Strategic Landscape Monitoring and Information:

Towards Coordination of Remote Sensing in the Nordic
Countries - Final Report from the NordLaM Project,
1999-2003

Strategic landscape monitoring and information: towards coordination of remote sensing in the Nordic Countries

Final report from the NordLaM project, 1999-2003

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Nordic Environmental Co-operation

Environmental co-operation is aimed at contributing to the improvement of the environment and forestall problems in the Nordic countries as well as on the international scene. The co-operation is conducted by the Nordic Committee of Senior Officials for Environmental Affairs. The co-operation endeavours to advance joint aims for Action Plans and joint projects, exchange of information and assistance, e.g. to Eastern Europe, through the Nordic Environmental Finance Corporation (NEFCO).

Nordic co-operation

Nordic co-operation, one of the oldest and most wide-ranging regional partnerships in the world, involves Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland and Åland. Co-operation reinforces the sense of Nordic community while respecting national differences and similarities, makes it possible to uphold Nordic interests in the world at large and promotes positive relations between neighbouring peoples.

Co-operation was formalised in 1952 when *the Nordic Council* was set up as a forum for parliamentarians and governments. The Helsinki Treaty of 1962 has formed the framework for Nordic partnership ever since. The *Nordic Council of Ministers* was set up in 1971 as the formal forum for co-operation between the governments of the Nordic countries and the political leadership of the autonomous areas, i.e. the Faroe Islands, Greenland and Åland.

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Preface

This publication is the last of three Nordic Council of Ministers (NMR) publications resulting from the NordLaM project (1999-2003), which was made possible mainly through support from the Environment Data and Monitoring working group (NMD) of the NMR. The scope and remit of that project was Nordic coordination in the use of remote sensing for strategic landscape monitoring. The first NordLaM publication, *TemaNord 2001:523* (Groom and Reed 2001), provided descriptions of the many Nordic activities that formed parts of the Nordic and wider European strategic landscape monitoring scene at the end of the twentieth century. The second publication, *ANP 2004:705* (Groom 2004b), provided detailed reporting of the project's activities that included four thematically focused workshops and method development activities during the years 2000-2002. This present publication is briefer than its predecessors, condensing details from the two earlier reports in relation to the current situation and the main issues regarding possibilities for coordination across the use of image data in Nordic strategic landscape monitoring. As such, the two earlier publications should be read alongside this concluding part.

The NordLaM project represented a loose network of many individuals, whose interest and willingness to be involved made the project possible. The first NordLaM meeting, at the Fuglsø Centre in Denmark in October 1999 now seems a long time ago. Over the years of the project more than 200 individuals have been in some way or other involved, either as co-workers on projects tasks, as delegates to project workshops or as contributors of information, papers and other material. That is too many to list here each person individually, and to try and name just a few would be hard. So, I hope that if my collective thanks are hereby expressed to all, everyone concerned will know how truly grateful I am for their help and support during the years of the NordLaM project.

Geoff Groom
NERI, Kalø.

Summary

The use of remote sensing interacts in various ways with Nordic programmes for strategic landscape monitoring and the related activities. As yet these activities are established mainly within national contexts and as such there is little formal international coordination in the application of image data. The increasing national and international requirements for information and knowledge on landscapes and landscape changes, such as in connection to habitat and biodiversity, urges movement towards coordination in the use of data gathering methods including remote sensing.

This report concludes a four year programme of activities examining the uses of image data within existing Nordic landscape monitoring work and developing possibilities for increased coordination in this area. In this programme, this coordination has been addressed not principally in terms of more traditional remote sensing issues, concerning for example sensing systems, image data types and image processing and analysis methods. Instead it has focussed on the characteristics of the landscape monitoring information that is acquired, and can be acquired with image data, placed within a more holistic data-information-knowledge context. Understanding and development at this level is seen as essential to providing the foundation for enhanced Nordic coordination.

Towards its goal the programme has seen broad participation from Nordic and other European landscape and related monitoring activities. Specific issues that have been addressed are the roles of very high spatial resolution data, the problems and possibilities relating thematic class sets, the uses of image data as complementary data to sample field survey data, and the relationship of information from image data to the use of indicators in monitoring. The result represents groundwork to be picked-up by subsequent initiatives that can also form operational partnerships between Nordic monitoring activities.

Sammanfattning

Användningen av fjärranalys samverkar på olika sätt med nordiska program för strategisk landskapsövervakning och relaterade aktiviteter. För närvarande formas dessa aktiviteter inom nationella ramar och formell internationell koordination beträffande användning av bilddata är därmed begränsad. De ökande nationella och internationella behoven av information och kunskap om landskap och landskapsförändringar, t ex i kopplingen mellan habitat och biodiversitet, kräver en ökad koordination av datainsamlingsmetoder inklusive fjärranalys.

Denna rapport avslutar ett fyraårigt program av aktiviteter som studerat användningen av bilddata inom existerande nordisk landskapsövervakning, samt utvecklat möjligheterna till ökad internationell koordination inom området. Detta projekt har inte primärt inriktat sig på koordination av de mer traditionella fjärranalysfrågorna rörande t ex sensorer, bilddatatyper, bildbehandlings- och analysmetoder. Istället har projektet fokuserat på karkarakteristika av den landskapsinformation som förvärfvas och kan förvärfvas ur bilddata i ett holistiskt sammanhang (data-information-kunskap). Förståelse och utveckling på denna punkt är avgörande för att lägga grunden till en ökad nordisk samverkan.

På vägen mot sitt mål har programmet haft ett brett deltagande från nordiska och andra europeiska landskapsrelaterade övervakningsaktiviteter. Särskilda frågor som har behandlats är; användningen av högupplösande rumsliga data, problem och möjligheter relaterade till tematiska klassindelningar, användningen av bilddata som komplement till samplade fältinventerade data, samt förhållandet mellan information från bilddata och användningen av indikatorer inom övervakningen. Resultatet utgör ett fundament att användas av framtida initiativ som också kan forma en operationell samverkan mellan nordiska övervakningsaktiviteter.

1. Structuring Coordination

1.1 Introduction

As the quest for knowledge to help ensure sustainability of the Earth develops, and the activities for acquiring this knowledge increase in number and sophistication, there is the imperative for efficiency and long term usability of the associated data. The acquisition of such data through distinct activities necessitates coordination processes and actions in order to meet this imperative. Thus, during the latter part of the 1990s interest in increasing coordination in remote sensing across the Nordic countries was expressed by the Environmental Data and Monitoring (NMD) working group of the Nordic Council of Ministers. This is the applied context that has provided the basis for four years (late 1999 – 2003) of activities into the Nordic coordination of the use of remote sensing in strategic terrestrial landscape monitoring, which has been known as the NordLaM project.

In the late 1990s remote sensing had reached a stage where it was widely used as a source of environmental data and information by many countries worldwide. That period represented some 35 years after the initial acquisitions and environmental applications of Earth images from satellites, and some 25 years since the first general availability of fine detail (e.g 1:500,000 mapping) image data by the Landsat MSS system. It was also some 5 – 10 years since the beginning of the widespread availability and use of small computers and associated affordable image analysis and geographic information system (GIS) software.

The last quarter of the century had also, largely independently, seen major increase in the efforts devoted to understanding of the Earth's environments and ecosystems. Manifestation of this has included expansion in the scope and depth of the questions being asked and the methods developed and used to provide answers. In particular, since the late 1980s there had been across Europe increasing numbers of activities devoted to monitoring of the European environment and ecosystem. A good number of these undertakings, including several in the Nordic countries was using, in one way or another, remotely sensed image data. 1999 was therefore a timely moment to begin to take stock and consider matters of Nordic coordination of remote sensing.

This first chapter examines the understanding and possibilities for coordination in this arena, including the essence of the topics that it covers and discusses the approach to coordination taken in the work that is reported here.

1.1.1 What Are the Scope, Purpose and Methods of Coordination?

The scope of coordination in the Nordic use of remote sensing in environment monitoring

That “monitoring” has become a major environmental activity, is in large part due to the fact that the adoption of sustainability as a primary objective of much environment and ecosystem management drives a continuous need for updated environmental data (Coppin et al. 2004). All aspects of the environment are open for monitoring, and as such there are largely distinct monitoring activities for the many diverse environmental arenas. Whilst many of these arenas do use remote sensing, the use of images within environmental monitoring has a wide diversity of forms, respecting both the various sectoral differences, but also differences between environmental media (e.g. gases, liquid water, ice, plants, etc) with respect to the fundamental physical interactions that make remote sensing possible. Thus, coordination that has a specifically international dimension largely finds itself working within rather than across sectoral arenas. The terrestrial landscape is a sector with major potential for enhancement of Nordic coordination in the monitoring use of remote sensing. At the same time it is a sector that aims to have general environmental and ecosystem relevance, associating in particular with issues of habitats, biota and sustainable land use. The sector includes monitoring that actively addresses large areas, such as whole countries, i.e. “strategic” terms of reference (see Section 1.2.4). Thus, this is a sector in which the large areal coverage that is possible with remote sensing has particular relevance.

The purpose to coordination and how coordination can be developed

A useful starting point is to consider a dictionary definition of “coordination”:

“coordination (noun) : the harmonious functioning of parts for effective results”
(Miriam-Webster Online, <http://www.m-w.com>)

Significantly, this suggests that the focus for the purpose behind coordination can be the involved data and information itself, over and above coordination between the specific activities that provide these goods. Thus, coordination does not necessarily imply a merging of distinct data generating activities. This has significance with respect to coordination across activities that have developed largely independently within distinct nation states.

Coordination can be made with respect to many levels in monitoring activity. As noted above, one level it may take can involve efforts to integrate or even merge distinct activities, such as separate monitoring programmes and projects. However, this implies significant overlap and/or redundancy between activities. It also requires the absence of significant

contra-indications. In the case of Nordic strategic landscape monitoring activities, there are the following factors limiting the possibilities for high level (top-down) integration of strategic landscape monitoring, at least in the time frame of the NordLaM project:

- whilst concerning common issues, the various Nordic national programmes have distinct, differing foci and objectives
- the various Nordic national programmes are at different stages in their development
- strategic landscape monitoring programmes represent major national undertakings, involving processes lasting several years for consultation, negotiation, technical development and operational implementation; this represents significant inertia with respect to possibilities for major changes in the short to medium term (i.e. under five years).

However, these factors are not obstacles to coordination on other levels, the base-line level being simple exchange of information and experiences between monitoring programmes. That in itself is a vitally important co-ordination process, which has been a significant aspect of the NordLaM activities. A second level of coordination activity is then discussion on monitoring aspects to explore differences and difficulties. From this position it is then also possible to consider two more substantive coordination processes:

- the building of agreement and consensus on how more fully coordinated monitoring could operate, and
- the establishment of methods and tools to enable the exchange of monitoring data and the integration of monitoring results.

It has also been in activities at this third level that NordLaM has been placed especial emphasis. Conducting coordination at this level is also in general agreement with the point made earlier that in coordination it is important to target the outputs of the involved activities. The significant implication of this point is that for coordination of the use of remote sensing it has been important to identify and examine a number of issues that are not directly ones often regarded as part of remote sensing. The justification for this approach to the NordLaM project is explored further in the discussion of the following sections. The particular coordination issues examined by NordLaM are presented in Section 1.4.

