Environ Monit Assess (2011) 173:579–595
DOI 10.1007/s10661-010-1406-7

National Inventory of Landscapes in Sweden (NILS)—scope, design, and experiences from establishing a multiscale biodiversity monitoring system

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Received: 4 June 2009 / Accepted: 15 February 2010 / Published online: 17 March 2010

Abstract The landscape-level and multiscale biodiversity monitoring program National Inventory of Landscapes in Sweden (NILS) was launched in 2003. NILS is conducted as a sample-based stratified inventory that acquires data across several spatial scales, which is accomplished by combining aerial photo interpretation with field inventory. A total of 631 sample units are distributed across the land base of Sweden, of which 20% are surveyed each year. By 2007 NILS completed the first 5-year inventory phase. As the reinventory in the second 5-year phase (2008–2012) proceeds, experiences and insights accumulate and reflections are made on the setup and accomplishment of the monitoring scheme. In this article, the emphasis is placed on background, scope, objectives, design, and experiences of the NILS program. The main objective is to collect data for and perform analyses of natural landscape changes, degree of anthropogenic impact, prerequisites for natural biological diversity and ecological processes at landscape scale. Different environmental conditions that can have direct or indirect effects on biological diversity are monitored. The program provides data for national and international policy and offers an infrastructure for other monitoring program and research projects. NILS has attracted significant national and international interest during its relatively short time of existence; the number of stakeholders and cooperation partners steadily increases. This is constructive and strengthens the incentive for the multiscale monitoring approach.

Keywords Aerial photo interpretation · Field survey · Land cover · Landscape changes · Landscape pattern

Introduction

The demands for reliable information about natural resources and environmental conditions continuously increase. Under a global change

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scenario with climate change, globalizing markets and a shifting balance from traditional landscape resources to new expectations, the research community and the policy and decision makers need accurate and timely information about the state and change of natural resources and the effects of human-induced environmental impact. Likewise, the public society today more proactively evaluates how the current policy and management options affect the environmental objectives. Thus, information is needed for several purposes, including assessments of current landscape and land use status and trends, specification of targets, understanding cause-and-effect relationships, providing input to scenario analysis, and evaluating whether or not policies have been effective (e.g., Inghe 2001; Haines-Young et al. 2003).

Continuous supply of information is imperative for decision making at all levels, from global policy conventions to land use management decisions on specific estates and sites (Bunce et al. 2008; Nassauer and Opdam 2008). As a consequence, much work in many countries is currently being devoted to developing environmental monitoring programs. A general understanding is that there needs to be an ultimate connection between basic data and decision making (Löfvenhaft 2002; Allard 2003; Ahlqvist 2008; Anonymous 2008). This requires understanding of ecosystem processes and their relation to policy and decision making, as well as what features are possible to monitor with adequate accuracy given the available techniques and resources (Noss 1990; Noss et al. 1992).

As reflected by the Convention of Biological Diversity (CBD), several EU agreements, as well as the Swedish Environmental Quality Objectives (UNEP 1993; United Nations 1992; Council of Europe 2000; Ministry of Environment Sweden 2004; European Commission 2008), maintained biological diversity is widely acknowledged as a central objective. Since the Rio Summit (Council of Europe 2000), massive work has been conducted to define the concept of biodiversity, to develop appropriate indicators, and to develop suitable monitoring techniques (e.g., Geoghegan et al. 1997; Yli-Viikari et al. 2002). Today, a mainstream definition of biodiversity suggests that the concept includes four levels of organization: (1) landscape, (2) community and ecosystem, (3) population and species, and (4) genetic level (Noss 1990). Thus, to monitor biodiversity, there is a need for methods and indicators that address compositional, structural, and functional attributes at different spatial and temporal scales (ibid.). Furthermore, because of the large number of species and the fact that many occur sparsely in nature, most species are difficult to assess with adequate accuracy. Assessment of habitats and substrates rather than of individual species is often a more practical approach.

A range of biodiversity-oriented environmental monitoring programs are currently in operation, although several of them have been established fairly recently. At present there is a lack of consistence between different programs that impede sharing of knowledge, experiences and information (cf. Schmeller et al. 2008). Approaches toward standardized framework of surveillance and monitoring on European level are being developed, however (Bunce et al. 2008). A program that has been operational for a long time is the British Countryside Surveys (e.g., Brandt et al. 2002; Haines-Young et al. 2003; Barr et al. 2003; Petit 2009), which integrates information at the species level with information about landscape composition acquired from mapping of randomly sampled 1-km^2 squares. Other monitoring program approaches have been made in countries such as Austria (Peterseil et al. 2004), Norway (Fjellstad et al. 2001), Canada (Stadt et al. 2006), Denmark (Brandt et al. 2001), Hungary (Takács and Molnár 2009), Spain (Bunce et al. 2006), and Switzerland (Bühler 2006).

In Sweden, trends in land use and landscape composition have previously been undertaken in the LIM (Landscape inventory and monitoring of the effects of the agricultural food production policy) monitoring program (Ihse and Blom 2000), which used subjectively selected landscapes as the basic inventory sample. The main objective of LIM was to assess the consequences of a changed agricultural policy. The Swedish National Forest Inventory has collected data since 1923 (Anonymous 2000) and gathered extensive plot level information about forests and, to some extent, other habitats (Fridman and Walheim 2000). As in most EU countries, the Corine Land Cover (CLC) program (Commission of European Communities 1994) has also been implemented in

Sweden. Despite efforts applying an even higher spatial resolution than in CLC, it still does not allow for sound biodiversity information across relevant spatial scales, however. On the foundation of LIM, the Swedish National Forest Inventory and other approaches, and in the frame of the need of additional, supplementary, and innovative landscape data and analyses, the development of a new monitoring program—the National Inventory of Landscapes in Sweden (NILS)—was initiated by the Swedish Environmental Protection Agency at the end of the 1990s (Inghe 2001). After a period of methodological and operational processing, the NILS was launched in 2003. The NILS setup requires 5 years of inventory to complete data collection on the national level, and hence, the first inventory phase was completed in 2007.

