes in biodiversity.

Figure 6. Data and information needs for application of spatial metrics as indicators of biodiversity

The scheme in Figure 6 summarises the different kinds of information that are needed for the application of spatial metrics as indicators of biodiversity. An appropriate assessment of the influences of habitat structure on biodiversity requires specific knowledge on the characteristics of the species or species group of interest. This includes information on habitat needs (including habitat quality), area requirements and dispersal range. On the basis of this information or eco-profile of the species or species group, decisions about the choice of indicator and type of spatial data (maps) are taken. The chosen spatial data should contain information appropriate to the characteristics of the species or species group. The type of land cover classification should correspond with knowledge on required habitat types and habitat quality. The spatial resolution should be sufficiently detailed to fit with the area requirements and dispersal range of the species or species group. Also the spatial extent (i.e. the area covered by the data) should be large enough to encompass the area requirements and dispersal range.

The availability of spatial data that fully reflect a particular species' or species groups' characteristics can be limited. Therefore, the choice of spatial metric and data to calculate the metric will often be based on a balance between the ability to indicate e.g. the abundance of a given species and the availability of spatial data that are appropriate in terms of classification of land cover, spatial resolution and extent.

Although spatial metrics can often not be applied as precise measures or indicators of the occurrence of particular species, they are still effective tools for assessing general influences of habitat structure and change in habitat structure on biodiversity. Tools are certainly needed for assessing the effects of landscape change on particular species – especially threatened or rare species – and this requires more detailed information on habitat quality than is currently available. For sensitive biodiversity

indicators, broad land use/cover information is not sufficient and a great body of scientists recommends that there should be a much greater international focus on detailed, ecologically meaningful mapping of habitats. Nevertheless, whilst we are waiting for this data to become available, spatial metrics can provide general measures of broad habitat change in the wider countryside and provide indications of the impacts of these changes on biodiversity.

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4. Examples of assessment of habitat structure and fragmentation

This chapter presents abstracts provided by the authors, with illustrations selected by the editors from the presentations. There were many recurring themes throughout the presentations. Virtually everybody touched on issues of data availability, quality and scale, agreeing that the lack of data at species and habitat levels limits the degree to which indicators can be meaningful and appropriate. This is perhaps most obvious for international approaches, where the development of methods and tools is far ahead of the provision of standardised data at a sufficient level of resolution. Yet the same challenges are seen at the national level. To overcome this we see various forms of sampling in use, both in national and international projects, aiming to provide relevant data of sufficient quality to elucidate links between biodiversity and landscape structure.

The mix of approaches and methods in use means that there is no single logical order in which to present the different projects. The order here simply attempts to emphasise some similarities of approach or scale or recurring themes. To set the scene, we start with one of the major causes of habitat fragmentation in Europe, transport infrastructure. We then look at several international projects that address landscape structure in some respect. Rania Spyropoulou and colleagues study the “ecological potential” of landscapes at a macro scale in Europe on the basis of data on land cover, designated areas and infrastructure. Christa Renetzedler and colleagues show a method to integrate a relevant regional/landscape level within an international project, though not currently operational on a European scale due to poor data resolution. Whilst international projects generally bemoan data quality and emphasise that they are doing their best with the data available, Duncan Stone more outspokenly suggests that we should concentrate our efforts at a level where data are available in order to bring about real changes on the ground. Jana Verboom’s “ecologically scaled landscape indices” and “key patch approach” continue the argument that landscape patterns must be linked to ecological functioning, and Jens Dauber uses very detailed ecological data to assess the relative roles of habitat quality and landscape structure. Rasmus Ejrnæs and Bettina Nygaard continue the debate on quality versus structure related to Denmark’s biodiversity, again coming back to the fundamental lack of adequate species and habitat data. This is followed by overviews of a number of Nordic monitoring programmes which, through

various sampling methods and with different emphasis on species versus landscape data, all attempt to gather sufficiently detailed data to provide meaningful biodiversity indicators.

The importance of producing results that can contribute to public discussion and decision-making is emphasised by several authors. In the case of transport sector, it is pointed out that there is a need for measures that are able to communicate the effects of fragmentation in relation to fragmenting forces as well as threshold values – and thus help to set future targets. In land use planning, location-based data on habitat networks, and methods to take habitat structure into account are yearned for. Integrating connectivity assessments into real site management choices through examining least-cost, functional habitat networks is presented as a way to build public understanding.

4.1 Habitat fragmentation due to transport infrastructure

Andreas Seiler, Swedish University of Agricultural Sciences (SLU)

Fragmentation of habitat and landscapes due to transport infrastructure has long been a well recognized yet unsolved environmental problem. Although much research has been done on immediate and some on cumulative effects of transport infrastructure on nature, there is a shortage of adequate measures of fragmentation (as a cumulative impact) that both rely on known dose-response relationships and can communicate the relevance by identifying threshold values and limits. So far, measures of fragmentation are mostly descriptive and do not support setting performance targets for the transport sectors' environmental work.

In comparison to land use practices such as forestry or agriculture, which are strongly regulated through object-oriented environmental law (referring to nature protection sites or threatened species), the transport sector has only limited direct impact in terms of area and thus receives only little guidance from existing regulations. However, although the overall land taken for roads and railroads often comprises less than 2% in a country, the area affected is probably more than 10 times as large. Including the effects of fragmentation (isolation of local habitats and populations), the influence is likely reaching substantially further. In other words, there is a mismatch between how environmental states are conventionally assessed and how transport infrastructure affects the landscape through fragmentation.

Probably the simplest but most conservative measure used so far is the density of transport infrastructure elements (roads, railways, canals, etc of specific type and class). Land uptake by transportation facilities and urban development provides an additional measure. These two measures can be improved by integrating information on traffic intensity, infra-

structure type and design, surrounding habitat type and the spread of disturbances (noise, chemicals, groundwater, etc). However, there are several drawbacks that obscure their interpretation from an ecological point of view.

Figure 7: Although roads may occupy a relatively small area, their effects may be wide-reaching.

Newer measures of fragmentation specifically focus on the characteristics of the infrastructure network or the mosaic pattern of the fragmented landscape. Relative mesh size, number of large unfragmented areas and size of remote, undisturbed habitats, number of designated nature areas cut by or near to infrastructure, are the most frequently applied measures in this category. However, these indicators are highly sensitive to the definition of the barrier effect comprised by infrastructure; a question that has not yet been sufficiently answered. In addition, infrastructure density is usually strongly correlated with urban development and agriculture, which obscures the interpretation of “network” measures.

An important extension in the discussion of fragmentation refers to the holistic, composite nature of landscapes, their natural, social, cultural and economic components. Fragmentation of landscapes cannot be solved solely by focusing on one of these components. This is especially evident in the context of transport infrastructure planning. Modern high speed roads and railroads affect social and cultural values in the landscape in very much the same way as they affect natural landscape assets: disruption of functional linkages and processes, degradation of the quality of nearby areas, intrusion into sites of designated interests for conservation – all this applies to natural as well as to cultural dimensions in the environment. Yet, there is very little empirical research on infrastructure effects on social-cultural values. Here, knowledge about ecological indicators and solutions can help to develop adequate social parameters.

Thus, one single measure of fragmentation will unlikely suffice to illustrate the whole picture. It appears more appropriate to combine a set of different indicators linking measures of specific (direct) impacts of transport infrastructure with the broader and more holistic measures. Research in this direction is currently undertaken within e.g. the INCLUDE program in Sweden. At international scene, the IENE network (www.iene.info) develops the interdisciplinary arena for developing updated indicators of habitat fragmentation caused by infrastructure.

4.2 Net Landscape Ecological Potential of Europe and change 1990–2000

Jean-Louis Weber and Rania Spyropoulou,

European Environmental Agency (EEA)

Tomas Soukup and Ferran Páramo,

European Topic Centre Land Use and Spatial Information (ETC-LUSI)

The European Environment Agency has been working on ways to measure and assess ecosystem integrity at a macro scale in Europe on the basis of land cover changes. Integrity is understood as a key determinant of the potential of healthy ecosystems to deliver over time those multiple services necessary for society development and human wellbeing. At the macro scale, for terrestrial ecosystems, an ecological potential can be described in terms of landscape characteristics, species diversity and biomass.

NLEP, the Net Landscape Ecological Potential is a macro indicator derived from Land and Ecosystem Accounts (LEAC) and spatial analysis tools developed at the EEA. NLEP is the combination of 3 different geographical datasets (layers, indexes) computed using the standard European 1 km² grid:

- The so-called green background landscape index (GBLI)¹ which expresses the vegetation potential of the territory according to land use intensity; at the most aggregated level, land cover types are aggregated in 2 classes, the “green” – the less intensive use – and the non-green – the most intensive use, conventionally: artificial land and cropland. The data are computed from Corine land cover and updated accordingly.
- The social value given to nature assessed via the importance of its designation by science and policy; this is computed from the combination of European (Natura 2000), internationally, and nationally (CDDA) designated sites maps. It captures what cannot be seen from the satellite images, namely, the species richness/habitats of landscape which has motivated designation for nature conservation.
- The fragmentation of landscape by roads and railways, which is not captured in the previous 2 layers. The indicator retained is the “effective mesh size” (MEFF), for its natural logarithm (ln) value. The lower the effective mesh size, the higher the fragmentation.