1.2 Key Terms and Concepts

The underlying topic of the NordLaM project has been “remote sensing”; this is set in the context of the “strategic“ “monitoring” of “landscape”. The approach taken by NordLaM has been to operate at the interface between these terms in order to explore and develop Nordic coordination in the use of remote sensing in strategic landscape monitoring. However, experience, including during the NordLaM project, shows that the broad meaning and usage that these terms have at present, associated with the multi-faceted character of the subjects that they cover, often leads to misunderstandings that can slow down coordination possibilities. This necessitates that the scope of this coordination work, with respect to its use of these key terms, is clearly described.

Thus, this section represents a guide to which aspects of these terms have been covered (and which have not been covered) by the work reported here. Whilst this discussion may seem somewhat pedantic, basic and even introspective, the importance of having within broad-based work sound pragmatic meaning and scope for its key terms should not be under-estimated. Furthermore, the aim within this section is to consider the working meanings of these terms as they have been used in this project, and not necessarily their definitive meanings.

This section considers the meanings of these terms in their general, rather than particularly Nordic contexts. At the same time it is also the case that the usage of these terms that is given here draws upon Nordic situations presented and opinions encountered through the project.

1.2.1 Remote Sensing

“Remote sensing” as used here refers to the application of images acquired from above as a data source to derive information about the Earth. This information is in turn itself also a data source, such as within a geographic information system (GIS). This meaning of “remote sensing” is one that is generally recognised by the remote sensing community itself, such as in the consideration of remote sensing in terms of an “information extraction problem” (Danson et al. 1995).

It is advocated throughout this report that distinction (but not disengagement) is maintained between remote sensing and GIS. Whilst the two topics are unquestionably very closely related, with innumerable examples of highly significant interaction, for practical purposes it is possible and useful to distinguish the derivation of information from image data from subsequent handling of that information. For a focus on remote sensing, as in this report, this distinction is a core consideration; this issue is discussed further in Section 1.3.1.

In principle “remote sensing” in this report encompasses all forms of remote sensing, i.e. all types of sensing device and all types of platform

for carrying the sensor. However, most particularly it includes digital and analogue images from sensors on both satellites and on aircraft. Within this work, “remote sensing” is considered as synonymous with “Earth observation”; “image” is taken to refer to the essentially raw form of remotely sensed data.

As implied by the opening sentence of this section, the scope of “remote sensing” within this work has been its applied sense. Whilst ultimately all remote sensing work only has meaning in relation to application, a focus on the applied implies that more “backstage” remote sensing activities that are not made manifest as aspects of available and used image data sets are outside of the current scope. Thus, issues of, for example, vegetation reflectance modelling or atmospheric image data correction are not covered.

1.2.2 Landscape

In its more popular usage “landscape” generally equates to the visual expression, and in particular the scenic and aesthetic aspects of an environment. Beyond this understanding however, and in particular within the scientific research community, “landscape” takes on a more complex mantle, explicitly developing itself in terms of the natural, cultural-historic, socio-economic and experiential components of an environment, all viewed in relation to their spatial, geographic, temporal and functional expressions and interactions. This is the holistic sense of “landscape”, easily recognised and widely accepted by planners, ecologists, geographers and others, and through which the term is used in this work. Crucially, “landscape” thus also implies an arena that acts across the various sectoral considerations under which environments are frequently studied and managed, such as agriculture, forestry, natural resources, transportation, etc.

“Landscape ecology” is widely used synonymously with the above understanding of “landscape”, but here the latter term has been adopted to reduce the tendency that can too easily be associated with “landscape ecology” to focus on the more natural science and wildlife related components of landscape.

“Landscape scale” and “landscape level” are two widely used terms in landscape related work. However, there is much discussion as to the spatial dimensions that these terms address (Wu 2004) and consequently their usefulness. “Scale” is currently seen as a hugely significant concept in relation to many areas of science (Goodchild 2001), but its generic parameterisation is still largely undetermined (Wu 1999). Whilst “level” helps convey that landscape work addresses some extended space, whether or not it also implies particular dimensions and scales is likewise debated. Thus, this work sees no general purpose in using either of these terms in place of the term “landscape”.

Alongside “landscape” are now also sometimes found the terms “seascape” and “waterscape”. Whilst it is not always a simple task beyond resorting to general topographic cartography conventions to define the line between land and sea or indeed other water bodies, the dichotomy to “landscape” that these terms present also helps formulate the scope of “landscape” used in this work. Thus, it is implied here that “landscape” encompasses that part of the Earth that is not permanently occupied by liquid water. Periodically water-inundated wetlands are thus included as part of “landscape”. Whilst glaciers are a major component of high mountain landscapes, extensive areas of ice (i.e. ice caps) have as yet not generally come under the “landscape” umbrella. Moreover, whilst of great significance in many ways, Norden’s glaciers and ice caps comprise relatively small and discrete areal extents. It is also useful to note here that “landscape” mainly considers environment at it is expressed at the Earth’s surface, as opposed to situations either beneath or above, beyond consideration of any effects these have on the surface conditions.

Within many landscape fora the term “landscape” recognises the significance of the artificial built environment alongside the non-built part. However, it is a fact that in terms of area, if not necessarily in terms of influence, the major part of environment in Norden is non-urban. This work has reflected also this balance.

1.2.3 Monitoring

Even within consideration of just the environmental arena “monitoring” carries very broad understandings. The term is used to cover a very broad range of activities, involving different monitored themes and objects, different contexts and aims and different data and methods. Its widespread currency today can be seen as related to the fact that the adoption of sustainability as a primary objective of much environment and ecosystem management drives a continuous need for updated data (Coppin et al. 2004). This finds echo in expressions such as that used in connection with the Danish NOVANA (national monitoring of water and nature) programme of “no monitoring without objectives, no objectives without monitoring”.

However, whilst its meaning and use is broad, the essence of “monitoring” is relatively easily found, in that it implies actions that enable changes over time to be objectively measured and expressed:

monitoring : “to watch, keep track of, or check usually for a special purpose”
(Miriam-Webster Online, <http://www.m-w.com>)

A lot of monitoring activity comes under the umbrella of “environmental monitoring”. However this term is better suited to the many monitoring activities that have their main focus on the making of mainly geophysical and/or biophysical measurements at a relatively small number of point

based stations. A useful distinction between the environmental arena and the landscape arena is that the notion carried by “landscape”, but not by “environmental” is that of being spatial explicit. Thus, an environmental monitoring activity might present the changes in grassland species richness for a certain level of administrative units, but without implicitly linking this to landscape patterns, characters and processes (R.Haines-Young & M.Potschin, pers comm). This difference is expressed not just in how monitoring data are analysed and reported, but also, and crucially, in the design principles used in determining how the data are recorded, i.e. the spatial organisation of the monitoring data collection operations.

“Monitoring” is also a term that better represents the general objective involved than the actual tasks that are required to be undertaken. Thus, to do “monitoring” generally involves, for the collection of monitoring data, a combination of activities that include elements of mapping, inventory, sampling and updating.

1.2.4 Strategic

Whilst there are many projects and programmes that comprise monitoring components only a small subset of these can be considered as spatially extensive in their coverage (i.e. national or regional) and also operational or quasi-operational, i.e. “strategic”. This term, implying also that results represent an official, prime resource, is often used to express this latter characteristic. In general, many more activities represent more spatially confined monitoring work and/or pre-operational developments in monitoring methods and systems. Focus in this work on the strategic Nordic monitoring activities recognises (a) the special significance for governments and international agencies and authorities that the results from these activities carry and (b) their particular characteristics, namely that:

- The programmes are often seen as forming a part of the infrastructure of a country, established just once, or undertaken only occasionally during a country’s development. Also, they might be established to provide input to major political discussions, such as changes to agricultural, nature protection or pollution control policy. As such, the programmes are often operating close to the core of the administrative and political arenas. They are often large projects, with large budgets, and high stakes.
- Often such monitoring programmes have an operating mode that is as much technological (human-need driven) as scientific (quest-for-knowledge driven) (Curran 1987). The operational objectives of these programmes, and the methods adopted to achieve them, are often defined in terms of a specific “design criteria” of the required precision and accuracy for resulting information.

- Highly efficient organisation and management are often integral parts of the programmes. In order to complete vast monitoring undertakings on time, strategic monitoring programmes are more often likely to adopt highly pragmatic modes of operation than is normal for other types of research related activities.

The ways that uses are made of remote sensing data for Nordic strategic landscape monitoring activities are closely related to these characteristics.

It is a direct consequence of being “strategic” in this sense that the number of relevant activities is rather limited, such as to just one major programme for actual landscape monitoring for each country. It is also necessary to state at this point that “Nordic landscape monitoring” as used here implies landscape monitoring by and of the Nordic countries, rather than landscape monitoring, undertaken by Nordic countries, of places elsewhere.

It is important to note that through this work it has been possible to consider activities in just Denmark, Finland, Norway and Sweden, rather than the full set of Nordic states. This has been augmented with inputs to workshops from several other European countries and organisations. In particular, national land cover mapping work undertaken in Estonia has been involved in one of the project’s method developmental activities.

1.3 Interfaces and Coordination Themes

Remote sensing is the topic around which the NordLaM project has revolved, and it is necessary to examine further the interface of remote sensing with strategic landscape monitoring. This is in order to present the specific themes through which the coordination activities of the NordLaM project have been applied.

The significance of the image of the Earth’s surface as seen from above for the understanding and management of landscape has been recognised at least since this was noted by Carl Troll in the late 1930s (Troll 1939). However, it is imperative to recognise that both subjects have major parts of their existences outside of their interaction, i.e. there is a lot of landscape work that does not reference remote sensing and a lot of remote sensing work that does not reference landscape. “Monitoring” is one part of the expression of the interaction between landscape work and remote sensing. However, just as with the over-arching arenas, there is landscape monitoring that does not involve remote sensing, use of remote sensing for monitoring that does not relate to landscape, and monitoring that sits outside of either the arena of landscape ecology or the use of remote sensing. It is then the overlap of these three arenas that defines the scope of the use of remote sensing for landscape monitoring. However, this overlap is not one with closed boundaries. Thus, it is important to see

the boundaries as open and loosely defined, in order to ensure that the overlap relates to broader landscape contexts, and to maintain the flow of principles and method developments from and to those remote sensing and monitoring activities that are extra-landscape.

Given that there is clearly scope for “no interaction” as well as interaction it could be said, without suggesting any lessening of the significance of Troll’s observations, that the interaction of remote sensing with landscape monitoring is clearly one that requires active realisation rather than autonomic functioning. It is suggested here that a focus on remote sensing in terms of its fundamental role as a source of information serves as a valuable lubrication for this interaction.

1.3.1 The Two Faces of Remote Sensing

The interface of remote sensing and landscape monitoring is just one example of the general situation encountered in applied remote sensing work. This can be summarised in terms of remote sensing being “a tool we can use to both know and understand our environment” (Curran 2001). However, beyond this clear position those engaged in using image data encounter that remote sensing has two rather different characters:

- There are very many examples of successful applications of remote sensing for landscape work. The easily received impression is therefore that image data represent a highly relevant and relatively easily applied tool for landscape applications, including monitoring (Groom et al. 2005).
- Remote sensing as a subject in its own right represents a wide and highly technical knowledge and experience base, with many, many image data supply and processing options and many image data analysis possibilities. Furthermore, when entered, the arena of remote sensing reveals itself as found to be populated with many indirect estimates (not direct measurements) of environmental variables and open, multi-part (rather grey-box, not black-box) data models.