The objective of this article is to present the background, scope, and design of the NILS program to illustrate some core parts of the development process and to provide examples of experiences and results from the first inventory phase. Deeper result-oriented outputs will be delivered elsewhere. We believe that this contribution is useful as similar programs are now developing in other countries and as pan-national harmonization processes are on the global environmental agenda (Svensson et al. 2009).

NILS scope and objectives

The overall objective of the NILS program is to provide national-level data for and perform analyses of landscape biodiversity conditions and changes in terrestrial environments in Sweden. Different environmental conditions, natural ecosystem processes, and anthropogenic impact that can have direct or indirect effects on biological diversity are regarded. More specifically, NILS should provide:

- National statistics on land cover, land use, and landscape structure for all terrestrial habitats in Sweden;
- Data needed to follow up and evaluate national and regional (county level) environmental quality objectives, environmental policy measures and frameworks (including the EU Common Agricultural Policy, CAP), and international indicators of biodiversity and sustainable development;
- Data that support and supplement other national monitoring programs, e.g., the Swedish National Forest Inventory, the Swedish Bird Survey, and monitoring according to the European Habitats Directive;
- An infrastructure for other monitoring and research initiatives, which can use the available landscape and vegetation data, among others for analyses and applied cause-and-effect research on conditions and changes over time.

The objective and more specific purposes emphasize temporal and spatial resolution; i.e., to monitor changes over time and on a landscape scale. For these reasons, the representativeness of the sample units is of fundamental importance. General data with variables that are in common for several habitat types allow for analyses of successional changes or ecotones that could be overlooked or misrepresented with a more context-specific design. It is also important to be able to discover unanticipated changes. Such an early-warning function is an important aspect of a monitoring program (Vos et al. 2000). Likewise, since the results will be used in different circumstances and by different types of stakeholders, the setup must allow enough flexibility to meet various expectations and demands. To match these expectations and demands and to survey the current knowledge and experiences, an information analysis was conducted during the development phase. About 90 researchers, state and regional agency officers and other stakeholder representatives were interviewed (individually or in groups) and asked to identify the most urgent information needs concerning type of impact, habitats, and species groups (Glimskär et al. 2001). General questions about methods, useful indicators, and relevant spatial and temporal scales were also addressed. In brief, there was an overwhelming agreement about the need for a national monitoring program that allowed for landscape-level approaches. A 5 × 5 km square unit was suggested for larger-scale landscape patterns, in combination with a 1 × 1 km square unit for more intensive assessments in accordance with other monitoring schemes in Europe (e.g., Bunce et al. 2008; Petit 2009). For applicable temporal resolution, many respondents suggested a 5-year monitoring interval as a general rotation period.

The information analysis highlighted a strong need for more data on landscape mosaic, fragmentation, connectivity, structural elements, and indicator species, with reference to processes (pressure), habitats (state), structures (state), and species (impact). In the agricultural landscape, e.g., there is an urge for data on the status of management regime (grazing, mowing), especially on more nutrient-poor grasslands, and on structural variation and maintenance of forest islets, stonewalls, stone mounds, and other biotope islets that contribute to landscape biodiversity. Examples of demanded data from wetlands and peatlands include changes in water regimes, substrate properties, peat excavation, and drainage. Examples of demanded data from shorelines along watercourses, lakes, and the sea include water level fluctuations, grazing as a means to maintain high bird diversity, and exploitation pressure by tourism and summer housing. Examples of demanded data from forests include forestry, dead wood and rare and red-listed species, and examples from urban environments include parks, lawns, ponds, and forests as important habitats for recreation and to serve as refuges and dispersal opportunities for various organism groups.

A key conclusion based on the information analysis was that many factors and possible indicators are similar across different types of ecosystems and habitats, e.g., ground disturbance, succession of woody plants in relation to management, effects of management, hydrology and nutrient availability on vegetation, amount and quality of landscape features, landscape fragmentation, and edge effects. As a consequence, it was assumed that similar methods and indicators can be used to cover several types of changes regardless of ecosystem or habitat type (Glimskär et al. 2001). Five broad monitoring targets were identified as main priority areas by the respondents in the information analysis (Esseen et al. 2004):

- Landscape patterns,
- Amount and status of sensitive or threatened habitats,
- Land use and disturbances,
- Structural indicators and substrates,
- Indicative or sensitive species.

These monitoring targets formed the basis for the NILS design, in terms of the sample design, in terms of which variables were actually included, and in terms of clarifying what expectations could be met in the monitoring system already in place and what could be seen as options for future extensions.

Also, the importance of monitoring for evaluation and refinement of the Swedish environmental quality objectives was emphasized during the information analysis. The Swedish Government has adopted 16 broad objectives as a framework for efforts to achieve sustainable development on the national level (Ministry of the Environment, Sweden 2001). The NILS currently provides data and information for the evaluation of existing interim targets and for the formulation of new targets within several of the objectives, including those for wetlands and mountains where NILS currently is the main data provider (cf. Inghe 2001).

NILS design

Following the information analysis, some important observations could be made regarding the design requirements. These can be summarized as needs for:

- Objective information that is relevant for and can be understood by all stakeholders;
- Reliable information on conditions and changes by regular intervals and at the level of biogeographic regions;
- Several different types of landscape information, separate and in combination, implying a design that captures landscape composition, configuration, totals of important types of homogeneous areas, linear and point features, and occurrences of individual species.