The decrease of the indicator reflects a degradation of the land potential, while the increase an improvement. Work is ongoing to refine the sensitivity of the indicator and to describe its advantages and disadvantages.

¹ Land accounts for Europe 1990–2000, op. cit. – see in particular page 71

Figure 8: Change in Net Landscape Ecological Potential of Europe 1990–2000

Web: <http://www.eea.europa.eu>

4.3 EuMon: EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest

Erik Framstad, Norwegian Institute for Nature Research (NINA)

The EuMon project is an EU 6FP project coordinated by Klaus Henle of UFZ, Germany. It aims to review, evaluate and improve methods and approaches to monitor trends in species and habitats for assessing progress towards the 2010 target of halting the loss of biodiversity. The project compares and integrates the most promising methods and approaches into a comprehensive and consistent framework and disseminate a comprehensive database on monitoring schemes and recommended methods via a user-friendly internet portal and seminars. Tasks are to:

- Design and collate a database on existing monitoring methods and approaches
- Assess feasibility of bringing together different types of schemes
- Evaluate schemes for relevance in assessing progress towards 2010 target
- Develop improved methods for handling uncertainty and combining different species monitoring data sets

- Develop recommendations for improving the statistical design and analytical framework of existing monitoring schemes.

EuMon started in November 2004 and finished in April 2008. Some elements of EuMon are carried over into the new EU-funded project EBONE. Main properties of interest for the monitoring of landscape structure are:

- Amount (area or number of patches)
- Quality
- Aggregated properties:
 - Size or patch type distribution
 - Indicators of spatial structure

The EuMon database currently includes 167 habitat schemes (and 446 for species). These are quite variable in scope and content.

Web: <http://eumon.ckff.si/monitoring>

4.4 ALTER-net: A long-term biodiversity, ecosystem and awareness research network

Erik Framstad, Norwegian Institute for Nature Research (NINA)

ALTER-Net is an EU 6FP Network of Excellence for terrestrial and freshwater biodiversity research in Europe, including 24 partners in 17 countries. The network is coordinated by Terry Parr of the Centre for Ecology and Hydrology, UK. The project started in April 2004 and will end in March 2009. The aim is to integrate research capabilities to address European-scale biodiversity issues. The project covers several topics, including:

- Socio-economic drivers of biodiversity change
- Biodiversity assessment and change
- Impacts of the main drivers of biodiversity
- Forecasting change in biodiversity

Landscape structure is not the main focus of ALTER-net. The focus is on living biodiversity. However, the landscape is seen as a manifestation of land use drivers and issues of habitat or ecosystem structure are therefore clearly relevant.

Web: <http://www.alter-net.info/>

4.5 Landscape Structure Analysis as Tool for Sustainability Impact Assessment on the Regional Level

*Christa Renetzeder and Thomas Wrbka, University of Vienna
Sander Mucher, Michiel van Eupen and M. Kiers, Alterra, Wageningen
UR, The Netherlands*

The assessment of sustainable use in European landscapes is the main objective of the SENSOR-project. Therefore, “landscapes” are of interest as spatial units in sustainability research. The concept of “landscape structure” is dealing with the spatial and functional relationship between distinct local ecosystems by describing the distribution of energy, resources and species in relation to size, shape, number and type of ecosystems in a particular landscape. It is reflecting not only the natural settings of the landscape but also its history and the impact of mankind throughout the centuries. Therefore, the present spatial patterns are a result of former activities and processes in the landscape. Hence, many European cultural landscapes developed their own regionally distinct pattern of landscapes elements over time and their changes are influenced by current processes in the landscapes.

Since landscape structure has been linked to biodiversity and other important landscape functions by various authors, it seems worthwhile to further explore the potential of landscape structure analysis as a proxy for the evaluation of such land attributes and functions which are much more complicated to assess. Since modern technologies in the field of remote sensing and geo-data analysis are available, identifying landscape patterns on the larger scale has become a solvable problem and an applicable approach.

A set of various landscape indices, describing important features of landscape pattern, such as shape, diversity, fractal dimension of patches and classes served as basis to assess sustainability of Austrian landscapes and a similar concept has been transferred to the European scale highlighting main differences between SRRF² regions in the view of different environmental indicators.

² SRRF = Spatial Regional Reference Framework – a division of Europe into regions.

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Web: www.univie.ac.at/CVL ; www.sensor-ip.org

Figure 9: Although landscape metrics show high variability within regions, there are also clear differences between regions. A set of rules may allow calculation of sustainability indicators based on average/median values for the region, e.g. “if Shape Index in arable land is higher than the median for the region, then it is more sustainable”

4.6 Application of indicators for habitat structure and fragmentation in Streamlining European Biodiversity Indicators 2010 (SEBI2010)

Duncan Stone, Scottish Natural Heritage

The discipline of Landscape Ecology has a fundamental division in the assessment of fragmentation and habitat structure. On one side, there is a large body of work measuring aspects of structure, often through sophisticated shape or pattern analysis. This work seeks to assess ecological/biodiversity meaning through a somewhat abstract set of spatial metrics or proxy measures. On the other side is a more recent approach, seeking to assess function i.e. trying to explicitly incorporate ecology and species characteristics into the analysis of landscape and habitat patterns.

Assessment of structure tends to rapidly produce large amounts of data, which can be hard to interpret. Assessment of function is characteristically much harder, much more limited by data availability, but the results it produces are a much better description of how real ecology works.

My presentation seeks to reflect this distinction. The SEBI2010 process debated these issues extensively, and the draft Indicator that has emerged – Fragmentation of natural and semi-natural areas – seeks to provide an indication of fragmentation by measuring the mean patch size of a small number of categories from the Corine Land Cover dataset. Whilst the overall SEBI2010 requirements perhaps did not allow for any other outcome, this indicator has significant problems in establishing links from the data outputs to actual trends in biodiversity loss. These include things it doesn't measure, and potentially perverse results which indicate the opposite of reality.

In contrast in UK and Scotland we have followed a 'functional' approach to assessment of fragmentation, structure and connectivity. This has advantages in that the outputs carry more meaning, both for the ecological professionals and for the public and politicians. The disadvantage is that species and land cover data requirements mean that we are only able to model a smaller number of habitat and species combinations, although our fairly good data coverage does help. This approach allows us also to model fragmentation and connectivity from national scales to site level, providing a consistent methodology that can influence national policy and real site management choices. This has been hugely beneficial in winning political and public support for our approach, and work is underway to provide national indicators, regional climate change adaptation analyses, designated site management advice and agri-environment/forestry incentives based on the functional fragmentation/connectivity measurement and modelling approach.

Figure 10: A measure of functional connectivity includes both habitat area and matrix permeability, identifying least-cost habitat networks for species with similar habitat needs and dispersal characteristics. In this example, a targeted grant scheme is used to reduce woodland fragmentation. Payments are made on the size of the woodland network created, rather than the amount of woodland planted. Ecological outcomes are expressed as spatial rules and land managers can find the solution that best complements their own objectives. (©Scottish Natural Heritage).

4.7 Fragmentation monitoring and biodiversity

Jana Verboom, Rogier Pouwels and Irene Bouwma, Alterra, Wageningen UR, The Netherlands

The Dutch approach:

Monitoring and predicting the impact of fragmentation on biodiversity in the Netherlands is based upon four principles:

- The ecological network approach, acknowledging that populations live in metapopulations which should have enough area and connectivity for long term survival.
- Ecologically Scaled Landscape Indices (ESLI, Vos et al. 2001), or “Perceiving the landscape from the species’ perspective” which means not considering patch size as plain area but relative to individual area

requirements (potential carrying capacity), and not distance in m but relative to dispersal distance.

- The key patch approach (Verboom et al., 2001); networks are sufficient for long term survival (a) if the largest patch supports an MVP, (b) if it supports a key patch and lies within a network of sufficient size, or (c) if large patches are not present, but the total area of the network is sufficiently large to compensate for this.
- Landscape cohesion (Opdam et al. 2003); the previous species-specific approaches can be combined for representative species into biodiversity indicators.

Take home messages:

- Think carefully about the goals of the monitoring effort
- Think carefully about thresholds – how much is enough?
- Consider how to deal with climate change and range shifts
- Consider ecosystem resilience and dynamics rather than focusing on the past as reference situation.
- Good detailed GIS maps of land use/land cover and vegetation are important.

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Figure 11: If the data are available, ecologically scaled landscape indices and a key patch approach can be combined to assess the numbers of species with viable populations.