This is the dichotomy of applied remote sensing. Whilst such a situation is stimulating within a research context, for establishment of strategic activities it can more readily represent a problem. Therefore, the general challenge of applied remote sensing is to find mechanisms that can establish the necessary crossovers between the relevant core remote sensing issues and the applied needs.

1.3.2 Remote Sensing, GIS and Information

It has earlier been suggested that it is useful, such as in consideration of Nordic coordination in the use of remote sensing in strategic landscape

monitoring to make distinction (but not disengagement) between remote sensing and GIS. This contention now requires elaboration.

On the one hand, as noted previously, from a text-book perspective it is rather easy to distinguish remote sensing from GIS. This is a distinction that is generally recognised by the remote sensing community and which respects the integrity of the remote sensing as a distinct process model.

On the other hand, strategic programmes for landscape monitoring, as with applied work in general, are generally defined and developed in terms of specific environmental / ecological situations, policy or management goals, and/or research objectives. The uses made of both remote sensing and GIS are generally seen as inter-connected and both as “means to an end” within these programmes. Given the importance to strategic activities of adopting pragmatic methods, the uses made of image data are most likely to be ones closest to black-box type applications of remote sensing. Furthermore, image data and GIS specialists engaged on monitoring programmes are also frequently drawn from integrated remote sensing and GIS units within organisations. It is not surprising therefore that making distinction between remote sensing and GIS does not have a high profile within most monitoring programmes.

To focus on the distinction between remote sensing and GIS might easily be seen as irrelevant; after all, most monitoring programmes do succeed in developing pragmatic solutions for using image data to meet their needs. However, it is at the same time often the case that:

- considerable resources are needed to realise the roles and implementation of image data into a landscape monitoring programme
- unless it is explicitly taken into consideration, pragmatic solutions to the use of image data do not necessarily also provide a foundation for subsequent outward coordination, such as with other monitoring programmes

The complexity of strategic landscape monitoring activities, with work across many different thematic areas using many monitoring methods and data sources provides fertile ground for such challenges. However, these are not features just of the use of remote sensing in landscape monitoring. “Information” lies at the core of monitoring, i.e. monitoring is an information orientated activity, taking information on a situation at time-1 and time-2 to establish knowledge on change.

A line that has been followed through the NordLaM project has been to emphasise and develop the informational aspects of Nordic strategic landscape monitoring activities. This is seen as valuable in that:

- It easily provides a foundation for a modular approach, which is useful for simplifying complex programmes of activities, while retaining a strong basis for integration of components.

- It draws directly from a model for science that recognises as its core components, data, information and knowledge.
- It enables focus on the special characteristics carried by the various information components, e.g. their differences in terms of precision, accuracy, error models, and the spatial and temporal units that the information components relate to.
- It recognises that a focus on informational characteristics represents a generic approach, rather than one that is the preserve of particular components of the programme or professional communities. In particular, it spreads more widely the onus that is often placed on remote sensing activities within a larger programme to find a level for its activities that relates to the applied arena. Thus, a monitoring issue such as “land cover data” need not be seen as associated particularly to the use of remote sensing, but rather as an over-arching informational issue within a monitoring programme. Thus, the relationships between components are two-way and reciprocal.

If such an informational approach is used to examine and develop coordination in monitoring activities, it is also natural and indeed necessary to demarcate between remote sensing and GIS components. In this demarcation, the former is identified as processes that deliver low-end informational goods from specific technical data, namely data supplied through non-contact measurement of optical and electromagnetic properties. The latter is then identified as processes for transformation of low-end spatially organised information goods from various sources into higher order informational goods and knowledge.

But what does it mean for activities towards coordination development that there is a focus on informational aspects? The answer to this lies in the observation that has been made in Section 1.1.1 that coordination made at the level of deliverables is at least as significant as coordination made at the level of the mechanisms by which deliverables are produced (e.g. sensing instrumentation and analysis methods). Therefore, it is possible to see that a valuable arena for coordination activity is the characteristics of the information delivered by remote sensing for monitoring. In practise this arena can be expressed through examination and developments within issues that include:

- how landscape monitoring programmes address a range of information needs, and how image data fit into the overall information demand and supply situations.
- the special characteristics of monitoring information derived from different sources, in particular how they compare in terms of the scales they represent and at which they operate, their underlying classificatory concepts and their associated strengths and weaknesses.

- how contrasting types of information can be worked together to provide the basis for a target that is greater than merely the sum of the parts.

Thus, it is the hypothesis that has been followed in the NordLaM project that working through from the generic issue “information in landscape monitoring” provides a basis for more holistic development towards co-ordination in the use of remote sensing for Nordic landscape monitoring than an approach that is focussed on mainstream remote sensing issues alone.

1.4 Coordination Themes

From the principle outlined above, coordination in the use of remote sensing for Nordic strategic landscape monitoring as been implemented in the NordLaM project through work on the following four themes.

1.4.1 Classification Systems

Thematic “classification” in the sense of allocation of image pixels (or multi-pixel objects) to classes in order to derive application-relevant information from image data is one of the major components of the classic remote sensing process. However image classification in this sense has to be also set within the wider context of a “classification system” that comprises in full (European Commission 2001):

- - demarcation of the thematic domain
- - arrangement of objects into groups on the basis of their relationships
- - naming and describing of the groups
- - procedures for allocation of any object to one and only one group

This wider context to classification is especially relevant in relation to the use of image data in landscape monitoring, since this involves consideration of various classification activities, such as in relation to different themes (e.g. habitat, vegetation, land cover, land use) and different observation methods (manual image interpretation, image classification, field survey). Moreover, for coordination between monitoring activities there is a need for harmonisation and translation between the different sets of classes (Wyatt and Gerard 2001). The objectives under this theme have been to increase the knowledge and understanding of the classification systems currently used in the Nordic monitoring programmes, and gain experience with methods for making correspondence between class sets.

1.4.2 Sample and Census Integration

Many of the current Nordic landscape and related monitoring programmes make extensive use of sample-based survey. Data from such surveys typically represent a partial spatial coverage. Other landscape monitoring related activities, in particular those using automated satellite image classification, typically create full coverage (“census”) monitoring information. The products from the full coverage operations, such as land cover /land use maps, typically have lesser thematic detail than the partial-coverage operations. There are various methods, already used in some Nordic and wider European monitoring projects, for integrating the thematic detail of the sample-based approaches with the coverage provided by census monitoring. The objective in this theme has been to provide a basis for presentation and discussion of integration possibilities between partial and full coverage landscape monitoring information.

1.4.3 Very High Spatial Resolution Image Data

During the past ten years, a significant development in image data supply has been the increasing availability of image data with spatial resolutions of less than five metres. This has included increased availability of digital orthorectified air photography image data with resolutions of less than one metre. Many of the current Nordic landscape monitoring programmes use air photography images to capture detailed landscape information (see Chapter 2). The aim in this theme therefore has been to examine the developments in very high spatial resolution image data, in terms of both their technical aspects and their significance and application in Nordic landscape monitoring activities.

1.4.4 Images and Indicators

The use of “indicators” is widely seen as a major issue in the management of environments and ecosystem, in particular in relation to monitoring changes and sustainability. Indicators are particularly seen as a way of efficiently reporting changes in complex spatial patterns and processes, and there has therefore been much work in recent years in the development of spatial landscape indicators. Many of these indicators and approaches make use of spatial information that can be derived from image data. It is therefore relevant to examine possibilities for coordination of the use of image data in Nordic landscape monitoring with respect to the information requirements of work with indicators.

1.4.5 Other Identified Informational Issues

During the course of the project a number of other issues relating to the use of remote sensing in Nordic landscape monitoring were noted by

project participants, but it was not possible to focus on these. Here, these other issues are briefly discussed.

Metadata of landscape monitoring and related information from remote sensing

Procedures for the production of standardised data about the information derived from monitoring programmes are essential aspects of monitoring. Such metadata are central to the quality assurance and increased coordination in the use and update of the monitoring data themselves. This is particularly important with respect to monitoring information derived from remote sensing. Many aspects of remote sensing are technically specialised. In providing results from remote sensing to workers in a wide range of applications it is often necessary to reduce this technical complexity. A danger in this is that subtle differences between data products are lost, but can represent significant differences in how the monitoring data, such as a land cover map, should be interpreted and used. However, it is now widely recognised that the production of metadata should not be done lightly, but instead should follow standardised procedures. The last five years have seen major developments in the standardisation of metadata for geographic information. The ISO 19115 that became definitive in May 2003 defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data. ISO 19115 represents the guidelines that will be followed for metadata profiles that will be supported by the INSPIRE (Infrastructure for Spatial Information in Europe (<http://inspire.jrc.it>) proposal that has been adopted for a Directive by the European Commission (Willeman and Kooistra 2004).

Remote sensing for monitoring of neglected Nordic landscape features

Across the Nordic countries there are elements of the landscapes that are inadequately covered by current monitoring programmes. These include areas of marginal agriculture, mires, and shorelines. In many cases, intensive ground based monitoring of these landscape areas is unlikely within current monitoring programmes. Therefore, special emphasis should be paid to providing at least basic landscape monitoring information for these areas using remote sensing image data.

Development of the use of major image archives in Nordic landscape monitoring

Steenmans and Perdigão (2001) describe the major, high spatial resolution, satellite EO image archive, IMAGE2000, that is being assembled for all of Europe within the CORINE programme. It is foreseeable that application of the IMAGE2000 data set will extend beyond its immediate use for the CLC2000 mapping activities within CORINE. Those involved in strategic landscape level monitoring in the Nordic area should coordinate efforts to make full use of this, and other, major satellite image archives.

2. The Uses of Remote Sensing in Nordic Landscape Monitoring

This chapter provides background and basis information on the Nordic activities that currently relate to the use of remote sensing for strategic landscape monitoring. The chapter examines the ways that image data are being used in and towards strategic Nordic landscape monitoring. Two levels of strategic Nordic landscape monitoring activities are identified:

- core strategic landscape monitoring programmes
- other strategic mapping and monitoring activities that are related to Nordic strategic landscape monitoring

A significant third level is the infrastructure of remote sensing activities that are supportive to the use of image data in Nordic strategic landscape monitoring. These include operational image data acquisition, pre-processing and archiving (sometime referred to as “ground segment” operations) and national coordination activities. However, it has been difficult to acquire information in order to make good description of this activities, given that they often represent processes with on-going change and development and are not as widely reported as specific monitoring projects and programmes.

This report does not include consideration of the many activities underway across Norden that are developing uses of image data for fulfillment of EU Habitat Directive (Natura2000 network) monitoring requirements or related activities. In general these have been, during the years of the NordLaM project research activities or other preparatory work towards future strategic programmes. In some cases, such as Denmark, the procedures recommended for Habitat Directive biodiversity and habitat monitoring of non-forested areas do not envisage use of image data other than reference to orthophotographs in preparation for field survey. It is still too early to get a good measure of just how image data is to be used operationally in these strategic monitoring activities across Norden. Furthermore, it has been too early to examine issues of coordination since procedures and methods for maintenance and monitoring of favourable conservation status are at present developed and applied nationally. However, the themes that have been examined in this project are nevertheless also relevant to Habitat Directive related monitoring. This therefore is an arena that should be returned to and reviewed as these activities and programmes mature over the next two years.

In the first part of this chapter the notable features that characterise the Nordic situation for strategic landscape monitoring are presented and discussed.