To obtain appropriate quality of the information in different biogeographic regions the land surface of Sweden was divided into ten strata, wherein sampling units were selected in a random systematic pattern (Fig. 1). Since the Swedish

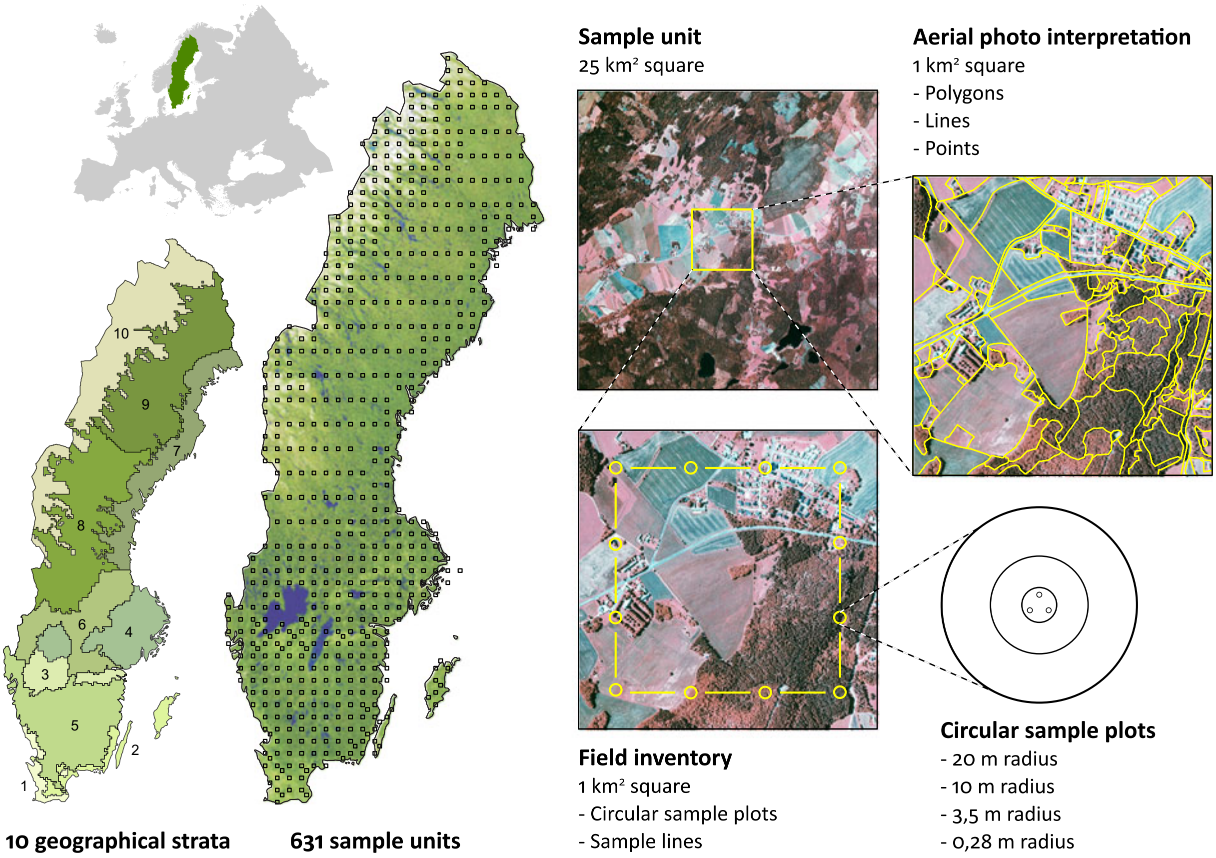

Fig. 1 A summary of the NILS sampling design. The land surface of Sweden was divided into ten strata (*left*) wherein basic sample units ($n = 631$) were selected using random systematic sampling with stratum-dependent densities. Each sample unit is composed of a 25-km^2 square with a 1-km^2 square in the center. The 1-km^2 squares are mapped by aerial photo interpretation and inventoried in the field with 12 sample plots and 12 sample lines. Each sample plot consists of several concentric circular plots of different radius

National Forest Inventory provides in-depth information about forest conditions, including ecological aspects (Anonymous 2000), the NILS sample was reduced in the boreal forest of interior northern Sweden. Hence, the sample effort in NILS was placed in south Sweden and on other land cover types, i.e., the alpine area, the coastal area, and in particular on the more agriculture-dominated and populated parts of central and south Sweden.

To achieve a representative sample and avoid bias, the NILS applied random principles for the sample selection (cf. Thompson 1992; Schreuder et al. 2001) and strict definitions and precise routines for the actual measurements (e.g., Vos et al. 2000). Furthermore, to derive information on landscape structure and on important landscape objects and species, a design was selected that captures data at different spatial scales. The basic sampling units of the NILS contain the following main parts (see Fig. 1):

1. An outer square (5 × 5 km, hereinafter termed the 25-km^2 square) within which extensive remote sensing-based and field inventory assessments are made;
2. An inner square (1 × 1 km, hereinafter termed the 1-km^2 square) at the centre of each 25-km^2 square, which is mapped in detail by colour infrared (CIR) aerial photo interpretation;

3. Within each 1-km^2 square, field assessments are made both by sampling on permanent plots and along line transects;
4. In each 1-km^2 square, there are 12 circular plots at a 250-m distance from each other, and 12 line transects, each 200 m long, starting 25 m from the center of the plots. Thus, line transects and sample plots are placed along the sides of a 750 × 750 m square inside the 1-km^2 square, leaving 125 m on each side to the boarders of the 1-km^2 square;
5. Each of the 12 circular sample plots is composed of a set of concentric circular plots: (a) a 20-m radius plot where assessments of tree cover, forest stand variables, and land use are made, (b) a 10-m radius plot where basic measurements of different vegetation components for land cover description are made, and (c) three small 0.28-m radius plots where the vegetation is documented in detail (see Table 2).

The combination of aerial photo interpretation and field inventory was chosen to obtain both landscape-level data and detailed field data with enough resolution. There are obvious advantages of aerial interpretation in capturing detailed data on the spatial structure of landscapes and the extent of general land cover types (e.g., Skånes 1996; Allard 2003; Ihse 2007; Bunce et al. 2008). Concerning detection and accuracy of specific features and objects such as individual species, substrates, or vegetation structure, on the other hand, field-based methods give much more detailed and reliable data.

