Geographic Information Systems as a Tool to Support Monitoring and Assessment of Landscape and Regional Sustainability

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Abstract

New policies in Sweden about intensive forestry and functional green infrastructure require involvement of different sectors for planning of landscapes and regions. However, Sweden has no territorial land-use planning at these spatial scales. Landowners, municipalities and regional governments work separately to implement policies about sustainability. There is thus a growing need for integrated spatial planning, and thus assessments of sustainability at local to regional levels by comparing monitoring results with norms expressed in policies. The aim of this thesis is to analyse and visualise such data using Geographic Information Systems (GIS) to enhance comprehensive spatial planning approaches for cooperation between different planning sectors. In paper I, habitat functionality was modelled for area-demanding focal species' requirements in five coarse forest types. Also clear-felling rates within and outside functional habitats for each of four forest owner categories were measured. The differences among landowner categories concerning planning for ecological values were linked to how biodiversity-friendly their policies were. Papers II and III analyses how forest management affects two endangered species, and show that GIS-based proxy variables can be used to predict occurrence of both terrestrial and aquatic focal species. Paper IV assesses how Forest Stewardship Council (FSC) contributes to biodiversity conservation in Sweden and Russia. Analyses of structural connectivity and habitat functionality show that the minimum standard in FSC set-asides is not compatible with higher levels of ambition to maintain biodiversity. Paper V explores how planners, locals and tourists perceive landscape values, and how these can be interpreted and used in spatial planning. Paper VI demonstrates a zoning approach to identify green infrastructures and areas suitable for intensive forestry. In paper VII indicators for ecological, economical and socio-cultural values were summarised to compare municipalities' sustainability. To conclude, there are large opportunities for analysing and visualising data to support integrated spatial planning about sustainability using GIS. However, there is a need for new education programs including all dimensions of sustainability in combination with use of GIS.

Keywords: assessment, Geographic Information Systems, green infrastructure, indicators, intensive forestry, landscape, monitoring, regions, sustainability.

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Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Angelstam, P., Andersson, K., Axelsson, R, and Elbakidze, M. Implementation of biodiversity conservation policies in Swedish boreal forest ecoregions: habitat networks and planning processes. Manuscript.

II Stighäll, K., Roberge, J.-M., Andersson, K. and Angelstam, P. 2011. Usefulness of biophysical proxy data for modelling habitat of an endangered forest species: the white-backed woodpecker *Dendrocopos leucotos*. *Scandinavian Journal of Forest Research* 26(6): 576-585.

III Degerman, E., Andersson, K., Söderberg, H., Norrgrann, O., Henrikson, L., Angelstam, P. and Törnblom, T. Predicting viable populations of freshwater pearl mussels (*Margaritifera margaritifera, L.*) using instream and riparian zone land cover data. Manuscript.

IV Elbakidze, M., Angelstam, P., Andersson, K., Nordberg, M. and Pautov, Y. 2011. How does forest certification contribute to boreal biodiversity conservation? Standards and outcomes in Sweden and NW Russia. *Forest Ecology and Management*, 262(11): 1983-1995.

V Andersson, K., Angelstam, P., Axelsson, R., Elbakidze, M. and Törnblom, J. Planning post-modern rural development? Appreciation and visualisation of forest landscape values at a Swedish tourism destination. Manuscript.

VI Andersson, K., Angelstam, P., Elbakidze, M. and Axelsson, R. Intensive forestry and green infrastructures: need and opportunity for spatial planning? Manuscript.

VII Andersson, K., Angelstam, P., Axelsson, R., Elbakidze, M. and Törnblom, J. Connecting municipal and regional level planning: analysis and visualization of sustainability indicators in Bergslagen, Sweden. *European Planning Studies*. In review.

Paper II is reproduced with the permission of the publisher Scandinavian Journal of Forest Research, www.tandfonline.com and Paper IV by the publisher of Forest Ecology and Management.

The contribution of Kjell Andersson to the papers included in this thesis was as follows.

I 40 %

II 40 %

III 40 %

IV 40 %

V 70%

VI 80 %

VII 80 %

Abbreviations

ASL	Above See Level
CETS	European Landscape Convention
DEM	Digital Elevation Model
EC	European Community
EEC	European Economic Community
EIA	Environmental Impact Assessment
ETOUR	European Tourism Research Institute
EU	European Union
FOMA	Fortlöpande miljöanalys
FSC	Forest Stewardship Council
GIS	Geographical Information System
HSI	Habitat Suitable Index
INSPIRE	Infrastructure for Spatial Information in Europe
ITPS	Swedish Institute for Growth Policy Studies
IUCN	International Union for Conservation of Nature
k-NN	Constant – Nearest Neighbourhood
MCPFE	Ministerial Conference for the Protection of Forests in Europe
NRA	National Strategic Research Agenda
PBL	Planning and Building Act
SCB	Statistic Sweden
SEA	Strategic Environmental Assessment
SFM	Sustainable forest management
SMD	Swedish Land Cover Data
SOU	Sweden's Official Investigations
ULI	Swedish Development Council for Land Information
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WSSD	World Summit on Sustainable Development

1 Preface

In the early 1990s, the forest sector labour market was in a difficult economic situation, and only those who had practical forestry experience could find work. As a newly hatched graduate forester, I could not find work in forestry. At the same time a new technology called Geographic Information Systems (GIS) spread in many sectors. Vacancies, which requested knowledge in the use of GIS, increased sharply. Because digital databases had to be built, the introduction of GIS in forest planning was costly, both in terms of the digitalisation of maps, and in the form of collection of attribute data. As a rule, only those in the organisation who were interested in computers used GIS for planning. The Swedish state forest company AssiDomän (the equivalent of today's Sveaskog Co.) was a forest company that then invested heavily in the development of GIS as a planning tool.

A problem in the development of spatial planning processes was that foresters did not know much about computers, and GIS programmers knew little about forestry. As I was acquainted with forestry, computers and programming, I therefore acted as a link between these different fields of expertise. At that time only a few people worked with GIS. Later, as university courses in GIS started and programmes to become a GIS engineer appeared, it became more difficult for those who worked with GIS without formal education to get a new GIS related job. Working with GIS consequently became a specialist job that required a formal GIS engineer education. Subsequently, GIS expertise became an important part of municipalities', county administrative boards' and forest companies' work. However, when municipalities in the early 2000s were forced to reduce their expenditures to finance basic political objectives concerning human well-being, some staff was dismissed and then often also the development of GIS use, especially in small municipalities.

As a rule, each municipality, county administration and forest company is presently planning their own territory. Many organisations have created their own digital databases suitable for their particular geographic area, themes and way of working. The availability of data is great today. However, the way the data is used today among practitioners is mostly to look at and make different selections for maps and illustrations, while it is unusual to make advanced analysis and modelling to support planning decisions and to examine alternative solutions. This is in contrast to the advanced and abundant use of a multitude of GIS applications in both basic and applied research.

Combining data from different sources and time periods in order to extract decision-support information as maps could provide a common language among different planners, as well as to provide new opportunities for collaboration. However, this requires the ability to bridge gaps between academia, policy and practice on the one hand, and among actors and stakeholders from different sectors and with different interests on the other. My postgraduate studies gave me the opportunity to develop the use of GIS that could serve as a link among different fields of expertise, and that could support the process of implementing policies about the sustainable use of the goods, ecosystem services and values that forest landscapes provide to all of us.

2 Introduction

All development should be sustainable. That is a statement that many world summits have agreed upon (e.g., UNCED 1992, WCED 1987, WSSD 2002). The United Nations Conference on Environment and Development (UNCED 1992) resulted in agreements about Agenda 21, the Convention on Biological Diversity, the Framework Convention on Climate Change, the Rio Declaration, and a statement of Forest Principles. The World Summit on Sustainable Development (WSSD 2002) adopted a political declaration stating that all development should be sustainable, with integrated treatment and equal priority of the ecological, economic and socio-cultural dimensions of sustainability. Satisfying ecological, economic and socio-cultural values of landscapes as sustainable social-ecological systems is a contemporary challenge for the implementation of policies about sustainable development, SD, as a process (Baker 2006, Wackernagel et al. 1996). Far-reaching changes in lifestyles and societal organisations will be necessary in order to achieve the objectives agreed in the world summits. Our relation to nature has become integral to how we are addressing the future of humanity and the management of ecosystems. The ecosystem services approach can be a part of a larger solution (Norgaard 2010). Rockström et al. (2009) identified nine Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. The processes they mention are: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification; global freshwater use, change in land use; chemical pollution, and atmospheric aerosol loading. Rockström et al. (2009) suggested that three of the Earth-system processes; climate change, rate of biodiversity loss and interference with the nitrogen and phosphorus cycle, have already transgressed their thresholds. They concluded that the evidence so far suggests that, as long as the thresholds are not crossed, humanity has the freedom to pursue long-term social and economic development.

At the same time, the commitments promoting the three interdependent pillars of sustainable development open up new opportunities (Sommestad 2002). In Sweden, municipal governments are responsible for most of the planning of the urban and rural land use to realize political and societal expectations related to sustainable development (Nilsson 2001, PBL 1987, Åkerskog 2009). For example, the new legislation about planning and building (PBL 2011) emphasises that municipalities must include in their plans a declaration on how they shall work with climate issues.

Forest landscapes dominate in most Swedish municipalities, and the objectives of forest management vary in time and space. Starting in the early 19th century the forest policy development in Sweden moved from a focus on non-wood forest products and bioenergy for the iron industry, to sustained yield wood production for the forest industry (Arpi 1959, Hagner 2005, Streyffert 1950). The forest policy from 1948 that emphasised increase of timber production for high economic output of the forest industry using clear-felling, planting, cleaning and thinning was an important step in this direction (SFS 1948:237). As a consequence, natural disturbance factors essential for the maintenance of biodiversity were increasingly replaced by disturbances caused by forest management (Östlund et al. 1997). Three decades of sustained-yield focus led to a demand for a greater consideration for the environment and other public interests, which was included in the Forestry Act of 1979. New requirements for regulated forest felling, reforestation, and forest management plans were implemented. A multi-scaled model for biodiversity conservation in forests was introduced in Sweden. Presently, trees are set aside for biodiversity purposes at multiple scale levels with landowner responsibility at local levels and with increasing state involvement at higher levels (e.g., Angelstam et al. 2011, Eriksson and Hammer 2006, Gustafsson and Perhans 2010). The new approach was manifested in the Forestry Act of 1993 (SKSFS 1993:2), in which environmental and production goals were given equal importance. This new environmental quality objective were linked to action strategies like landscape planning approaches for biodiversity conservation (e.g., Angelstam and Pettersson 1997, Fries et al. 1998) and urban green space zoning (Rydberg and Falk 2000) aimed at promoting sustainability in Swedish forests and woodlands in both rural and urban landscapes.

At the international policy level, sustainable forest management, SFM, is one sector-specific direction of sustainable development as a societal process toward sustainability (MCPFE 1993). SFM implies a commitment to deliver a sustained yield of timber, ecological sustainability and rural development including the need to satisfy socio-cultural dimensions of forest management (e.g., Innes et al. 2005). Also, Swedish forest companies' policies and guidelines aim to be generally compatible with the visions of SFM, even if there are differences in the focus on economic versus ecological and socio-cultural dimensions. Sveaskog Co (RiR 2010), StoraEnso (Stora Enso 2010) and SCA (SCA 2010) represent a gradient in companies from more broad objectives to a focus on satisfying the needs of the forest industry. The forestland (productive and unproductive) covers 69% of Sweden's total land area. Thus SFM is a particularly important component for sustainable development in Swedish municipalities.

In Sweden, national policies (NRA 2006, Larsson et al. 2009, Proposition 2007/08:108) stress the need to enhance the outcomes from forests in terms of increased production of renewable raw material as well as the conservation of biological diversity and socio-cultural values. NRA (2006) emphasised increased use of renewable raw material from forests, including wood-based buildings, fibre-based packaging and energy from wood. Similarly, the current Swedish forest policy (Proposition 2007/08:108) underlines that the forest is a renewable resource, the growth of which should increase through more intensive forest management. In relation to that, Larsson et al. (2009) assumed that 3.5 million hectares of forestland and 0.4 million ha of farmland can be used for intensive forestry in Sweden. This policy also requests a follow-up of the role of voluntary nature conservation, and stresses that the knowledge about forests' socio-cultural values must increase.

How can international and Swedish policies about more intensive forest management to increase wood and bioenergy production on the one hand, and more concern about conservation of biodiversity and environmental socio-cultural values on the other, be implemented on the ground? Seeking answers to this question requires analyses of methods coordinating efforts towards a system under which all development takes place within the limits determined by the carrying capacity of ecosystems and positive social development (Sommestad 2002).

Continuous monitoring and assessment of progress in relation to SFM policy is a part of the long-term process of change towards sustainable development based on forest goods, services and values (Merlo and Croiteru 2005). Monitoring means repetitive observations over time, and may focus on various aspects and serve several purposes (Lammerts van Buren and Blom 1997). Assessment is about comparing monitoring outcomes with standards, objectives or norms, and may implicate a need for an adjustment of management. Environmental quality objectives, environmental law and Sweden's commitment to reporting in relation to EU directives and international conventions determine what is monitored. In particular, EU environmental policy place considerable demands on international reporting (Directive 92/43/EEC, European Commission 2009a, European Economic Community 1992). At the other end, there is a need for regional and local monitoring to be able to assess the effectiveness of planning and management (Angelstam et al. 2004a).

Combined with the ongoing transformation from natural to managed forest, intensified wood production will induce new types of land use over large areas already containing different types of land use and cover with different land ownerships in both urban and rural landscapes. This will increase the requirements for environmental monitoring and assessment to support collaborative planning at local to regional levels (Petersson and Jennische 2007, Schmidt 2009). Environmental impact assessment (EIA) and strategic environmental assessment (SEA) play a central role in identifying, predicting and managing the impacts of human activities on environmental sustainability. Recent studies of biodiversity planning processes (Angelstam et al. 2010a, 2011, Blicharska et al. 2011, Eriksson and Hammer 2006, Paper I) show that landscape and regional planning do not satisfy contemporary policies about biodiversity conservation. Current practice suggests that the complexity of the task is underestimated and that new methodological approaches encompassing entire landscapes and even regions are needed (Gontier 2008).

There are many definitions of the term landscape depending on the research field or management context. One, widely accepted, definition is "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (European Landscape Convention 2000). The composition of land cover types in an area and the spatial arrangement of them are two essential features that are required to describe any biophysical landscape (Dunning et al. 1992). Landscape as a scale between the local patch and ecoregion is suitable for integrated spatial planning for two reasons. First, landscapes are usually large enough to contain many different ecosystems with enough redundancy in ecosystem composition, structure, and function to accommodate natural variability in the system while maintaining the flow of ecosystem goods and services. Second, landscape is usually consistent with the scale of human perception, decision-making, and physical management (Leitão et al. 2006). According to contemporary policies a landscape should be sustainable in its ecological, economic, and socio-cultural dimensions, meaning there is more benefit than cost environmentally, financially, and humanly (Doxon 1996). But ancient landscapes disappear gradually with changing life-styles, and new ones emerge. Thus, sustainability relates to the scale and time horizon one is aiming at (Antrop 2006).

Considering both ecological and social systems in spatial planning at a spatial scale between the local and national is consistent with the concept of landscape approach (Axelsson et al. in press, Borrini-Feyerabend 2004, CBD 1998, Dudley et al. 2006, FAO 2003, Singer 2007, World Forestry Congress 2009). This approach to sustainability and SD can be described by five key features for spatial planning (1) a large geographical area, (2) collaboration among actors and stakeholders, (3) commitment to sustainable development and sustainability, (4) knowledge and solutions (Nowotny 1999) including education of people that need this new knowledge, as extension training and trough relevant educational programmes and (5) sharing of knowledge and experiences (Axelsson 2009).

The need to include both ecological and social systems in sustainable development processes has clear implications for spatial planning for all sectors affecting or able to affect forest landscapes (Opdam et al. 2006). Spatial forest planning is an approach that accommodates spatial requirements as well as multiple, often conflicting management objectives (Baskent and Keles 2005, Öhman et al. 2011). These include wood production as well as identification of landscape composition, structure and function, and characterization of various forest values such as biodiversity, recreation, visual quality, erosion control and rural development. Spatial planning activities need to be carried out at several levels (e.g., stand, landscape and region) (see Paper IV) by both public and private sectors. To do this there must be clear strategies at all these levels, and ecological knowledge as well as land cover data for multiple scales should be available to support planning. Additionally, activities of cooperation may also have to be implemented in cross-border, trans-national and European contexts (Elbakidze and Angelstam 2009, Lindén et al. 2000). This includes methods used to influence the distribution of people and activities in space at various scales as well as the location of the various infrastructures, recreation and nature areas (Council of Europe 2006).

The amount of information that must be handled to assess SFM outcomes on the ground is very large, and consists of data on the current status and trends of ecological, economic and socio-cultural variables. Using this information, policy objectives and norms, and planning tools, it is possible to plan toward sustainability (Burton et al. 2003, Skidmore et al. 1997). Planning to implement sustainability policies needs to take into account the entire social-ecological system, and to integrate various specialised areas of expertise (Asplund and Hilding-Rydevik 2001).

To present data using a common spatial and visual interface is a good method to support all actors in the planning process (Boverket 2005, Mozgeris 2008). A GIS is a computerised information system that supports the collection, storage, processing, analysis and visualisation of geographic information (Harrie 2008). A GIS provides a multitude of tools for spatial analysis and modelling, and visualisations that can be used for communication and stakeholder involvement in planning processes (Rambaldi et al. 2006, Zetterberg 2009). Multiple criteria analysis, MCA, has been used as a decision support tool for a wide number of applications (Curtis 2004, Hajkowicz et al. 2007, Marinoni et al. 2009). It has the potential to be used as a tool for sustainability assessment, because it can bring together the sustainability criteria from all dimensions, ecological, economic, and socio-cultural, to give an integrated assessment of sustainability (Graymore et al. 2009). Lately, there has been a rapid increase in the use of GIS-based methods and models to understand, predict, and visualize the spatial distribution of organisms in a landscape.

GIS has sparked interest for three main reasons (Sieber 2006). First, most information used in policy-making contains a spatial component (e.g., address or coordinate). Second, extending the use of spatial information to all relevant actors and stakeholders may lead to better policy implementation through better communication and collaboration. Third, policy-related information can often be analysed and visualised spatially, and the resulting output (mainly maps) can persuasively communicate ideas and convince people of the importance of those ideas. Involving actors and stakeholders of different backgrounds in planning processes, the GIS tool has proved to be flexible and effective in the communication and negotiation of indicators, targets, and impacts (Zetterberg 2009).

The aim of this thesis is to explore the usefulness of GIS as a tool for integration and spatial analysis of ecological, economic and socio-cultural monitoring data for the assessment of SD and SFM policy implementation to inform and support governance processes at multiple levels toward sustainability. Specifically, I address the need to fill the gap in monitoring and assessment of SFM by expanding the spatial scale from the local level to landscapes and regions, and to include the full range of sustainability dimensions. Being a GIS practitioner I want to bridge the research-practitioner gap, by monitoring and assessing landscape conditions (Gontier 2005, Knight et al. 2008, Opdam et al. 2002), and to thus contribute to supplying different actors who need to collaborate in planning processes for sustainability with a common language (Boverket 2005, Mozgeris 2008).

3 Conceptual framework

3.1 Policy cycle

Ideas about what society wants in terms of natural resources provided by landscapes are not constant. Policies therefore change. To understand the main steps of the processes of creating and implementing policies they can be described as a cycle (Mayers and Bass 2004) of iterative policy formulation, decision-making processes, implementation on the ground, and evaluation of the outcomes by monitoring and assessment against the policy norms (Figure 1). Assessment is thus a crucial part of the policy cycle. This implies to compare these results from monitoring with the standards, objectives and norms pronounced in policies of different kinds (e.g., Lammerts van Buren and Blom 1997).