2.1 The Nordic Situation: Characteristics and Contrasts

In 1999, justification for the particular Nordic focus for this work included identification of a number of aspects that could be seen to characterise the Nordic situation. These factors were:

- the short growing seasons of these high latitude countries
- the occurrence of major climatic and geomorphologic changes in the geologically recent past (last 10,000 years)
- similar socio-political systems, with strong traditions of involvement in matters concerning the environment by central and local government
- consensus and a high degree of awareness of the importance of environment issues
- high levels of development and use of computer based information technology in administration and research sectors
- logistical difficulties for undertaking strategic field based monitoring associated with the vast extents of areas with limited access infrastructures and short field work seasons.

Five years further on, some of these aspects, highlighting differences between the Nordic situation in general and that elsewhere, appear less stark. For instance, sophisticated use of computing technology is now normal practice in environment monitoring work across Europe, and levels of awareness of the need for monitoring are also more broadly similar.

Moreover, it is now more clearly the case that each of the Nordic countries has its own background and situation that has resulted in its particular blend of strategic landscape monitoring activities, i.e. as well as similarities there are also significant differences. A particularly notable intra-Nordic contrast is that between Denmark on the one hand, and Norway, Sweden and Finland on the other. This contrast is expressed in particular with respect to (a) the total area of territory to be monitored, and (b) the proportions of different major land uses and landscape types present, and thus the patterns in the landscape monitoring activities undertaken.

Thus, for Denmark, with an area that is just 12% of the mean for Norway, Sweden and Finland and with much easier physical access around the country, monitoring does not represent such large logistical difficulties as is the case for the other Nordic countries. Overall Denmark also has a more intensively used and more highly agricultural landscape

(65% of land in cultivation) than Norway, Sweden or Finland (2.7%, 6%, 8% cultivated, respectively) (Dramstad et al. 2002a). However, notwithstanding this marked intra-Nordic contrast, it is necessary to note at the same time that national monitoring requirements are not merely reflections of the proportions of the major land uses or land cover types present. Thus, in Norway, Sweden and Finland the smaller total proportions of land that is farmed are spread unevenly, resulting in some regions that are similar to the Danish situation. More significantly, as is generally seen across Europe, it is also the case in each of the Nordic countries that it is the cultivated and associated intensively used peri-urban areas that are currently experiencing many significant changes. Thus, in this respect, Denmark and the other Nordic countries are not so dissimilar, both requiring monitoring that provides data and information on the particular characteristics of the changes affecting the more developed, more intensively agricultural areas.

The intra-Nordic contrast in major land use and land cover proportions does however represent a difference in the range and scale of other, non-agricultural landscape, strategic landscape monitoring activities that are needed and indeed are already established. For example, whereas Norway, Sweden and Finland have undertaken sample plot based national forest inventory for many decades, it is only since the late 1990s that this has been strategically developed also for Denmark (Söderberg and Johannsen 2001; Stokland et al. 2003). Similarly, there has traditionally been greater need for and more development in the strategic monitoring of semi-natural, non-forested areas in the Scandinavian countries apart from Denmark. The sheer vastness and the remoteness of much of the forested and the semi-natural areas in Norway, Sweden and Finland has also led to a greater emphasis on using large area coverage image data in monitoring. Thus, these three countries also show a contrast to Denmark in the development of their infrastructures for using image data in strategic monitoring.

Whilst being particularly marked, the intra-Nordic contrast represented by Denmark is not the only one significant to strategic landscape monitoring needs and possibilities. Norway, more so than the other countries is characterised by mountainous terrain, indeed being one of the Europe's most mountainous countries. In more senses than just the literal, this adds a major extra dimension to the monitoring requirements and difficulties encountered by Norway. In Finland, as well as northern parts of Sweden and Norway, wetlands and mires are particularly widespread and extensive. The main emphasis in strategic monitoring activities has reflected this.

There is at least one other way, whilst not a consequence of the actual landscape but nevertheless significant for strategic landscape monitoring activities, in which Norway differs from these other Nordic countries. Sitting outside of the European Union, Norway has, more so than Den-

mark, Sweden or Finland, developed its agenda and timetable for monitoring activities independently of EU directives and programmes (e.g. Habitats Directive, CORINE, LUCAS, EFIS/EFICS). However, neither is it the case for the EU-member Nordic states that EU processes represent fully operational mechanisms for standardisation and synchronicity in strategic landscape monitoring:

- Reflecting that landscape monitoring is a recent and as yet not fully developed area of work in general, such monitoring is not fully or directly addressed by these EU processes. Instead, the EU processes target distinct themes – land use, habitats, land cover – that while highly relevant components of landscape are not entirely synonymous with it.
- The EU processes are variable in the degree that they represent a basis for standardisation in monitoring methods. Whilst exact, highly standardised techniques are followed in the case of LUCAS (Bettio et al. 2002), far more variable methods have been developed for the Habitats Directive the principle coordinating pillar being that of ensuring “favourable conservation status”. CORINE Land Cover (CLC) represents with respect to the three EU Nordic countries a rather special case. In general CLC has provided a strong basis for standardisation of land cover mapping between EU countries, with procedures and protocols for selection and processing of image data and mapping of land cover units (Steenmans and Perdigão 2001; European Environment Agency 2002). Whilst for Denmark and Finland CLC has followed a relatively standard path, in the case of Sweden CLC mapping has developed and been implemented rather differently (see below; Ahlcróna et al. 2001).

Moreover, the EU processes are just one example of international coordination. Beyond these EU processes it must also be noted that all the Nordic countries are part of various other European and Global processes, including:

- Ministerial Conference on the Protection of Forests in Europe (MCPFE, 1990, 1993 and 1998)
- IUFRO Global Forest Information Service (GFIS) Taskforce <http://iufro.boku.ac.at/iufro/taskforce/hptfgfis.htm>
- European Forest Institute <http://www.efi.fi/>
- The European Landscape Convention of the Council of Europe (as of 1/3/2004, signed by each of the Nordic states, ratified by Norway and Denmark) <http://www.coe.int/T/E/Cultural%5FCo%2Doperation/Environment/Landscape/>
- The Ramsar Convention on Wetlands (<http://www.ramsar.org/>)

As well as the processes originating from the EU and Global arenas towards developments in coordination of landscape monitoring related activities, the Nordic region itself presents significant moves in this direction too, emphasising the positive motivations for consideration of the Nordic situation noted at the start of this section. Two significant developments in this have been the subdivision of Norden into 76 biogeographical (or physical geographical) regions (Påhlsson et al. 1984) and the database and mapping of Nordic vegetation types (Påhlsson 1994). Numerous other works conducted under the auspices of the Nordic Council of Ministers have similarly promoted and developed the concept of coordination in landscape related monitoring activities across the Nordic countries, e.g. Lawesson (2000) and Bionord (Stokland et al. 2003). The NMR project “Nordens Landskap” (Gaukstad and Sønstebo 2003) assesses national and Nordic activities relating to protection, management and planning of landscape in relation to the general articles of the European Landscape Convention. Whilst not focussed on development and use of specific instruments, the Nordens Landskab project group notes that “the Nordic countries should cooperate on developing methodology for the (Convention) theme «Identification, analysis and assessment of the landscape and landscape quality objectives»”. That “priority be given to identification and identification methods, tolerance limits and methods and indicators for monitoring landscape changes” is recommended.

As noted above, landscape monitoring *per se* is a relatively recent development in general, with as yet no formal international processes in motion towards its coordination. It is therefore the case that, as in many other European countries, contrasting developments in landscape monitoring in each of the Nordic countries reflect the differing degrees and interplay of three factors:

- The work (mainly science driven) of landscape ecologists towards development and use of the monitoring data required in their research
- The development and implementation of dedicated landscape monitoring by state agencies as national strategic work.
- The approaches and methods developed and adopted for national implementation of international monitoring requirements.

The first of these factors represents a propensity for contrast between monitoring activities, reflecting the differences in research foci and experiences of largely independent research groups. Nationally defined Nordic policies and foci for landscape monitoring represent a basis for contrasts too. However, the overall variability in landscape and related strategic monitoring activities is mainly just one dimensional, i.e. between states, since within each state there is in general impetus to find compromise between these factors, such as in order to ensure efficient use of resources. The degree of European and global coordination activity

in the arena of forestry is noteworthy and is one in which the Nordic countries are very active.

Finally, within this section, it is necessary to note one further Nordic pattern that is particularly significant to the use of image data in monitoring. Remote sensing, apart from with radar systems, is highly weather dependent, requiring for strategic use of satellite images, albeit for brief time periods, cloud-free conditions extending over tens of thousands of square kilometers. The Nordic countries in general are all notable for their cloudiness.

2.2 The Uses of Remote Sensing Data in Nordic Landscape Monitoring

Sections 2.3 and 2.4 that follow examine the ways that image data are being used in and towards strategic Nordic landscape monitoring. In focusing on the use of image data aspect, these descriptions do not necessarily represent complete descriptions of the programmes, more briefly describing aspects not directly related to the use of image data. The sections identify and work with two levels of strategic Nordic landscape monitoring activities:

- core strategic landscape monitoring programmes
- strategic mapping and monitoring activities that are supportive or in other ways related to the core strategic landscape monitoring programmes

2.3 Core Strategic Landscape Monitoring Programmes

Much focus in landscape monitoring work in general within Europe is directed towards the detailed following of changes within sample sites. In order to capture change information on the range of features that are relevant for landscape study, sample sites are typically considerably larger than those associated with more focussed monitoring activities such as vegetation change alone. Since a major focus in landscape work is the cultural landscapes, and in particularly agricultural activities, the sample size used in landscape monitoring is typically an area that is large enough to include several of the basic components of many cultural landscapes, i.e. fields or other single land use units. Typically therefore sample areas with sizes between 1 sq km and up to two order of magnitude larger (i.e. 100 sq km¹) are used. For ease of location and use of data in analysis the areas are typically regular quadrilaterals, most generally squares.

¹ e.g. 10 x 10 km, not 100 x 100 km

A major strategic landscape monitoring challenge is therefore to develop methods that adequately capture all relevant landscape information of such sample areas. This includes some information that can be adequately gathered through the use of plots within the area. Typically plant species occurrence and abundance, soil characteristics and invertebrate monitoring data can be effectively collected with plots.

However, monitoring information on the types and spatial patterns of land use, land cover, habitat types and vegetation types cannot be adequately represented through merely sample plots, but needs instead methods that represent the whole sample area. This level of information is typically provided by ground based survey and/or mapping from image data.

The monitoring data collection situation described above is typical of a number of strategic Nordic landscape monitoring activities. In particular it represents, at least in some aspects, the monitoring that has previously or is now being undertaken by the following Nordic programmes: 3Q (Norway, 1998-), NILS (Sweden, 2000-), Finnish farmland biodiversity survey (Finland, 2000 -) and Small Biotopes monitoring programme (Denmark, 1978-).

2.3.1 3Q (Tilstandsovervåking og resultatkontroll i jordbrukets kulturlandskap)

The so-called 3Q (“Treku”) programme is an operational activity for monitoring of change in the agricultural landscape of Norway (Fjellstad et al. 2001; Dramstad et al. 2002a; Dramstad et al. 2002b).

The 3Q monitoring programme is based on aerial photography of a systematic sample of ca. 1,400 1 x 1 km squares. The sample squares are located using the 3 x 3 km grid already established for sampling in the national forest inventory (NFI) of Norway. If the point falls on land used for agricultural purposes (as defined by the Economic Map Series), a 1 x 1 km square centred on this point is included in the 3Q monitoring sample. (Where a grid point falls on forest land types, a National Forest Inventory sample point is established.) Sample squares are thus distributed across the country in proportion to the amount of agricultural land.