Since estimation of change is a major concern, all sampling units are permanent as this is known to be efficient for increasing the statistical power of change estimators (e.g., Green 1989; Schreuder et al. 1993). The total number of selected sampling units (the 25-km^2 square with the 1-km^2 square and plots and linear transects) was randomly split into five annual inventory panels, which all comprised squares evenly distributed over the country. Hence, each year, one fifth of the total sample size is covered, and each sampling unit will be re-inventoried after 5 years. A detailed outline of the statistical premises of the NILS monitoring setup and the estimation procedures for the different variables within the NILS is currently under development by Christensen and Ringvall (in preparation). To be able to determine status and trends in different ecosystems it is important to know the statistical power (i.e., the probability that you will observe a given change when it actually occurs) of the sampling design. The evaluation by Christensen and Ringvall (in preparation) shows that even quite small changes are detectable on a national scale, but also that the resolution is more limited for many variables on regional scales (county level).

Data acquisition procedures with result examples

One of the main features of the program is the use of quantitative variables in a context-dependent variable flow. NILS applies similar basic variables across all data collection methods (CIR aerial photo interpretation of area, linear, and point objects, and field inventory of plot and linear objects) to allow comparisons across different spatial scales (Inghe 2001) and to make data useful in many contexts while at the same time not compromising robustness and precision (cf. Brandt et al. 2002; Di Gregorio and Janssen 2005). This is essential also for the relevance of NILS as a platform for other initiatives using landscape data. Monitoring a general gross list of a large number of straightforward, categorical, and quantitative variables provides the opportunity to adjust classification to current problems and issues, to the state and changes for selected variables and to a variety of habitat quality measures (cf. Ahlqvist 2008; Metzger 2008).

A total of 356 variables are monitored in the NILS program, of which 269 in the field inventory and 87 in the aerial photo interpretation. The lower amounts in the aerial photo interpretation is due to given technical and practical limitations. The variable content of the field inventory and the aerial photo interpretation was developed and integrated to secure that data are compatible, i.e., to allow two-phase estimates (Esseen et al. 2007a). Thus, the variables are selected to be useful for a posteriori classification of land cover classes, vegetation types, and habitats, which permits a flexible approach that allows compatibility with other schemes, e.g., the Biohab approach (Bunce et al. 2005), the European Environment Agency EUNIS habitat type classification (Davies et al. 2004), and the FAO Land Cover Classification system, LCCS (Di Gregorio and Janssen 2005; Ahlqvist 2008).

Inventory by colour infrared aerial photos

The aerial photo interpretation is based on CIR aerial photographs taken from an 4800-m elevation, which provides high spatial resolution (0.5 m on ground level) of vegetation structure and other landscape data as a parallel and complementary method to the field inventory (Allard et al. 2005; Esseen et al. 2007b). An important aspect as well is that the photo interpretation can be done in areas that are not possible to visit in field owing to practical and security reasons (e.g., steep mountains). The interpretation methods are described in detail in Allard (2003). Strict rules are applied for spatial mapping accuracy (<2-m Root Mean Square error in the absolute orientation of the stereo models) and timing in the vegetation season. The technology is based on viewing the digital images in stereo in a computer-based photogrammetric system. Field-based calibration of interpretations, inter-calibration of inventory personnel at regular intervals, and continuous development of visual tools for calibration of percentage of cover are performed to reduce the variation between persons (Allard et al. 2007). The detailed polygon interpretation of the 1-km^2 square is extended 50 m outside the borders of the square to avoid edge effects.

External databases are integrated into the NILS database when supplementary data are needed in the interpretation, e.g., concerning watercourses and roads or houses. A decision tree has been developed to make the polygon delineation as interpreter-independent as possible. A total of 67 variables are estimated for each delineated polygon (Table 1). When the objects are too small in size for being delineated as polygons—the smallest mapping unit is 0.1 ha—important features are mapped as linear or point objects with ten variables, respectively. This is the case, e.g., for ditches, stonewalls, small ponds, and biotope islets in agriculture fields.

A large number of statistics and landscape metrics can be derived from the polygon delineations and the extracted attribute data. Figure 2 illustrates two types of landscapes with delineated polygons and corresponding examples of classification of vegetation type. Since data collection from the aerial photos is based on quantitative variables rather than on a priori classification, various data combinations and systems of vegetation classification can be applied to satisfy the specific needs of different stakeholders. Inventory using aerial photographs adds substantially to the

Table 1 Groups of main variables captured by CIR photo inventory in the NILS polygon (area), linear, and point data sets

Polygon data	Linear data	Point data
Land cover	Transport routes	Broad-crowned solitary trees
Exposed substrate	Enclosures, fences	Biotope islets
Tree layer	Vegetation strips	Boulders, rocky outcrops
Shrub layer	Soil banks	Stone mounds
Field and bottom layer	Ditches/watercourses	Ponds, wells, wetlands
Site moisture	Man-made tree rows	Pit wastes
Mires and other semiaquatic sites	Hedge rows	Buildings
Water bodies	Railways, air cables	Constructions in water
Glaciers or snow-covered land	Screes, steeps	
Settlement and built-up areas	Other linear objects	
Land use		
Former land use		
Pits		
Waste deposits		
Anthropogenic disturbance		
Influence of grazing		
Attributes/notations		