4.8 Effects of habitat structure and habitat quality on species diversity

Jens Dauber, School of Natural Sciences, Trinity College Dublin

There is a growing recognition that local patterns and processes of biodiversity are controlled by factors operating over a broad spectrum of spatial and temporal scales. Fundamental changes in land use and farming systems in Europe are occurring due to changes in socio-economic conditions and agricultural policy. They lead to increasing intensification in regions of high production potential and abandonment in regions less favoured for agricultural production. Both trends induce a homogenisation of landscapes and farming practises, interacting with biodiversity through factors operating at field, farm, and landscape scale. The developments are expected to be detrimental for biodiversity because many

species associated with agroecosystems require different food resources and habitat conditions through their life cycles and so can only thrive in heterogeneous and fine-grained landscapes.

Our studies aimed at determining the relative importance of habitat quality vs. landscape structure in shaping local communities. Focal taxa were surface-dwelling soil macroinvertebrates differing in mobility and habitat requirements. For most taxa a large amount of the variation in local species richness depended on land use and habitat characteristics but also on the surrounding landscape. Moreover, significant interactions between land use and both habitat characteristics and landscape variables indicated that the effects of the different drivers of species richness do not operate independently of each other. The strength of the variables operating at the different spatial scales differed greatly among taxa and also among organisms within one taxon which were characterised by different ecological traits. In conclusion, agri-environment schemes for the conservation of biodiversity in cultivated landscapes have to secure management for both habitat quality and heterogeneous landscape mosaics. The prevalent restriction of agri-environmental schemes to land-use intensity and management type of agroecosystems does not take into account the important influence of the surrounding landscape for local diversity.

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Web: www.uni-giessen.de/~gf1072

Figure 12: Landscape effects on carabids of different dispersal ability. The white part of the columns represent the habitat quality measurements (i.e. plant species richness) and the black part represents the landscape composition (i.e. cover of non-crop habitats). (From Dauber & Purtauf, 2007).

4.9 The relative importance of fragmentation for the conservation of biodiversity in Denmark

Rasmus Ejrnæs and Bettina Nygaard, National Environmental Research Institute (NERI), Denmark

In this presentation, we gave a brief summary of the methods and results of the Danish article 17-report to the European Commission concerning the conservation status of species and habitats protected by the Habitats Directive. The habitats were emphasised, and it was shown that most habitats have been assessed as favourable with respect to their distribution range and the area occupied, whereas 58% of the habitats were assessed as unfavourable with respect to their structure and function – i.e. the quality of the habitats rather than the quantity was found to limit conservation status.

The presentation carried on reporting from a detailed experimental study of community assembly in microcosms investigating the role of species arrival order and habitat quality for grassland succession. In this context, species arrival order represents the fragmentation issue. The experiment revealed that arrival order was controlling species composition of the microcosms whereas habitat quality, in the form of repeated defoliation and nutrient addition, was controlling the diversity of the vegetation and colonisation of new species. Low nutrient status in combination with simulated grazing most strongly promoted diversity and colonisation.

Another anecdotal example was presented. *Osmoderma eremita* is on Annex II of the Habitats Directive. Its habitat is old hollow trees, where the larvae feed on decomposing wood for years, followed by a short-lived imago phase, implying a beetle with limited capacity for dispersal. In the lifespan of a few months, this beetle needs to find a new habitat, i.e. an old hollow tree. Unfortunately Danish forests are effectively emptied of old trees and dead wood. We are thus not short of forests for conservation in Denmark, but short of old trees and dead wood.

In conclusion, fragmentation or connectivity indices based on maps of broad habitat categories, such as forests or hedgerows are bound to fail because mapped features include no useful information about soil fertility, land use history, grazing and availability of old-growth woodland with coarse woody debris.

On the day that habitats are mapped in sufficient detail, we believe there is a scientifically meaningful role for GIS-exercises and spatial modelling.

4.10 Norwegian programme for terrestrial nature monitoring

Erik Framstad, Norwegian Institute for Nature Research (NINA)

The Norwegian programme for terrestrial nature monitoring (TOV) focuses on common Norwegian nature types and species, mainly in boreal forests and mountains. The objective is to document long-term changes and geographical patterns in natural ecosystems and, as far as possible, to link these to human causes. The programme is based on integrated monitoring at 7 selected sites, spanning a climate and pollution gradient from the southwest to the north, as well as country-wide surveys of selected variables. The monitoring covers variables for the ground vegetation, epiphytic vegetation, small mammals, birds and other selected parts of the ecosystems. Being mainly situated in conservation areas, the selected sites are not well suited to monitor changes in land use or landscape structure. However, a planned landscape analysis in approximately 15 x

15 km around the central part of each site will provide important data on land cover and landscape structure. The programme was established in 1990 and is organised and funded by the Directorate for Nature Management and operated by the Norwegian Institute for Nature Research.

Web: <http://www.nina.no/?io=1001450>

Figure 13: Location of TOV monitoring sites in Norway

4.11 Assessing landscape structure and biodiversity in Norwegian agricultural landscapes

Wendy Fjellstad, Norwegian Forest and Landscape Institute

The Norwegian monitoring programme for agricultural landscapes – the 3Q Programme – is a sample-based programme to record state and changes in Norwegian agricultural landscapes. The programme aims to give feedback to shape policy development and control that environmental goals are met.

The sample comprises 1400 monitoring squares of 1 x 1 km, with agricultural land at their centre. The main data source is interpretation of true colour aerial photography. From detailed maps of the squares, different measures of landscape content and structure are recorded. Based on landscape ecological theory and evidence from the literature, aspects of

landscape content and structure are assumed to have relevance for biodiversity, for cultural heritage and for accessibility for people. The focus has been on providing simple, transparent indicators that are easily interpreted and communicated. Examples include area of different land types, continuity of grasslands, length of ditches, streams and field margins, length of corridors and area of different types within corridors, number of farm ponds, and number of habitat islands in the fields (“åkerholmer”).

Figure 14: Even simple, transparent indicators calculated from very detailed map data need careful interpretation to avoid spurious results. This example shows increases in number of mid-field islands from 1998 (left) to 2003 (right), but the changes are due in part to fragmentation of larger patches and do not reflect positive changes for biodiversity.

Analysis of change over a five-year period has shown that even simple, transparent indicators calculated from relatively detailed data may require thorough interpretation to avoid misleading results. This may involve comparison of numerous indicator values together and suggests that, although less transparent, aggregate biodiversity indicators may be a necessity to simplify communication. At the same time, biodiversity is a complicated issue and we should avoid over-simplification. We need better species data to verify assumed links between landscape composition and biodiversity and to enable an appropriate and meaningful level of simplification in communicating with policy-makers.

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4.12 Opportunities within Swedish nature monitoring

Marcus Hedblom, Swedish University of Agricultural Sciences (SLU)

The main objective for national monitoring of the Swedish landscapes, NILS, first and foremost is to provide data for national environmental protection and follow-up of environmental goals, but will also offer authorities, county administrative boards and other regional programs the benefits of more frequent random sampling. NILS is to monitor the conditions for biodiversity in a landscape perspective. NILS includes all different types of landscapes within the framework of a nationwide random sampling. The random sampling consists of over 600 permanent sample plots (5x5 km) that are inventoried every fifth year. Every year about 120 plots scattered over the entire country are inventoried. In 2007 all plots were inventoried once and in 2008 the plots will be inventoried a second time. An expansion of NILS will provide increased possibilities of results on a regional level.

In order to accurately investigate agricultural land, wetlands, alpine and populated environments in our forest rich country, the placement of the NILS sample plots have been concentrated on these, more rare, types of landscapes. In pronounced forest regions the intensity of sample plots is somewhat lower, since this type of landscape is carefully supervised by The Swedish National Inventory of Forests (RIS).

The composition and structural changes in the landscape are large scale events that are hard to detect from the ground, but that can easily be interpreted from infrared aerial photos. A general interpretation and digitizing is made of the NILS plots. Many different types of landscapes are registered in order to give a general picture of the structure and composition of the landscape. Within a kilometer square (1x1 km), a more detailed interpretation with digital readings of landscape elements and biotopes is made. Interpretation and analysis of historical aerial pictures and maps makes it possible to follow the historical development.

The year after the NILS plots have been photographed and the aerial photos interpreted, several field teams take field inventory of the detail-interpreted central kilometer squares. The field measurements are used as a complement to the results of the aerial photo interpretation, but also to inventory objects, structures and species that can not be detected by the aerial photos.

Figure 15: An example of a 5 x 5 km NILES sample square, including detailed mapping of the central 1 x 1 km. In addition, extensive field work provides data that should, in time, allow analysis of the effects of both habitat quality and landscape structure on biodiversity.

4.13 Measuring spatial structure and its effects on biodiversity in Finland

Raisa Mäkipää, Finnish Forest Research Institute (METLA)

Abundances of many forest and mire plant species have changed since the 1950s (Reinikainen et al. 2000). Apparent reasons for this are changes in forest and peatland management (e.g. intensified forestry, site preparation), which have resulted in alteration of site properties as well as age structure, tree species composition, stand density and volume of the growing stock of the forests. The changes in the abundances of bryophyte and macrolichen species were further analysed by biogeographical provinces (Mäkipää and Heikkinen 2003). The most notable changes have taken place in the southern Finland, e.g. a decrease of *Hylocomium splendens* and an increase of *Dicranum polysetum*.