The sample squares are mapped through interpretation of true colour aerial photographs (scale 1:17,000 in 1998 and 1:12,500 thereafter). Land types within each square are digitised according to a hierarchical classification system. The first level identifies eight classes, which at the second level are split into ca. 25 types (Fjellstad et al. 2001). At the third level these are again split into ca. 100 sub-types. In addition, linear elements and point objects are recorded, including both natural and cultural features. A wide array of landscape metrics is calculated based on the digitised maps, and these form the basis for reported indicators.

The features mapped from aerial photographs are digitised as points, lines and polygons. Features larger than 4 m², but smaller than 100 m², are recorded as points. Linear features that are less than 2 m wide are recorded as lines. The minimum size for digitising polygons belonging to the level one class (agricultural land), or having a joint border with an area belonging to that class is 100 m². For other areas the minimum size is 1,000 m². These are typically smaller polygons in larger forested areas, e.g. a small deciduous area within a larger coniferous wood. This larger minimum mapping area reflects the focus on agricultural areas in the 3Q programme.

The 3Q programme reports indicators of change related to four main themes: spatial structure, cultural heritage, biological diversity and accessibility. Since cultural heritage sites and monuments are difficult to register from aerial photographs, field inventory is conducted on a sub-set of sampling squares (10%). In addition, information is gathered from national cultural heritage databases, such as the National Database for Historical Buildings. Fieldwork is also conducted to supplement map-based indicators of biological diversity, with monitoring of breeding birds and vascular plants at sub-sets of sample squares.

The monitoring is conducted according to a five-year inventory cycle. Each year a combination of counties is monitored that comprises approximately 20% of the sample squares. The first coverage of the sample areas was completed in 2003, providing national baseline data against which future change can be compared. The national data were reported in the first ever statistical description of the Norwegian agricultural landscape regions (Puschmann et al. 2004).

2.3.2 NILS (National Inventory of the Landscape in Sweden)

The use of image data for landscape monitoring activities and national programmes has been developed over a period of more than 30 years (Ihse and Wastenson 1975; Ihse 1995; Ihse and Blom 2000; Allard 2003b). The current national programme, NILS, is a major activity in Sweden for monitoring of the landscape, which has been actively developed since 2000 and became operational from 2003. NILS is part of the national environmental monitoring programme of the Swedish Environmental Protection Agency and concerns all terrestrial components – cultivated land, wetlands, built upon areas, forests, coast and mountains. Particular foci of NILS are monitoring with relevance to biological diversity and monitoring of the development of the landscape (Allard et al. 2003; Esseen et al. 2004b). Results from NILS are to be applied in the following of national environmental targets, including those relating to the EU Habitats Directive. The following variables are used in NILS: land use and exploitation, vegetation cover, lists of characteristic plant species,

structures and substrates, linear landscape features (Esseen et al. 2004a), spatial relations and patterns.

NILS is based upon sampling, with ca. 630 permanent 5 x 5 km sampling areas across Sweden that are to be monitoring on a 5-year cycle (approx. 120 areas per year). The sampling areas are systematically distributed. The spatial density of points relates to ten regions (strata), with higher density in the main agricultural regions (south and central Sweden) and the mountain region (northwestern Sweden) but lower densities elsewhere (north east coastal region and central and northern inland regions).

All sample areas are monitored with both aerial photo interpretation (API) and field survey. General mapping with API is made of the full, 5 x 5 km, sample area. More detailed mapping with API and field survey is made of the central 1 x 1 km part of the sample area. The requirements of using API in NILS are:

- To provide through mapping of the 5 x 5 km area a general description of landscape composition at a large scale, and through detailed mapping of the inner 1 x 1 km area obtain more detailed information on the landscape diversity and landscape structure.
- To obtain data for analysis of landscape change and spatial character.
- To provide, within the inner 1 x 1 km area, first phase data for two-phase estimation of totals and averages for various variables, based on coupling of the API mapping and the field survey data.
- To provide, with mapping of the 1 x 1 km area, a basis for field sampling that ensures inclusion of all the relevant features of the 1 x 1 km area.
- To enable inventory on areas where it is not possible to undertake field survey, such as due to a lack of access.
- To provide, as 1:5,000 scale orthophotos working material with classified polygon, linear and point features to use in the field based mapping and survey.
- To provide, by mapping of past landscapes from historical aerial photographs, historical data for analysis of, and comparison to today's landscape.

Thus, the image data represent for NILS the basis for a combination of pragmatic survey, core landscape information collection and analytical solutions.

The image data used have been obtained with an analogue camera, using colour-infrared film, i.e. film with a colour-shift. Colour-infrared film has been widely used for earlier and other landscape related work in Sweden (Ihse and Wastenson 1975; Ihse 1995; Skånes 1996; Allard 2003a; Allard 2003b; Groom et al. 2005). It is seen as important for enabling distinction between forest types, vegetation types, between living

and dead vegetation and different moisture conditions. Early test images from the Zeiss Intergraph Digital Mapping Camera (Z/I DMC) airborne digital sensor (see <http://imgs.intergraph.com/dmc/default.asp>) are becoming available and these will, in all likelihood, be the image data used in NILS in the near future. The images from the Z/I DMC are seen to represent good possibilities for the computer-based interpretations of landscape features.

Stereo imaging with approximately 60% overlap is made from a flying height of 4,600 m (amsl), with a resulting image scale of 1:30,000. With this image scale, it is possible to map with a precision of 0.5 – 1.5 m, depending on the contrast and object properties. The analogue film has been digitised with a resolution of 14 microns, which represents 0.4 m on the ground. Further processing, stereo-modelling and interpretation is made with a digital photogrammetry workstation (Erdas Imagine Stereo Analyst and Leica Photogrammetry Suite); achieving the stereo effect involves polarisation, requiring the operator to use special glasses.

The model for NILS operations is that aerial photography is done in the summer, which over the following winter and spring is processed and used for API mapping of the 1 x 1 km area, with field based mapping and data collection in the forthcoming summer, i.e. one year after the aerial photography. The detailed methodology for the API mapping of the inner 1 x 1 km areas is described in Allard et al. 2003) and involves around 50 groups of parameters that are being considered when the landscape is mapped. The methodology for API mapping of the 5 x 5 km areas, such as for capturing of landscape diversity and structure and data for analysis of landscape character and change is still being developed by the NILS project.

As auxiliary data for the image interpretation several additional items of data are used, both as maps and as data bases. These include linear object information from the topographic maps produced by the Swedish land Survey (Lantmäteriet) and map data of cultivated areas from the Swedish Board of Agriculture (Jordbruksverket).

Obtaining landscape monitoring information for NILS from the aerial photograph data of the 1 x 1 km areas involves use of rules for (a) mapping (i.e. delimitation) of area, line and point objects and (b) the description of mapped objects in terms of land cover parameters. The principle therefore is production of a database, which can then be used to make classification and analysis as required. The instructions for these operations are detailed and precise (Allard et al. 2003), reflecting the great variety and complexity of situations encountered in strategic landscape monitoring. The habitat classifications used for area estimates will be made *a posteriori*, based on a combination of quantitative (e.g., vegetation cover) and categorical (e.g., land use) variables. By this approach, the data can be used in a more flexible way, as a basis for several differ-

ent classification systems. It also increases the possibilities to use the data for analysing trends.

2.3.3 Finnish Farmland Biodiversity Survey

Major changes in Finnish agriculture during the last 50 years have spurred numerous monitoring studies of farmland biodiversity. These studies, focussed mainly on specific plant and animal species (e.g. Luoto et al. 2003; Virkkala et al. 2004) and providing important overall national results have more recently been augmented by developments towards a more spatially comprehensive landscape monitoring. This has taken the form of an extensive biodiversity survey in randomly selected agricultural landscapes (Kuussaari et al. 2004). Fifty-eight 1 x 1 km areas are randomly sampled from four strata; the sample selection procedure, as well as field data collection procedures, is described in Kuussaari et al. 2004). One key aspect of this work, which started in 2000, is to obtain quantitative information on the relationship between agricultural landscape structure and biodiversity. Landscape structure information, for three time slots (1990±2 years, 2000±2 years, 2005±2 years) is being obtained through use of habitat maps produced by interpretation of image data. The images being used are low altitude black and white aerial photographs. These are digitised to have pixels representing either 32 or 62 cm and mapping is done with a screen scale of 1:2,000. Mapping is made for 21 habitat categories (see Kuussaari et al. 2004). Subsequent landscape structure analysis is made on a 1 x 1 m raster.

2.3.4 Small Biotopes Landscape Monitoring in Denmark

A programme for surveillance (i.e registration) of small biotopes on the Danish agricultural landscape was established in the late 1970s (Brandt et al. 2001), with “small biotopes” considered as being uncultivated areas that are permanently covered with vegetation (or water) within or between agricultural holdings and also meeting certain size criteria. Since then this has developed into a monitoring system, which has seen detection of changes each five years from 1981 to 1996 at 32 2 x 2 km stratified sample areas distributed across Denmark. The Small Biotopes recording system involves direct registration of agricultural land use and delineation of all landscape elements on rectified and enlarged colour aerial photos (1:5,000), and separate sheets for all semi-natural areas for coding of a number of attributes. The air photos are used for these steps before going to the survey areas. In the field the marked-up images are augmented with additional land use data since this information can only partially be interpreted from the springtime air photos. The monitoring methodology includes interviews with farmers and other land managers concerning functionality and management practice, since this type of

information is seen as a vital part of monitoring in these in general culturally conditioned landscapes.

An important aspect of the Danish Small Biotope monitoring is the ability to follow changes through time. This has resulted in use since 1996 (with reclassification of earlier data) of a precise physiographical description and classification as a precondition for repeatable detection of land cover changes (Brandt and Jakobsen 1998). This is seen as preferable to the earlier mixture of genetic, functional and ecological classification units. 1996 was the first occasion on which the air photos were from the survey year. The change-through-time principle has also resulted in use of an integrated-layer model for the programme's GIS. This model places emphasis on registration of changes compared with the previous registration rather than on comparison between independent surveys made for the different time points (i.e. separate-layer model). Air photo image data of the survey areas were collected in spring 2001 but there was no field campaign. The next change survey will be in 2006, using the same set of sample areas and API mapping but with the addition of ground based survey of biodiversity. It is also planned that the field based registrations of 1996 and 2006 will provide a good basis for interpretation of the 2001 images for the changes at that time point too.

2.4 Other Strategic Mapping and Monitoring Activities that Are Related to Nordic Strategic Landscape Monitoring

2.4.1 *National Forest Inventories*

Sample plot based national forest inventories (NFI) are a major Nordic strategic monitoring activities, particularly in Norway, Sweden and Finland, where they have been established since approximately the early 1920s (Stokland et al. 2003). However, in the NordLaM work the NFIs have not been considered as core landscape monitoring activities in the same sense as those described in Section 2.2. In general the sample plots are too small (typically 0.1 ha. or less) to describe landscape patterns and until quite recently these monitorings were mainly addressing traditional forest management issues, such as for timber production purposes, alone.

The three long established NFIs and the newly established (2002) NFI for Denmark are similarly based on periodic monitoring at a large number of systematically distributed sample plots. The following four national NFI descriptions are after Stokland et al. (2003).