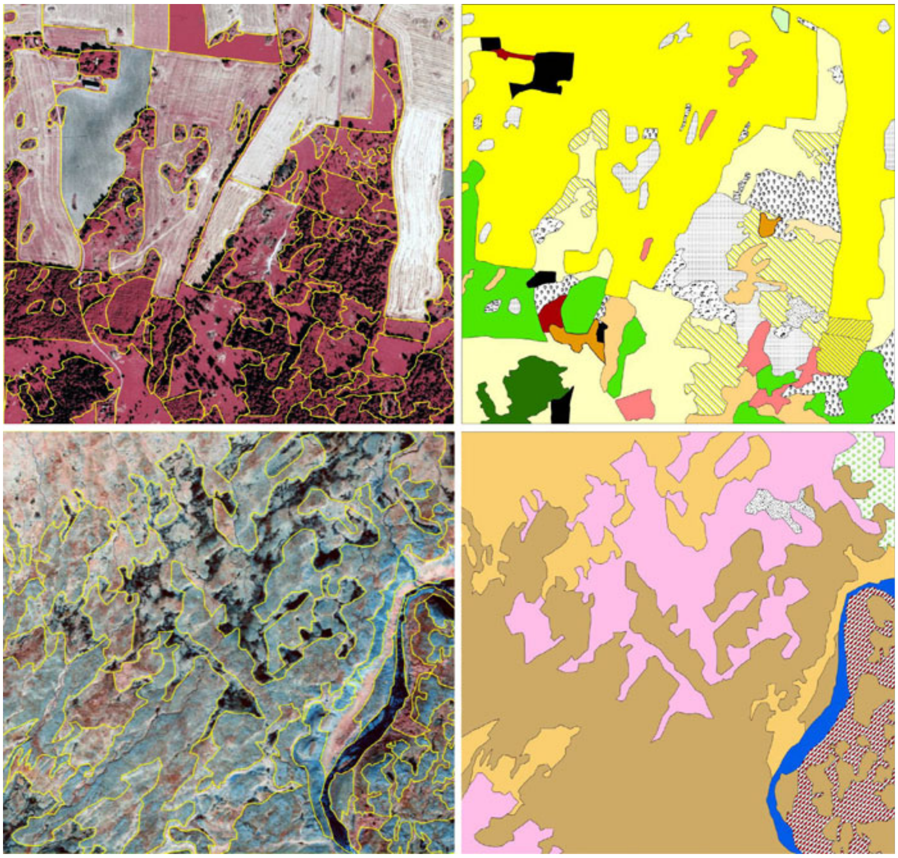

Fig. 2 Polygon delineation in an agriculture-dominated landscape (*above*) and in an alpine landscape in the Scandinavian Mountain Range (*below*), 1 km^2, based on manual interpretation of CIR aerial photo with examples of categorical classification

capacity to operate on various spatial scales in landscape analysis, which is needed to approach landscape ecology understanding (cf. Shao and Wu 2008; Wiens 2008). In the original NILS design it was planned that the aerial photo interpretation should forego the field assessment. Hence, preinterpreted information could be used to assist and simplify the field inventory. Owing to a number of technical and practical obstacles, however, the aerial photo interpretation currently is lagged compared to the field inventory. This issue needs further attention and will be explored through continuous revision of data accuracy and fusion of field generated and aerial photo interpretation generated data.

Field inventory—circular sample plots

The field inventory is conducted in the 12 permanent circular sample plots within the 1-km^2 squares (see Fig. 1). All plots are visited in the field, except those that are situated in arable fields, in water, in built-up areas, or areas that are not physically or legally available. Some basic variables are always registered, however, i.e., land use and type of land cover, either from a distance or from maps and other additional data sources. The main field inventory modules in the NILS circular plots are summarized in Table 2. The 20- and 10-m radius plots are used mainly for recording land cover classification and land use, but also for other documentation and change analyses, e.g., on cover of individual tree and shrub species. The tree layer is mainly assessed within the 20-m plot, whereas most other variables are assessed in the 10-m plot. In addition, three small sample plots (0.25 m^2, 0.28-m radius) are situated at 3-m distance from the plot center, with the main purpose to provide detailed data for subtle changes in the ground vegetation. In these small plots, also the presence/absence of a number of common or characteristic vascular plants, lichens, and bryophytes are registered (159, 16, and 33 species, respectively, per species group).

Table 2 Main inventory modules in NILS field inventory by size of circular sample plots

20-m radius	10-m radius	3.5-m radius	0.28-m radius
Land cover type	Number of trees >10 cm (dbh)	Number of trees <10 cm (dbh)	Field layer
Land use	Shrub layer	Animal droppings	Bottom layer[a]
Activities and disturbance	Field layer		Vascular species
Tree layer	Bottom layer[a]		Bryophyte species
Habitat type	Soil and site description		Lichens species
	Lobaria lichens		

[a] Bryophytes, lichens, and exposed substrates

A list of preselected species was preferred instead of complete species documentation to get sufficient data quality within a reasonable time of training of the inventory personnel. The species were selected according to the following criteria:

- Fairly common; at least a minimum number of observations can be expected for most of the species;
- Easy to recognize, also in a vegetative stage;
- Characteristic of a certain group of habitats responding in a predictable way to known environmental factors.

The two former criteria were the most decisive ones in the selection process. Extra care was taken to include bryophytes and lichens, which are indicative of certain environmental changes (e.g., hydrological changes o eutrophication) and comprise the bulk of the ground vegetation in mires and alpine heaths (Rydin and Jeglum 2006) and in many forests.

For ground vegetation (field and bottom layer) in all plots, cover estimates are made for different life forms and species groups (dwarf shrubs, broad-leaved herbs, graminoids, etc.) to generate indicative values and to allow comparable change analyses in different types of habitats. This is a compromise between cost and accuracy considering the very large range of habitats included in the monitoring. Many land cover classification systems are based on life forms and only to a lesser extent on individual species, e.g., BioHab (Bunce et al. 2005) and LCCS (Di Gregorio and Janssen 2005).