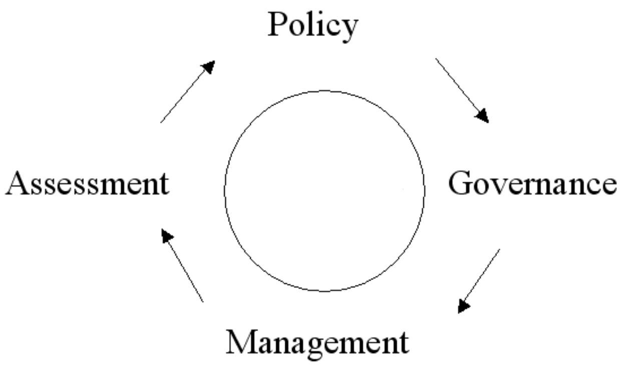

Figure 1. Policy implementation processes illustrated in form of policy cycle.

A standard, such as SFM policy, is defined as a set of principles (P), criteria (C) and indicators (I), or some combination of these hierarchical levels, that serves as a tool to promote sustainability as outcomes, and sustainable development processes (Lammerts van Buren and Blom 1997). A standard describes what should be achieved (P & C) and enables an assessment if, or to what extent, accomplishment is realised (I + norm) (see Table 1). Assessment is critically important both for the longer policy cycle, but also for adaptive management and governance within a cycle (e.g., Walters 1986).

Table 1. Hierarchical levels for assessment of sustainability (Lammerts van Buren and Blom 1997).

Principles	A principle is a fundamental law or rule, serving as a basis for reasoning and action. Principles have the character of an objective or attitude of society concerning the function of the forest ecosystem or concerning a relevant aspect of the social system that interacts with the ecosystem. Principles are explicit elements of a goal e.g., sustainable forest management or well managed forests.
Criteria	A criterion is a state or aspect of the dynamic process of the forest ecosystem, or a state of the interacting social system, which should be in place as a result of adherence to a principle of sustainable forest management (or well managed forest). The way criterias are formulated should give rise to a verdict on the degree of compliance in an actual situation.
Indicators	An indicator is a quantitative or qualitative parameter, which can be assessed in relation to a criterion. It describes in an objectively verifiable and unambiguous way features of the ecosystem or the related social system, or it describes elements of prevailing policy and management conditions and human driven processes indicative for the state of the eco- and social system.
Norms	A norm is the reference value of the indicator and is established for use as a rule or a basis for comparison. By comparing the norm with the actual measured value, the result demonstrates the degree of fulfilment of a criterion and of compliance with a principle.

In this thesis I focus on the assessment part of the policy cycle, and thus:

- Monitoring of ecological, economic and socio-cultural dimensions of sustainability as outcomes of governance and management using data from remote sensing, statistics representing indicators for sustainability and digital maps with different themes.
- Comparison of the parameter values for different indicators with a target or norm as defined for example by an explicit policy, the requirement of a species, or that indicator values should improve and not deteriorate.

3.2 Landscape

Research about policy, governance, management and assessment toward sustainable forest landscapes requires a common theoretical platform for inclusion of (1) ecological, economic, and socio-cultural values, including the related scientific disciplines, and (2) the societal actors balancing these values between policy and practice. Landscape is an important concept within humanities, social sciences as well as in natural sciences (e.g., Forman 1995, Grodzinsky 2005). Thus the landscape concept can be used as a theoretical framework for the integration of data and theories from human and natural sciences (Myrdal 2005), as well as policy makers, practitioners and other stakeholders. The landscape concept can thus improve the understanding of dependencies between social and ecological systems that make up forest, rural and urban landscapes (Mikusinski et al. in press), which in turn will improve the prerequisites for SD and SFM as a societal process toward sustainability. I use the landscape concept and its constituent (1) biophysical, anthropogenic and perceived dimensions, at (2) multiple spatial scales, to bridge divides among research disciplines, and among academic and non-academic actors.

4 The development towards GIS-assisted policy implementation

4.1 Policies and sustainability indicators at different governance levels

Satisfying ecological, economic, and socio-cultural dimensions of landscapes as social-ecological systems is a contemporary challenge for implementation of policies about sustainability as a goal (e.g., WCED 1987) and sustainable development as a process (e.g., Baker 2006, Wackernagel et al. 1996). Focusing on sustainable forest management, traditionally each Swedish forest owner exercises the use rights of wood and some non-wood goods on the own property. New forest-related policy objectives (e.g., Larsson et al. 2009, MCPFE 2007, NRA 2006, Proposition 2007/08:108) stress the need to enhance the outcomes from forests in terms of increased production and use of wood and biomass as well as the conservation of biological diversity and socio-cultural values, and increased value-added production for export (Erlandsson 2011). These ambitions require improved collaboration among different actors at different levels of organisation (Armitage et al. 2009, Folke et al. 2005, Sommestad 2002) and different governance levels from local and regional to nationally and internationally (e.g., Elbakidze et al. 2010).

Locally, forest owners are responsible for stand scale operational management on forestland. To implement the Swedish Forestry Act it is important to use locally suitable tree species in reforestation, and proven methods for soil scarification, planting, seeding or use natural regeneration after clear cutting. Thinning must be used to promote sustained-yield forest development. Timber stock after thinning must be such that site's timber-producing capacity is utilized. At the same time environmental issues such as forest biodiversity should be considered by sustaining some large deciduous trees, old trees, dead trees, groups of trees and securing protection zones near to water, agricultural land and buildings.

Regionally, Swedish municipalities are responsible for spatial planning of the urban and rural landscape to realize political and societal expectations related to sustainability and sustainable development (Alfredsson and Wiman 1997, Nilsson 2001, Åkerskog 2009). To identify potential synergies or conflicting interests the collaboration among municipalities and other actors at the regional level is often necessary (Johannisson and Ancarstig 2007). Sustainable development and planning for sustainability thus requires a comprehensive approach with integration of a wide range of different disciplines and sectors (Asplund and Skantze 2005). There is thus a need to develop planning and governance approaches that provide decision-makers with knowledge about the state and trends of indicators for ecological, economic and socio-cultural criteria of sustainability in relation to agreed norms as support to their decisions (Dovlén 2004).

Nationally, the recently revised Swedish forest policy (Proposition 2007/08:108) accentuates that the forest is a renewable resource, and that growth should increase through more intensive forest management. This proposition also wants a follow-up the role of voluntary nature conservation, and admits that the knowledge about forests' socio-cultural values must increase. Swedish Government commissioned the Swedish University of Agricultural Sciences to investigate the possibilities for intensive forestry on forested land of low value for nature conservation and on abandoned agricultural land (Larsson et al. 2009). Sweden is one of the 16 countries that have developed a National Research Agenda, NRA, with 14 goals for the forest sector in Sweden (NRA 2006). The NRA emphasises more multi-use of renewable raw material from our forests, including building and living with wood, fibre-based packaging and energy from wood.

Internationally, several policies with relevance to sustainable forest management state the need for biodiversity conservation and functional habitat networks (e.g., EU's Bird Directive (European Commission 2009a), Habitat Directive (European Economic Community 1992), and Water Framework Directive (European Commission 2000). There are also policies that accentuate an extended sustainable production of wood as a renewable raw material for value-added production and as a renewable energy source, and thus to enhance wood supply (FTP 2005, MCPFE 2007). Pan-European SFM policy (e.g., MCPFE 1993) stresses that the use of forests and forest lands shall be made in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and socio-cultural functions, and that does not cause damage to non-forest ecosystems. The European Landscape Convention (2000) promotes landscape protection, management and planning, and to organise European co-operation on landscape issues.

Thus, policies at national, EU, European and international levels describe the need for sustaining economic development to support human welfare and quality of life and to avoid negative environmental impacts, as well as require collaboration among societal actors and stakeholders at multiple levels (Table 2a, left column). The different papers in my thesis focus on the challenge of assessing sustainability outcomes of different combinations of these policies (Table 2a, b).

Table 2a. *Policy documents used as backgrounds for assessments of different sustainability dimensions in the seven papers of this thesis. For details about policies, see Table 2b.*

Policy	I	II	III	IV	V	VI	VII
Global level							
1. World Commission on Environment and Development (WCED 1987)	X				X	X	X
2. The Convention on Biological Diversity (CBD 1998)	X	X	X	X		X	
3. Forest Stewardship Council (FSC 1999)				X			
4. World Summit on Sustainable Development (WSSD 2002)	X			X		X	X
5. United Nations Environment Programme (UNEP 2004)	X			X		X	
Pan-European level							
6. Sustainable Forest Management (MCPFE 1993)	X				X	X	
7. European Landscape Convention 2000 (CETS 176)				X	X		X
8. The Ministerial Conference for the Protection of Forests in Europe (MCPFE 2007)	X					X	
EU level							
9. EU Habitat Directive	X	X	X	X		X	
(European Economic Community 1992)							
10. EU Water Framework (European Commission 2000)			X				
11. EU Bird Directive (European Commission 2009a)		X					
12. Renewable energy (European Commission 2009b)						X	X
Swedish national level							
13. NRA 2006						X	X
14. Intensive forestry (Larsson et al. 2009)	X					X	X
15. Proposition 2007/08:108	X			X	X	X	X
16. Proposition 2009/10:155	X			X		X	X
Municipal level							
17. Municipal comprehensive plan (PBL 1987, PBL 2011)						X	X
Local level							
18. Species habitat requirements	X	X	X	X	X	X	

Table 2b. *Policy documents listed in Table 2a used for assessment of sustainability in the seven papers of this thesis.*

Level	Policy
Global	1. The World Commission on Environment and Development (WCED 1987) report gathered different issues related to environment problems and launched a comprehensive gateway to sustainability, which included ecological, economic social, and political-institutional criteria. 2. The CBD-Workshop (1998) adopted the ecosystem approach based on the application of appropriate scientific methodologies that encompass the essential processes and interactions amongst organisms and their environment. The ecosystem approach recognizes that humans are an integral component of ecosystems. There are 12 principles e.g., Management objectives are a matter of societal choice. Management should be decentralized to the lowest appropriate level. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems. A key feature of the ecosystem approach includes conservation of ecosystem structure and functioning. The ecosystem approach should be undertaken at the appropriate scale. The ecosystem approach should involve all relevant sectors of society and scientific disciplines. 3. Forest Stewardship Council (FSC 1999): Shall promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests. Environmentally appropriate forest management ensures that the harvest of timber and non-timber products maintains the forest's biodiversity, productivity, and ecological processes. Environmentally appropriate forest management ensures that the harvest of timber and non-timber products maintains the forest's biodiversity, productivity, and ecological processes. 4. World Summit on Sustainable Development (WSSD 2002): All development should be sustainable, with integrated treatment and equal priority of the ecological, economic and social pillars. 5. United Nations Environment Programme (UNEP 2004): Outlined recommendations for sustainable management of forests and protected forest areas. These include integrating non-protected intact forests with high potential for biodiversity conservation into the large-scale ecological network, analyse potential threats to forest corridors, identify the potential role and functional impact of managed productive forests on the network of protected areas, to prevent and mitigate loss of forest biological

	diversity due to fragmentation and isolation, and restore ecological connectivity, where appropriate. Finally, it is recommended that different stakeholders are involved with the establishment of forest-related ecological networks, and that public awareness is promoted.
Pan-European	6. Sustainable Forest Management (MCPFE 1993): The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, international and global levels, and that does not cause damage to non-forest ecosystems.
	7. European Landscape Convention 2000 (CETS 176): The aims of the Convention are to promote European landscape protection, management and planning, and to organise European co-operation on landscape issues. That means ensuring that due consideration is given to European landscapes through the adoption of national measures and the establishment of European co-operation between the Parties. Sweden had not ratified the Convention in May 2010.
	8. The Ministerial Conference for the Protection of Forests in Europe (MCPFE 2007): The importance of using sustainable produced wood as a renewable raw material for value-added production and as a renewable energy source, and thus to enhance wood supply. MCPFE also emphasised the need to maintain, conserve, restore and enhance the biological diversity of forests and ensure that forests and their sustainable management play an active role in the sustainable development and well being in European society, for both rural and urban areas. MCPFE also stresses the need for effective measures to improve understanding between policy makers, practitioners and the scientific community in order to better use scientific knowledge and research results relevant to forest and forest sector as a sound basic for decision making.
EU	9. Habitat Directive (Council Directive 92/43/EEC): Essential objective are the preservation, protection and improvement of the quality of the environment, including the conservation of natural habitats and of wild fauna and flora.
	10. Water Framework Directive (Directive 2000/60/EC): The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems.

	11. Bird Directive (Directive 2009/147/EC): This Directive relates to the conservation of all species of naturally occurring birds in the wild state in the European territory of the Member States to which the Treaty applies. It covers the protection, management and control of these species and lays down rules for their exploitation.
	12. European Commission (2009). Directive 2009/28/EC sets mandatory national targets of 20% for the overall share of energy from renewable sources in gross final consumption of energy and 10% for the share of energy from renewable sources in transport by 2020.
Swedish	13. NRA with 14 goals for the forest sector in Sweden. The NRA emphasises more multi-use of renewable raw material from our forests, including building and living with wood, fibre-based packaging and energy from wood.
	14. The MINT report (Larsson et al. (2009) assumed that 3.5 million hectares of forestland and 0.4 million ha of farmland can be used for intensive forestry to increase the production of biomass.
	15. Proposition 2007/08:108: The forest is a renewable recourse and their growth must increase through intensified forest management. In addition the follow-up about the voluntary nature conservation should be strengthened, and the knowledge about the forests social values must increase.
	16. In Proposition 2009/10:155 emphasis that increased knowledge about ecosystem services and their values are central to efforts to achieve environmental objectives and provide a basis for further work on the development milestones and strategies for the 16 environmental goals.
Municipal	17. Municipal comprehensive plan (PBL 1987, PBL 2011): Swedish municipalities are responsible for physical planning of the urban and rural landscape to realize political and societal expectations related to sustainable development. That means for example that the dimensions ecological, economic and social values shall be balanced. Municipalities must also include in their plans how they shall work on climate issues, both to prevent climate change and their readiness for change.
Local	18. Species habitat requirements: An umbrella species is a species whose conservation confers protection to a large number of naturally co-occurring species (Roberge and Angelstam 2004). The umbrella species concept is one way to use species requirements to assist conservation planning. Its main assumption is that the requirements of demanding species would encapsulate those of other, co-occurring species that have lower requirements (Lambeck 1997).

4.2 Spatial planning at local to regional scales

One approach to assess the extent to which ecological, economic, and socio-cultural sustainability dimensions as pronounced in policy are implemented, is to detect signs of unbalanced relationships and trade-offs between sustainability components. Ideally, multiple governance levels need to be included in such analyses (Borgström et al. 2006, Vierikko et al. 2008, Table 3).

Different forest owner categories, municipalities, counties and regions have different opportunities and roles regarding the governance of natural resources, value-added production, networking and entrepreneurship, conservation, recreation and providing a sustainable environment for its inhabitants. People have different cultural values, lifestyles and life modes (Thellbro 2006, Frykman and Hansen 2009). A successful sustainable development process requires the municipal planning process to take local responsibility for implementation of policies also at the county and regional level (Frykman and Hansen 2009, PBL 2011).

Focusing on sustainable forest management policy, the inclusion of new criteria and increased levels of ambition regarding biodiversity conservation (SKSFS 1993:2), urban forestry and rural development (ETOUR 2006, MCPFE 2007), have led to a need to expand the spatial scales of planning, and thus assessment (Table 3).

Table 3. Summary of the development of forest management in the US and Europe during the past 100 years. The numbers indicate the order of appearance of different challenges towards SFM and sustainable development *(see also Andersson et al. 2009).*

<table>
<tr><td rowspan="4">Scale of spatial planning</td><td>Regional</td><td colspan="3">(7) Municipal and Regional Planning for the management and utilization of natural resources.</td></tr>
<tr><td>Landscape</td><td>(6) Zoning</td><td>(4) Ecological landscape planning</td><td>(5) Rural development</td></tr>
<tr><td>Stand</td><td>(1) Sustained yield forestry</td><td>(2) Green tree retention</td><td>(3) Urban forest, socio-cultural considerations</td></tr>
<tr><td></td><td>Economic</td><td>Ecological</td><td>Socio-cultural</td></tr>
<tr><td></td><td></td><td colspan="3">Dimension of sustainable development</td></tr>
</table>

4.2.1 Sustained yield forestry

Today's high and sustainable wood production took a long time to develop in Sweden (e.g., Angelstam et al. 2010b, Axelsson and Angelstam 2011, Hagner 2005). The political awareness of the need for active forest management grew gradually from the early 1800s, and the forest product export breakthrough was after 1850 (Enander 2007, Streyffert 1950). From the 1950s a large-scale transition was completed from a low level of logging due to dimension fellings, insufficient or lack of forest management and a previous over-exploitation of forest resources, to the clear-felling systems including site preparation, planting, pre-commercial cleaning of young forests and thinning. The result was a sharp increase in timber growth and timber volumes in the whole of Sweden (Riksskogstaxeringen 2010). Forestry and forest industry now accounts for approximately 3% of GDP, and 11.7% of the total export value from Sweden 2010 (SCB 2010).

4.2.2 Green tree retention

The intensification of forest management with a focus on conifers resulted in smaller and more fragmented areas of old forest and deciduous forest, less dead wood and fewer large old trees (Andersson and Östlund 2004, Angelstam et al. 2004c, Linder and Östlund 1998). This is linked to the challenge of maintaining biodiversity, i.e. species, habitats and ecosystem processes, and led to forest policy amendments in 1993 so that production and environmental objectives were given equal importance. Planning for sustainable economic use of wood and at the same time maintaining biodiversity resulted in green-tree retention (Rosenvald and Lohmus 2008) and a need for education of private forest owners and forest planners (Persson 1990). At the same time new forms of forest conservation and environmental concerns to conserve species were developed (Mikusinski et al. 2007) by mimicking natural forest composition and structure (Angelstam and Kuuluvainen 2004), and also by trying to maintain ecological processes such as fire (Angelstam 1998) and flooding (Nilsson and Berggren 2000).

4.2.3 Urban forest, socio-cultural considerations

As in many other developed countries also in Sweden access to forest close to cities, towns and settlements is valuable for human quality of life and human well-being (Björk et al. 2008, Fredman et al. 2008, Grahn and Stigsdotter 2010). About 85% of Sweden's population lives in urban areas. Urban forests that are easily accessible affect people's opportunities for recreation and contact with nature. Forest environments of various kinds can be used as classrooms in schools to children already at a young age, and thus opportunity to learn why societies are dependent on nature and its conservation (Fredman et al. 2008). There is often an interest to develop alternative forestry methods, such as continuous cover forestry in urban forests (Axelsson and Angelstam 2011, Rosell et al. 2010). An EU project, (EU LIFE 2005) demonstrated new ways to increase the number of visits and recreational value due to urban forest by increasing accessibility for all, management advice, coordination and guidance.

4.2.4 Ecological landscape planning

The guidelines in forestry and environmental policy about the conservation of biodiversity requires sufficiently large areas of representative habitat of suitable quality that form functional networks of representative forest habitats so that viable populations of all naturally occurring species can be maintained (Angelstam et al. 2010a, 2011, Mikusinski et al. 2007). This requires spatial planning for contiguous areas of tens of thousands hectares within a region (Angelstam et al. 2004a, Fries et al. 1998). Functional habitat must be identified and, where it is necessary, be protected, maintained and developed with the support of spatial plans followed by appropriate management. With the large number of private landowners in Sweden, collaboration between landowners is a prerequisite for achieving both production and environmental goals (Naturvårdsverket 2005).