Structure of forest landscape and availability of habitat patches were analysed with the help of nation-wide inventory data of forest properties combined with other sources of geo-refered data. Habitat suitability models were developed in order to assess forest landscape quality (Luque and

Vainikainen, in press). Thematic maps of MS-NFI together with derived landscape metrics and species data was proven as an efficient method to monitor Finnish forest landscape structure. However, the obtained patterns depend strongly on scale and resolution.

Currently we are aiming to link landscape metrics with models of species habitat requirements. Major objectives of our current and future projects are:

- To model habitat requirements of wood decomposing fungi
- To model dead wood dynamics in managed and unmanaged forests
- To analyse relationship between rate of decomposition and species diversity of wood decaying fungi
- To model spatial and temporal availability of suitable dead wood substrate

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4.14 Opportunities to integrate landscape structure information into Finnish nature monitoring and land use planning

Antti Rehunen, Finnish Environment Institute (SYKE)

Nature monitoring requires and can take more advantage of information on landscape structure and related habitat quality (Niemi 2006). A set of biodiversity indicators is being prepared and implemented in Finland. They help to monitor most important overall changes in the state of biodiversity and in pressures affecting it, including changes in habitat structure.

Different types of data can be applied to landscape structure analyses. Large-scale GIS data is available on water areas, streams, ditches, boglands, cultivated areas, transport networks, buildings, and real estates. Other, middle and small-scale data exists e.g. on soil, bedrock, and climate. Digital data on the whole country covers only quite recent years.

Aerial photographs provide opportunities to study longer-term historical changes and detailed landscape patterns. However, their digitizing and interpretation demands a considerable amount of manual work and can be done only in smaller sample areas. In many nationwide GIS datasets, the attribute data is often quite general and not collected from a biological point of view and needs to be complemented by accurate field data. Inventory and census data on biotopes and species is gathered in varying scales and extents. The national Corine Land Cover 2000 data has been produced in 25 m grid by Finnish Environment Institute on the basis of digital maps, interpretation of satellite images, and specifically digitized areas. An update of the national CLC to the situation of the year 2006 is in the process, and when it is completed, it is possible to detect land cover changes. Finnish Forest Research Institute (Metla) has formed multi-source datasets of forest inventory measurements, remote sensed data, and other digital data sources.

In the analysis of landscape structure, it is possible to apply a number of metrics, such as the size distribution of patches, edge length, and the isolation of patches. The interpretation of results has several limitations and challenges. It is difficult to determine how well patches have remained in natural condition and to estimate the exact effects of fragmentation on biodiversity, as implications for species are complicated and may add up in different ways. The determination of key landscape elements enhancing biodiversity should be based on the analysis of multiple taxonomic groups, because species have different requirements. Many metrics are more suitable for analysing remnant patches than describing the matrix. Landscape transformations take place in multiple ways and in different spatial and temporal scales. Possible key aspects and indicators may be e.g. the size distribution of mature forest patches, average distance between mature patches, the construction of forest roads, the isolation of unditched mires, the connectivity and amount of grasslands and traditional rural biotopes, and the amount and edge density of field margins and buffer strips (Hietala-Koivu 2003; Hietala-Koivu et al. 2004; Kallio & Aapala 2001; Kivinen 2005; Kivinen et al. 2006; Löfman & Kouki 2001, 2003).

In land use monitoring and planning, nature fragmentation is reflected against other land use interests, such as construction pressures, infrastructure development, recreational demands, and the use of natural resources. When data on habitats, their fragmentation and its implications is location-based, it is easier to consider it in planning. In urban regions, many significant changes are taking place in the transitional fringe zone around densely populated areas, where extensive, scattered and uncontrolled building causes fragmentation. The definition and mapping of nature core areas, ecological connections and networks as well as different ecological barriers are tools that can be applied to regional planning. However, more methods and datasets need to be developed to examine biodiversity and

ecosystem services with spatial data and to take them into account in land use planning.

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4.15 Opportunities within Danish nature monitoring

Bernd Münier and Morten Elmeros, National Environmental Research Institute (NERI), Denmark

Nature monitoring in Denmark is carried out by the “National Monitoring Programme for Species and Habitats” organised under NOVANA, the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment. NOVANA is an integrated monitoring programme of nature and the environment including groundwater, aquatic and terrestrial habitats, species, air quality and point sources. With this programme Denmark can fulfil its international monitoring and reporting obligations and other important national obligations pertaining to nature and the environment – at least at a minimum level.

Monitoring activities within NOVANA are carried out within six years cycles, where the first period covers the years from 2004 to 2009. Main activities taking place during the start-up phase of this period have been elaboration of technical instructions, including the assessment of conservation status and definition of ‘favourable conservation status’. A main novelty in NOVANA, compared to the previous NOVA program covering the aquatic environment, is the extension to terrestrial monitoring. In total, NOVANA consists of a number of sub-programmes which are:

- Background monitoring of air quality and atmospheric deposition
- Point sources
- Agricultural catchments
- Groundwater
- Watercourses
- Lakes
- Marine waters
- Species and terrestrial natural habitats
- The National Air Quality Monitoring Programme

Regarding monitoring of species and terrestrial natural habitats, it is important to assess natural as well as anthropogenic pressures. The most important anthropogenic pressures are:

- Eutrophication due to nutrient inputs via atmospheric deposition and fertilization
- Changes in hydrology by drainage and groundwater abstraction
- Changes in land use and management practice.
- Attenuation of natural dynamics through regulation
- Habitat fragmentation

The main focus of the monitoring program is on habitat types according to the annexes of the habitat directive, with a further monitoring of the wider countryside. As a consequence, the monitoring program consists of a species and a habitat part. Monitoring of species is carried out as so called intensive monitoring regarding population size and with high frequency. Furthermore, an extensive part to monitor the distribution range of the species with regard to its size and geographical changes is taken place with low frequency.

For the time being, landscape monitoring is undertaken as a small part of NOVANA with focus on small biotopes, the former ‘Small Biotopes Project’ lead by the University of Roskilde. The availability of sets of auxiliary maps on protected areas, physical geographical settings, maps covering spatial planning and potential impacts from human activities like agricultural land management should give the opportunity to extend monitoring, following a more general habitat and landscape perspective.

References:

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NOVANA. Nationwide Monitoring and
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gramme Description – Part 1. National</p> | <p>Environmental Research Institute, Den-
mark. 53 pp. – NERI Technical Report
No. 532.</p> |
|---|---|

5. Overview of data for the assessment of habitat structure in the Nordic countries

The table in Appendix C presents the outcome of a first attempt to produce an overview of data, available for the assessment of habitat structure in Norway, Sweden, Finland and Denmark. Seemingly there is quite a lot of available data in the four Nordic countries. However, there is also considerable variation in spatial resolution, thematic resolution and geographical coverage and therefore also large differences in suitability for indicator calculation, both within and between countries.

Broad scale maps such as the Corine land cover maps, national protected areas, physical-geographical maps and land use / land cover maps are available for all four countries covering most part of the countries. Moreover, all four countries have good coverage of human activity such as agricultural areas and roads. Norway, Finland and Sweden have long time series, many sample plots and good resolution sampling of forested areas. Sweden has monitoring data covering the whole country through NILS, including small to large scales in a 5 year time series.

In addition, all countries have monitoring data covering certain habitats or certain species but not covering the whole country. Finally, at a local/regional level all four countries have more data than shown in the table in appendix C that would be appropriate for a case study approach to the analysis of landscape structure. Suitable data at this level will be easier to identify when working with common issues in a possible future collaboration.

6. Discussions and conclusions

As highlighted in the preface, biodiversity and its supporting landscapes are highly dynamic, driven by pressures occurring from human as well as physio-geographical and ecological forces. Presentations given throughout the workshop as well as lots of references to scientific publications clearly indicate the relevance of habitat fragmentation as a main pressure on biodiversity, species survival and adaptation. Consequently, a main issue in the workshop discussions was whether and how spatial indicators in a Nordic context can be applied in a way, making them meaningful descriptors of impacts on biodiversity. This discussion led to following main conclusions:

- Theoretical concepts and empirical studies clearly indicate effects of the spatial structure of habitats on biological diversity
- Land-cover and land use changes lead to changes in the spatial structure of habitats, often having negative consequences for biological diversity
- Spatial indicators can be applied as descriptors for state and change in biological diversity
- In order to reasonably describe biological diversity, spatial indicators must be ecologically scaled, i.e. they must be based on specific knowledge on (groups of) species' requirements for habitat quality
- Data (maps) for calculation of spatial indicators must contain information, which reflect these requirements, or it must be possible to add these information from auxiliary data – like monitoring programmes, agricultural registers, or traffic flows

6.1 Ecological scaling of spatial indicators

The concept of ecological scaling of spatial indicators is based on the argument that landscapes spatial pattern, including the spatial structure of habitats, must be linked to the addressed ecological functions. With respect to biological diversity (embracing species diversity and abundance), the application of spatial indicators must be based on specific knowledge on species' habitat requirements. These requirements include quality and the spatial structure of the habitat. Although the spatial structure of a habitat in principle is part of the habitat quality, they are in this context treated separately.