In Table 3, we illustrate some basic results from the plot inventory on areal features of habitats with a layer of accumulated peat, i.e., mires and other peatlands. The data are based on a complete national-level NILS sample set for 2003–2007. We found that peatlands ($\geq$30-cm deep peat layer) with characteristic mire vegetation and structural attributes were the most common type in all strata, compared to peatlands with less characteristic vegetation and structures (other peatlands, where the mire vegetation has disappeared often due to influence by draining) and wetlands with less than 30-cm peat layer. Both in terms of absolute and relative amounts, the

Table 3 Areal features (1,000 ha) for peatlands in the agriculture-dominated and more populated regions in south and central Sweden (strata 1–4; see Fig. 1), for the transitional forest-dominated regions in south and central Sweden (strata 5–6), for the forest-dominated interior north Sweden (strata 7–9), and for the Scandinavian mountain area (stratum 10)

	Mires on peatland (>30-cm peat)[a]	Other peatland (>30-cm peat)[a]	Peat-covered land (10–30-cm peat)	Sum	Percent of land surface
Strata 1–4	115	84	82	281	4.9
Strata 5–6	885	263	280	1,428	16.4
Strata 7–9	3,238	427	540	4,205	22.8
Stratum 10	993	47	230	1,270	15.7
Total	5,231	821	1,131	7,184	17.5

[a] Mires hold characteristic mire vegetation features (lawn, carpet, mud bottom, and swamp fen), other peatland hold other vegetation types (e.g., mesic, on 30-cm peat or more; cf. Rydin and Jeglum 2006)

boreal zone of interior northern Sweden (strata 7–9) contained most of the peatland area in Sweden. Total amounts in the mountain region (stratum 10) were about equal to the amounts in the hemiboreal transition zone in central and southern Sweden (strata 5–6), but with more mires and less other peatlands in the mountain region. Based on data from the NILS inventory, the total amount of peatland and other peat-covered land in Sweden was estimated to about seven million hectares, equal to 17.5% of the land surface. The NILS estimate of mires (5.23 million hectares) corresponds well to the 5.48-million hectare estimate by Sohlman (2008). The estimate by Olsson (2002) on peatland areas in the mountain region (0.998 million hectares) and the NILS estimate (0.993 million hectares) are very similar. Thus, compared to earlier estimates, it may be assumed that the NILS method provides accurate measures on peatland areas in Sweden and for larger regions. Further analyses need to be done, however, with respect to possible divergence in the applied stratification systems.

To estimate the total area of wetlands with less than 30-cm peat, as well as peatland with and without mire vegetation, variables for cover of mire vegetation types were combined with variables for peat depth to provide the three classes (Christensen et al. 2008). Other criteria, e.g., tree cover, may be added if other or more detailed classifications are required by the stakeholders.

The example presented in Table 3 shows how NILS variables can be combined to form classes as a basis for area estimates or other new and needed environmental information where data so far are missing or incomplete. Habitats with accumulated peat layer, i.e., mires, peatlands, and wetlands, are important and extensive landscape features in Sweden (Rydin and Jeglum 2006). Previous cover estimates in Sweden are based mainly on National Forest Inventory data collected only below the alpine tree line and only on peatlands with ≥30 cm peat depth (e.g., Hånell 1990) or from the National Wetland Inventory of Sweden (Gunnarsson and Löfroth 2009) that only included areas larger than 5 to 10 ha in south Sweden and larger than 50 ha in north Sweden (Westerberg and Rynbäck Andersson 2004). Moreover, with reference to climate change, the effects on peatland ecosystems as a potential carbon and methane source is a major issue (Rydin and Jeglum 2006), it is especially important that the area estimates are as accurate and complete as possible including also the alpine region and wetlands with thin peat layer.

Field inventory—line intersect sampling

Twelve 200-m line transects are situated between the 12 permanent plots. When the inventory line crosses a linear object, the position along the line is recorded, and the line object is described by a set of variables, basically a short version of the variable list used for the sample plots (Table 4). The variables can be combined into subclasses and used for estimating amounts the total length of a specific type of linear object in Sweden or for a region. For example, transport routes can be divided according to type or function, forest edges can be classified according to surrounding vegetation types or land use, and water courses can be classified according to width and degree of human impact.

Line intersect sampling provides good estimates of total length of linear objects, but only if the intersect points are well-defined (De Vries 1986). To assure that this is the case, reference lines are defined for each type of object, in general at the very middle of symmetric features such as roads and fences. For shores, however, the reference lines are defined at the high water level and for forest edges at the average tree line (the outer line of trees with a stem diameter of >10 cm). Much effort has been spent on developing detailed definitions of subtypes and strict delimitation criteria (Glimskär et al. 2007).

The length of linear landscape objects in Sweden has been estimated from the line intersect sampling in 2003–2006, representing 80% of the NILS national sample (Glimskär et al. 2007). Figure 3 shows some examples of linear landscape objects where the results are broken down into regions, here south Sweden (Fig. 1, strata 1–6), north Sweden (strata 7–9), and the mountain region (stratum 10). The results indicate that the total length of linear objects in Sweden was 5,617,000 km, including man-made as well as natural objects. The density (in meters