Finland

Using regular grids of 7 x 7, 7 x 8 and 10 x 10 km the sampling frame covers the whole of Finland. At each point in the grid sampling is made for a tract (cluster) of 21 plots that are 200 to 300 meters apart. Thus, the full NFI system comprises 85,672 plots, of which about 70,000 are forest or mire plots. In southern Finland plots are used just once, but in northern Finland the same plots are re-used. (An additional national coverage grid of 3,009 permanent plots was established in 1985.) The plot radius used for measurement of most parameters is 12.46 m. In addition to this field inventory the Finnish NFI has also, since 1990 comprised a multi-source inventory that integrates the plot data with image data and digital map data (Tomppo 2001).

Sweden

Like the Finnish NFI this also uses a regular sampling grid and a cluster-based system, but with a lower number of plots per cluster. (A tract-based system is seen generally as improving logistics and reducing survey costs.) There are (in 2004) 857 permanent clusters (6,052 plots) and 558 temporary clusters (4,699 plots). Both sets of clusters have national coverage (i.e. all land use classes) but the set of parameters is more comprehensive for forested land. The grid spacing is regionally variable, with 3 km used in the south but 15 km used in the north; this reflects therefore the variable grid spacing used by NILS.

Norway

For its main set of approximately 10,500 permanent plots the Norwegian NFI does not use a cluster system. These plots lie on a grid that varies in size, with 3 x 3 km spacing in most counties for the area up to the coniferous tree line, 9 x 9 km spacing in Finnmark county and 18 x 18 km spacing in the sub-alpine birch forest areas. Clusters of between 1 and 6 temporary plots are used in association with the permanent plots to derive county statistics. Although the NFI network covers all land use classes, very few parameters are measured at plots that are not forest plots.

Denmark

The more recently (2002) established Danish NFI uses a 2 x 2 km grid that covers the whole country (Söderberg and Johannsen 2001). At each grid point a cluster of four plots (15 m radius) is located but only those plots in each cluster that are either “likely to contain forest or wooded cover” or “may contain forest or wooded cover” are selected for field inventory. This selection is based on interpretation of air photos and maps, with heath and wetland plots allocated to the “may contain forest / wooded cover” category. The inventory data are not compiled in terms of the tracts, so plots are included regardless of the interpretation of the tract as a whole. However, the initial AP and map interpretation of all plots

also provides a basis for inventory of other land that is “unlikely to contain forest / woody cover”. About 3,500 plots, or 12 – 14% of the total are inventoried in the field over five years. About 40% of the plots are permanent. For subsequent cycles (i.e. after five years) a new 2 x 2 km grid will be used for placement of the temporary plots.

Thus, in their collection of field-based data the Nordic NFIs have relatively equivalent approaches and methods. This similarity has been the basis for successful harmonisation across Nordic NFIs for indicators of forest biodiversity (Stokland et al. 2003). This reflects the presence of long established practises within the field of forest measurement and monitoring in general and also the work of international forestry fora (e.g. EFICS, IUFRO).

The use of image data within Nordic NFIs is at a less stabilised stage, with important operational applications but also ongoing developments on several fronts. Research and development work in Finland in the 1980s developed the use of image data and other full coverage information (e.g. map data) to compute reliable forest statistics for smaller areas than is possible from the sparse distributions of NFI sample plots alone. This resulted in the “multi-source forest inventory” (MSFI) method that has been operational in the Finnish NFI since 1990 and has received widespread international recognition and application (Tomppo 2001). In MSFI high spatial resolution image data (mainly Landsat TM) are used alongside digital map data and traditional NFI field data in a k -nearest-neighbour (k -NN) estimator to produce both statistics and thematic maps for areas as required (Tomppo 2001). The k -NN methods estimates an attribute (such as stand age) as a weighted average of the k - spectrally nearest field plots (Burnett and Groom 2004). Work with the k -NN approach in Sweden during the 1990s has led to recent implementation of a national project, “ k -NN Sweden”, to produce a database with estimates of total wood volume, wood volume by species, age, and height for the whole of Sweden (Reese et al. 2003). This is implemented as a production line (“Munin”) operation. In Norway there has also been testing of the k -NN approach for a few municipalities, with satisfactory results for estimation of top height, dominant tree species, total number of trees, number of conifers and the mean height of young trees (Burnett and Groom 2004).

The k -NN approach therefore represents an important use of image data for strategic monitoring. However, as stressed by (Reese et al. 2003) it is important to be aware of the proper uses for the data, the accuracy of the estimates, and the minimum mapping unit. Forest variable estimates produced using the k -NN method usually have a low accuracy if assessed on a per pixel basis. In addition, the accuracy is limited for stands with high stem volumes. Accuracy levels are higher, and generally regarded as acceptable when the estimates are aggregated to a larger area, such as landscape or stand level. The accuracy also depends on the character of

the forests and the other associated data. Thus, the small average size of stands across southern Finland (1.5 ha.) combined with the relatively coarse spatial resolution of the NFI field data are seen as factors contributing to low k -NN accuracy at plot and stand levels in the Finnish MSFI work.. (Pekkarinen 2002) has also noted that errors in the geo-location of the NFI plot data and plots that relate to mixed images pixels close to the edges of stands further hamper the use of the standard MSFI procedures.

This situation has led in recent years to various further developments in the use of image data for Nordic NFIs. The use of higher spatial resolution image data, such as digital or digitised aerial photographs or data from very high spatial resolution satellites is one possibility for better local estimation of forest attributes. However, pixel based image analysis methods, such as the standard k -NN method are not appropriate with these data because, being smaller, an individual pixel may represent just one part of a stand or tree (Pekkarinen 2002). Methods based on the spectral characteristics of each pixel are compromised. Object-based analysis methods and image segmentation are another possible solutions that have been investigated and developed in Finland in particular (Burnett and Groom 2004); this work has included the development of operational tools for use in forest inventory. However, in general such techniques are relatively new, with research ongoing into their applications (e.g. Pekkarinen 2002; Burnett et al. 2003). Results indicate new application possibilities, such as for change estimation, but also implications for traditional forest data collection methods, such as the need for field data that relate to the image segment rather than forest stand or sample plot. Traditional forest inventory using multi-phase sampling (Tuominen et al. 2003) to address spatial auto-correlation associated with tree, stand and regional variables could also incorporate image segmentation. It is necessary to note too that beyond developments in the use of image data that are explicitly associated with existing strategic operation, such as Nordic NFIs, the development of uses for image data in forest mapping and monitoring is a vast and diverse international field of work.

The current developments in and applications of image data in multi-source forest inventory represent sophisticated geostatistical principles and techniques. More generally, Stokland et al. (2003) advocate that greater use should be made of image data to address landscape issues within forested areas, such as to overcome the problem of landscape pattern representation due to the small size of the NFI sample plots. Unfortunately, in focusing on use of the Nordic NFI plot data, the degree to which Nordic multi-source practices address the identified forest-landscape need, and what other specific image-based approaches could be useful is not discussed by that work.

As noted earlier, image data are also put to other, operational use in the Nordic NFIs, such as within the new Danish NFI for interpretation of the criterion used in selecting sample plots from the national 2 x 2 km

grid. This early stage use of image data for extraction of relatively simple (i.e. single attribute, three-class) information may not be considered feasible were it not for the small total area to be covered (i.e. Denmark, 43,096 km²) and the availability of very high spatial resolution digitised orthophoto image data (COWI A/S 2002).

2.4.2 Land Cover and Land Use Mappings

Land cover mapping has been one of the mainstays of the use of image data for many decades. Within Europe in general this is reflected in the numerous national activities undertaken to map land cover with image data and the EU's CORINE Land Cover programme (ca. 1990 - present). The biophysical characteristics that constitute the contrasts between different land cover types are closely and directly associated with the physical processes that result in differences in image data values, i.e. characteristics and patterns of Earth surface photosynthesis, wetness and colour. In many cases the same principles have been extended to the mapping of at least some types of land use, i.e. a broader concept for describing the Earth surface that relate to the activities applied to land covers to enable production, change or maintenance (Di Gregorio and Jansen 2000). It is generally accepted that land cover and land use represent distinct but complementary items of information, and that land use is less easy than land cover to observe such as with image data (European Commission 2001). For example, it is often difficult to determine whether or not a grassland area is used for agriculture or recreation, and, as is particularly emphasised in current landscape contexts, single land covers may have multiple functional uses, such as a dune area used for coastal protection, recreation and nature conservation. Likewise, an area with a specific land use may comprise areas with different land covers. Thus, as the land use "agriculture" can include bare soil, vegetated and even build-upon land cover and the land use "airports" can include bare ground, sealed ground (runways), grass and build-upon land covers.

CORINE Land Cover mapping has been made for the three EU Nordic states, Finland, Denmark and Sweden, albeit following somewhat different pathways from each other and the general pattern of the other CORINE participant states. This situation reflects the considerable history of national land cover and land use mapping activities in the Nordic countries, such as in Finland where the first major inventory of land cover was made in the late 1980s (Sucksdorff and Teiniranta 2001). It also reflects the concern that has been frequently expressed that the standard 44-class CORINE Land Cover nomenclature is not well-suited to northern European situations, with relatively few classes representing the variety of forest and wetland land covers in particular.

In Finland Landsat TM image data were used to produce in 1991 the SLAM (Satellite based land use and forest classification). Between then

and 1997 two further versions of the SLAM were produced. Whilst mapping to almost the same nomenclature, different source data and methods were used for the three versions. Running parallel to the SLAM programme since 1992, the Finnish CORINE Land Cover mappings have been made by automated data integration and generalisation procedures applied to the SLAM-3 data plus some additional data, rather than the standard CORINE Land Cover techniques. Starting in 1997, strategic land cover and land use mapping for Finland was completely revised, reflecting changes in the needs for the information. The result of this has been the SLICES (Separated Land Use / Land Cover Information Systems) programme (Sucksdorff and Teiniranta 2001; Jaakkola and Helminen 2002). Production of the entire database was completed by the end of 2000. One of the 10 input sources to SLICES, representing the main use made of image derived information, is the Finnish CORINE Land Cover data. The mapping scales used in both SLAM and SLICES have been finer than those required for CORINE Land Cover, with the main products being 25 x 25 m rasters. For the Finnish part of the multi-national programme for update of the CORINE Land Cover database (Steenmans and Perdigão 2001), availability of completed national CLC2000 vector data expected during the first quarter of 2005 (see <http://dataservice.eea.eu.int/dataservice/>).

In Denmark, CORINE Land Cover mapping and update has followed standard CORINE techniques, with availability of completed national CLC2000 vector data expected during the first quarter of 2005. However, there has also been undertaken during the late 1990s, independent of CORINE, a strategic spatial data programme, the AIS, with production of both land use and image derived land cover mappings (Groom and Stjernholm 2001). As in Finland, the AIS national spatial environmental database programme has been seen as a basis for providing more comprehensive, and higher spatial detail information. The production of the land cover mapping has been the main direct use of image data into the AIS programme. Semi-automated classification of image data (Landsat TM) has been the basis for production of the land cover mappings.