Habitat quality is determined by the biophysical conditions characterising a habitat. Relevant parameters for habitat quality highly depend on

the type of habitat and the addressed species. E.g. for forest species, important parameters for habitat quality are the age of forest, species composition and the amount of dead wood. In comparison, for many species, which are found in or close to agricultural landscapes, nutrient load is an important parameter for habitat quality.

The spatial structure of habitats includes the habitat area, habitat shape and the degree of spatial isolation/connectivity between habitats. Requirements for habitat area (both total area and area of single habitat patches) must be based on the area thresholds required to sustain a species population. Habitat shape highly influences boundary effect, i.e. disturbances from surrounding land use. Requirements for habitat shape must therefore be based on species' requirements for core area, where such disturbances are relatively small or not existent. Finally, requirements for spatial connectivity must be based on species' natural dispersal distance.

Spatial data (maps and auxiliary data) for the application of spatial indicators must reflect these habitat requirements. The detail of classification must be fine enough to include relevant parameters for habitat quality. The spatial resolution and coverage must fit with the spatial characteristics in terms of area requirements and dispersal distances.

6.2 The relevance of the matrix

An important issue, which appeared during the discussions, is the relevance to include information on the type and condition of the landscape matrix. Many approaches have a narrow focus on the habitat patch, while the role of the matrix (the area between patches) often is neglected. Especially in highly fragmented landscapes, the survival of species populations highly depends on species' possibility to move between habitat patches. Species' possibility to move across a specific land-use type depends on the degree of permeability. E.g. the degree of permeability is usually much higher in an area characterised by extensively managed grassland compared to an intensively managed cropland. In order not to neglect the importance of the matrix, spatial data (maps) for the application of spatial indicators should contain information on the permeability of the land uses, which are located between habitat patches.

6.3 Availability of data

In chapter 5 we made a preliminary review of available data in the Nordic countries. Especially at larger regional and continental scales there exists a fundamental lack of spatial data, which encompass adequate information about habitat quality and spatial structure of habitat. However, within the Nordic countries there exist different spatial datasets, which are more

detailed and therefore more suitable for the application of spatial indicators for biological diversity. Data, which contain information on habitat quality and structure at a suitable spatial scale, include topographic maps, different types of registration of protected areas and nature types, data from national forest inventories as well as data from landscape monitoring programmes. Furthermore, information on habitat quality can be enhanced through the spatial integration with physical geographical maps (such as soil properties, humidity, climate) and spatial data for specific influences or pressure, e.g. from agricultural management or from infrastructure.

All in all it can be concluded that data available within the Nordic Countries and knowledge gained within the international scientific community is satisfactory to permit a project demonstrating potentials and advantages in assessing landscape and habitat fragmentation in monitoring of biodiversity in Nordic Countries.

7. Recommendation for further actions and research

The central aim of the workshop was to gather experts in order to clarify opportunities and limitations to integrate assessments of the spatial structure of habitats in nature monitoring in a Nordic context. Considering the presentations, discussions and conclusions of the workshop, a number of specific recommendations and guidelines for further actions and research in the Nordic countries can be given.

A central message of the workshop was a fundamental demand of spatial data, encompassing adequate information about habitat quality and spatial structure of habitats and landscapes. These are needed for a reasonable assessment of spatial indicators on biological diversity. Consequently, an important recommendation for future action is twofold – targeting monitoring and harmonising data and assessments. For the first, existing monitoring programmes and geographical data should be enhanced and eventually extended, so that data from nature monitoring programmes include this information. More specifically there is a decisive demand on more spatially explicit data on habitat types, habitat quality and spatial structure of habitats. Secondly, existing data and methods within the Nordic Countries should be harmonised in order to enable cross-country evaluation and assessments.

Scientifically reasonable recommendations for nature monitoring depend on a more focused research effort. In general, there is a need to establish research platforms which integrate biological and more geographical competences. Specific needs for further research are:

- The establishment of a proper knowledge base of existing theories and methodologies to integrate measures of spatial structure of habitats in nature monitoring. This knowledge base must be founded on a thorough literature review, which to some degree already has been done during the workshop.
- A critical examination of available spatial data and methods for assessment of habitat quality and spatial structure of habitats. A preliminary review of data has been provided in this report. However, the applicability of data and differences in data between countries need to be examined and targeted further at monitoring of habitats spatial structure.
- Specific example studies for application of spatial indicators on basis of existing spatial data in the Nordic countries. An important premise for these studies is a close cooperation between experts with a

biological; species based approach and experts with a spatial and geographical approach. Results and experiences from these studies will deliver important inputs to the evaluation of opportunities and limitations for the assessment of spatial structure of habitats.

Together, a review of existing theories and methodologies, a critical examination of available data and the conduction of specific example studies form the basis to evaluate opportunities as well as limitations for the assessment of spatial structure of habitats. This evaluation is crucial in order to give scientifically qualified and sound recommendations for the future exploitation of existing map data and for the design of nature monitoring programmes in the Nordic countries.

Recommendations from the workshop suggest the necessity to include measures on spatial structure of habitats as an important contribution for the assessment of the overall quality of habitat and changes in biological diversity. Data available throughout the participating countries enable demonstration projects and further integration of data and spatial indicators. The outcome of a pilot project could make a considerable contribution to the aim of halting loss of biodiversity within the Nordic Countries.

Sammenfatning (dansk)

Ændringer i habitaters rumlige struktur, såsom faldende habitatarealer og en rumlig fragmentering, er, sammen med en generel nedgang i habitatkvaliteten, en hovedårsag for et fald i den biologiske mangfoldighed. Rumlige indikatorer kan anvendes til vurdering af habitaters rumlige struktur og dens indflydelse biologisk mangfoldighed.

I maj 2008 blev den Nordiske Workshop *En sammenhængende natur i Norden (CONNOR)* afholdt. Formålet var at samle forskere og naturforvaltere fra de nordiske og andre europæiske lande for at diskutere muligheder, begrænsninger og nødvendig forskning for at integrere rumlige indikatorer i naturovervågningen i de nordiske lande. Denne rapport samler workshoppens resultater.

Workshoppens præsentationer indikerede tydeligt relevansen af habitaters rumlige struktur i forhold til biologisk mangfoldighed. Desuden er rumlige indikatorer i en række studier med succes blevet anvendt til at beskrive tilstand og ændringer i biologisk mangfoldighed. For at beskrive biologisk mangfoldighed på en forsvarlig måde, skal rumlige indikatorer være baseret på konkret biologisk viden omkring specifikke arters behov for kvalitet og rumlig struktur af habitater. Anvendte data skal indeholde information, som reflekterer disse behov.

Selv om der er en generel mangel på data, som indeholder denne information, findes der i de enkelte nordiske lande en række datasæt, som er detaljerede nok til en biologisk meningsfuld anvendelse af rumlige indikatorer.

Ud fra workshoppens resultater peges på nødvendigheden for at oprette en forskningsplatform som omfatter eksperter med en biologisk, arts-specifik tilgang og eksperter med en rumlig geografisk tilgang. Anbefalinger for en fremtidig forskningsindsats inkluderer etableringen af et mere grundlæggende viden omkring eksisterende teoretiske og metodiske tilgange. Derudover er det vigtigt at lave en grundig og kritisk gennemgang af tilgængelige data i de Nordiske lande. Endelig er det afgørende at udføre konkrete eksempelstudier. På baggrund af resultater og erfaringer fra sådanne praktiske studier er det muligt at vurdere muligheder, begrænsninger samt nødvendige tiltag for at styrke anvendelsen af rumlige indikatorer i de nordiske lande. Disse forskningsindsatser er afgørende i forhold til at udarbejde videnskabelig kvalificerede og fornuftige anbefalinger for mere hensigtsmæssige kortlægningsaktiviteter og udformning af naturovervågningen i Norden.

Gregor Levin, Bernd Münier, Wendy Fjelstad, Antti Rehunen and Marcus Hedblom, June 2008

Tiivistelmä (suomalainen)

Eliölajien elinympäristöjen alueellisessa rakenteessa tapahtuu muutoksia, kuten pinta-alan vähenemistä ja pirstaloitumista. Nämä muutokset yhdes- sä elinympäristöjen laadun heikkenemisen kanssa aiheuttavat huomatta- vaa painetta luonnon monimuotoisuudelle. Maisemarakennetta kuvaavia indikaattoreita voidaan käyttää hyödyllisinä työkaluina arvioitaessa elin- ympäristöjen rakennetta ja sen vaikutuksia luonnon monimuotoisuuteen. Toistaiseksi tällaisia indikaattoreita on hyödynnetty Pohjoismaissa hyvin rajallisesti.