4.2.5 Rural development

As large-scale mechanization of forestry and larger production units for processing of wood developed in the 1970s the role of forestry for rural areas decreased by reducing the number of forestry jobs (Svensson 2009). Approximately 15% of Sweden's population live in different types of rural areas, which account for 99% of the total land area (SCB www.scb.se). EU has developed a concept called Leader, to develop the local interaction with a focus on sustainable development in rural areas (European court of auditors 2010). The Leader approach identifies problems and opportunities as well as actors who must work together to create viable local collaborative processes for sustainable development. However, there is a need to develop synergies between Leader, municipal planning processes, and other forms of regional and local development with local landscapes as the base.

4.2.6 Zoning

To increase and develop the use of wood as a renewable natural resource is an important part of achieving SFM and this is supported by several new policy documents (Larsson et al. 2009, MCPFE 2007, NRA 2006, Proposition 2007/08: 108). Improved conservation through the protection, management and restoration of biodiversity, and use of forests and woodlands for recreational purposes is also accentuated. If all interests shall be met in a sustainable manner, there is a need for spatial planning of both landscapes and regions (Opdam et al. 2006). One model is to divide the landscape into different zones for different goals such as intensive timber production, ecologically valuable areas or for recreation (Innes et al. 2006). Making this zoning to accommodate different dimensions of SFM requires collaboration among many different stakeholders and landowners in landscapes and regions.

4.2.7 Municipal and regional planning for the management and utilization of natural resources

Municipal governments have the responsibility to plan for realizing the policy goals of sustainable development in Sweden (Alfredsson and Wiman 1997, Nilsson 2001, PBL 1997, Åkerskog 2009). This responsibility has been strengthened and one example is environmental planning (PBL 2011). The goal and challenge is to plan for long-term economic development and social well-being, while achieving the ecological objectives set. To guide planning processes it is therefore important to collect, analyse and present data for all sustainability dimensions. Using this information and planning tools, including both "hard" technology such as GIS and "soft" as the collaborative social processes, it becomes easier to plan for sustainability and sustainable development. Good communication among policy makers, planners and local citizens, cooperation among municipalities in regions and among different institutions, is the core of the planning process (Boverket 2005).

4.3 The use of GIS in Sweden

The Swedish Development Council for Land Information, ULI, has carried out surveys about the use of GIS and geographic information in Sweden since 1990 with a few years interval. In the survey 2000 (Andersson 2001), 327 of 412 respondents answered that their organizations was using or planning to use GIS. The respondents represented municipalities and county councils (58%), government agencies (10%), county administrative boards and corporations (24%) and universities (8%). The number of people who use GIS in their daily work had increased by 39% between 1997 and 2000. The most common GIS applications used were for planning, general mapping and technical supply. Other areas were properties, environmental protection and forestry. The majority of the respondents argued that the price of spatial data is too high, and 50% of them reported this as a reason for refraining or delaying projects. The majority believed that the quality of available data is acceptable. The most important elements of success in terms of GIS use was indicated as; the organisation management must be positive, data must be stored in bases which are accessible for the whole organisation, and there must be a clear IT-strategy where GIS is a part.

There was a clear concentration of organisations using GIS in large urban regions (Ottosson and Samuelsson 2005). The largest application areas for geographic information (more than 150 organisations) were in planning, map production, environment, utilities, real estates, traffic, transports, and water. Additionally, 50-150 organisations used geographic information in forestry, education, sports, tourism, geology, health and social care, IT services, rescue, and agriculture. The most used data sets were addresses, data of protected areas, land cover data, real estate data, soil data, and data of river basins. These data was used by 350-450 organisations. Almost 400 organisations in the survey say that they would buy more data if the price were lower. Most informants were satisfied with the present data quality. In order to obtain better success with the use of standards, the informants say that main actors, like the National Land Survey, must be predecessors. It is also important to inform about standards and give better technical support for adaptations in existing systems.

The informants said in both surveys that the largest obstacles for a continuous development are the cost for data and systems. Other obstacles were the lack of knowledge within the personnel and the interest and understanding for the usefulness of GIS within the organisation. Internal billing and funding arrangements are also regarded as major problems.

The largest perceived benefit of using GIS was improved quality of analysis, presentations, and decision support. The most important elements for success were skills and education of staff. Another important advantage of GIS was that organisations were considered to be more effective in their work, and that the entire organization becomes more efficient. Another important advantage was that geographic information and business information will be collected in one place, which makes it available to the entire organisation.

The reason for the increased use around the year 2000 was primarily increasing availability of geodata, meaning all information linked to a geographic place. Geodata had previously been expensive and unavailable to many businesses. What happened in 2000 was also that Google, Microsoft and others made GIS more commonly known in its simple form (Patrik Ottosson, ESRI-sgroup, pers comm.). The largest increase could be found in the use of simple systems as data viewers. Advanced usage, data acquisition, research and support functions in year 2000 were approximately on the same level as before (Ottosson and Samuelsson 2005).

Also in the research field the interest for GIS use has increased. Search in the SCOPUS database for articles with "geographic information system" or "geographical information system" in title, abstract or keywords for the period 1979-2010 shows a clear increase of articles over time (Figure 2). This investigation was done October 2011. The increasing interest of GIS as a tool for research thus follows the same pattern as the organisations' use of GIS in Sweden.

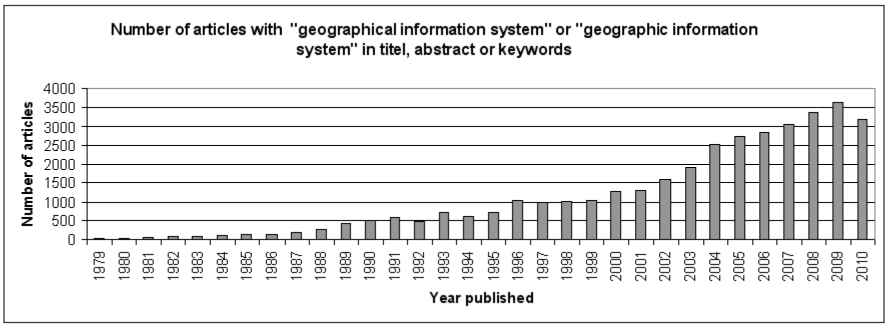

Figure 2. A selection in SCOPUS about articles with "geographic information system or geographical information system" in title, abstract or keywords, summarised for each published years.

An extensive training in GIS for municipalities and county boards was implemented with a government mandate under the StrateGIS project during the years 1999-2002 (Söderström 2003) and later education books (e.g., Arnberg 2006, Harrie 2008). The training was designed with the intent to support a parallel development process within organizations and with the target groups, i.e. decision makers, GIS coordinators and administrators, and other users of GIS. Overall, about 17,900 participants were trained. In particular, the second training stage attracted attention even outside the directly affected audience as it dealt with aspects of planning, deployment and operation of GIS in a way that has not previously been made in Sweden. The project resulted in the introduction and development of GIS in many municipalities. The project also resulted in training compendiums, which can be utilized in various forms of internal and joint training. Furthermore, the project established a series of regional and national contact networks, which contribute to collaboration on continuing education, development and use of GIS.

In recent years, the use of geographic information has been broadened (ULI 2008) and it is only one percent of the organisations in the survey that do not use GIS. The use of GIS increased most in the fields of health, epidemiology and school management. Nevertheless, it is the simple use of GIS that has increased most, e.g., data viewing, whereas more advanced analyses are still uncommon. A total of 90 percent of the organisations see a need for greater expertise on geographic information.

The Environmental Systems Research Institute, ESRI, is one of the largest actors in GIS tools development worldwide and in Sweden. Their customers can be divided into four groups: economic, environmental (including health and socio-cultural values), collaboration, and security. In recent years there has been a small slowdown of the traditional GIS users, particularly in the public sector (P. Ottosson, ESRI-sgroup, pers comm.). In contrast GIS use increases in companies with logistics/supply chain, sales/marketing and other processes with spatial objects in order to increase economic benefits. More organizations are also considering using Open Source GIS. The E-delegation's proposal (SOU 2009:86) to the Swedish authorities is that open standards is the first choice when choosing a technical solution, and that open source software should always be considered when selecting the solution.

5 Planning for sustainability: the use of GIS

Predictive ecological models have been developed within strategic conservation planning and forest management to model and visualise the distribution of habitats (Gontier 2005, Guisan and Zimmermann 2000). However, practical application of such models is limited due to poorly developed collaboration and planning across the borders of different forest owner categories (Angelstam et al. 2011, Axelsson et al. in press). The use of GIS in public planning has thus not reached the level that scholars have envisioned (Merry et al. 2008), and planners are not aware of the full potential of GIS for planning purposes (Göçmen and Ventura 2010, Vonk et al. 2005). This reflects the situation that the knowledge about GIS in planning is not sufficient, and that GIS is mainly used as a database (Wei et al. 2011). Thus, GIS is seldom used for modelling or spatial analysis (Göçmen and Ventura 2010, ULI 2008) and GIS-experts and planning staff often are different persons, and who are not communicating well (Göçmen and Ventura 2010, Reneland 2000).

In this thesis I provide examples of how common GIS-tools and freely availably data in combination with knowledge from different areas of expertise, can make data useful for supporting spatial planning of all dimension of sustainability. To support implementation of sustainability policies, impacts on biodiversity of urbanisation, transport infrastructure, land use changes and other developments must be considered on landscape and regional scales (Mörtberg 2004). Municipalities form the lowest level of formal democratic governance in Sweden (Ekstedt and Wolvén 2003) and are responsible to realize political and societal expectations related to sustainable development (Nilsson 2001, PBL 1987, Åkerskog 2009). My approach in this thesis has thus been to focus on the municipalities as the local level, and to expand and connect that spatial scale to both finer (landscapes) and coarser (regions) spatial resolutions (see Table 4). This thesis consists of seven papers. The common denominator for all papers is the use of GIS to analyse, integrate and present data concerning different dimensions of sustainability. In the following I concentrate on the use of GIS analyses in the seven papers.

Table 4. *Overview of the papers in this thesis with respect to the spatial scale of planning and dimension of sustainability. Roman numbers refer to particular papers included in the thesis.*

Regional	(VII) Municipal planning;		
Landscape	(VI) Sustained yield regional planning	(I) Habitat network functionality (II) Terrestrial focal species (III) Aquatic focal species (IV) Forest certification	(V) Tourist recreation selection
	Economical	**Ecological**	**Socio-cultural**

(Paper I). I compared the outcomes of efforts to implement biodiversity conservation policies among four forestland owner categories in Sweden with different internal policies and planning approaches with respect to habitat suitability outcomes on the ground. Using publicly available national level raster data from year 2000, I estimated the amount and location of functional habitat tracts for area demanding focal species representing five coarse forest types in four boreal ecoregions. Then I calculate clear-felling rates within and outside functional tracts of habitat for each of the forest owner categories were estimated by overlay analyses for the period 2001-2008.

(Paper II). The white-backed woodpecker, (*Dendrocopos leucotos*) is a focal species for forest biodiversity conservation in Sweden. As a complement to raster data to assess the quality of forest habitats for this focal species I used proxy variables expected to indicate either a lower intensity of forest management or the occurrence of natural processes favouring creation of deciduous trees and dead wood being vital for the species. The GIS-based proxies used were farmland-edge forest, forest far from roads, forest on steep slopes, water-edge forest, wetland forest and highest coastline. These were measured in a radius of 500 meter around each known white-backed woodpecker territory.

(Paper III). I tested the hypothesis that it is possible to predict population viability (reproducing/not reproducing) and status of an aquatic focal species, the Freshwater Pearl Mussel, (*Margaritifera margaritifera*) from raster data describing land cover in the riparian zone, water chemistry data and electro fishing data describing the abundance of the host fish species (Brown Trout, *Salmo trutta*) for mussel larvae.

(Paper IV). In this paper I analysed the ability of commercial forestry to satisfy different levels of ambition concerning biodiversity conservation, and if the FSC forest certification standard requirements were implemented. Forests set aside formally and voluntarily for biodiversity conservation in two large forests management units in the Russian Federation and Sweden, respectively, were used for assessment of structural and functional landscape connectivity using Morphological Spatial Pattern Analysis (e.g., Vogt et al. 2007a, 2007b) and habitat suitability modelling (e.g., Store and Jokimäki, 2003), respectively.

(Paper V). This study explored the differences among nature tourists, local inhabitants and municipal civil servants with respect to what they appreciate in terms of ecological and socio-cultural landscape values, and how these values can be used to improve the attractiveness of an area. I used digital databases and GIS to model interpretations of these perceived values and visualised the results as maps.

(Paper VI). Here I combined assessment of ecological and socio-cultural sustainability values, to identify landscapes and regions with low risk for conflicts between green infrastructure functionality and intensive forest management. Because municipalities are responsible for comprehensive planning the results are presented as thematic maps to identify those municipalities that would need to develop communicative planning skills because of high risk of conflicts.

(Paper VII). Using indices built on statistical data representing ecological, economic and socio-cultural criteria, I compared the state and trends of sustainability for municipalities in the historically industrially prosperous Bergslagen region in Sweden as an example, with surrounding more diversified municipalities, and visualize the results as maps using GIS.

6 Methodology

6.1 Study areas

6.1.1 The boreal forest biome

My thesis focuses on the boreal forest, the second largest forest biome of the world (Millennium Ecosystem Assessment 2005). Using the most developed region in terms of sustained yield forestry, central Sweden with the Bergslagen region in Sweden as a base, I also chose study areas that represent other boreal contexts in terms of different biophysical conditions, environmental history and forest governance (Angelstam et al. 1997) (Figure 3).

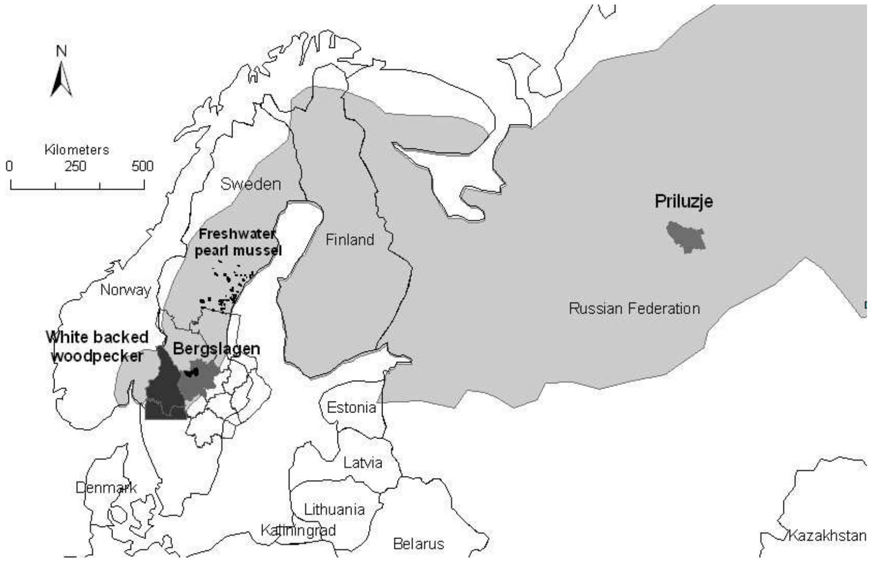

Figure 3. Location of study areas overlaid on a map of the boreal forest (grey) in Europe according to the Millennium Ecosystem Assessment (2005). Papers I, VI and VII focused on the Bergslagen region and the surrounding 9 counties, Paper II on the white backed woodpecker in Dalsland/Värmland, Paper III on the freshwater pearl mussel in Västernorrland County, Paper V on the Säfsen Resort in Ludvika municipality in Bergslagen, and finally Paper IV on Bergslagen in Sweden and the Priluzje forest management unit in SW Komi, Russian Federation.

6.1.2 Central Sweden

Ecoregions is a classification of the representative type of nature in the Nordic countries made by the Nordic Council of Ministers (1983) with the aim of providing stratification for the physical planning of the countryside. To cover the variation in biogeography, and linked socio-cultural conditions, from mountains to the sea in Sweden, including forest ownership and diversity of municipalities, I chose the urban-rural gradient from hemiboreal to north-boreal in south-central Sweden, (Figure 4). This area is composed of nine counties with 119 municipalities and with a total area of 145 000 km^2 (SCB) of which (50%) are forest.

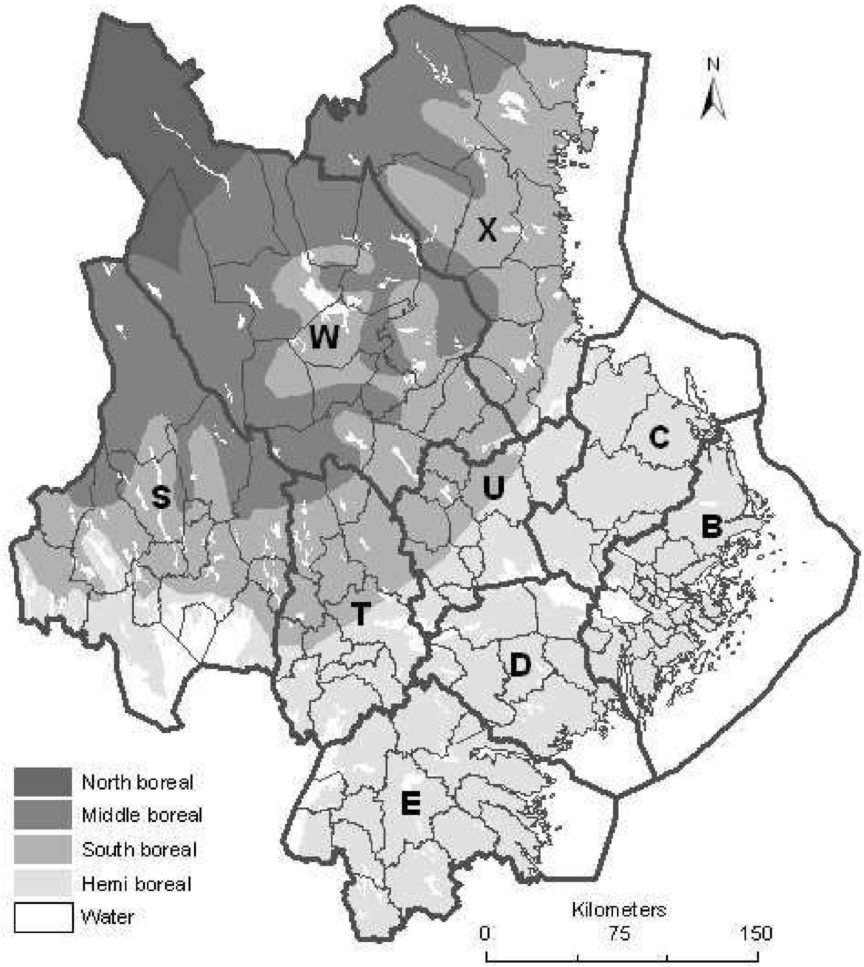

Figure 4. Location of four different boreal sub-ecoregions in the nine counties Stockholm (B), Uppsala (C), Södermanland (D), Östergötland (E), Värmland (S), Örebro (T), Västmanland (U), Dalarna (W) and Gävleborg (X) in south-central Sweden. The smallest polygons represent the 119 municipalities in these nine counties.

Being a biogeographically extended country with a diverse environmental and economic history the decision landscape in Sweden's forests is strongly related to the type and structure of land ownership. The landowners can be divided in four categories (Table 5). In general, most productive land is owned by non-industrial private owners in the south (Angelstam and Pettersson 1997). The public owners have the least productive land (Götmark and Nilsson 1992). In addition, non-industrial private forest owner groups have different possibilities to manage their forests depending on the skill, interest, economic potential and policy of the owner (e.g., Ingemarsson 2004).