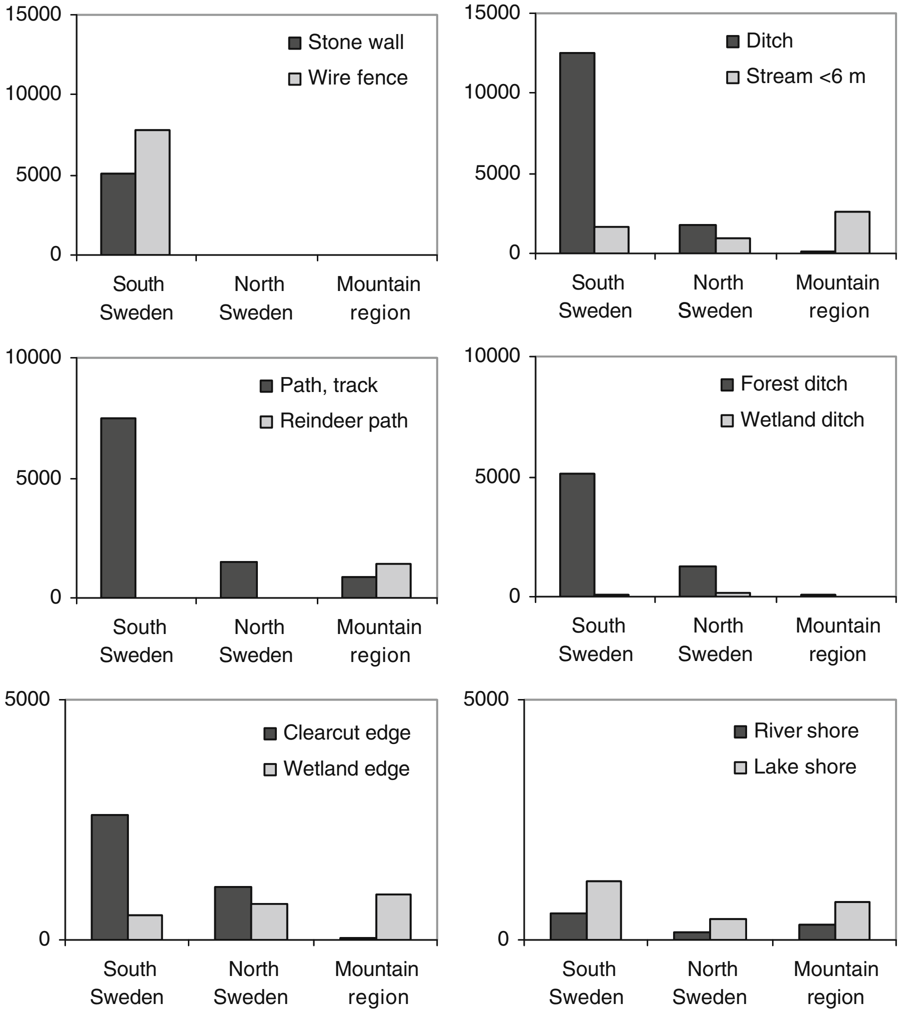

Fig. 3 Estimated density (in meters per square kilometer) of linear landscape elements in Sweden. Data were collected by field-based line intersect sampling in 2003–2006. The classification of ditches was made in a GIS-analysis based on official land cover maps

per square kilometer) showed a large variation among different types, with the highest numbers for transportation routes (roads, trails, etc.), watercourses, ditches, and forest edges adjoining clear-cut forests and farmlands. The total length of stonewalls was estimated to 145,000 km, a length that equals 3.6 times around the equator. Stonewalls are mainly found along the borders of agricultural fields or in abandoned, now mostly afforested, farmlands in south Sweden, whereas

Table 4 Key variables for different types of linear landscape objects in NILS line intersect sampling

Transport routes	Vegetation strips	Forest edges	Fences	Ditches, streams, shores
Type/function	Type/location	Forest type	Type/function	Type
Width	Width	Land use, open habitat	Height	Width
Substrate	Tree/shrub layer	Canopy profile	For stone walls specifically	Stream flow
Pavement	Field/bottom layer	Shape	Width	Water depth
	Management	Direction	Stone shape	Aquatic plants
	Clearing		Tree/shrub layer	Substrate type
	Disturbance		Field/bottom layer	Tree/shrub cover
			Clearing	Shore width
				Shore vegetation

modern wire fences are in active use. The total length of ditches was nearly twice as high as that of small natural streams (width $\leq$6 m), 983,000 km compared to 532,000 km. Some 4% (50 m/km^2) of the streams ($\leq$6 m) in Sweden (in total, 1,150 m/km^2) have been modified (e.g., straightened to increase drainage).

Owing to the biogeographic gradients in Sweden from south to north and from east to west as well as to regional differences in former and present land use, there are significant regional landscape composition differences that directly have implications on how natural and anthropogenic factors may influence the direction and magnitude of landscape and ecosystem change. Stonewalls, fences, and ditches are more common in south Sweden owing to a longer term and more intensive land use. In the mountain region there has been much less impact by ditching compared to other regions in Sweden; only about 2% out of 1,700 m/km^2 watercourses have been modified. This can be compared with in south Sweden (approximately south of the 60th parallel) where about 10% of 650 m/km^2 have been modified. A higher human population in the south also results in more paths and trails, except for animal tracks here exemplified by reindeer tracks that only occur in the north and in the mountains. Moreover, higher densities of edges toward clear-cut forests in the south are due to a more small-scale forestry there compared to the north. These results also exemplify types of information that is required by national and regional agencies for the evaluation of environmental quality objectives. Stonewalls, for example, are seen as landscape elements of high conservation value in cultural landscapes (Ministry of the Environment Sweden 2001) and river-, lake-, and seashores are critical areas for exploitation by summer houses and general urbanization, i.e., urban sprawl (Hedblom and Gyllin 2009).

Data from the line intersect sampling have several possible additional applications. Line intersect data can be combined with data from the aerial photo interpretation to estimate the length of linear objects by type of land cover. Another application is to assess changes in the quality of objects. For example, changes in vegetation cover on and management of vegetation strips and stonewalls provide important information for managing biodiversity associated with these objects. Our initial results clearly illustrates that linear landscape objects and linear habitat structures (e.g., forest edges and shorelines) are significant features of the Swedish landscape and contribute to landscape diversity.

Data management

The NILS program generates numerous data and metadata. To make the registrations efficient and simple, rugged handheld computers with an elaborate, robust, and strictly regulated data flow are absolutely necessary. The computer program includes a number of control functions to assure that all necessary variables are registered and kept within certain tolerance limits. Also, much effort is put on training and calibration of inventory personnel at the beginning of each inventory season, regarding, e.g., cover estimation, species identification, and delimitation or definition criteria. Since the exactness and reliability of cover estimations is a crucial aspect of all NILS data collection, a specific computer-based calibration tool has been developed (Gallegos Torell and Glimskär 2009).

The data from both the field inventory and the aerial photo interpretation are being checked for errors and thereafter stored in a relational database system. The development of data management and data analysis systems is in progress and will gradually expand following the addition of new data, data from reinventory rotations that allow temporal assessments, and the specific requirements of different estimates and analyses.