Toukokuussa 2008 järjestettiin pohjoismainen työpaja luontoalueiden jatkuvuudesta Pohjoismaissa *Connectivity of nature in the Nordic coun- tries*. Työpajan tarkoituksena oli koota yhteen tutkijoita ja muita aiheen parissa työskenteleviä Pohjoismaista ja muualta Euroopasta. Keskustelun aiheena oli maisemarakenneindikaattorien käytön mahdollisuudet ja ra- joitteet sekä lisätutkimuksen tarve luonnon seurannan näkökulmasta. Tämä raportti sisältää yhteenvedon työpajan tuloksista.

Työpajassa pidetyissä esityksissä tuli selkeästi esille elinympäristöjen alueellisen rakenteen merkitys luonnon monimuotoisuuden kannalta. Useissa tutkimuksissa maisemarakenneindikaattoreita on käytetty menes- tyksellisesti luonnon monimuotoisuuden tilan ja siinä tapahtuneiden muu- tostien kuvaamiseen. Jotta luonnon monimuotoisuutta voidaan kuvata mielekkäästi, indikaattoreiden täytyy perustua tietoon lajien vaatimuksis- ta elinympäristön laadulle ja rakenteelle. Vaikka tarvittavia tietoja ei ole useinkaan saatavilla, Pohjoismaissa on olemassa monia paikkatietoaineis- toja, jotka ovat riittävän yksityiskohtaisia biologisesti merkityksellisten maisemarakenneindikaattorien käyttöön.

Työpajassa suositeltiin tutkimusverkoston perustamista. Siinä tulisi ol- la mukana sekä biologisen lähestymistavan ja eliölajien tuntemuksen että maantieteellisen lähestymistavan asiantuntijoita. Olemassa olevien teori- oiden ja menetelmien kokoamista osaksi yhteistä tietopohjaa pi- dettiin erityisenä tutkimustarpeena. Myös saatavilla olevien tietoainei- stojen kriittistä tarkastelua pidettiin tärkeänä. Lopuksi todettiin tarpeelli- seksi toteuttaa esimerkkitutkimuksia, joiden avulla voidaan käytännössä arvi- oida maisemarakenneindikaattoreiden käytön mahdollisuuksia, rajoi- tteita ja tarvittavia toimenpiteitä Pohjoismaissa. Näiden tutkimustoimien poh- jalta on mahdollista tuottaa tieteellisesti laadukkaita ja luotettavia suosi- tuksia olemassa olevien paikkatietoaineistojen hyödyntämiseen ja luon- non seurantaohjelmien suunnitteluun Pohjoismaissa.

Gregor Levin, Bernd Münier, Wendy Fjellstad, Antti Rehunen and Marcus Hedblom, June 2008

Appendices

Appendix A: Workshop programme

Connectivity of nature in the Nordic countries (CONNOR) Assessing landscape structure in habitat monitoring in the Nordic countries – potential approaches, methods and data

Roskilde Vandrehjem, Denmark, 14–16 May 2008

Wednesday 14 May

11:00–12:00 Registration
12:00–13:00 Lunch

Welcome

13:00–13:10 Introduction to the workshop
Gregor Levin, Dept. of Policy Analysis, National Environmental Research Institute, Denmark

Overview over existing approaches to measure habitat fragmentation

13:10–13:30 Approaches to the assessment of habitat structure and fragmentation
Gregor Levin, Dept. of Policy Analysis, National Environmental Research Institute, Denmark

13:30–13:50 Development of the Net Landscape Ecological Potential indicator across Europe
Rania S. Spyropoulou, Project manager Nature Protection and Biodiversity, European Environment Agency

13:50–14:20 Application of indicators for habitat structure and fragmentation in Streamlining European Biodiversity Indicators 2010 (SEBI2010)
Duncan Stone, Scottish Natural Heritage, member of the SEBI2010 expert group

14:20–14:30 Discussion
14:30–15:00 Coffee break

Assessing landscape structure and biodiversity

15:00–15:40 The relative importance of habitat quality and fragmentation for the conservation of biological diversity in Denmark
Rasmus Ejrnæs, Dept. of Wildlife ecology and Biodiversity, National Environmental Research Institute, Denmark

15:40–16:20 Effects of habitat structure and habitat quality on species diversity
Jens Dauber, Institute of Integrative and Comparative Biology, Faculty of Biological Sciences, University of Leeds

16:20–17:00 Assessment of habitat structure and effects on biodiversity
Jana Verboom, Landscape Centre, Alterra, Wageningen University, The Netherlands

17:00–17:30 Discussion
18:30 Dinner

Thursday 15 May**Specific examples of assessments of habitat structure and biodiversity**

- 09:00–09:20 Landscape structure analysis as tool for sustainability impact assessment on the regional level. Experiences from the SENSOR-project (Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions)
Christa Renetzedler University of Vienna, Dep. of Conservation Biology, Vegetation- and Landscape Ecology
- 09:20–09:30 Experiences from EuMon (EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest) and ALTER-Net (Long-Term Biodiversity, Ecosystem and Awareness Research Network)
Erik Framstad, Norwegian Forest and Landscape Institute
- 09:30–09:50 Measuring spatial structure and its effects on biodiversity in Finish boreal forests
Raisa Mäkipää, Finnish Forest Research Institute
- 09:50–10:00 Coffee break
- 10:00–10:20 Assessing landscape structure and biodiversity in Norwegian agricultural landscapes
Wendy Fjellstad, Dept. of Landscape Resources, Norwegian Forest and Landscape Institute
- 10:20–10:40 Infrastructure development, habitat fragmentation and species development in Sweden
Andreas Seiler, Dept. of Conservation Biology, Grimsö Wildlife Research Station, Swedish University of Agricultural Sciences

Opportunities and limitations to integrate habitat fragmentation in Nordic nature monitoring

- 10:40–11:00 Opportunities within Finnish nature monitoring and land use planning
Antti Rehunen, Finish Environment Institute (SYKE)
- 11:00–11:20 Opportunities within Swedish nature monitoring
Marcus Hedblom, Department of Conservation Biology, Swedish University of Agricultural Sciences
- 11:20–11:40 Opportunities within Norwegian nature monitoring
Erik Framstad, Norwegian Forest and Landscape Institute
- 11:40–12:00 Opportunities within Danish nature monitoring
Morten Elmeros and Bernd Münier, National Environmental Research Institute, Denmark
- 12:00–13:00 Lunch

Discussion, conclusions and recommendations:

- 13:00–14:30 Group work on data-availability and possible approaches to assess landscape structure and related effects on biodiversity in the Nordic context
- 14:30–14:45 Coffee break
- 14:45–16:00 Summarizing issues and cooperation platforms for further research in assessment of habitat structure and fragmentation in the Nordic context
- 16:00 Departure

Friday 16 May

Project group consisting of project leader and one researcher from each Nordic country works on the workshop proceedings and preparation of an application.

Appendix B: List of participants

Name	Affiliation	Country	E-mail
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Appendix C: Overview of available data for assessment of spatial structure and quality of habitats in the Nordic Countries

DATASET IDENTIFICATION				OTHER DATASET INFORMATIONS				CONNOR
Title	Country	Remarks	Topic category	Format	Scale / Spatial resolution	Attribute data	Geographic coverage	Relevance for calculation of indicators
	DK= Denmark FIN= Finland SWE= Sweden NO= Norway			V=vector R=raster or given format	Accuracy of the dataset	Classified data / data format for continuous data	Spatial extent of the dataset	Issues related to quality and spatial structure of habitats
ECOLOGICAL CHARACTERISTICS								
Physical-geographical maps								
Soil texture	DK	Soil type, classification by texture and organic matter content	Soil	V	1:50.000	8 classes	DK	Environmental variable of habitat quality
Quaternary geology	DK	Subsoil geology in 1 m depth	Subsoil	V	1:25.000	112 classes	DK 85 %	Environmental variable of habitat quality
Quaternary geology	DK	Subsoil geology in 1 m depth	Subsoil	V	1:200.000	~ 25 classes	DK	Environmental variable of habitat quality
Hydrosol areas	DK	Areas with high groundwater table year ~1900	Soil	V	1:25.000	4 classes	DK	Environmental variable of habitat quality
Digital terrain model (LIDAR beta)	DK	Elevation – derived slope, aspect, morphology	Surface	R	1,6 m	Continuous	DK	Environmental variable of habitat quality (vertical structure)
Climate database	DK	Data from Dansk Met. Survey	Climate	Point	10km grid		DK	Environmental variable of habitat quality
Quaternary deposits	FIN		Soil	V/R	1:20.000 / 50.000, 1:100.000, 25 m pixel	17 classes	FIN 40 %	Environmental variable of habitat quality
Pre-quaternary rocks	FIN		Bedrock	V/R	1:100.000		FIN 50 %	Environmental variable of habitat quality
Digital elevation model	FIN		Topography	R	25 m		FIN	landscape structure, habitat quality
Groundwater areas	FIN		Groundwater	V	1:10.000		FIN	Habitat quality
Pre-quaternary rocks	SWE	http://www.sgu.se/sgu/sv/produkter-tjanster/tjanster/kart-tjanst_start.htm	Bedrock	R	1:1.000.000 (some areas with better resolution)		SWE	Environmental variable of habitat quality
Groundwater areas	SWE	http://www.sgu.se/sgu/sv/produkter-tjanster/tjanster/kart-tjanst_start.htm	Groundwater	R	1:1.000.000 (some areas with better resolution)		SWE	Habitat quality
Gravel and moraine	SWE	http://www.sgu.se/sgu/sv/produkter-tjanster/tjanster/kart-tjanst_start.htm	Land cover	V	1:50.000–1:250.000		SWE	Environmental variable of habitat quality