Both biogeography and forest ownership are closely associated with the land use history. A shorter history of land use has led to lower loss of past natural forest areas in more northern ecoregions (e.g., Angelstam et al. 2004b), while longer land use history in the southern regions have resulted in quite diverse cultural woodlands (Ihse 1995, Selander 1957). This provided opportunity for species specialised on natural forest properties to be temporarily rescued by natural succession in gradually abandoned cultural landscapes (Paper I). Additionally, the size and spatial configuration of forestland ownerships varies among regions. Thus, landowners in different ecoregions have different opportunities to spatial planning at the landscape level and different needs for collaboration and data (Papers I and VI).

Table 5. *Landowners divided in four categories and their proportions of forestland in the nine counties.*

Landowner category	Proportion of all forestland (%)
Non-industrial private forestland owners (NIPF) have not engaged themselves in spatial planning, other than at very small spatial extents.	44.8
Forest industry landowners initiated in the late 1980s efforts towards biodiversity conservation by landscape planning at spatial scales between the local stand and ecoregional levels (Angelstam and Pettersson 1997, Fries et al. 1998).	32.0
Sveaskog Co.'s environmental policy has higher policy ambitions compared to other industrial forest companies, including a 20-% target for set-aside of trees and stands (Sveaskog 2007), and to identifying ecoregional concentrations of areas with the highest conservation values with good chances of maintaining viable populations of specialised species, i.e. so-called Ekoparks (Sveaskog 2004). This merits Sveaskog Co. to forms there own a third group.	12.2
The public sector in Sweden focus on conservation and not on material resource production.	6.2
Other forestland owners not analysed	4.9

6.1.3 Bergslagen

Located in the middle of the nine counties in central Sweden (Figure 5), Bergslagen is a historical region of great historical importance to Sweden (Isacson 2004). In particular, the integrated use of forests, water and mineral deposits shaped the region through several centuries (e.g., Heckscher 1935-49, Nelson 1913, Seebass 1928, Wieslander 1936). The spatial extent of Bergslagen has no single official geographical definition. To offer a neutral spatial definition of Bergslagen I compiled 20 maps of parishes using different definitions of Bergslagen (Table 6), and ranked parishes according to how many definitions they were a part of. Municipalities for which at least parishes that belonged to more than 10 definitions made up 50% of the area were used to define 18 municipalities as the core of Bergslagen (Figure 5). This definition of Bergslagen consists approximately of 500 000 inhabitants and the total area 15 000 km2 of which 12 000 km2 are forest (calculated from topographic land use map). Thus, with 80% forest, planning for SFM is important for the area. There are 10 different large forest landowner categories (Naturvårdsverket 2005) and many have their forest scattered over the entire Bergslagen. There are also many non-industrial forestland owners scattered across the area. Bergslagen has long forest use history due to the use of wood in the iron industry. The main forest tree species are Norway spruce (Picea abies) and Scots pine (Pinus sylvestris) but the agriculture areas have also mixed coniferous and deciduous forests.

Table 6. *Different definitions of Bergslagen used to estimate the location of the core of the Bergslagen region (see Figure 5).*

Id	**Description**	**Reference**
1	Bergslagen defined by Geological Survey of Sweden.	Sveriges Geologiska Undersökning, SGU 2007
2	Bergslaget – Member Municipalities	www.bergslaget.com
3	Bergslagen in sense of legal framework for the iron works at the time, "brukslagstiftning"	Heckscher 1935–49
4	Parishes containing places those have companies with Bergslagen in their name	Eniro, www.eniro.se
5	Trains in Bergslagen - parishes within a buffer of 20 km from railways.	Using GIS I made a 20-km buffer around the railway line, (Linjekarta, www.tagibergslagen.se), and selected the parishes that intersected the buffer.
6	Mining areas	Seebass 1928
7	Bergskraft Bergslagen.	Based on the bedrock map, SGU 2007
8	Bergslager in Sweden	Riksantikvarieämbetet, Atlas covering Svedens "bergslager"
9	Destination Bergslagen	web.telia.com/~u22317052/ (Closed)
10	Ekomuseum Bergslagen	www.ekomuseum.se
11	Bergslagen Geological extent	Seebass 1928
12	Iron industry	Seebass 1928
13	Culture Geographical provenance	Seebass 1928
14	Rural area Bergslagen 1918	Seebass 1928
15	Rural area Bergslagen 1921	Seebass 1928
16	Bergslagens approximate border	Nordisk familjebok 1925
17	Region Bergslagen	Seebass 1928
18	Topographic Bergslagen	Seebass 1928
19	Agricultural census Bergslagen	Agricultural census 1932
20	Leader Bergslagen	leaderbergslagen.se

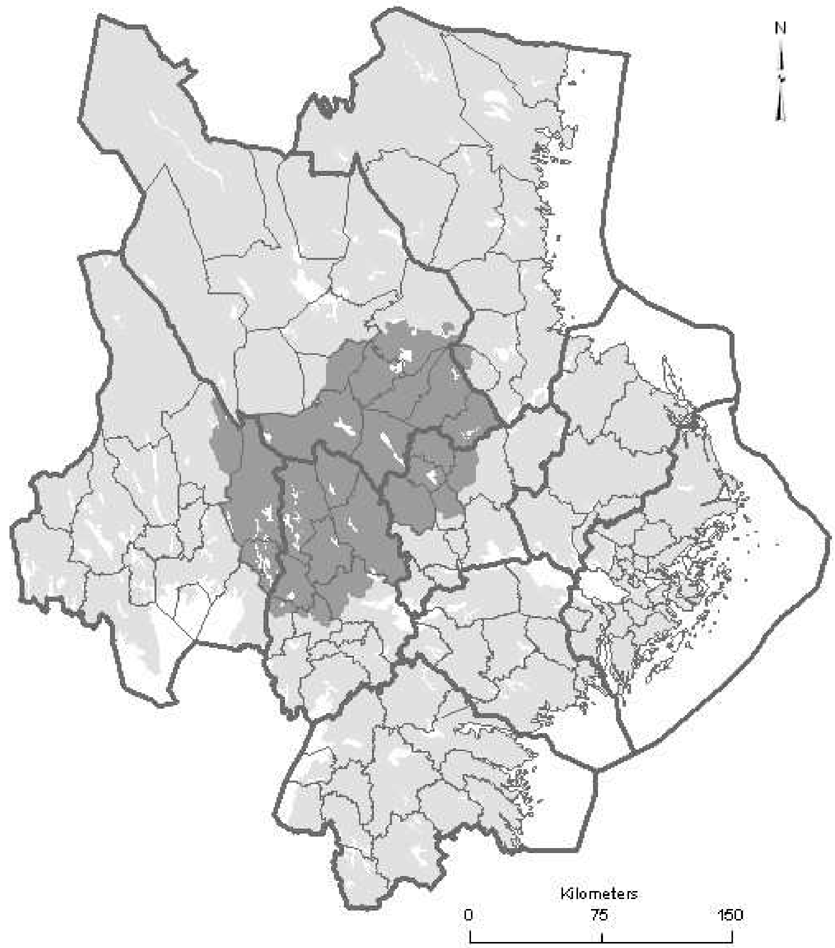

Figure 5. Municipalities in south-central Sweden showing the location of Bergslagen according to 20 maps with different definitions (see Table 6). The 18 municipalities within the light grey area, and for which at least 50 % of the municipal area was made up by parishes that belonged to more than 10 definitions were used to define 18 municipalities as the core of Bergslagen (Avesta, Borlänge, Fagersta, Filipstad, Gagnef, Hedemora, Hällefors, Karlskoga, Lindesberg, Ljusnarsberg, Ludvika, Nora, Norberg, Skinnskatteberg, Smedjebacken, Storfors and Surahammar).

6.1.4 Västernorrland County

The Västernorrland county in Mid Sweden (Figure 3) covers 21 700 km^2 of which (76%) is forestland (SCB 2008). The county is located in the middle boreal and south boreal ecoregions. The county has only 7 municipalities with a total of 242,625 inhabitants (in 2010). There are 9 different forest landowners (Naturvårdsverket 2005) and many have their forest scattered over the entire county. The main tree species are Norway spruce, Scots Pine and birches. The county hosts most of the streams with viable populations of freshwater pearl mussel in Sweden (Söderberg et al. 2008).

6.1.5 Komi Republic in NW Russia

Assessments of sustainability in social-ecological systems with different histories of forest use are likely to yield different results. To contrast Sweden with a generally long forest use history with data from a region with a short history of forest I used a Russian study area in Komi (Paper IV). The Komi Republic located in the south, middle and north boreal ecoregions in the Russian Federation's northwest (Figure 6). In the southernmost part of the Komi Republic the Priluzje forest management unit the Komi Model Forest project was carried out with the aim to support implementation of SFM policy (Elbakidze et al. 2010). This management unit covers 810,000 ha, and forms one contiguous block of forested land 126 km from north to south and 118 km from west to east. Similarly to the situation in Bergslagen, the main tree species are Norway spruce and Scots pine. However, forests with domination of birch (Betula spp.) and aspen (Populus tremula) occupy almost 40% of the total forested land as a consequence of previous large-scale disturbances, by fire and logging without silviculture. Priluzje still hosts pristine forests with natural dynamics and, consequently, near-natural composition, structure and functions. Forests classified as pristine in Priluzje occupy almost 12% of the total forested area (Anonymous 2008).

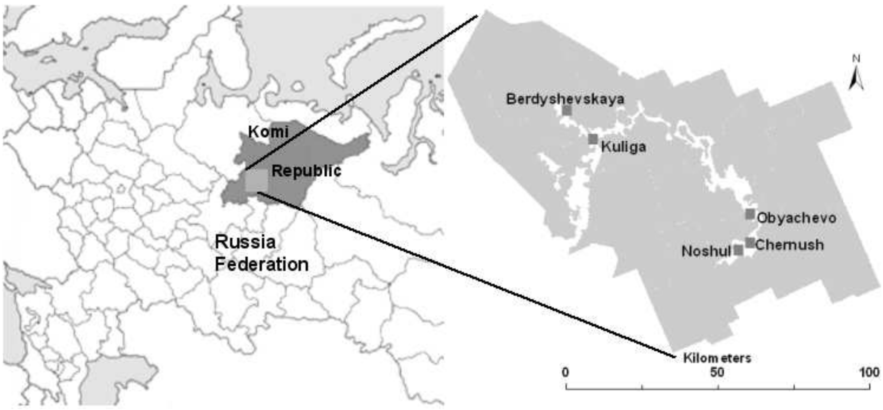

Figure 6. The Priluzje forest management unit the Komi Republic.

6.2 Overview of data used for different sustainability dimensions

Table 7. *All data used in this study, the dimension of sustainability and in which paper different data have been used.*

Criteria	Paper I	Paper II	Paper III	Paper IV	Paper V	Paper VI	Paper VII
Economical	Clear-cut monitoring			Forest data	Clear-cut monitoring	Clear cut monitoring	Employed 20-64 year
	Land owners						Salary level
							Business climate
							Commuting
							Tax base
Ecological	k-NN Sweden	k-NN Sweden	Topographic Map	Forest data	k-NN Sweden	Topographic Map	Energy consumption
	SMD	SMD	SMD	Protected area	SMD	k-NN Sweden	Protected area
	Topographic Map	Topographic Map	DEM			SMD	Greenhouse gases
	Ecoregions						Biological production capacity
							Travelling with car
Social					Topographic Map	Topographic Map	Level of education
					DEM	DEM	Exposed for violence
					Historical remains		Expected life span
							Sick leave
							Democratic provide

6.2.1 Raster data

For habitat modelling four spatially explicit land cover raster databases were used. First, the k-NN Sweden database produced by the Dept. of Forest Resource Management, Swedish University of Agricultural Sciences derived by using a combination of remote sensing of satellite scenes from year 2000, and data from National Forest Inventory. The dataset describes the spatial distribution of forest stands with attribute data about the volume of tree species, average stand age and height for each 25 by 25 m grid cell (Reese et al. 2003). Second, I used the Swedish Land Cover Data (SMD) from the National Land Survey. SMD emits from the EU CORINE land cover programme (Engberg 2002). The dataset describes the spatial distribution of land use in 60 different classes for each 25x25 m grid cell. Third, clear-felled areas from the Swedish Forest Agency's yearly monitoring of clear-felled areas (Persson and Banck 1998) between 2001 and 2008. Those areas are calculated by change analyses from satellite images and connected to clear-cut announcements made by forest owners. Finally, the Digital Elevation Model, DEM, from the National Land Survey describes the meter above see level for each 50x50 m grid cell (Lantmäteriverket 2001). These data sources were used in Papers I, II, III, V and VI.

6.2.2 Openly available sustainability indicators

Indicators representing relevant information about different sustainability dimensions have frequently been used to summarize the complex array of information sources to recognizable patterns (Bell and Morse 2003, Lammerts van Buren 1997). The Swedish government and Statistics Sweden (SCB) have defined 84 indicators applicable to sustainable development at the national level (Anonymous 2006). SCB and the government offices of Sweden consider 12 of these indicators as main indicators of which five are available at the municipal level and were all included in this study. I used nine additional indicators defined by county administrative boards in the Bergslagen region, and by the Swedish Institute for Growth Policy Studies (ITPS 2004). Finally, one indicator (the area of productive agricultural land per capita) is not an official indicator but instead related to the concept of the ecological footprint of humanity (Wackernagel and Rees 1996), and thus highly relevant for this study. The ecological footprint is a measure of human use of the earth's biological production capacity, and often used in sustainability assessments because of its capacity to relate consumption to sustainability. The indicator data was used in Paper VII.

6.2.3 Other digital maps

First, a landowner map with holdings of more than 1000 ha of forest in 2004 (Naturvårdsverket 2005) was used. Second, data about ancient and historical remains was used from The Archaeological Sites and Monuments database (National Heritage Board 2010). Third, protected areas from County Administrative Boards GIS services and key biotopes from Swedish Forest Agency were used. All data above are freely availably to download from Internet. In addition the topographic map 1:100 000 and 1:50 000 from the National Land Survey of Sweden (Lantmäteriverket 1998, 2005) was used. This database includes roads, lakes, water, elevation, and main land cover categories (e.g. forest, mire, field, urban area). To define the administrative borders of parishes, municipalities and counties in Sweden the database "Sverige 1000plus" (Kartcentrum 2004) was used. Geospatial data bases used for forest planning by the forest companies Sveaskog Co in Bergslagen and Priluzje state forest management unit in Russia and finally Ecoregions (Nordic Council of Ministers 1983). Those digital spatial data were used in all the seven papers in this thesis.

6.3 Habitat Suitability Index – modelling

To maintain viable populations of naturally occurring forest species is a goal of the Swedish forest and environmental policy. This requires sufficient amounts of functional habitat, which can be assessed by spatial modelling. The focal species approach means that conservation of specialised and area-demanding species can contribute to the protection of many other naturally co-occurring species (Angelstam et al. 2003, Hess and King 2002, Roberge and Angelstam 2004). The creation of habitat suitability index (HSI) models involves three main steps (e.g., Store and Jokimäki 2003). First, the land cover types at the pixel level are selected in the raster database to mirror the habitat selection of the focal species, and a buffer is added round those pixels. This buffer links the neighbouring patches and thus simulates species' ability to move within a home range. Second, patches that provided sufficient amount of the relevant vegetation type necessary to meet the resource requirements of focal species individuals are identified. Finally, a nearest neighbourhood window size is then chosen to match the distance of local movement for the selected focal species at the local population level (e.g., Manton et al. 2005). Tracts with concentrations of suitable habitat that satisfy critical thresholds for the occurrence of a local population were then identified. This provided an assessment of the species-specific connectivity of habitat patches in tracts at the landscape scale as perceived by the focal species with different habitat selection.

6.4 Research questions and applied GIS-analyses

6.4.1 Paper I: Habitat network functionality in space and time

The United Nations Environment Programme (UNEP 2004) has outlined recommendations for sustainable management of forests. These include integrating non-protected intact forests with high potential for biodiversity conservation into the large-scale ecological network to prevent and mitigate loss of forest biological diversity due to fragmentation and isolation. UNEP (2004) also recommended that different stakeholders are to be involved with the establishment of forest-related ecological networks, and that public awareness is promoted. Similarly, at the European level several EU Directives and the European Landscape Convention stress the need for landscape and regional spatial planning that involves stakeholders (Council of Europe 2000). To promote long-term persistence of functional ecological networks necessary for maintenance of viable populations of species and ecological integrity, both the quality and size of the constituent habitat types representing different ecosystems, and as well as their spatial configuration at the level of landscapes and regions, need to be considered (e.g., Angelstam et al. 2004c, Ferrier 2002, Leitao and Ahern 2002).

The aim in this study was to test if the outcomes of spatial planning efforts among the four land owner categories in Sweden (Table 5) in the study area with four ecoregions (Figure 4) with respect to the functionality of habitat networks are related to their ambitions in their biodiversity conservation policies.

Habitat network functionality by forestland owner categories

To test if different landscape planning approaches among different forestland owner categories result in different levels of connectivity, a nation-wide forestland owner map (Naturvårdsverket 2005) was used to make owner-specific (Table 5) analyses of habitat network functionality. The result from the HSI-models of riparian forest, old spruce, deciduous, old pine and forest-field edge was then overlaid with the layer of landowner categories.

Loss of habitat due to clear-felling in functional tracts

Polygons of all clear-felled areas from the Swedish Forest Agency's yearly monitoring of clear-felled areas between 2001 and 2008 were used to assess the loss of habitat patches located in functional tracts for each of the five coarse forest habitat types. The clear-felled areas were identified by change analyses using satellite images (Persson and Banck 1998). The result from the HSI-models of riparian forest, old spruce, deciduous, old pine and forest-field edge were overlaid with the layer of clear-felled areas. The rate of clear-felled area inside and outside functional tracts was calculated for each forest owner category.

6.4.2 Paper II: Biophysical proxy data for modelling habitat

Efficient conservation planning in managed forest landscapes requires knowledge about the location and amount of functional habitat for specialised species. Attributes characteristic of near-natural forests are more likely to be abundant in those parts of the landscapes that have been subjected to historically lower management intensity (Angelstam and Dönz-Breuss 2004). Present-day raster data are of limited utility for modelling habitat suitability for wide-ranging species dependent on fine-scale forest attributes such as forest age or the amount of dead and dying trees over large regions (Edman et al. 2011, Manton et al. 2005). Hence, an approach for facilitating habitat suitability modelling for specialised threatened forest species would be to complement raster data with proxy data linked to management intensity or other processes potentially influencing habitat suitability for those species. The importance of different variables to predict habitat suitability for the white-backed woodpecker, a proposed umbrella species for biodiversity conservation in deciduous forest in Europe was explored (Mild and Stighäll 2005, Roberge et al. 2008). The aim of this study was to test whether or not biophysical proxy variables indicating management intensity and the occurrence of natural processes constituted a useful complement to traditional raster data on tree species composition and forest stand age for modelling the woodpecker's habitat.

To monitor population status of the white-backed woodpecker, ornithologists have performed annual surveys in western Sweden during the period 1986-2006. A total of 94 white-backed woodpecker territories were identified and monitored over time, most of which located in south central and western Värmland as well as in northern Dalsland (Figure 3). Within each territory, a point corresponding to either the location of the nest, the middle point between several nests, or if no nest was found, the site with most frequent observations was selected as the 'territory centre' for the GIS analyses. In addition, an equal number (94) of random sites were selected to represent localities without any known occurrence of the woodpecker during the study period.

Acknowledging that the ability of publicly available raster data reflect the deciduous component, forest management intensity, and the occurrence of natural processes in forests is limited (Manton et al. 2005), habitat suitability analyses were based on two complementary sources of data: (1) traditional raster data about tree species composition and forest age, and (2) proxy data based on biophysical factors that are likely to influence habitat quality for the woodpecker. I used proxy variables (Table 8), which were expected to indicate either a lower intensity of forest management or the occurrence of natural processes favouring deciduous trees and creation of dead wood. The parts of the forest landscapes which are difficult to access for forestry operations are generally characterised by a lower intensity of management, e.g. in terms of cleaning and thinning (e.g., Angelstam et al. 2004b). In these areas, dead wood is more likely to accumulate and also deciduous-rich stands are more likely to develop. The circular plots around territory centres and random plots were overlaid with the layers with forest and proxy variables in order to receive the quantitative description of each plot expressed in areas (see Table 8).