The need for a national land cover mapping that not only satisfies European needs but also provides a more detailed product better suited to national conditions has also been a major characteristic of strategic mapping activities in Sweden. The result has been development and production of the Swedish Land Cover Data (SMD) mapping. This product has more classes, at more levels, than the standard CORINE Land Cover product and the minimum map element size is smaller (1, 2 or 5 ha, depending on the class). Furthermore, production of the SMD data has involved use of both image and non-image (National Land Survey and National Forest Inventory) data and a mixture of visual interpretation, semi-automated classification and GIS-manipulation techniques. Subsequent production of the CORINE Land Cover data has involved generalisation

of the SMD data. Thus, the SMD mapping represents the situation around 2000. As yet there are no plans for down-dating for production of the CORINE Land Cover data representing the situation in 1990.

Norway is not obligated in the same way as Denmark, Finland and Sweden to produce CORINE Land Cover data. However, in 1996 the Norwegian Ministry of Environment commissioned work towards production of a Norwegian version of CORINE Land Cover and test data were produced (Bloch et al. 2004). In Norway importance is given for many years to the need for area resources data. Thus, there has been production of various mappings related to the resource base and economic possibilities; these are mainly based on the DMK (digitalt markslagskart) 1:5,000 scale land type mapping that covers agricultural and forest areas. Satellite images (manual interpretation of Landsat TM images) are being used as the most cost effective means for mapping of the mountainous areas (the AR-FJELL product; Strand and Karbø 2002) and are also being used in development of resource mapping of forested areas (AR-SKOG). Development work has been made towards production of a national land cover map, such as formulation of a classification, but as yet Norway has not started a national land cover map program. Also, the need for data with high statistical value as well as high cartographic quality has been emphasised, with the generalisations involved in the national small-scale land use / land cover maps seen as compromising the former (Strand 2001). Thus, sample based systems for monitoring of national land resources have been developed, such as the "A thousand places" project (Strand 2001). In this 1,074 1 x 1 km areas are mapped using a stereo pair of colour aerial photographs in scale 1:12,500.

3. Results from the Thematic Activities

The aim of this Nordic work has been to develop coordination in the use of remote sensing within Nordic strategic landscape monitoring. Furthermore, the aim has been to achieve this by examination of a set of issues that relate to the characteristics of the information associated with the use of remote sensing within strategic landscape monitoring. As was discussed in Chapter 1, this approach has been seen as complementary to development of coordination through examination of standard remote sensing issues. The topics examined through the project represent a mixture of some standard remote sensing themes and some more informational themes.

Thus, the theme “Full Coverage – Partial Coverage Integration” requires consideration of landscape monitoring information acquired through remote sensing side-by-side with information acquired from other techniques.

The theme “Classification Systems” represents a major cross-running informational issue but one which is often treated singularly within different scientific and technical arenas.

The theme “Very High Spatial Resolution Image Data” mainly represents an examination of classic remote sensing issues of image data types, pre-processing and analysis techniques and the results of investigations into monitoring application possibilities.

The theme “Images and Indicators” represents an end-point in the data-information-knowledge chain, examining how information coming from remote sensing data corresponds to high-level abstractions of landscape.

This chapter presents summary discussion for these themes since fuller technical discussion of results from each theme has been made in the chapters of the second report from the NordLaM project (Groom 2004b).

3.1 Information from Image Data and Thematic Class Sets

The issue of classification lies at the heart of science and interweaves through landscape monitoring and its use of image data in many ways. However, the issue is often relegated in the attention it receives, coming after consideration of the purpose and objectives of the monitoring and

development of core monitoring methods such as sampling procedures and change detection. Furthermore, for landscape monitoring the issue of classification is particularly complex.

Firstly, there is complexity since there is as yet no standardisation of what landscape monitoring represents. Consideration of many diverse themes is involved, including land cover, land use, vegetation, habitat, landforms, cultural structures and socio-economic aspects. None of these in themselves represents a generally acceptable concept for landscape classification, but at the same time each is represented by at least one, or more, established and applied classification systems or nomenclatures.

Secondly, in landscape mapping operations, such are components of the Nordic landscape monitoring programmes, the relationships between classification, technique and object delimitation compounds the complexity. In much of science, classification is applied to more-or-less discrete objects, such as living organisms or minerals. A classification can be made that is based upon objective characteristics of the objects, and which can be objectively applied using different data measurement techniques. Such situations have provided a basis for clear classification concepts and principles in, for example, biology and geology. In landscape monitoring also there are some aspects of the landscape that can similarly be regarded as discrete objects, e.g. agricultural fields or types of small biotope (walls, solitary trees, earth mounds, water holes, etc.). However, for much of the subject matter of landscape monitoring there is as yet no objective understanding of the base monitoring objects. The Finnish farmland biodiversity survey illustrates a case in point of a choice that is frequently faced by landscape monitoring programmes: Does obtaining information on landscape structure require specific mapping or can it come from mapping of other issues such as land cover or habitats? In some cases this is resolved by including habitat categories that relate directly to issues of landscape structure. Thus, in landscape related monitoring activities many data objects are delimited, and hence classified, on the basis of (a) the monitoring purpose and (b) the mapping technique (field survey, manual image interpretation). The widespread use in landscape and related mapping and monitoring of pixel-based automated image analysis procedures adds further potential for complication since many remote sensing methods represent a basis for classification based around artificial objects (image pixels) and the possibility for applying a classification system that is tied to use of a specific data resource, i.e. a particular image data type.

One form of landscape classification is typologies and/or mappings that relate to the character of the landscape for an extensive area (see <http://www.elcai.org> for overview of European landscape character classification). The most developed national landscape character classification system of the Nordic countries is the Norwegian Landscape Reference System (Puschmann 1998). In landscape character classifications the

classes represent a synthesis of selected thematic attributes over a large number of individual landscape features. Landscape character classifications can provide a frame for sample based landscape monitoring, as has been implemented in Austria (Peterseil et al. 2004). However, for the purpose of the project theme, these classifications are not directly relevant to the classification required for landscape monitoring data capture, which mostly is focussed on the level of the individual landscape features. Of course, the monitoring data for these features may subsequently be analysed in terms of changes in the character of the landscape they are part of.

During the years 2001 – 2003 these issues were investigated through a focused NordLaM project workshop (Groom 2004a) and follow-up work testing the possibilities for use of a standardised land cover classification system to enable coordination and correspondence between Nordic landscape monitoring class sets. A land cover classification system strongly based on classificatory principles that has a proven track record as a basis for production of harmonised land cover mapping legends and possibilities for making quantitatively comparison between legends was identified for this exercise. This was the so-called Land Cover Classification System (LCCS) developed by FAO and UNEP (Di Gregorio and Jansen 2000). As noted previously, land cover is a major component of the broad set of thematic domains that consideration of landscape encompasses. The use of a land cover focused classification system was therefore considered as having potential for making harmonisation and correspondence between landscape monitoring class sets.

Several current international initiatives for development of spatial data infrastructures, e.g.. INSPIRE (Lillethun 2002), GMES (Wyatt et al. 2003), GEOSS (<http://earthobservations.org/>) and GLCN (Jansen 2004a) stress the importance of harmonisation between legends but as yet the technical aspects of such an undertaking are not discussed. In some cases correspondence crosswalks have been produced showing “same as”, “includes” and “is included by” relationships, such as between the EUNIS habitats and other European habitat class sets (e.g. Moss and Davies 1999); <http://eunis.eea.eu.int/habitats.jsp> However, it is not certain whether this has been done by expert judgement (which can be subjective) or more automated objective procedures. The LCCS provides a basis for objective, quantifiable correspondence through translation of classes in terms of a common set of land cover parameters. As such it represents the only software application. Beyond evaluation of the LCCS software itself its use by the project provided a basis for evaluation of the concepts and principles that it embodies and for examination of the use of land cover class sets within Nordic landscape monitoring. Jansen (2004b) provides a full description and discussion of the results of this exercise. During the same period as the NordLaM work with LCCS there has also been evaluation of the possibilities of a nomenclature for national land

cover mapping in Norway that follows some of the concepts and methods of the LCCS (Gjertsen et al. 2004). However, in very many ways for the Nordic countries, as more generally across Europe, the de facto class set for coordination work involving land cover information is that of Corine Land Cover (Steenmans and Perdigão 2001).

Habitats are a major component of landscape monitoring too, particularly where there is focus on the relationships of landscape to biodiversity. There are now several European classification systems of habitats, such as EUNIS and Habitats Directive Annex-1 that are being used in coordination and reporting work by European agencies and within legislative frameworks. In the face of problems of on the one hand, incomplete coverage of landscape habitats, and on the other hand class sets that largely could not be used effectively in strategic field surveys, other options are being considered. Since the NordLaM work in this theme, the EC's Biohab project (http://www.alterra-research.nl/servlet/page?_pageid=744&dad=portal30&_schema=POR TAL 30) has been developing a parameterised and rule-based classification system for European habitats within the context of landscape monitoring that places emphasis on the vegetation life-forms. Development of this approach has involved consultation with the Nordic countries (Skånes 2005).

Beyond consideration of habitat, land cover or other adopted singular components of the landscape picture, the question remains whether increased coordination in landscape monitoring demands that there is a specific classification system that addresses more completely the particular, broad feature set involved. Data collection and data structuring are central aspects of Nordic landscape monitoring and related activities. That these are also core aspects of remote sensing work, including its application for landscape information, inevitably juxtaposes the classification undertaken as remote sensing with that undertaken as landscape ecology. With regard to this juxtaposition the following point can be noted:

- Where there is already landscape ecological classification remote sensing has a major role to play in the ongoing monitoring and management of the landscape units, even if it has not been involved in their delimitation.
- Frequently image data are being used to map a thematic issue that is a subset of the "landscape complex", such as vegetation, land cover or habitat type. The associated classification is consequently not one of "landscape" *per se* but nevertheless a partial element of landscape. Integration of the classification associated with the use of image data with that for landscape typology is a non-trivial undertaking.

There is the following overarching issue: Remote sensing is in essence a *technique* for information gathering. It has been argued that classification

in the sense of “the arrangement of objects into groups on the basis of their relationships” (Sokal 1974) should be done independent from specific data sets or techniques (Di Gregorio and Jansen 2000; European Commission 2001). This is seen as essential for ensuring longer-term use of the resulting products such as maps and legends made using specific data and techniques. The significant corollary of this is that remote sensing cannot take-on classificatory roles within landscape ecology, as opposed to essentially mapping roles. However, the indication, supported by the examples in this paper, is that classification, remote sensing and landscape ecology *de facto* interact in many different and rather *ad hoc*, but not unsuccessful or necessarily wrong ways. It may be considered that whether or not this situation represents a problem relates to the type of applications involved:

- for smaller, localised, more experimental landscape ecology applications classification system principles can be regarded in rather relaxed ways;
- for regional and national applications, of environmental components of landscape, such as land cover and habitat, classification system principles are significant, and there are important international classificatory developments that need to be taken into account;
- with regard to landscape typologies and related themes, such as landscape indicators (Section 3.4) within this scope for remote sensing there is a major need for investigation and development of the appropriate roles of image data within the classification system.

Considered directly, there is as yet no development of a specific classification system for landscape monitoring. There is however, coming in particular from the GIS community, development towards more standardisation of the information systems relating to all manner of geographic features. The development of object-orientated data and information is seen as a key requirement in this : “Ideally, the structure of spatial data ... would reflect the high-level categorisation of real world spatial objects that are logically related. ... This structuring will be the first step towards a future more stable categorisation, based on object-oriented modelling ...” (Lillethun 2002). At the same time it seems possible, that if it is handled well, a “habitat” umbrella can provide a strong basis for coordination of general landscape monitoring data capture.