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Soil texture	SWE	http://www.sgu.se/sgu/sv/produkter-tjanster/tjanster/kart-tjanst_start.htm	Land cover	V	1:1.000.000 (some areas with better resolution)		SWE	Environmental variable of habitat quality
Quaternary geology – Bed-rock	NO	http://www.ngu.no/kart/bq250/	Bedrock	R/V	1:250.000		NO	Environmental variable relevant for habitat potential
Quaternary geology – Superficial deposits	NO	http://www.ngu.no/kart/losmasse/	Superficial deposits	V	1:20.000– 1:250.000		NO	Environmental variable relevant for habitat potential
Soil types	NO	Includes themes derived from soil type e.g. texture, suitability for different crops, erosion risk. http://www.skogoglandskap.no/temaer/jordsmonn	Soils	V	1:10.000	Uses international classification system: World Reference Base for Soil Resources	NO – covers ca. 50 % of Norway's agricultural area.	Environmental variable relevant for habitat potential
Climate	NO	E.g. monthly average temperature and precipitation	Climate	R	1km squares		NO	Environmental variables relevant for habitat potential
Digital Terrain Models (DTM25 & DTM50)	NO	http://www.geonorge.no/Portal/ptk	Topography	R	25 x 25 m or 50 x 50 m		NO	Environmental variables relevant for habitat potential
Biogeoclimatic zones (Norwegian Vegetation Atlas)	NO	Regionalization based on botanical criteria and distributions of species and vegetation types.	Climate / topography / geology	V		Vegetation zones	NO	
Biogeoclimatic zones (PCA-Norge)	NO	Regionalization based on PCA-analyses of 54 variables of climate, topography and geology. Similar result to the vegetation zones and sections described above, but more explicit methodology.	Climate / topography / geology	R	10km grid	PCA-axes interpreted in terms of oceanity and biogeographic regions	NO	
Land use / land cover								
Topographic base map	DK	forest, wetlands, heathlands, built up areas, roads, water courses, lakes, ...	Land use, land cover	V	1:10.000	~50 categories	DK	Landscape structure, pressures causing fragmentation, environmental variables
Corine +	DK	Corine DK (=EU, but with 4 class levels)	Land use, land cover	V	25 hectares	~50 classes	DK	Landscape structure, pressures causing fragmentation, environmental variables

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Topographic base map	DK	forest, wetlands, heathlands, built up areas, roads, water courses, lakes, ...	Land use, land cover	V	1:10.000	~50 categories	DK	Landscape structure, pressures causing fragmentation, environmental variables
Digital property map	DK		Property boundaries	V	1:5.000		DK	Ownership structure can help explain patterns of landscape change
Forest census maps	DK						DK	
Topographic database	FIN	Transmission networks, transport networks, rock exposures, mineral soil, relative elevations, cultivated areas, man-made structures, boglands and waters	Topography, land cover, land use	V	1: 5.000– 1:10.000		FIN, except for the northernmost parts of Lapland	Landscape structure, pressures causing fragmentation, environmental variables
SLICES	FIN	Produced mostly on the basis of topographic database and building data	Land use	R	10 m, 25 m	44 classes	FIN	Landscape structure, general habitat quality, pressures causing fragmentation, environmental variables
National Corine 2000 Land Cover	FIN	Produced on the basis of digital maps (e.g. SLICES), interpretation of satellite images, and specifically digitized areas.	Land cover	R	25 m	44 classes	FIN	Landscape structure, general habitat quality pressures causing fragmentation, environmental variables
European Corine 2000 Land Cover	FIN	Generalized from national CORINE data	Land cover	V	25 hectares	44 classes	FIN	General level land cover
Multi-source National Forest Inventory (MS-NFI)	FIN	MS-NFI applies field measurements, remote sensed data and other digital data sources. Forest characteristics are estimated for areas laying between the field measurement plots.	Forest	R	25 m resolution		FIN	habitat quality, key habitats, habitat suitability, landscape structure, pressures causing fragmentation, environmental variables, species richness
European Corine 2000 Land Cover	SWE		Land cover	V	25 hectares	44 classes	SWE	General level land cover
Swedish terrain map	SWE	Including cover of mixed deciduous & coniferous trees, agriculture land etc. The most complete land cover of Sweden in one map	Land cover	V/R	1:50.000 (5 x 5 m)	> 40 classes	SWE (except Västerbotten and Norrbotten county)	Landscape structure
Property map	SWE	The most detailed general map available in Sweden, based on orto photo	Land cover	R	1:10.000– 1:12.500	> 40 classes	SWE	Landscape structure

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Mountain map	SWE		Land cover	R	1:50.000– 1:100.000		SWE (only the mountain areas)	Landscape structure
Wetland	SWE	http://www.vmi.slu.se/Vmi/VmiPub/Index.jsp?PageType=0&PageID=0	Land cover	R				
Forest census maps	SWE (see monitoring data)							
European Corine 2000 Land Cover	NO	Created by re-classification of de- tailed national maps, plus interpreta- tion of satellite images for mountain areas.	Land cover	V	25 hectares	44 classes	NO	General level land cover
Digital Land Type Map (Digital markslag – DMK)	NO	The most complete and detailed map of land use/cover for Norway. Pro- duced by updating and digitising analogue maps (Økonomisk kartverk) going back to the 1960s. Original focus was on production potential of land for forestry/ agriculture. To be updated from 2007, with “AR5” - a simplified version. http://www.skogoglandskap.no/kart/markslagskart_og_statistikk	Land use/cover	V	1:5.000	Land use/cover, production potential for forest, suitabil- ity for agricul- ture, character- istics of bogs/mires. More than 2000 possible combinations of attributes.	NO – only below the tree line	Detailed maps with information relevant for habitat potential and routines available to reclassify into biologically relevant classes. Disadvantages: 1) mountain areas are not mapped 2) will not be updated in same level of detail
AR5 Land re- source map	NO	http://www.skogoglandskap.no/kart/markslagskart_og_statistikk	Land use/cover	V	1:5.000	Land use/cover production potential for forest, suitabil- ity for agricul- ture	NO – but with less detailed information above the tree line	Detailed maps with data relevant for habitat potential and routines available to reclassify into biologically relevant classes. Disadvan- tages: Mountain areas not mapped with same detail as areas below the tree line
AR50/AR250 Land resources	NO	Generalised data based on DMK/AR5	Land use/cover	V	1:50.000 / 1:250.000	Land use/cover (broad classes)	NO	Coarse level land cover, landscape struc- ture
Digital property map (DEK)	NO		Property boundaries	V	1:5.000			Ownership structure can help explain patterns of landscape change

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NATURE PROTECTION AND DESIGNATION								
National protected areas	DK	Semi-natural terrestrial biotopes		V	1:25.000	6 classes	DK	Key habitats, designation as a response to fragmentation
Natura 2000	DK	EU habitats directive & RAMSAR convention		V	1:25.000	Habitat types	DK	Key habitats, designation as a response to fragmentation
National protected areas	DK	Semi-natural terrestrial biotopes		V	1:25.000	6 classes	DK	Key habitats, designation as a response to fragmentation
Protected areas and wilderness areas	FIN			V	1:5.000–1:20.000		FIN	Key habitats, designation as a response to fragmentation
Natura 2000 sites	FIN			V	1:5.000–1:20.000 mostly		FIN	Key habitats, designation as a response to fragmentation
Restrictive areas	FIN	Areas with restrictions for water and cross-country traffic		V	1:20.000		FIN	Responses to fragmenting pressures
Valuable rock formations	FIN			V	1:20.000		FIN, except for two regions	valuable habitats
Natura 2000 sites	SWE	http://w3.vic-metria.nu/n2k/jsp/search.do		V	1:5.000–1:20.000		SWE	Habitat quality, landscape structure
Protected areas in Sweden	SWE	http://sn.vic-metria.nu/skyddadnatur/faces/index.jsp		V			SWE	
Nature protection sites	NO	National Parks, Landscape Protection Areas, Nature Reserves, Natural Heritage Objects. http://dnweb12.dirnat.no/nbinnsyn/	Protected areas	V		Boundaries, type of protection	NO – boundaries of all legally protected areas	Overlay with other map data allows some analysis of landscape structure within and surrounding protected areas. Limited data availability – especially in "wilderness" areas.
Valuable habitats	NO	Mapped by the municipalities using methods designed by the Directorate for Nature Management. http://dnweb12.dirnat.no/nbinnsyn/	Valuable habitats	V	Highly variable resolution	Boundaries, ca. 70 habitat types, priority (A, B, C)	NO – habitat boundaries – great variation in quality and completeness of records	Overlay with other map data allows analysis of landscape structure within and surrounding valuable habitats. Limited data availability – especially in "wilderness" areas. Quality of data may cause spurious results.