Table 8. *Summary of the variables used in model building. All areas were calculated inside the radius of 500 m around the territory centre respective the random sites. The area of forest types expected to contribute to habitat suitability for the white-backed woodpecker was computed in each territory within a radius of 500 m around the territory centre, i.e. an area of 78.5 ha. This scale is similar to the area required by individual breeding pairs.*

Variable	Description
Traditional forest variables	
Deciduous forest	Area of deciduous forest
Forest >60 yrs	Area of forest older than 60 years
Proxy variables linked to naturalness	
Farmland-edge forest	Area of forest located < 50 m from farmland
Forest far from roads	Area of forest located > 500 m from roads
Forest on steep slopes	Area of forest located in slopes > 33°
Water-edge forest	Area of forest located < 50 m from water
Wetland forest	Area of forest on wetland
Highest coastline (HCL)	Territory located below or above the HCL

6.4.3 Paper III: Predicting the occurrence of the fresh water pearl mussel

The freshwater pearl mussel, FPM, has become listed as "Endangered" by International Union for Conservation of Nature, IUCN. It has also been suggested as an umbrella species (Geist 2005). The surface water and groundwater bring solid and dissolved matter from catchments to lakes (Björk 2004). Thus, water bodies reflect the management of the catchments. Stream water chemistry and substratum characteristics are influenced by land cover patterns in the riparian area (Sponseller et al. 2001). There are factors at multiple scales in catchments that affect FPM population's viability e.g. bottom substrate composition (Geist and Auerswald 2007), acidification (Henrikson 1996), eutrophication (Dolmen and Kleiven 2004). Björk (2004) showed a significantly decline in a FPM population after the forestry in the catchments changed from deciduous forest to coniferous forest. The aim was to test if it is possible to predict where viable populations of FPM exist with instream data comprising water chemistry as well as with land cover data in the riparian zone.

This study involves 56 streams with FPM populations in catchments in the County of Västernorrland in Mid Sweden (Figure 3). The water chemistry was measured within the County Board's monitoring program. The main method is based on visual search in wadable streams for specimens where the present FPM population has its highest abundances or where recruitment is known. Measured parameters were pH, alkalinity, colour, conductivity, Ca+Mg, total-phosphorus and turbidity. Average values of all parameters were used to describe the FPM sites. For the statistical analysis the FPM population's status were ranked in a two-graded status scale: 1 (viability) and 2 (not viable – soon extinct).

To derive the catchments upstream the 56 FPM sites, a digital Elevation Model, DEM, (Lantmäteriverket 2001) and algorithms in GIS tool was used. The streams inside the catchments were selected from Topographic map 1:100,000 (Lantmäteriverket 1998). Swedish Land Cover Data, SMD, was used to describe the land cover in the 50- m riparian zones upstream the freshwater pearl mussel sites.

6.4.4 Paper IV: Assessment of FSC outcomes for biodiversity conservation

The Forest Stewardship Council, FSC, is one of the leading forest certification schemes, which encourages responsible forest management on the ground. Many studies have addressed the political and social outcomes of FSC (e.g., Auld et al. 2008, Bass et al. 2001, Cashore et al. 2003, 2005). However, little is known about the contribution of certification to biodiversity conservation (Gulbrandsen 2005, Rametsteiner and Simula

2003). In Europe, the Russian Federation and Sweden have the largest areas of FSC certified forest. These countries have different forest histories and forest governance systems (Angelstam et al. 1997), which are likely to influence the potential of FSC for biodiversity conservation. As study areas Sveaskog Co.'s forest management district Bergslagen in Sweden and the Priluzje forest management unit in the Russian Federation's Komi Republic were used. The aim was to analyse how do the national FSC standards in Sweden and the Russian Federation contribute to the national ambitions in biodiversity conservation through protection, maintenance and restoration in managed forests? First I assessed structural habitat connectivity created by the forests formally and voluntarily set aside for biodiversity conservation using Morphological Spatial Pattern Analyses (MSPA) (Ostapowicz et al. 2008, Vogt et al. 2007 a,b). Second, I assessed the functional connectivity of set-aside forests in my study areas by habitat suitability index modelling (Angelstam et al. 2004c, Store and Jokimäki 2003) for virtual species (Mikusinski and Edenius 2006).

Assessment of structural landscape connectivity

Structural connectivity describes only physical relations among habitat patches such as habitat corridors or inter-patch distances, and does not provide functional connectivity if corridors are not used by target species (Taylor et al. 2006). MSPA describes the geometric arrangements and connectedness of map elements and allocates each forest pixel to one of the mutually exclusive thematic pattern classes defined in MSPA (Ostapowicz et al. 2008), (see Table 9). The seven classes cover a wide range of forest spatial patterns, which are of interest in biodiversity assessments.

Table 9. *Definitions of Morphological Spatial Pattern Analysis (MSPA) classes. The foreground is pixels of set-aside forests and the background is pixels representing the production forest and all other land cover types (Soille and Vogt 2009).*

Class	**Explanation**
Core	Foreground pixels surrounded on all sides by foreground pixels and greater than the specified edge width distance from the background.
Islet	Foreground pixels that do not contain core. Islet is the only unconnected class.
Perforation	Pixels that form the transition zone between the background and foreground for interior regions of the foreground. The pixels forming the inner edge would be classified as perforations, whereas those forming the outer edge would be classified as edge.
Edge	Pixels that form the transition zone between the foreground and background.
Loop	Foreground pixels that connect the area of core to itself.
Bridge	Foreground pixels that connect two or more disjunct areas of core.
Branch	Foreground pixels that extend from the area of core, but do not connect to another area of core.

For morphological modelling it is important to define the edge width, which is critical for characteristics of MSPA classes. Moen and Jonsson (2003) indicated that in the boreal forests edge effects vary among species groups, but they generally extend at least 25 m into the forest and probably greater than 50 m for some groups (Aune et al. 2005, Esseen 2006). Therefore, in MSPA processing the connectivity were quantified twice with edge width of 25 and 50 m.

Assessment of functional landscape connectivity

To assess the functional connectivity of set aside forests in the study areas, habitat suitability index modelling (e.g., Store and Jokimäki 2003) was applied using the focal species approach (Lambeck 1997). Rather than focusing on given species, the habitat requirement of which may not be the same in Bergslagen and Priluzje, an approach called virtual species (Hirzel et al. 2001, Mikusinski and Edenius 2006) was employed. The functional connectivity of forests was estimated from the perspective of species that require old-forest with different ecological characteristics.

The creation of habitat suitability index models involved several steps. First pixels of all forest pattern classes, which were created by the forests set aside for biodiversity conservation, were selected using the output MSPA map. Then habitat suitability index maps were created for a suite of virtual species with patch size requirements of 1, 10, 100 and 1000 ha (c.f. Mikusinski and Edenius 2006). Finally, nearest neighbourhood analyses (Manton et al. 2005) were made for a local landscape habitat threshold of 20% based on experiences from modelling (Andrén 1997, Fahrig 2002) and empirical studies (e.g., Angelstam and Bergman 2004), corresponding to local neighbourhoods of 5, 50, 500 and 5000 ha, respectively. This provided an assessment of the functional connectivity of habitat tracts at the landscape scale.

6.4.5 Paper V: Perceptions of forest landscape values

New post-modern products of forest landscapes are increasingly developed based on non-wood goods and immaterial landscape values (Erkkilä et al. 2005, Johannisson 2003, Mather 2001). Claims and tensions among forest landscapes' users may be escalated by intensification of wood and biomass resource use (Lindkvist et al. 2009), as well as of businesses focusing on mass-tourism recreation and outdoors life (Butler and Boyd 2000, Prato and Fagre 2005). To reconcile conflicts among different landscape users there is a need to include post-modern uses of landscapes' non-wood goods, ecosystem services, natural and cultural values (Mather, 2001) into spatial planning processes (Antonson et al. 2010, Mikusinski et al. in press, Nordström et al. 2011).

Destinations for tourism are often formed through collaboration between different public institutions, in most cases municipalities, with the aim to develop the local economy. The National Heritage Board (2007) concluded that planning for destination development is a neglected area because of tourism's weak position in regional development, lack of knowledge about planning for destinations, general lack of understanding of tourism conditions, and poor municipal organization for the destinations.

The aim of this study was to compare the natural and cultural landscape values that are perceived as attractive to locals, tourists and municipal civil servants at a recreation resort in the rural western Bergslagen region in south-central Sweden. Those values were interpreted and expressed using spatial data and GIS-modelling as thematic maps. By this method I show to locals, tourists and municipal civil servants different appreciated immaterial values connected to recreation and human wellbeing. That may give municipalities opportunity to improve spatial planning to become more attractive to new inhabitants, and to identify, encourage development and market specific areas to attract visitors.

6.4.6 Paper VI: Intensive forestry and functional green infrastructures

Sweden has a long tradition of efficient sustained yield wood production. During recent decades society's view on forest management has, however, been gradually broadened. Currently, forest-related policies in Sweden stress the need to enhance the outcomes from forests in terms of increased production of renewable raw material as well as the conservation of biological diversity and socio-cultural values (Larsson et al. 2009, NRA 2006, Proposition 2007/08:108). In Sweden the government proposed a recreation policy goal to support people's ability to spend time in nature and pursue outdoor activities (Proposition 2009/10:238). At the same time green infrastructures for ecological and socio-cultural values should be enhanced toward functionality (Carlgren and Löfrotht 2010, European Commission 2010). The need and opportunity for spatial planning among landscapes to accommodate ecological and socio-cultural dimensions of sustainable forest management will thus increase. Identification of municipalities with high diversity of ecological, economic and socio-cultural profiles of forest values, and therefore increased demands for collaborative spatial planning among stakeholders would be a start toward developing adaptive management and governance as deemed necessary by Larsson et al. (2009).

The aim of the study was to use spatial modelling of ecological and socio-cultural landscape values to explore the opportunity for providing empirical data about forestland qualities to governors and managers working with spatial planning for intensive forestry and green infrastructures at the scale of municipalities and regions in Sweden. First, I modelled the amount and spatial distribution of functional green infrastructures in terms of three forest types of with high ecological values (see Paper I and Table 10) and three sociotopes (Ståhle 2006) with high socio-cultural values (e.g., Björk et al. 2008, Lindhagen 1996 a,b, Rydberg and Falk 2000, Skärbäck et al. 2009), (Table 10). The remaining forest areas should thus have low risks of conflicts with the development of intensive production of wood and biomass.

Table 10. *The forest types that habitat suitability indexes was made for representing the ecological values and the socio-cultural values people want for recreation linked to costs and difficulties for planning.*

Ecological variables	Socio-cultural variables
Old spruce forest located in functional habitat networks	Old spruce forest located in functional habitat networks
Old pine forest located in functional habitat networks	Cultural landscape/forest-field edge
Old deciduous forest located in functional habitat networks	Quiet forest areas

6.4.7 Paper VII: Indices for municipalities' sustainable profiles

Sustaining economic development to support human well-being and quality of life, and to avoid negative environmental impacts, require collaboration among societal actors and stakeholders at multiple levels. A key issue is to provide those with a comprehensive and transparent knowledge base representing the state and trends of different dimensions of sustainability. This study addresses municipalities' need to compile, analyse and present available data as a foundation for the sustainable development process of steering toward agreed goals at the regional level.

To describe the sustainability profile for a given municipality 15 indicators (Table 7) from years 2001 and 2006 of ecological, economic and socio-cultural criteria were analysed in four steps. First, to summarize and compare indicators with different units, the datasets were normalized (OECD 2008, http://composite-indicators.jrc.ec.europa.eu/). The normalisation approach means that the datasets get a common scale for all indicators. The formula

$$\text{norm}X_n = (X_n - \text{median}X)/(\text{upper quartile}X - \text{lower quartile}X)$$

was used to transform the datasets for all municipalities (n=119), where $\text{Norm}X_n$ is the normalized value of indicator X for each municipality. X_n is the value of indicator X for municipality n and medianX is the median for indicator X. The use of the median in the formula gives a robust normalization since it decreases the influence of extremes. Indicators for which positive values represent unwanted states were multiplied by (-1). For each index, a zero value corresponds to the median, which means that half of the municipalities have positive and half have negative index values. The summarized value thus only presents the relative level of the sustainability for the chosen indicators in the municipalities, and does not provide any information about the sustainability of a particular municipality. To assess the level of sustainability requires comparisons with an agreed standard or norm as presented in different policies (e.g., Lammerts van Buren and Blom 1997, Angelstam et al. 2004b), which is not the aim of this study.

Second, the five normalized indices for each of the ecological, economic, and socio-cultural dimensions for all municipalities in Bergslagen region (n=18), and for the surrounding municipalities (n=101) was summarized. The mean for each sustainability dimension was calculated to get an index in both Bergslagen region and the surrounding area. The normalized indices for year 2006 yielded a relative value of the sustainability of each Bergslagen municipality in relation to the other municipalities in the 9 counties.

Third, data from 2001 and 2006 used and compared to analyse the development of the indicators over time. Normalised data were used to compare the situations in 2001 and 2006 for all municipalities (n=119), as described below:

$norm\_diffX_n$ = (X_n2006 - X_n2001) / (upper quartile (X_n2001 + X_n2006) - lower quartile (X2001+ X2006))

where $norm\_diffX_n$ is the normalized value of indicator X_n for each municipality, X_n2001 is the value of indicator X year 2001 and X_n2006 is the value of indicator X year 2006 for municipality n. Note that $norm\_diffX_n$ is zero for municipalities with no changes of indicator X_n between 2001 and 2006. For each index a positive value indicates sustainable development (at average) and negative values indicate unsustainable development over the period.

Fourth, the normalized differences in step three were summarized for each of the ecological, economic and socio-cultural dimensions for all municipalities in the Bergslagen region (n=18) and the surrounding area (n=101) and then the mean for each dimension was calculated for Bergslagen and for the surrounding area.

Summarizing the five indices in each of the sustainable dimensions in steps two and four yields a new index representing each dimension of sustainability. Various large positive and negative values are then summed for each municipality so that it can be more communities that have positive total for a dimension than those with negative, and vice versa. Therefore, one cannot talk about better or worse half of all municipalities, but only better or worse relative to other municipalities in the study area.

7 Results

7.1 Landscape level assessment - ecological sustainability

7.1.1 Paper I - Habitat network functionality

The proportions of clear-felled forests located within and outside functional tracts of the five coarse forest types that took place during the period 2001-2008 were very similar inside and outside functional tracts on average, but different for different coarse forest types (see Table 5 in Paper I). There was a clear gradient in the average ratio for clear-felled areas inside and outside functional tracts of the five coarse forest types (Figure 7) and thus the landscape planning was different among the four forest owner categories during the studied period. The public owners have an average ratio of about 40% clear felled areas inside functional tracts but NIPF have even average area clear felling inside and outside functional tracts (within/outside = 1).

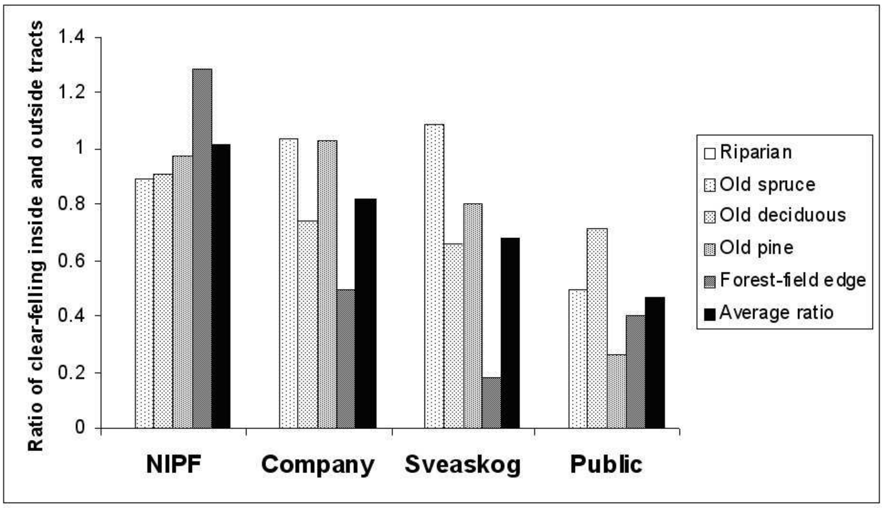

Figure 7. Ratio of clear-felling within /outside tracts of functional habitat networks in four forest owner categories for five coarse forest types, and the average ratio for each forest owner category. Note that the ratio for riparian forest was zero for all owner categories.

7.1.2 Paper II - Biophysical proxy data for modelling habitat

Presence-absence of the woodpecker during the study period (1986-2006) in west Sweden was explained by the area of permanent edge habitats (forest bordering water or farmland) and wetland forest. The area of forest bordering water and wetland forest had the highest occurrence of the woodpecker. Among traditional forest variables, the area of deciduous forest had a strong positive effect both on woodpecker presence-absence and the number of years with occurrence. The results suggest that edge habitats and forest types subject to natural processes favouring deciduous trees and dead wood creation are most valuable to the woodpecker, and should be prioritised in conservation planning. However, the addition of proxy variables to the models greatly improved their performances. The results thus show that biophysical proxy variables can be used in combination with traditional forest data for modelling habitat suitability of sensitive forest species dependent on natural forest.

Table 11. *Generalized linear model for presence-absence of the white-backed woodpecker at the study sites (n = 188).*

	Coefficient	Standard error	*P*-value
Traditional and proxy variables			
Constant	-3.279	0.572	
Deciduous forest	0.788	0.158	< 0.001
Farmland-edge forest	0.077	0.029	0.006
Water-edge forest	0.134	0.043	0.001
Wetland forest	0.170	0.088	0.038
Highest coastline	0.944	0.430	0.023

7.1.3 Paper III - predicting the occurrence of the fresh water pearl mussel

Mussel status was best predicted by total-phosphorous (Table 12). Mussel status is classified in a two-graded scale: viable and not viable. Pearl mussel has a host fish (brown trout). There was also a high correlation for mussel status with the abundance of brown trout. For the land cover data in the riparian zone the proportion of agricultural/pasture land and deciduous/mixed forest was positively correlated to total-phosphorous and thus negative correlated to mussel status. Thus negative values in column for Mussel status mean viability of the species. Brown trout abundance, however, was correlated to bottom substrate. Geospatial data could thus be used to predict levels of total-phosphorous on a larger scale and thereby indirectly identify streams with potential non-reproducing populations, but not to predict the host fish abundance. However, this shows that with less explained variation, geospatial data of land cover in the riparian zone may be a useful tool to screen for waters with potential non-reproducing populations due to high levels of total-phosphorous.