Experiences and future prospects

The NILS program was designed to collect selected biodiversity and vegetation data on landscape level for analysis of state conditions and temporal trends across different spatial scales, ecosystems, and habitats. With a few examples in this paper, we illustrate that new knowledge and conclusions on landscape features can be extracted. Likewise, NILS should provide an infrastructure for other monitoring and research initiatives that need basic landscape data. After only a few years we can conclude that this is a reality; an increasing number of other initiatives have started to apply, or connect to, the NILS infrastructure, both in terms of co-location of activities to the sample units and in terms of methodological approaches. A monitoring program on semi-natural grassland, pastures and meadows (Swedish Board of Agriculture) was attached to the NILS infrastructure in 2006 and continues parallel and integrated with the original NILS monitoring. Another example is the habitat monitoring under the European Habitats Directive (Swedish Environmental Protection Agency) that was connected as a new and integrated program in 2009. Also, European level initiatives such as EBONE (European Biodiversity Observation Framework, EU 7th framework program; Anonymous 2008) are connected, as well as a number of other national-level monitoring and research initiatives. For example, pilot projects are ongoing for national-level wildlife monitoring using the NILS sample units, for merging data from the Swedish Bird Survey with NILS landscape data to explain population behavior and distribution of birds and for the potential in the 144 NILS 25-km^2 squares in the Scandinavian Mountain Range to contribute to climate change-related monitoring and research. Using NILS data as background landscape data has the advantage that connected projects and programs can use standardized general descriptions of land use, land cover, etc., which simplifies collaboration and comparison. The NILS multipurpose approach including communication and collaboration with multiple stakeholders is demanding but also central for the purpose and incentive for monitoring (cf. Lovett et al. 2007) in a societal context.

The NILS program shares many features with the National Forest Inventory (NFI). Both inventories are sample-based and cover the entire land area of Sweden, although NFI has a clear focus on forests and NILS a more general focus on all terrestrial habitats. Identical variable definitions (in everything essential) have been selected to ensure comparability and exchange between the programs. One example of exchange is that the NILS provides tree and forest data from remote areas to the NFI, i.e., the mountain region that is not visited in the field by the NFI. This has contributed to an improvement of the Swedish forest area estimates. There is also a continuous dialogue between the two programs regarding what parameters should be included and their definition, to avoid unnecessary overlap and gaps. It is occasionally argued that the NILS and the NFI programs should be merged. The experiences so far within both programs are, however, that there is a clear limit regarding what can be included into inventory programs without sacrificing robustness and information quality (problem understanding, capacity of field workers, etc.). A merge probably would put both NILS and NFI far beyond that limit.

The status of the field assessment is, in general, satisfying. In 2007 the NILS finalized its first 5 years of operation and completed a first full national data set. Attention is now directed toward evaluating which features of the program that have been successful and which have not. During 2003 to 2007 there has been a continuous process of fine-tuning in the definition and measurement of the variables to fit practical and analytic premises, to ensure good and even data quality, to maximize the comparability with other monitoring schemes, and to increase general efficiency (Svensson 2009). Additional fine-tuning is expected to continue as the major and critical challenge of interpreting ecosystem and landscape change (cf. Metzger 2008) becomes central in the NILS program.

The close relationship between the NILS program and the research community as well as with other stakeholders (state authorities, etc.) that use NILS data and analysis calls for continuous improvements in data quantity and quality. Not the least this is valid for the aerial photo interpretation and other remote sensing techniques that may be applied in the near future (satellite images, airborne laser, and radar scanning). The methodological and technological development in the field of remote sensing is vibrant (e.g., Shao and Wu 2008), and NILS do aim to have a position in the forefront. In the meantime it is important to maintain stable definitions of core variables and ensure that methodological changes do not imply difficulties in assessing trends and changes. Certain emphasis will be placed on continuous development of the aerial photo interpretation from a methodological point of view, as such in the NILS program but also more generally concerning the applicability of the technique under various circumstances. A close interaction with researchers within different disciplines along with continuous and critical evaluation will avoid the risk to keep collecting data that are of marginal use (cf. Lovett et al. 2007; Lindenmayer and Likens 2009). An important aspect in this regard is the critical but difficult trade-off between changes to satisfy users, and continuity in methods and definitions allowing for meaningful time series analysis. As mentioned above, many users add their own measurement schemes to the NILS infrastructure, rather than enforcing changes to the NILS monitoring system. Through this approach, NILS can maintain its basic variables and methods without sacrificing the important adoption of novel features.

It is evident that NILS has been successful in attracting other initiatives and providing a platform for various approaches. The inherent flexibility of the NILS design and methodological setup is an obvious strength both in terms of its applicability and usefulness for other initiatives, and in terms of its capacity to add and make use of supplementary information, which is certainly of critical value (cf. Bunce et al. 2008). Hence, externally generated information can be used to deepen and broaden the NILS scope. Linked to this, there is a current need to keep building databases with high quality NILS data that are available to stakeholders, to develop analysis tools, routines to communicate data, data compilations, reports, and other regular deliverables. In this perspective, the link to the Swedish environmental quality objectives (Ministry of the Environment, Sweden 2001), which provides much of the background context for NILS, has a certain status as key customer of data and evaluation feedback.

The need to apply a landscape perspective in biodiversity, ecosystem resilience, sustainability in using and managing natural resources, and other central environmental issues is undisputed (e.g., Ahlqvist 2008; Wiens 2008). Adjustments to international frameworks and compliance of national environmental objects rely on input of reliable data. Despite fundamental advances in landscape ecology, the routes to policy and decision making is still undeveloped (Bunce et al. 2008; Nassauer and Opdam 2008). In particular, under a climate change scenario, empirically derived cause-and-effect analysis is central to evaluating ecosystem response and processes (e.g., Metzger 2008; Shao and Wu 2008). We envision that the NILS program has the capacity and potential to provide this kind of information and that it will remain a core element of Swedish environmental monitoring.

Acknowledgements The base funding for the NILS is provided by the Swedish Environmental Protection Agency. Additional funding is provided by the Swedish Board of Agriculture, Swedish University of Agricultural Sciences, and various county administrative boards. So far, some 35 persons have been involved in office work and in aerial photo interpretation, and about 80 different persons have been involved in the field inventory. You have all contributed.

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