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Vegetation maps	NO	Mapped on a project-by-project basis, but w standard methods. Some areas only available as paper maps. http://www.skogoglandskap.no/kart/vegetasjonskart	Vegetation	V	1:20.000– 1:50.000	Vegetation type – own classification system.	NO – ca. 10 % of the country. Mainly extensive grazing lands.	Habitat potential/quality, landscape structure. Not updated.
Norwegian coast	NO	Waters around the Norwegian coast	Water	V	1:50.000			
ELVIS River network	NO	http://www.vannportalen.no/hoved.aspx?m=41482&amid=1952866	Water	V	1:50.000	Direction of flow	NO	Potential habitat
HUMAN ACTIVITIES								
Infrastructure								
Road and rail-road network	DK	incl. road classification.	Transport	V	1:10.000	6 classes	DK	Pressures causing fragmentation
Data on traffic density and amount	DK	distributed on road network	Transport	V	1:10.000	continuous	DK	Pressures causing fragmentation
Buildings	DK			Point	1:10.000	Classes of buildings	DK	Pressures causing fragmentation
Buildings and population	FIN		Buildings	Point		77 classes for the use of buildings	FIN	Pressures causing fragmentation, landscape structure
Digiroad: road network	FIN		Roads, streets	V	1:5.000– 1: 20.000	12 classes for road type	FIN	Pressures causing fragmentation, landscape structure
Cadastral map	FIN	Digital real estate register	Real estates	V	1:5.000– 1:20.000		FIN	Landscape structure
Territorial divisions of community structure: densely populated areas, residential areas, villages	FIN		Community structure	V	250 m squares		FIN	Pressures causing fragmentation, landscape structure
Outdoor recreation opportunities in nature	FIN	Nature recreation areas, routes and services	Recreation	V	1:10.000	12 + 18 + 28 classes	FIN, partly finished	Habitat quality, pressures causing fragmentation
City map	SWE		Buildings	V/R	± 10 m			Landscape structure

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Road map	SWE		Roads	R	1:100.000	< 15 classes	SWE	Landscape structure
Built-up areas	NO	Defined by Statistics Norway (mini- mum 200 people, 50m between houses) http://www.ssb.no/arealbruk/	Land use/cover	V			NO – bounda- ries of built-up areas	Landscape structure (using overlay with other data sources)
Road map (Vbase)	NO	http://www.geonorge.no/Portal/ptk	Roads	V	1: 50.000		NO – all roads longer than 50 m	Landscape structure (using overlay with other data sources)
Agriculture								
LPIS, Land Parcel Informa- tion System	DK	Database from EU agricultural subsi- dies	Crops, agricul- tural manage- ment					Pressures on habitat quality, landscape structure
Husbandry for each farm loca- tion	DK		Location of animal hus- bandry					Pressures on habitat quality
FLPIS, Finnish Land Parcel Identification System	FIN		Agriculture	V	1:5.000– 1:10.000		FIN	Landscape structure, pressures causing fragmentation, habitat quality
Farmland	SWE		Crops, agricul- tural land cover	V				Habitat quality
Farmland	NO	Part of DMK/AR5 mentioned above. Also generalized for use at coarser scales (AR50/AR250).	Land use/cover	V	1:5.000– 250.000		NO – all arable land and inn bye land (but not outfield pastures)	Landscape structure
MONITORING DATA								
Integrated national monitor- ing program, only for selected sites and habitats (NOVANA).	DK							Environmental variables for habitat quality, habitat structure, species richness

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Small biotope monitoring program (SBMP)	DK	Part of NOVANA	Land use / land cover	V	1:5.000	Land use, land cover classes (focus on biotopes)	32 test sites of 2x2 km in agricultural landscapes	Environmental variables for habitat quality, habitat structure, species records
Forests (National Forest Inventory)	FIN	66 000 sample plots	Forest, mires			over 100 measurements per plot	FIN	Habitat quality, pressures causing fragmentation, environmental variables, species richness
Birds: several monitoring schemes	FIN	Line transects, bird atlas in 10 km x 10 km squares	Birds					Species richness
Butterflies	FIN	Line transects, observations in 10 x 10 km squares	Butterflies					Species richness
Moths	FIN	Light traps	Moths					Species richness
Wildlife (game)	FIN	Fixed routes						Species richness
Ground water	SWE		Water	R	1:1.000.000 (county)		SWE	Habitat quality
Wetland	SWE			R			SWE (not mountain range)	Landscape structure, habitat quality
NILS (National inventory of Sweden)	SWE	Covering landscape scale down to single species http://nils.slu.se/	Everything	R, V, Digital photo	5 * 5 km orthophoto (N= 600), 1 * 1 km interpreted aerial pictures, 10 meter field	over 100 measurements per plot	SWE (600 squares á 5 *5 km)	Landscape structure, habitat quality, species registrations
Swedish national forest inventory (RIS)	SWE	RIS comprises an annual sample of 10 400 sample plots since 1923. Since 2003 is ground inventories incorporated within RIS http://www-riksskogstaxeringen.slu.se/	Forest and ground	R	local, landscape and regional	over 100 measurements per plot	SWE	Landscape structure, habitat quality

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LUCAS – Land Use/Cover Area Frame Statistical Survey	NO	Norwegian part of European LUCAS. Field survey and aerial photo interpretation. All landscape types.	Land use/cover	V	1.000 sample areas of 90 ha (1.5 km X 0.6km) in a regular 18 x 18 km grid	Same classification system as Vegetation maps (above), translated to less detailed, European LUCAS classification system	NO – statistical sample	Landscape structure, habitat quality
3Q Monitoring Program for Agricultural Landscapes	NO	Started 1998. Land use/cover and changes over time in agricultural landscapes. 20% of sample squares mapped each year in a rolling program with 5 year interval. Indicators derived from maps. Some field recording of species (vascular plants at 100 sample squares; breeding birds at 130 sample squares)	Land use/cover	V	1.400 sample squares, 1 x 1 km. (Same 3 x 3 km grid as forest inventory). Mapping of point elements down to 4m2	Own classification, over 100 land types	NO – statistical sample (agricultural land)	Landscape structure, habitat quality, calculation of landscape indicators, analysis of drivers of change (linked to other databases, e.g. agricultural census)
JOVA Water and soil monitoring	NO	Started 1992. Focus on effects of agriculture on water and soils.	Water, soils		11 reference areas		NO – reference areas	
Vegetation monitoring in spruce forest	NO	10 case sites of spruce forest: ground vegetation in permanent plots	Ground vegetation species cover, frequency		10 reference sites		NO – reference sites	Species observation, habitat quality, ecosystem health
TOV Monitoring Programme for Terrestrial Ecosystems	NO	Monitoring in case sites: 6 mountain birch sites + 1 coniferous forest site. Permanent plots. Ground vegetation, epiphytes, passerine birds, raptors, grouse, small rodents, defoliating moths, birch seed set. http://www.nina.no/?io=1001450	Species composition/ abundance	MS Access, Excel	7 reference sites	soil chemistry, modelled met data, preliminary landcover	NO – reference sites	Species observation, habitat quality, ecosystem health
TOV-E Breeding Bird Monitoring	NO	Started 2005–2009 (in various regions)	Common birds composition & abundance	MS Access	ca 500 sample squares, 1.5 x 1.5 km		NO	Species composition & abundance; NOTE: not all potential sites actually censused due to practical difficulties

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Norwegian National Forest Inventory	NO	Started 1919. Currently in 9th cycle – now using interval of five years, in a rolling programme	Forest	MS Access	16.000 circular samples (250m ²) on a regular 3 x 3 km grid. 11.000 are in forest and are visited in the field	Tree species, number, height, breadth and condition. Vegetation type, conditions for forestry.	NO – statistical sample (below tree line)	Habitat quality
AR-SKOG (SKOG-SAT Multi-Source Forest Inventory)	NO	Map based on Forest Inventory data, combined with land use/cover from both DMK/AR5 and satellite images. Not monitoring as such, but could be repeated to provide change data.	Forest				NO – selected municipalities	Landscape structure
Species recording	NO	Digital georeferenced data for over 12000 species (3 million records). Norwegian part of the Global Biodiversity Information Facility http://data.gbif.org/ http://artskart.artsdatabanken.no/	Species				NO – point records	species observations (incomplete data)