Table 12. *Pearson bivariate correlation between variables. Significant correlations noted with * p<0.05, ** p<0.01 and *** p<0.001.*

	Mussel status	pH	Alkalinity	Colour	Conductivity	Ca+Mg	Phosphorus	FNU_log
pH	-0.12	1						
Alkalinity	-0.15	0.67***	1					
Colour	0.19	-0.52***	-0.49***	1				
Conductivity	0.18	0.26	0.45***	-0.17	1			
Ca+Mg	0.02	0.50***	0.75***	-0.33*	0.80***	1		
Phosphorus	0.45***	-0.20	-0.15	0.24	0.37**	0.14	1	
FNU_log	0.39**	-0.23	-0.17	0.36**	0.49***	0.18	0.71***	1
Agricult_pasture	0.35**	0.03	-0.01	-0.04	0.51***	0.25	0.55***	0.51***
Coniferous	-0.22	0.01	-0.03	0.21	-0.30*	-0.18	-0.32*	-0.24
Deciduos_Mixed	0.17	-0.09	-0.03	0.03	0.30*	0.15	0.48***	0.33*
Clear_Young	0.22	-0.05	-0.01	0.11	0.20	0.18	0.25	0.17
Wetlands	-0.33*	-0.16	-0.32*	0.21	-0.31*	-0.32*	-0.31*	-0.18
Other	0.33*	0.07	0.00	0.01	0.42**	0.27*	0.37**	0.36**
Trout0_log	-0.55***	0.06	-0.09	-0.17	-0.18	-0.14	-0.48***	-0.40**
Trout1_log	-0.35**	-0.18	-0.23	-0.06	-0.16	-0.17	-0.23	-0.14

7.1.4 Paper IV - Assessment of FSC outcomes for biodiversity conservation

Structural connectivity

In Bergslagen, core and edge occupied 36% respective 34% of the forested area set aside for biodiversity conservation in the forest pattern when the edge width was defined as 25 m. Branch and islet classes were represented by 14% and 12% of forested area, respectively. When the edge width was increased to 50 m, the core area decreased almost to a third, from 36% to 13%, while islet increased almost four times, from 12% to 42%. In Bergslagen pine, spruce and deciduous-coniferous forests occupied 84% of the total forested area set aside for biodiversity. Therefore, the majority of the forest pattern classes (core, edge, bridge and branch) were associated with these forest types, and mostly with pine forests. The coniferous-deciduous and deciduous forests were underrepresented, and the main pattern classes created by these forests were edges and branches.

In Priluzje, core areas occupied 70% of the forested area set aside for biodiversity conservation in the forest pattern when the edge width was defined as 25 m. With an edge width of 50 m, the forest pattern changed. The core areas decrease to 47%, and the area of branch and edge increased. In Priluzje, the deciduous and coniferous-deciduous forests were the dominant forest types set aside for biodiversity, and occupied 61% of the total area set-aside forests.

The majority of cores in Bergslagen (almost 70% of the total number of stands) were less than 1 ha large, and almost half of the total core area was located in a fairly low number of larger cores (Figure 8a). In Priluzje the majority of cores ranged from 0.1 to 10 ha, however, more than 90% of the total core area was larger than 1000 ha (Figure 8b). This shows that in Bergslagen the forests set aside for biodiversity were more fragmented than in Priluzje.

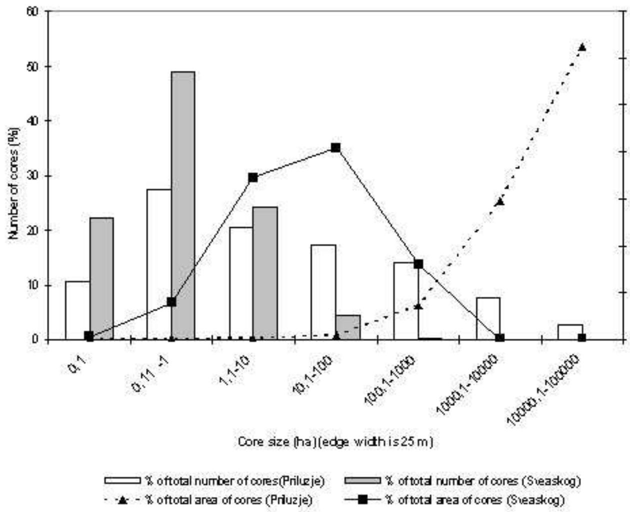

Figure 8a. Distribution of area and size of core areas of formally and informally protected forests with edge widths of 25 m in the Priluzje state forest management unit in the Russian Federation and the Bergslagen holding of Sveaskog Co in Sweden.

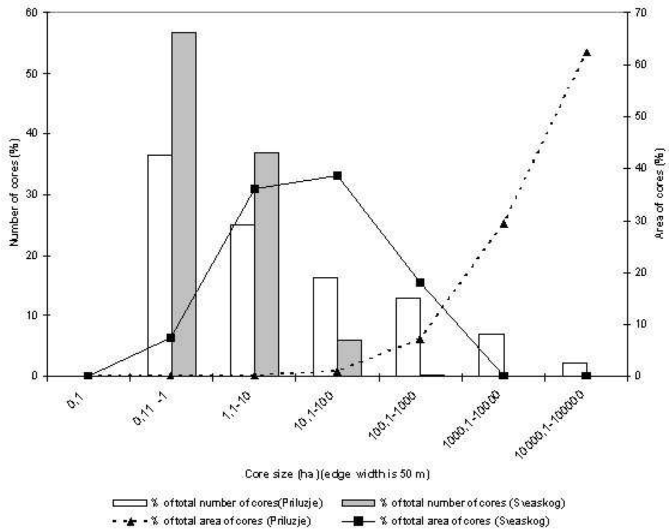

Figure 8b. Distribution of area and size of core areas of formally and informally protected forests with edge widths of 50 m in the Priluzje state forest management unit in the Russian Federation and the Bergslagen holding of Sveaskog Co in Sweden.

Functional connectivity

In both Bergslagen and Priluzje over-mature and old forests were highly functionally connected for virtual species with small habitat requirements (1 ha). For virtual species with area requirements of 10 ha the functional connectivity of these forests in Bergslagen was highest for deciduous-coniferous (around 40% of the area of over-mature and old set aside forests), and lowest for coniferous-deciduous old forests (less than 20%). In Priluzje, almost 100% of deciduous forests and 80% of spruce and deciduous-coniferous over-mature and old forests were functionally connected for virtual species requiring 1 to 10 ha of habitat area. In Bergslagen over-mature and old forests were not functional for species with area requirements more than 100 ha. By contrast, in Priluzje, the functionality of deciduous forests was almost 70% and around 50% for species with habitats requirements of 100 and 1,000 ha, respectively. For over-mature and old spruce and deciduous-coniferous forests functional connectivity was low for species requiring 100 ha of habitat area. The functionality of over-mature and old spruce, pine, deciduous-coniferous and coniferous-deciduous forests was very limited or absent for species with area requirements of 1,000 ha (Figure 9a-e).

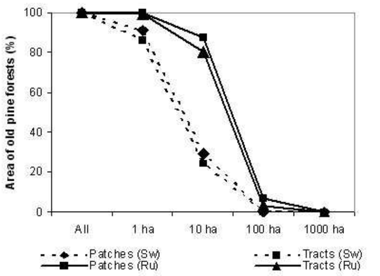

Figure 9a.

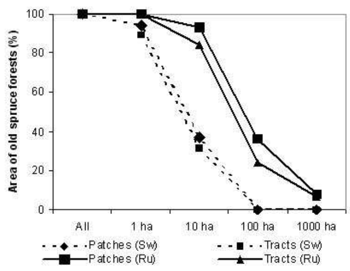

Figure 9b.

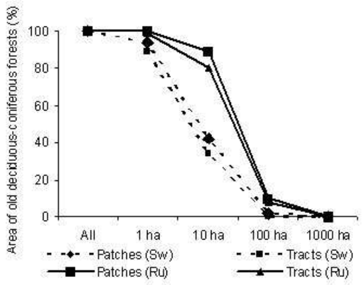

Figure 9c.

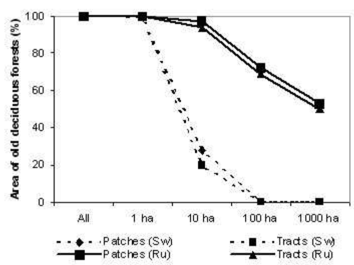

Figure 9d.

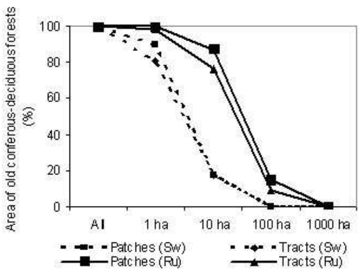

Figure 9e.

Figures 9a-e Results from modelling of habitat network functionality in the Swedish and Russian forest management units for forest with >70% Scots pine (a), >70% Norway spruce (b), >70% pine and spruce (deciduous-coniferous) (c), >70% deciduous (d) and 31-49% deciduous (coniferous-deciduous) (e) forests. The graphs show the proportion in percent of all 25x25 pixels that are located in sufficiently large stands for the focal species (patches), and in functional tracts of habitat.

7.2 Landscape level assessment - socio-cultural sustainability

7.2.1 Paper V- Perceptions of forest landscape values

Interviews with locals, tourists and municipal officials showed that a total of seven different natural and cultural landscape values were identified. These were water, old forest, small clear-cuts along roads, chance to see moose, scenic views, quiet areas, and cultural landscape heritage. Except for water bodies and old forests, which all three categories of interviewees valued, they had different use priorities for the five other landscape values. Locals stated that they avoided too large clear-cuts, and appreciated look-outs, quiet areas and cultural heritage as the key landscape values. Tourists, preferred absence of clear-cuts along principal roads leading to tourism facilities, and appreciated look-outs, quiet areas, and chance to see moose. Civil servants perceived smaller clear-cuts and cultural heritage as the most important additional landscape values.

Biophysical values could be directly analysed because they form distinct themes in different digital maps, and anthropogenic values could be analysed indirectly using databases with themes about forest, agricultural land, transport infrastructure and settlement (Table 13). To illustrate how the different interviewees' categories viewed the Säfsen parish landscape the natural and cultural values important for locals, visitors and municipal civil servants, respectively, are presented in Figure 10 a-c. Pooling all seven values, the north of Säfsen parish had the highest density of landscape values (Figure 11) and thus an interesting area to plan for tourist attractions.

Table 13. *Overview of how maps of perceived landscape values in Säfsen were modelled.*

Perceived landscape value	Data	Algorithm/method
Water	Topographic map 1:100 000	Selected lakes and water streams in Säfsen parish.
Old forest	k-NN Sweden	Selected forest older than 110 years.
Clear cuts near principal roads	Clear cuts years 2001-2008, Topographic map 1:100 000	Selected clear-cuts in 25 meter from principle roads (roads with number).
Chance to see moose	k-NN Sweden	Selected deciduous and pine younger than 10 years.
Look-outs	Digital elevation model	Selected areas over 525 asl.
Quite area	Topographic map 1:100 000	Selected area outside 4000-meter buffer from principal roads and outside 500-meter buffer from forest roads.
Cultural heritage	The Archaeological Sites and Monuments database.	Selected all sites in Säfsen parish.

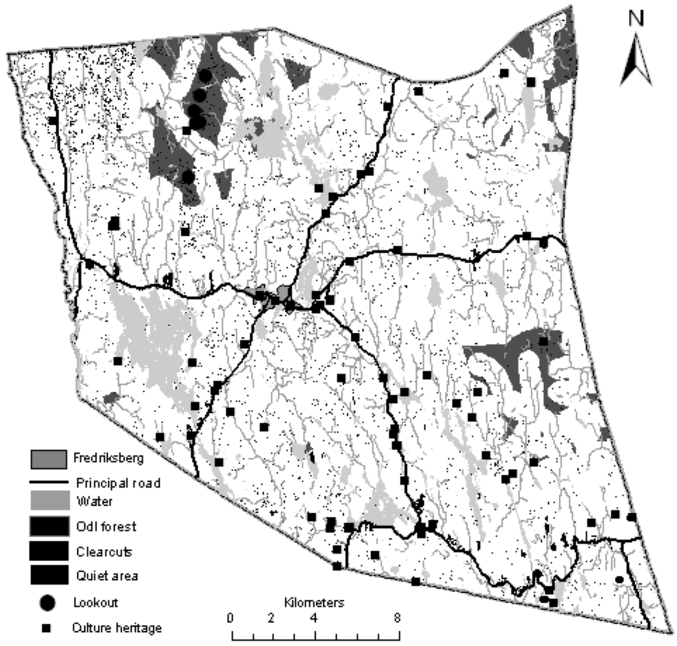

Figure 10a. All perceived values by the locals in Säfsen parish.

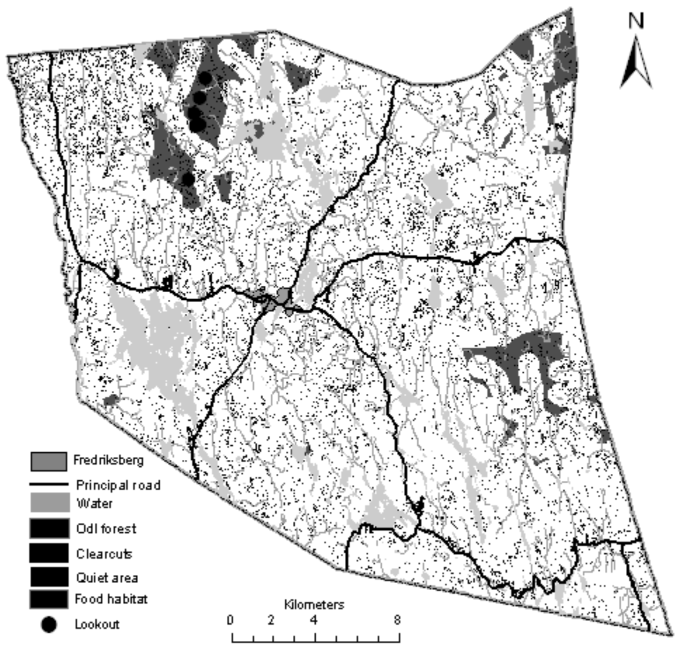

Figure 10b. All perceived values by tourists in Säfsen parish.

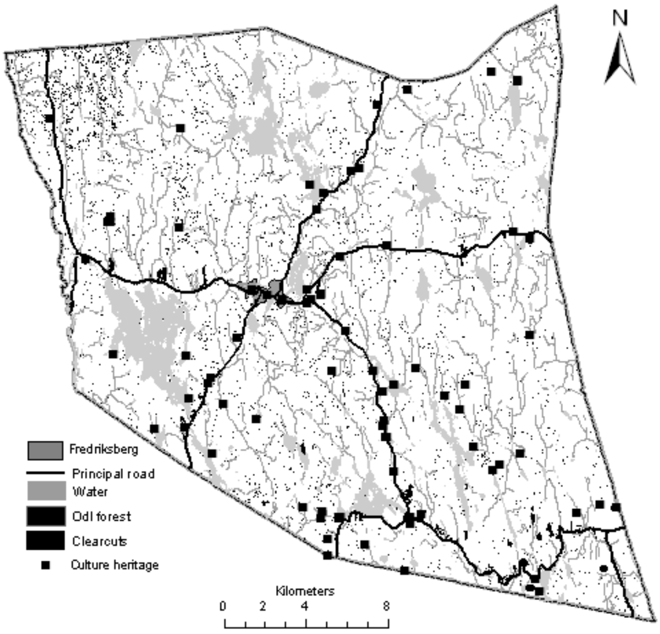

Figure 10c. All perceived values by municipal servants in Säfsen parish.

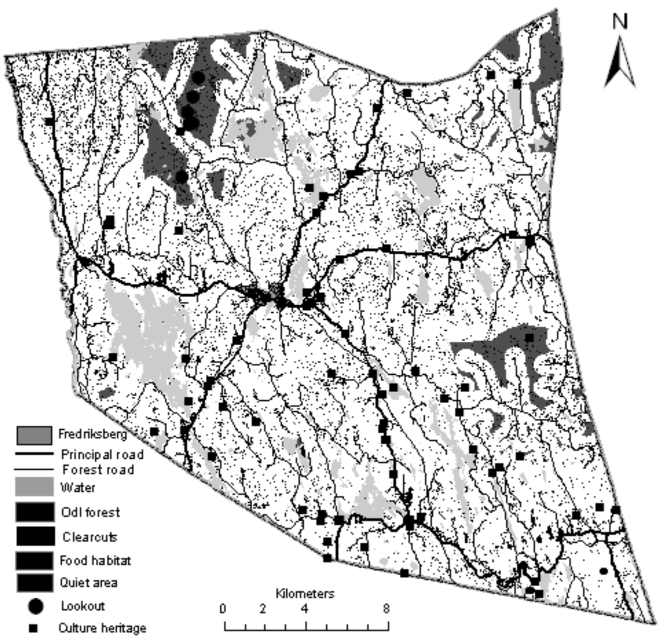

Figure 11. All seven perceived landscape values in Säfsen parish. In northwest exists an area whit high density of perceived values.

7.3 Landscape level assessment - economic sustainability

7.3.1 Paper VI – Intensive forestry and green infrastructures

The three layers (Table 10) representing different kinds of old forest patches located in functional habitat network tracts were merged to one layer (Figure 12). The mean proportion of forestland that habitat model identified as functional habitat networks in each municipality was low for the union of all three models (7%) and close to the sum of all three, which indicates that the three green infrastructures were non-overlapping.

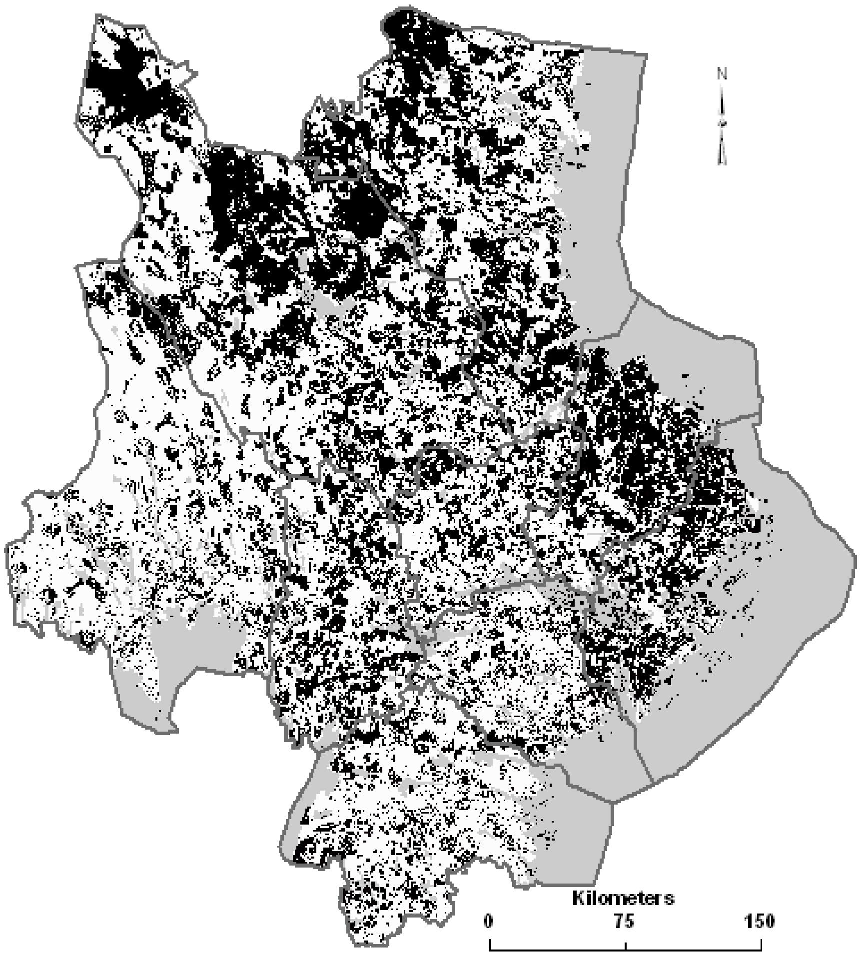

Figure 12. Three types of old forest green infrastructures merged to one layer.

The three layers of sociotopes (Table 10) were also merged to one layer (Figure 13). The proportion of forestland that sociotope models identified as functional was relatively high for the union of all three models (42%). The sum of all three was 55% indicating that they were partly overlapping.