3.2 Integration of Full Coverage and Partial Coverage Information

“Integration” can build upon complementarity between parts. As such, it is necessary to recognise and understand the differences between the

parts. In Chapter 2 of this report, the review of the ways image data are currently used in Norden towards aspects of strategic landscape monitoring noted that there are in fact two distinct spheres of image data application. One is for capture of spatially fine detail and often also thematically detailed information for a set of sample areas. The other sphere is for capture of spatially and thematically relatively coarse information of extensive areas, including complete national or regional coverages.

The widespread use of photographic, albeit then digitised, image products for the former sphere actually represents rather limited complementarity to field survey data capture in that both are fulfilling similar monitoring programme tasks. This is not to suggest that there should be any under-estimation of the necessity and significance of the use of image data in this way within Nordic landscape monitoring activities. Thus, it is necessary to note the scope for complementarity that is present in the use of very high spatial resolution images of sample areas in order to make base mapping more cost-effectively than is possible through ground-based survey. Also there is the necessary use of such images for help in selecting sampling locations and for ground survey logistics. With so much of the extent of the Nordic landscapes remote and/or difficult to access on the ground, the use of images in place of ground survey has a high profile.

However, the more major opportunity for integration involving image data is in the other arena in which image data are associated with strategic monitoring, i.e. the use of images for monitoring information that is characterised by large coverage, but lower spatial and lower thematic resolutions. Integration is then a matter concerning this information and the partial coverage, spatial and thematically detailed information from sample based information albeit whether that is derived from field survey or very high spatial resolution images. As was seen in the NordLaM project's workshop under this theme that was held in 2001 (Groom 2004c) this issue is very wide-ranging in the ways that integration can be achieved.

The major exploitation of "census – sample" integration in Nordic strategic monitoring is, as described in Chapter 2, in relation to various national forest inventories, i.e. through the k-nn methodology. This is most extensively developed for Finland and Sweden. For Sweden there is also further significant potential for census-sample integrations relating to the general landscape, given that there is now both spatially detailed (sub-hectare) national land cover data (SMD) and extensive 1 x 1 km and 5 x 5 km sample based survey for landscape monitoring (NILS). For Norway there is not yet spatially detailed full coverage mapping to complement the major sample based landscape monitoring (3Q), whilst for Denmark there is not yet national sample survey relating to landscape to complement the detailed national land cover and land use mappings (AIS).

In discussions throughout the project it has however also been clear that there is a strong tendency also to see the sample-census-integration issue mainly from the classical remote sensing perspective of ground survey data serving as means for verification or possibly also calibration of maps derived from image data, i.e. the so-called “ground-truthing” of remote sensing. Hopefully, it has been possible to advance coordination ideas and developments beyond this level to one which places greater emphasis on the gestalt that is also possible through integration of partial and full coverage monitoring data and information.

Furthermore it has been noted that it is essential to recognise and understand that information coming from image data and information coming from other means each have specific characteristics as “baggage” and both represent only models of the real world. I.e. both are only partial representations and neither is intrinsically either incorrect or correct. It is for this reason that, in relation to calibration and accuracy assessment of information from image data, it is important to not read too much into referral to any reference data or information as “ground truth”. Rather, an open and even-handed informational arena is seen as important for developing integration possibilities within a context of a set of informational components.

It has been seen that there are two sets of issues to consider in order to exploit complementarity between census and sample monitoring information:

- One, more qualitative and rudimentary but nevertheless significant set relates to the general characteristics of the census and sample information, i.e. their comparability in terms of the major theme (object set) they address, their expression of that theme in terms of classes or other values, the time periods they relate to.
- The other, more fundamental set relates to the more quantitative and statistical aspects of the integration. This involves consideration of the various possible integration approaches, such as simple accounting methods, simultaneous equations, or regression based estimation.

The quantitative / statistical aspect is moreover a matter of consideration of the statistical characteristics of the census and sample data and information. Bias and error in both parts need to be considered. The spatial characteristics of the real-world objects and patterns are significant, influencing the modelling of objects and patterns within in the census and sample data and the modelling involved in the integration. The spatial aspect is particularly significant for landscape monitoring since many of the objects that are significant for understanding landscape and landscape changes occur with low frequencies (e.g. solitary old growth trees within an agricultural landscape) and with spatial distributions that relate to many factors and processes.

Development of these integration aspects require detailed scientific work, analysing the results of different models and methods. Such activities are now widespread within geography and related Earth and environmental science research communities, advanced by active work across Europe and beyond, drawing upon many recent developments in computer based GIS modelling and analysis possibilities. In this, the physical landscape situations occurring across the Nordic countries can quite easily be accommodated alongside those of other places, i.e. there is no particular expectation that developments made elsewhere should not be applicable also to Nordic situations. Nordic coordination can therefore be advanced through active participation in these research fronts, with demonstration of developments through linkages to strategic Nordic monitoring programmes.

3.3 Very High Spatial Resolution Image Data

Advances in supply and quality and increases in the use of very high spatial resolution (VHSR, less than 5 m) image data has been a major development within remote sensing since the late 1990s. VHSR image data now comprise data provided by several operational satellites (Birk et al. 2003; Stoney 2004; Groom et al. 2005) and also from aircraft. The latter mainly take the form of conventional hard copy aerial photographs that are then digitised and orthorectified, but some digital airborne systems are now also used.

Higher spatial resolution implies the capability for seeing in image data finer detail objects and patterns. Landscape studies involve consideration over a range of spatial scales. Fixed artificial objects (e.g. buildings, water-holes, roads, ditches, hedges) and similar sized natural / semi-natural features (e.g. grassland / heathland vegetation patches, forest gaps, rock outcrops) are commonly regarded as representing the bottom end of the range. Thus, the information scales presented in very high spatial resolution image data have major significance to landscape monitoring. The interface between VHSR image data and Nordic landscape monitoring was the topic of a workshop held in late 2001 (Burnett and Groom 2004). The workshop participants' respective positions on the use of HSR/VHSR image data for Nordic landscape monitoring can be summarized as:

- University and institutional researchers are actively developing theory and methods that extend the utility of VHSR data for landscape monitoring and related activities. In particular, these researchers are striving to understand and encapsulate in proven methodologies the relationships between remotely sensed data, landscape pattern & processes, and landscape indices, at very high spatial resolution. Work with VHSR datasets (aside from aerial photographs) has been limited

mainly due to the costs of these new data sets. Research into VHSR also requires intensive new ground-referencing programmes. Work with both HSR and VHSR datasets to date have shown that landscapes contain processes operating over a range of scales: one survey resolution (i.e. 30 m Landsat ETM) will thus be appropriate for only a narrow range of monitoring goals. The response to this realisation has been research into the use of scales within an image; and a move within research work beyond 'pixel-based' techniques to 'object-based' theory and methodologies is occurring (Burnett et al. 2003).

- National programme representatives have successfully developed methods for landscape monitoring using high spatial resolution image data. They have found, however, that very high spatial resolution is not applicable to every monitoring task: it is well suited to regional and national reporting, but is less accurate for local estimates. The use of VHSR in the form of traditional aerial photo interpretation is still common, especially where broad area coverage is not required (e.g. the Swedish landscape monitoring programme, NILS). Space-borne VHSR as an expensive and as yet unproven tool, but currently being examined by several groups.
- Industry providers have interesting new VHSR data, including digital ortho-photo mosaics with accompanying digital height models (derived from airborne digital camera & scanning LIDAR combinations). New software tools are also now available which should improve the speed and accuracy of the traditional aerial photograph interpretation method, an important tool for landscape monitoring at the local level.

3.4 Landscape Monitoring, Indicators and Information from Images

Indicators have an implicit association with monitoring since a major aspect of the use of indicators is concerned with changes, such as changes in driving forces, pressures, states, impacts and responses. Hence indicator development is a major aspect of monitoring with indicators seen as important means of processing and summarising, such as for reporting complex change patterns. The significance of indicators, as means channeling information on change to the policy making processes cannot be underestimated.

A major and significant aspect of the changes within landscapes is expressed spatially. Since images provide a major means for capturing the spatial complexity of landscape changes it has become widespread to also see image data and information derived from image data as a basis for development and production of landscape indicators. Indicators serve to facilitate standardisation and comparisons and these are functions for

which the standardisation that is implicit in many types of image data and which is possible through use of image data (Groom et al. 2005) is well suited. In these ways, the issue of landscape monitoring indicators and their use of image data was a theme addressed by the NordLaM project, drawing upon the major development and use of indicators in national Nordic landscape monitoring programmes and related methodological developments (Frederiksen et al. 2004). For this theme a workshop was held in October 2001 and based on that meeting Fjellstad and Frederiksen (2004) present and discuss the issues involved including Nordic experiences with landscape monitoring indicators.

A clear conclusion from the workshop was that there is a great need to test indicators using real landscape data. Some major themes for indicator development include:

- identifying the audience for landscape indicators (who needs the indicators and what values are they interested in?)
- working more closely with policy makers to identify measurable goals
- developing methods and techniques to extract information from image data
- refining spatial metrics and finding new measures to capture complex issues such as fragmentation and connectivity
- developing methods to integrate data from different sources - particularly socio-economic data – to identify driving forces
- testing existing indicators to determine whether they are sensitive to landscape change
- identifying gaps in the existing set of indicators
- developing better ways to communicate the implications of indicator values

It was agreed that the major problem in dealing with landscape issues is that different groups have different values and that indicators must take account of all of these. Many social groups are very active in thinking about and analysing the landscape, but they may need the help available through indicators to quantify and communicate their interests. Indicators must capture the issues thrown up in social debate and structure these in a scientific way. Only when information can be provided in an objective and balanced way is it possible to make democratic decisions about the development of the landscape. Inevitably some values will be sacrificed to the advantage of others – for example, preserving biological and recreational values may lead to a loss of possible economic values. However, the provision of indicators is not intended to decide the outcome of such trade-offs, simply to inform the debate.

Clearly, the interaction of images with landscape monitoring indicators is only one part of a far larger discussion and developmental process regarding indicators, landscape and related environmental issues. It is

hard to discern whether this larger process is reaching a settled state or is still in a more volatile phase. Current activities around Europe point in both these directions. In the midst of the larger landscape and indicator sphere it is important to keep sight of the main contributions that image data represent. In this, as much as anywhere else in the arena covered by the NordLaM project it is important to distinguish between the processes that deliver low-end informational goods from image data and the processes for transformation of low-end spatially organised information goods from various sources into higher order informational goods.

3.5 Summary

In summarising the development towards Nordic coordination achieved through the NordLaM project it is useful to focus attention on the tangible essence of what remote sensing brings to landscape monitoring, or indeed to any domain. Thus, first-and-foremost remote sensing is about the delivery of real world information (into landscape ecology). This simple point seems increasingly important to bear in mind as projects of landscape monitoring become increasingly interwoven between the many issues, concepts and approaches that now comprise landscape work.

It is not without significance for landscape ecology that remote sensing has been described in terms of the “information extraction problem” (Danson et al. 1995). However, to see the relationship between landscape ecology and remote sensing as one of information delivery implies also a two-way process, engaging landscape ecology as an active partner too. Thus, the information delivered to landscape ecology by remote sensing sits within an “information landscape”. It is, now as much as ever, necessary to have a holistic and reciprocal model of our informational mind-sets, regarding how image data, maps, field data, experimental data, etc. interact with each other. Our understandings and implementations of core informational issues such as classification, accuracy assessment, error modelling and metadata will shape this model.

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