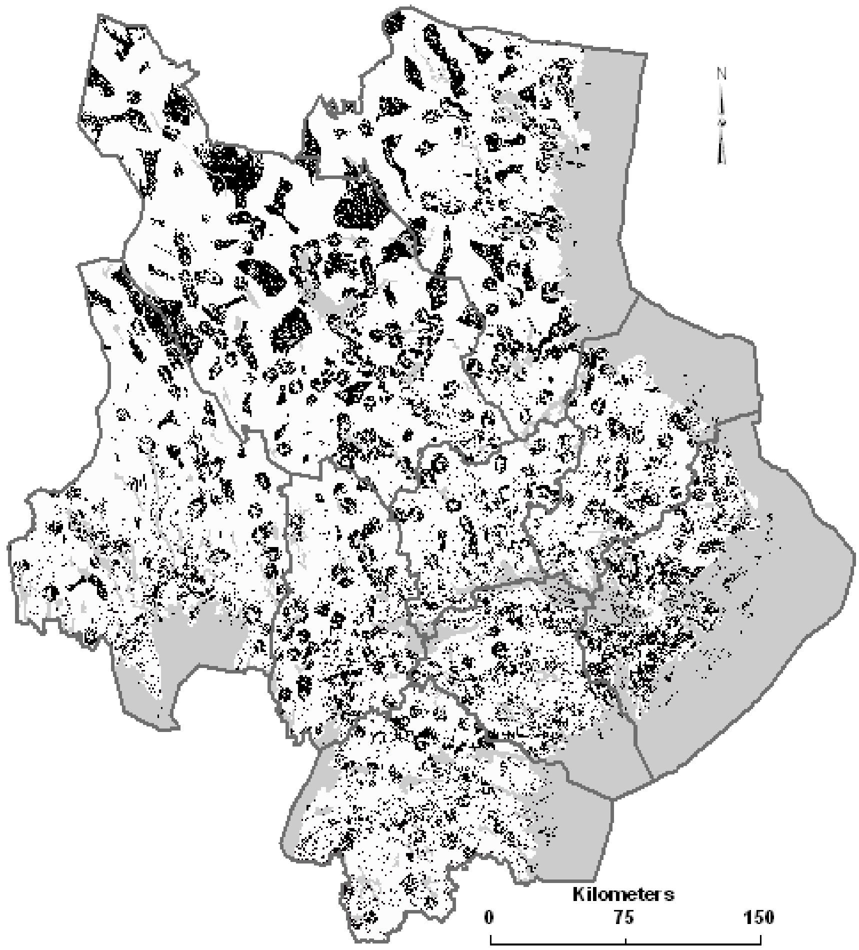

Figure 13. Three sociotope models merged to one layer.

The forestland was overlaid with the union of functional habitat and the union of sociotopes. Those areas without any of functional green infrastructure or sociotopes are defined as "conflict-free" forest and hence suitable for intensive forestry. The proportion of "conflict-free" forest in 119 municipalities in south-central Sweden was very diverse (Figure 14).

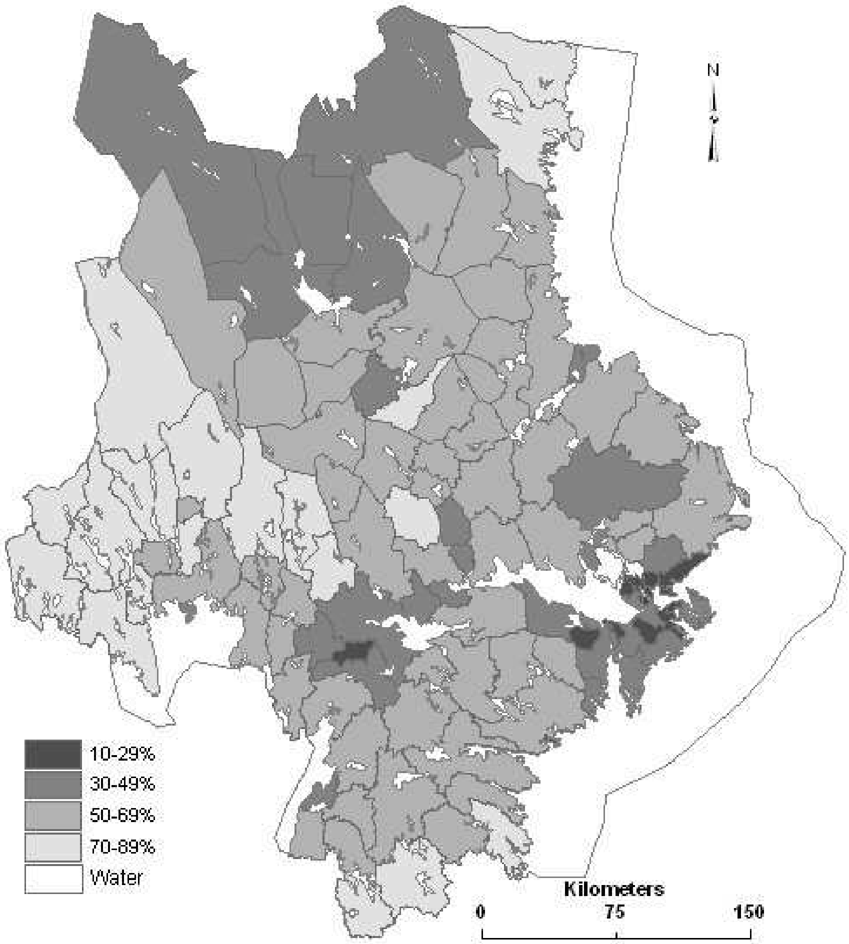

Figure 14. The proportion of all forest land without functional green infrastructures for focal species or sociotopes in 119 municipalities in nine counties in south-central Sweden. Those municipalities with high percent (lighter colour) have thus high amount of "conflict-free" forest and hence suitable for intensive forestry.

This modelling approach to estimate the spatial distribution of functional green infrastructures for biodiversity and sociotopes for human well-being in a steep biographical and rural-urban gradient clearly demonstrate that there are large regional differences in green infrastructure and conflict free areas among municipalities. Municipalities varied 7-fold in the amount of forestland deemed without risks for conflicts between intensive forestry and green infrastructures. This indicates that the opportunity of intensive forestry also varies substantially among regions (Figure 14).

7.4 Regional level integrated assessment

7.4.1 Paper VII - Indices for municipalities sustainable profiles

The analyses of ecological, economic and socio-cultural indicators of sustainability showed that the Bergslagen region had lower values than the surrounding municipalities for all dimensions in year 2006 (Figures 15 and 16). Consequently, the Bergslagen region performed less well compared to surrounding municipalities.

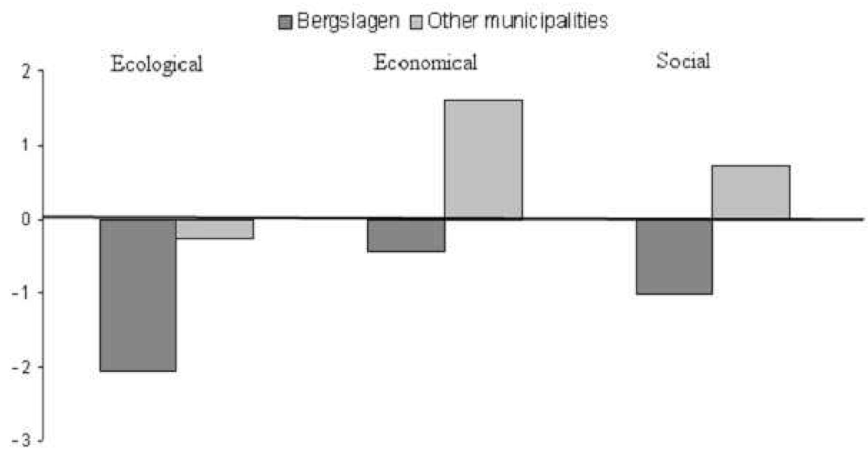

Figure 15 The mean of the normalized values for five indicators each for three dimensions of sustainability in 2006 within 18 municipalities in the Bergslagen region as defined in Figure 5 and the region outside Bergslagen in south-central Sweden. Positive value means higher level of sustainability and negative lower level of sustainability relative the entire area of the 119 municipalities.

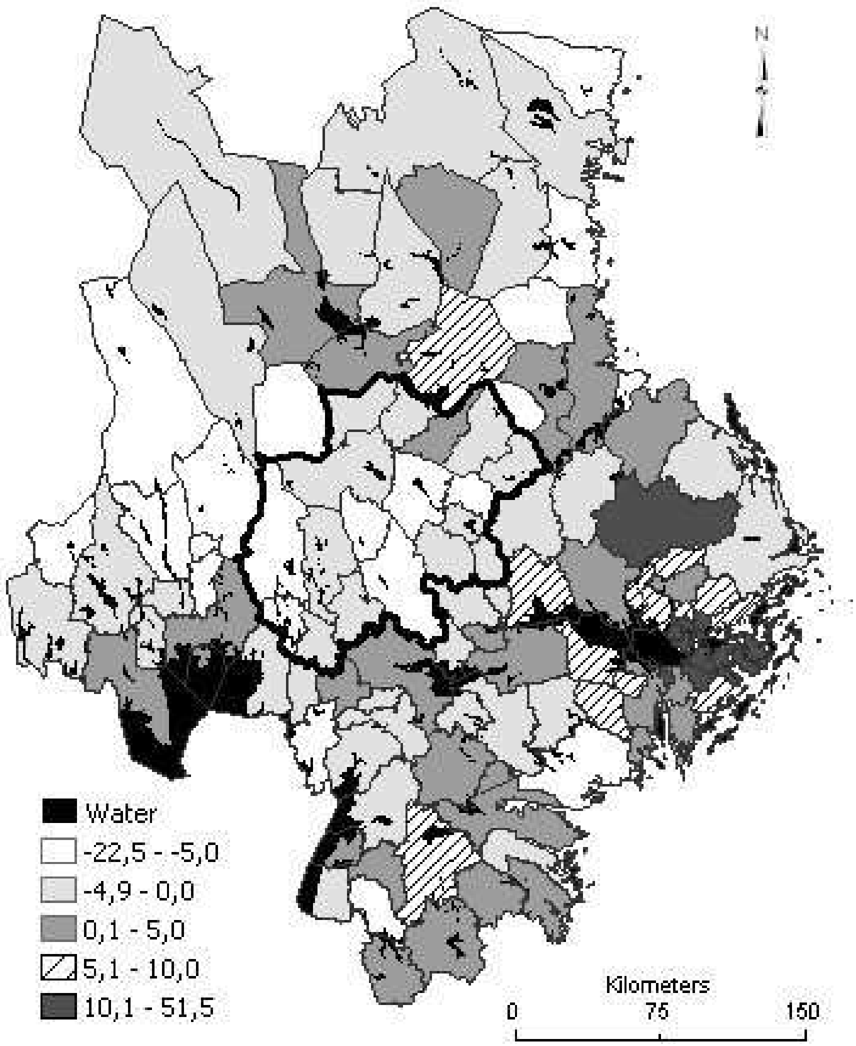

Figure 16. The summarised normalized values for all fifteen indictors. Darker colour means higher level of sustainability and white the lowest level of sustainability relative the entire area of the nine counties. The black border denotes the Bergslagen region.

The development of the indicator values from 2001 to 2006 indicated that the economic and socio-cultural dimensions developed positively while the ecological dimension had a negative development for both Bergslagen and the surrounding area (Figures 17 and 18).

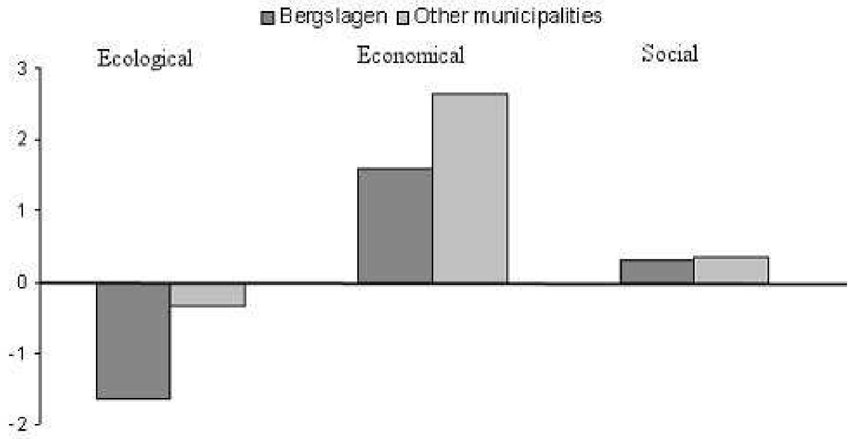

Figure 17. The mean of the differences of the summarized normalized values for five indicators each for three dimensions of sustainability give the development of the dimensions between 2001 and 2006 for region Bergslagen and for the region outside Bergslagen (see Figure 5). Zero value means no change, positive value means improvement and negative value means deterioration.

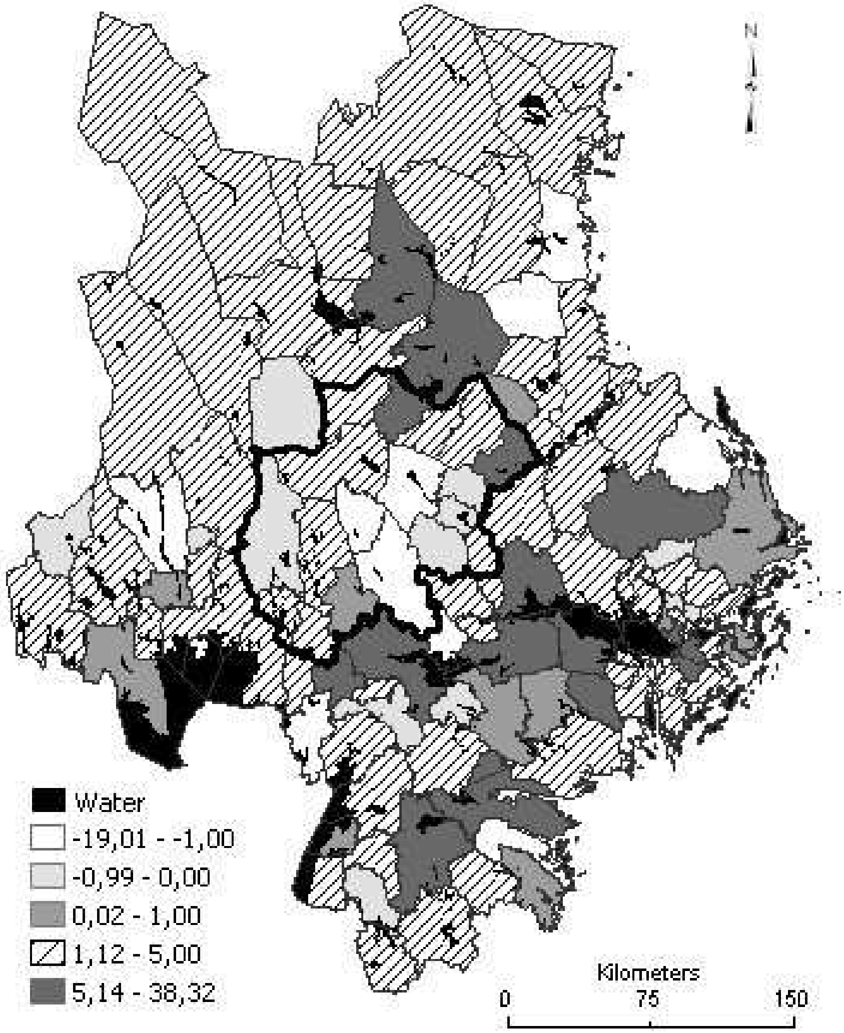

Figure 18. The development of the normalized sustainability index values for all fifteen indicators from 2001 to 2006. Darker colour indicated positive development (at average) while lighter colours indicates negative development. Zero in the legend indicates no change from 2001 to 2006. The Bergslagen region is marked with a black border.

8 Discussion

8.1 Spatial assessment of sustainability is possible

This thesis demonstrates that the data derived from monitoring of the state and trends of different dimensions of sustainability at different spatial scales can be compared with norms included in relevant policies. This approach can thus be used to assess the consequences of policy implementation outcomes (Rauschmayer 2009). Statistics and the result from GIS analysis can also be presented as maps, and thus be used as an interface that facilitates communication among different stakeholders involved with governance at multiple levels (Balram et al. 2004, Voss et al. 2004). To derive information useful for planning toward sustainability I have given examples of GIS-analysis in relation to several different aspects of planning that were designed in cooperation with experts from different knowledge fields. Taken together, the papers attempt to visualise the multitude of aspects that need to be considered when planning for sustainability.

GIS is a good tool to produce spatial information as maps that can be fed into planning processes. One advantage is that data like digital maps and statistics can be combined to derive new data. Also raster data can be transformed using different algorithms to create new data. Thus, it is not the input data that is most useful, but the derived new data that did not exist before. In many cases, planning professionals using GIS see the lack of data as a problem (e.g., ULI 2008). However, I believe that the data often exist, but the planners are not skilled in innovative and advanced analysis (Göçmen and Ventura 2010, ULI 2008) that would enable them to obtain this data. This problem calls for education of planning professionals in relation to different data analysis methods, and making planners aware of the possibilities with GIS as a general tool.

In the first four papers I focus on the ecological dimension of landscape, while Papers V and VI investigate social-cultural and economic aspects of planning in landscapes. Finally, the last paper shows possibilities of working with all three pillars of sustainability among municipalities at the regional level. The common denominator of all seven papers is the use of GIS analysis as a tool to assess and visualise different landscape values.

The results in Paper I show that prior to the emergence of forest biodiversity conservation planning in practice around year 2000, presence of functional habitat networks as green infrastructure in landscapes was more related to land use history than forest landowners' management planning. The level of actual logging of old forest in a later phase of biodiversity conservation policy implementation indicates that the forest owners' ambition level regarding biodiversity conservation may also be important for the conservation of functional habitat networks in actual forest landscapes.

The studies of how spatial modelling of one terrestrial (Paper II) and one aquatic (Paper III) focal species' presence can be validated using independent observations of the species (e.g., Edman et al. 2011). That confirms the realism of using spatial modelling of habitat suitability in decision-support processes (Elith and Leathwick 2009). Some proxy data can be used in combination with knowledge about the impact of human activities and different biophysical conditions to rapidly identify habitat for endangered species (Brambilla et al. 2009). This is important, because there is often an urgent need to make plans to maintaining suitable habitat to prevent local extinctions of these species. This means that, using GIS analysis, planners can identify presently functional habitat networks, as well as areas that need to be managed or restored to improve green infrastructure functionality. Additionally, Paper IV showed that GIS analysis could also be useful for rapid assessment of the extent to which the results of management comply with voluntary norms such as a forest certification standard.

The need for habitats to be functional for particular species may also apply to social and cultural values in the landscape (Antonson et al. 2010, Mikusinski et al. in press). GIS and digital spatial data can be used to interpret and visualise socio-cultural immaterial values, for example, as in Paper V, connected to recreation and human wellbeing (Chhetri and Arrowsmith 2008, Mikusinski et al. in press). This may have importance for municipalities' land use planning. First, the GIS analysis may be a useful tool for improving their planning by identify where values that are important exists in the landscape, for example to market the landscape or region as being attractive to tourists. Second, GIS-based visualisations of social or cultural values may be used for education of both planners and the general public on the different values in the landscape (Mikusinski et al. in press).

Ecological and socio-cultural values in forests may be in conflict with economical values (Beland Lindahl 2008, Keskitalo and Lundmark 2010, Lindkvist et al. 2009). Thus, it is important to identify areas with high ecological and socio-cultural values to maintain and create functional green infrastructures for both people and conservation. Forestland with no documented values of this kind may then be managed for intensive wood production, and then hopefully the result will be fewer conflicts in land use and management. Paper VI is an attempt to identify areas with different risks for conflicts in landscapes, and consequently also areas suitable for intensive forestry.

Statistics of indicators for sustainability are not intended originally be used in GIS and visualised as maps, because these data tables don not fit GIS-standards. However, Paper VII shows that such indicators can also be used to visualise state and trends for sustainability as thematic maps for municipalities. Visualisation of sustainability indicators as maps may provide opportunity for planners to becoming informed about the present situation, and thus to be better prepared to develop plans that will address sustainability gaps. Presented as maps, the results of the analysis in all papers can be used to collaboratively produce plans that will address or handle different sustainability issues (e.g., Sandström et al. 2003).

Table 14. *Summary of the conclusions with respect to the usefulness of the GIS-related results in the thesis papers.*

Paper	Conclusion	Usefulness
I. Functional habitat modelling.	Presence of functional habitat networks depended on the forest owners' ambition level regarding biodiversity conservation.	Identification of functional habitats provides base data for collaborative planning
II. Biophysical proxy data for habitat modelling of the white-backed woodpecker.	Proxy variables can be used to identify habitat for a terrestrial focal species used in conservation planning.	Support conservation and restoration planning.
III. Predicting the occurrence of the fresh water pearl mussel.	Land cover data as a proxy could be used to identify streams with potential reproducing populations of aquatic focal species.	Faster detection of ecological integrity in water streams.
IV. Assessment of FSC outcomes for biodiversity conservation.	Spatial modelling can be used as a tool to assess consequences of forest certification	Rapid assessment tools for biodiversity conservation
V. Visualising perceived landscape values.	With GIS it is possible to model different perceived values in a landscape.	Encourage planning and use of landscape values for recreation, tourism and human wellbeing.
VI. Intensive forestry and green infrastructures	GIS is useful to identify conflict free tracts that can be used for intensive forestry.	Zoning of functional green infrastructure and tracts for intensive forestry.
VII. Indices for municipalities' sustainable profiles.	Indicators can visualise state and trends for sustainability as thematic maps for municipalities.	Develop plans that will address sustainability gaps

8.2 GIS as a tool – a SWOT- analysis

Based on the studies in my thesis I conclude that by using GIS it is possible to combine spatial monitoring data and policy norms to assess sustainability. Additionally, the results of GIS analysis and map visualisations of different sustainability dimensions may encourage communication and support participatory planning as a collaborative learning process. In the following section I discuss the extent to which GIS and spatial data can be a useful tool that can support sustainability outcomes in planning. I thus made an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) of GIS and spatial data as a tool to plan for the implementation of sustainability policies (Table 15).

Strengths include that much digital spatial data that can be used to describe different dimensions of sustainability is available. In addition, geographic patterns and trends of statistic data can easily be showed as maps in a GIS. In Sweden, there are several nation-wide land cover databases suitable for planning of landscapes. Most of the data that were used in this thesis are available at no cost on Internet. Another strength is that the different kinds of spatial data described above can be combined using GIS to produce new otherwise unavailable information useful for spatial planning. Moreover, there are many GIS tools for spatial planning, both to view the data and for more advanced modelling (e.g., Karl 2010). GIS may also be a good platform to communicate spatial information among planners, decision makers and the society (Boverket 2005, Mozgeris 2008, Sandström et al. 2003).

One of the main weaknesses is that in most cases planners do not use advanced GIS analysis for landscape planning. Thus, an informed sustainable development process is often not present in municipalities, landscapes and regions (Göçmen and Ventura 2010, Sandström et al. 2006, ULI 2008). In addition, the co-operation of spatial planning across administrative boundaries is often limited (Blicharska et al. 2011, Paper VI). Additionally, information from biological surveys has a limited distribution and accessibility (SOU 2005:94). Another important issue is that in many municipalities GIS-experts and land use planners often are different persons (e.g., Reneland 2000). In contrast, GIS analyses for land use planning require that different professional perspectives meet (e.g., Sandström et al. 2003).

Opportunities are abundant because GIS techniques and special programmes are continuously being developed, and the amount of open source GIS applications and data that are available is increasing (Steiniger and Bocher 2008). For example, with the aim to support more use of spatial data and GIS in planning, the EU INSPIRE directive encourages gathering data at one place to make spatial data more interoperable and easier to access (European Commission 2007). Also a Swedish national forest database is planned to be developed and may allow deeper inter-agency cooperation as well as improved access for other stakeholders (Skogsstyrelsen 2009). With the expansion of new GIS tools and better access to databases, the development of predictive distribution models is increasing (Elith et al. 2006, Gontier 2008). The use of GIS is also spreading to new sectors like healthcare, epidemiology and school management and the number of professionals who can use GIS is increasing (ULI 2008).

One of the threats in GIS use for planning is the lack of competence in using GIS. According to ULI (2008) 90% of organisations using GIS claim that they need higher GIS competence (ULI 2008). Moreover, many planners may not have enough resources to do all that they want concerning biodiversity conservation (Blicharska et al. 2011, Paper I).

Table 15. *Strengths, weaknesses, opportunities and threats concerning GIS and data in this thesis (the Roman numerals in brackets denote the papers included in my thesis that support the SWOT analysis findings).*

	Now	Future
Bridge	***Strengths:***	***Opportunities:***
	Data are abundant (VI, VII).	GIS techniques and special programmes are continuously developing, and open source GIS are increasing.
	Nation-wide land cover databases (I, II, III, V and VI)	The EU INSPIRE directive
	Data can be combined to produce new information (I, V, VI and VII)	Swedish national forest database
	Many GIS-tools have been developed for landscape analysis	GIS use increases in new sectors
	Visualising geographic patterns and trends for statistic data (VII).	Development of predictive distribution models is increasing
	GIS is a good platform to communicate spatial information (I, IV, V, VI and VII).	Professionals who can use GIS is increasing
Barrier	***Weaknesses:***	***Threats:***
	Planners do not use advanced GIS analysis for landscape planning (I, IV, V, VI and VII).	There is a need for increased GIS competence for planners.
	Limited co-operation of spatial planning over administration boundaries (I, IV, V, VI and VII).	Not enough resources concerning biodiversity conservation (I).
	Limited distribution and accessibility of data from biological surveys.	
	GIS-experts and planners are often different persons and different professional perspectives meet.	

8.3 What affects the quality of models describing sustainability?

Making GIS analyses of ecological, economic and socio-cultural dimensions of sustainability as demonstrated in this thesis requires (1) relevant digital data, (2) sufficient knowledge about different dimensions of sustainability, and (3) suitable spatial modelling algorithms. All three are subject to potential errors that may have an influence on the results of modelling.

In my studies I mostly used data based on remote sensing to describe land cover. These data are subject to several potential problems. First, the spatial and thematic resolutions not always match the studied issue. For example, remote sensing data have limited thematic resolution for modelling of habitat suitability for wide-ranging species dependent on fine-scale forest elements such as dead wood over large regions. Manton's et al. (2005) study of deciduous forest illustrates this. The definitions of forest types vary among databases, and the amount and spatial distribution of a theme, such as deciduous forest, is often not consistent among data sources across all spatial scales. This is due to that estimates of forest variables are derived from a network of sample points in field or by training areas derived from aerial photos with supervised classification. There are also deciduous trees outside the forest areas in Topographic map, such as succession on former agricultural land (Mikusinski et al. 2003), which is not included in k-NN Sweden. Second, the acquisition of both remotely sensed information and corresponding field data is only estimations of reality. For k-NN Sweden the accuracy of the estimated values are low at the pixel level (30x30 meter) (Reese et al. 2002). In my studies, I worked at landscape and regional scales and these scales are less influenced to errors present at the stand level. Forest at over 70 years cannot easily be separated from biologically older forests, and the accuracy is limited for stands with high stem volume (Reese et al. 2003). This is due to difficulties in estimating volume beyond a certain canopy closure, and there can also be over estimation of lower volumes. The information in k-NN Sweden is derived from information measured in a network of points from Swedish National Forest Inventory. This information has errors due to errors in data collection (Toet et al. 2007). The estimation accuracies remote sensing data can be improved if two or more data sources are combined. For example a combination of multi-spectral optic satellite end tree height data or CARABAS-II radar data improved the Root Mean Square Error, RMSE, of stem volume at stand level (Magnusson 2006).

The knowledge about different components of sustainability originates from different fields and has highly varying characteristic. Interpretation of these components in a GIS environment must therefore be performed carefully. Knowledge on spatial aspects of ecological, social and cultural dimensions is important for landscape planning (Fry et al. 2009, Mikusinski et al. in press). Knowledge of species' habitat requirements is necessary to define appropriated algorithms for modelling (Lambeck 1997). Knowledge about species ecology is relatively well known but there is less knowledge about landscape processes. In modelling habitat suitability, one must simplify species requirements into algorithms able to deal with insufficient knowledge and uncertain data. Variables may include tree species composition, species' ability to move within a home range and species-specific critical thresholds for habitat connectivity at the landscape scale (Angelstam et al. 2004c). The models predictions need to be evaluated by comparing with field data and if necessary, combined with other landscape information (Manton et al. 2005). If data needed for required analyses not exists, knowledge is needed about how proxy data can be used to indirectly calculate for example probability of existing habitat as made in Papers II and III.

Perceived values for recreation are strongly associated with good health (Skärbäck et al. 2009). Outdoor recreation is widespread and many networks of organisations and agencies need to work on this (Proposition 2009/10:238). Therefore, there is a need for knowledge about appreciated recreation values in landscapes and skills to translate these values to make GIS-analysis and visualise as maps (Chhetri and Arrowsmith 2008, Reed and Brown 2003). As for ecological values there can also be errors related to perceived values that may have an influence on the results on analysis about appreciated values. For example quietness was a high ranked value in Paper V. To select these quiet areas the distance from roads was used. But apart from the roads, there may also be other sources of noise, and the spreading of it depends on topography, land cover etc. There can also be noise in some area for example twice a day and be quiet the rest of a day. Thus it is important to have knowledge about what is the source data about and what the result of the analyses means.

Cultural values are even harder to interpret because they may have several meanings for different persons and there is a lack of unified tools to identify the values (Antonson 2009). Traditionally, more attention has been given to economic and ecological dimensions, while social and cultural issues seem to be neglected in planning for landscapes (Antonson 2009). Compared to ecological features, less tangible values such as many social values are more difficult to measure and include in the planning process (English and Lee 2004, Erikstad et al. 2008).

The model inputs are usually only estimates, therefore it is important to have knowledge not only about the parameters' influence on the outputs of a particular model, but also depending on the use of different GIS models and algorithms. For example, combined parameters can interact with an exaggerated effect or a reduced effect on output (McElhany et al. 2010). Algorithms that describe ecological, social and cultural dimensions of sustainability may have very different level of complexity ranging from simple selections or overlays of data sets to very advanced mathematical models in many steps. In my thesis I used mostly simply overlays between themes to identify areas that satisfy different criteria. Simple models may be robust if included parameters are relevant to the studied issue because they are easy to use and therefore gives fewer errors. Moreover, the greatest advantage of such models is that actors with different backgrounds may relatively easily understand these. To visualise data as maps is important if the information is intended be implemented and used in planning process (Mikusinski et al. in press).

The resulting maps from GIS models may be seen as a probability map of the spatial distribution of different values over the landscape. GIS algorithms can then be used to identify where different landscape values has the best chance to be developed, as well as to design approaches to zoning of landscapes and regions (e.g., Innes et al. 2005). The usefulness of those maps lies in possibility to identify where field investigations shall be done, and which landowners and stakeholders are connected to those areas in the future planning to alleviate communication and negotiation of indicators, targets, and impacts (Boverket 2005, Mozgeris 2008, Zetterberg 2009).

8.4 Trends in data availability and education

8.4.1 Availability of data

The former problem in terms of data supply (ULI 2008) has been alleviated due the increased availability of data. Currently a major paradigm shift is going on with respect to the amount and availability of spatial data (P. Ottosson, ESRI-sgroup, pers. comm.). Cooperation in Europe and globally is increasing, and demands for harmonization and interoperability of national geospatial data are clear. The EC directive INSPIRE (Infrastructure for Spatial Information in Europe) provides a legal basis for the further harmonization of many data themes important to promote sustainable development (European Commission 2007). In the context of INSPIRE directive all authorities have obligations to make their geospatial data available through online services until 2019. When the INSPIRE directive is implemented, ideally it will be possible to seamlessly combine data from different EU member countries. For example in Sweden, the Civil Committee's report (Yazdanfar 2010) defines government responsibilities for data themes shared between different authorities. In Sweden, over 25 agencies have a designated responsibility for information, which means that they are obliged to make their information available.

There are, however, some weaknesses in the distribution and accessibility of information from biological surveys and studies (SOU 2005:94). There is no single entry for those who need such information. The user needs to search data on different web locations and in written sources. Therefore, there is a need for a national distribution portal on the Internet to be built. For example in Sweden, the Swedish Forest Agency (Skogsstyrelsen 2009) suggested actions for more effective information management, inter-agency cooperation and access to information for the forest owners. Their report from 2009 stated that there were gaps in the availability of information for many forest owners and contractors, which hampered and complicated the use of data to allow including natural and cultural considerations in an efficient way during planning and operational management.

For these reasons the Swedish Government assigned the Swedish Forest Agency the mission to conduct a preliminary study about national forest database development, and the operation of a resource-effective approach to provide comprehensive information to all owners of their own forest (André 2010). That report shows how a modern coordinated supply of comprehensive information to forest owners in terms of national forest database can be established, and operated in a resource-efficient manner. The report points out the need for significant simplifications for individual forest owners and forest companies, increased incomes, and opportunities for positive effects on ecological aspects. About 75% of surveyed owners and contractors responded that good information management facilitates efficient natural and cultural considerations in connection with logging and forest management. The national forest database could be an important component of a deeper inter-agency cooperation, and one important element is to simplify the contacts between the forest owners and the authorities and make information available to forest owners, forest contractors, timber purchasing organizations and agencies. A database that exist today is called "Skogens pärlor" (Forest pearls) on the Swedish Forest Agency's website and is for free use. It is a nationwide database with information on different types of formally protected areas, woodland key biotopes and ancient/cultural remains.

When implemented in practice, the EU INSPIRE directive and together with the national forest database may facilitate the problems with data supply for spatial planning, and particularly for ecological sustainability development in landscapes and regions. This would make geospatial data much more accessible and easier to manage and use. The INSPIRE directive seems also to be a possible catalyst for greater data interoperability in general, which may lead to many benefits in society and more use of GIS in practical planning (European Commission 2007).

8.4.2 Need for education

The new planning legislation in Sweden (PBL 2011) emphasises that municipalities must report in their plans how they shall work with climate issues, both to prevent climate change and their readiness to take action for those change. A survey done by SKL (2009) about how the municipalities were prepared for the new responsibilities related to climate change indicated that municipalities have neither the technology nor the knowledge about the necessary data sources and modelling.

The need for spatial analyses at multiple scales to implement on the ground sustainability policies, and the actual opportunities to use existing data for that purpose demonstrated in this thesis, clearly stresses the necessity of more use of GIS in the planning processes for sustainable development. Various actors, such as landowners, municipalities, county administrative boards and other, could benefit from GIS-based analysis. Thus, there is a need for improved GIS-use skills of the key actors involved with planning for sustainable development in landscapes and regions as well as for investments in GIS modelling software, and more data such as land cover data from remote sensing (ULI 2008).

University educations for GIS-engineers have been available since the beginning of 1990s. Presently, about 250 college students graduated annually in GIS (Ottosson 2002) and additional 50 from qualified vocational training programmes (KY-utbildning). For a decade ago too few students were examined to replace the retirement of GIS specialists, which was between 1000 and 3000 people per year (Ottosson 2002). In Sweden 2006, 23 universities offer about 150 courses in GIS at different levels (Brandt and Arnberg 2007) and 6 provide GIS-programmes (Brandt et al. 2006). Some GIS-courses function as tool-kit courses for other subjects. As a result, more and more GIS-specialists are available "on the market". However, still the use of GIS in spatial planning is limited due to GIS-experts and planning staffs often are different persons (Göçmen and Ventura 2010, Reneland 2000). Thus, there is a need for specialists that have skills to combine both expertise in different planning fields and GIS modelling.

8.5 A vision for GIS in the future

According to the surveys by Andersson (2001), Ottosson and Samuelsson (2005), SKL (2009) and ULI (2008), a main problem to utilize the capabilities of GIS as an advanced planning tool in Sweden is the availability of suitable data. But the analyses in Paper VII showed that data not intended to be used as geographic information for GIS analyses, such as statistics, can be made useful as input to planning for sustainable development towards sustainability in municipalities (Westin 2011). I also showed in Papers I, IV, V, VI and VII that GIS may be a useful tool to produce new otherwise hidden data for further analyses useful for planning.

The other main problem according to the surveys is lack of planners' skills in advanced use of GIS. In Sweden there is no planning at the regional and national level even if these levels often provide strategies that should be taken into account by planners. Landowners and conservation planners often only make plans for their own territories (Paper VI). Using a diversity of data and GIS analyses I have explored the usefulness of spatial assessment to support landscape and regional planning toward sustainability. Specifically, I addressed the need of sustainability assessments at municipal, landscape and regional levels to support the SD and SFM societal processes. In the analyses I have used both administrative borders (municipality) and functional units (landscape and region) for the assessments. To plan for landscape functionality (functional structures for biodiversity, people and economic activities) there is a need for cooperation between planners, landowners and other stakeholders to develop shared plans. (e.g., Angelstam et al. 2010a, 2011). The analyses in this thesis are a result of collaboration with researchers with different expertise and that are committed to transdisciplinary knowledge production processes with local stakeholders (Tress et al. 2006). Data has been collected from stakeholders through qualitative interviews and was then included in the GIS analyses. Similarly, planners and those who have other special knowledge need to understand what could be done with GIS and to combine this with their specific knowledge to assign tasks to the GIS-specialist, or alternatively, GIS-specialists need to have different kinds of expert knowledge to make analyses as input to spatial planning (Balram et al. 2004).

Studies show that the development of GIS to a general tool for planning is only at the initial step (Göçmen and Ventura 2010, Ottosson and Samuelsson 2005, ULI 2008). Hence different organisations state that they need greater expertise to use GIS. But if education programs in planning train their students to be GIS users only, developments in GIS and the planning profession will evolve independently (Drummond and French

2008). Thus, there is also need for knowledge that is often available with researchers at universities and experts in different fields. For example, planners need better understanding of different levels of biodiversity: species needs, habitats quality and processes, for conservation planning (Paper VI). A solution can be an improved collaboration among universities and planners. For example Swedish University of Agricultural Sciences, SLU, has 4 missions: education, research, environmental monitoring and assessment (FOMA), and cooperation. One advantage is that SLU has data on several of the different production conditions for biological production - water, land, forests and species - which means that there are great opportunities to make such broad analysis of the entire ecosystem. There is a consistent understanding of the synergies between research, education and continuous monitoring is not fully utilized (Petersson and Jennische 2007). One important explanation is probably that there are too few people working with all three activities, research, education and FOMA. Current scientific methods can more quickly be integrated into the FOMA through close cooperation with research and researchers from different disciplines can contribute to science-based analysis. This means that today to use GIS to its full potential requires that planners need to develop collaborative learning processes (Daniels and Walker 2001) with a group of people that together have the required skills.

I argue that there is a need for broader educations for planners, landowners and other stakeholders to make GIS a generic knowledge for all relevant educational programmes, such as forestry, ecology, physical planning, logistics, marketing, school management and healthcare. This would also provide landowners, municipal civil servants, companies and county administrations with GIS as a common language, and maps would then become a tool for collaboration.

9 Conclusion

The extents to which political objectives and norms concerning sustainability are satisfied vary among different landscapes and regions. In my thesis I show that there are large opportunities for informed planning and governance towards sustainability using GIS-based analyses and visualisations. However, this requires that planners, landowners and other stakeholders acquire broader knowledge in different knowledge fields, appropriate data, and skills to make advanced GIS-analyses over larger landscapes and regions, as well as to communicate the results among stakeholders. Thus, there is a need for new education programs including a broad spectrum of economical, ecological and socio-cultural dimensions of sustainability as well as knowledge about how society is steered, in combination with GIS.

10 Reference

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