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## Abstract

Uneven-aged forest management based on selection systems is surrounded by strong feelings in Sweden and debates for and against have been going on for more than 100 years. The shift from selective felling, or high-grading, to sustained-yield forest policy eventually led to the use of clear cutting forest management systems on all boreal site types. The need for a more diverse set of silvicultural systems that emulate natural disturbance regimes has been emphasized in the recent Swedish forest policy debate. There are two aims of this thesis; 1) to estimate the amount of boreal continuous tree cover forest sites, i.e. sites that naturally were dominated by forests with gap phase and cohort dynamic, and the amount of pre-industrial agricultural woodlands, how much of such sites that hold old forest today and how they are managed, 2) To explore local forestry actor's views on and knowledge about alternatives to the clear cutting silvicultural system. Two study areas, one in the south and one in the north part of the Swedish boreal forest, were examined using multiple methods for estimates of forest conditions and qualitative interviews with local forestry actors. In both study areas about 10 % of the forest landscape consisted of continuous tree cover sites. In addition there were high altitude mountain forests in the northern study area, and anthropogenic wooded grasslands in the southern study area. The present harvesting system was similar on all site types. In the southern study area forestry actors were more positive to uneven-aged forest management systems than in the northern area. Foresters in both study areas blamed selection felling systems for the past unsustainable exploitation of the Swedish forests and were negative to using selection systems as alternatives for sustained yield production. However, they were positive to them as a complement to satisfy social and to some extent ecological values. To encourage the use of selection systems as a complement to the clear cutting system in areas with suitable site conditions and in areas with specific management goals there is a need for more knowledge about the consequences for different dimensions of sustainable forest management. Finally, to implement sustainable forest management a landscape approach is needed. This includes emulation of natural disturbance regimes for biodiversity, management of forests for social use, and improved co-operation among land owners at multiple scales in space and time.

**Key words:** continuous cover forestry, forest dynamics, forest management system, forest policy, forest governance, boreal forest, social forestry, biodiversity.

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I dedicate this thesis to my wife Lourdes that has managed to cope with me and care for our three children despite me being absent in front of my computer or away from home on field work. Without your support this work had not been possible.

## List of Publications

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

**I.** Axelsson, R., Angelstam, P. & Svensson, J. (2007). Natural forest and cultural woodland with continuous tree cover in Sweden: How much remains and how is it managed? Scandinavian Journal of Forest Research, 22, 545-558.

**II.** Axelsson, R., Angelstam, P. & Hagegård, E. Uneven-aged forest management in boreal Sweden: local forestry actor's perceptions (manuscript).

## Abbreviations

| | |
|---|---|
| ASIO | Absent or Almost never Seldom Infrequently Often |
| CTC | Continuous Tree Cover |
| DEM | Digital Elevation Model |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| GDP | Gross Domestic Product |
| ITTO | International Tropical Timber Organization |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| kNN | k Nearest Neighbour |
| MCPFE | Ministerial Conference on the Protection of Forest in Europe |
| NFI | National Forest Inventory |
| SI | Site Index |
| SUS | Skogsvårdsorganisationens Utvärdering av Skogspolitikens effekter (English: Swedish forest agency's Evaluation of Forest policy effects) |
| SMHI | Swedish Meteorological and Hydrological Institute |
| TWI | Topographic Wetness Index |
| UNEP | United Nations Environment Programme |
| VHU | Vetenskap för Hållbar Utveckling (English: Science for Sustainable Development) |
| WCED | World Commission on Environment and Development |
| WW1 | World War 1 |
| WW2 | World War 2 |
| WWF | World Wide Fund for nature |

# Contents

# Introduction

When local industrial use of Swedish forests began in the 17th century it started, as in most other countries, as an unsustainable exploitation of the most valuable trees. In this thesis I will use the term exploitative to describe the early industrial forest use in Sweden were efforts were concentrated on the development of technology to extract timber and with limited value-added production. This phase of Swedish forestry has afterwards been described as an unsustainable use of the forest resource and large forest tracts have even required restoration to regain productivity (for example Hagner, 2005b; Enander, 2007). Initially, industries where few and the forest resource was vast. It is thus quite a natural development to first learn how to use a resource and then when it is noticed that the resource need efficient management learn how to manage it in a long-term sustainable way. Larger trees were harvested but no regeneration measures followed. If a forest became degraded, timber was searched for in other areas. When the demand for timber increased, more or less all accessible large trees were harvested (Enander, 2004). During the late 19th century it became evident that the use of the forest resource was not long-term sustainable and that something had to be done. Development of modern sustained-yield forestry in Sweden developed gradually from its roots in the early 19th century (e.g., af Ström, 1830), through several local applications in southern Sweden (Obbarius, 1857), and the 1903 forest law.

More than a century ago it was debated whether clear cutting or selection felling was the best system to use (Wallmo, 1897). Held against clear cutting was the cost for manual regeneration (Enander, 2007). The first real effort towards a sustained yield of wood from the Swedish forests was the 1903 Forestry Act. Land owners were for the first time required to secure forest regeneration. The implementation of the 1903 Forestry Act until about 1920 started well and the area of new stands established by artificial regeneration (planting and sowing) increased year by year in southern Sweden (Enander, 2007). However, around 1920 many forest owners returned to harvesting methods that according to the law allowed them to use natural regeneration to save money (Appelstrand, 2007). The supervision of the law implementation was poor, and the demand for timber 1910-1920 decreased due to the recession and the WW1 (1914-1918). The economic situation continued to be unstable with a more or less world-wide depression in the late 1920s that led straight into WW2 (1939-1945). During this time of economic and general uncertainty the first national inventories of the Swedish forest resource took place.

The results were alarming (Anon., 1932). Large parts of Swedish forests were in a condition so poor that their capacity to supply timber to the industry was not possible to rely on (Hagner, 2005). It was clear that something had to be done.

After WW2 intensive work resulted in the 1948 Forestry Act with the aim to secure a long-term sustained yield of wood to the industry. At this time a window of opportunity for a major change had opened due to high demands for wood products on the world market and the alarming reports on the state of Sweden's forests. Thus, a major change in forest management and use of the forest resource began. A main condition for this was that forest managers and owners had to start to use a different time horizon. It was no longer enough to earn money on a yearly or shorter time frame. Now there was a need to plan for a full rotation of about 100 years or longer. This change in thinking, planning and management was the first step towards sustainable forest management in Sweden, i.e. the economic dimensions were realised. The 1948 Forestry Act meant a major change in forest management because of the emphasis on sustained yield and profitability led to the wide introduction of the clear cutting system. Economic sustainability, profitability and social considerations were included as general principles together with regulations on minimum harvesting age of the forest (Enander, 2007; Appelstrand, 2007). The years after the 1948 forest law coincided with the introduction of new technologies. First the chainsaw and then heavier and more efficient forest machines were introduced. Along with improved economic profitability this allowed for intensive management with secured regeneration and other measures that safeguarded a sustained yield of timber. About 1970 Swedish forestry was more or less fully reformed, highly mechanised, intensive and economically successful. The vision of a sustained yield of timber for the industry was secured even if large areas of forest still needed to be restored after the previous unsustainable exploitation. Among foresters the pride over the success grew big. Successful forestry was and still is associated with intensive even-aged clear cutting management systems. This exploitative phase has among foresters been associated with selective and selection felling systems. The harvesting method was most often selective but it was often carelessly called selection felling (Enander, 2005; Siiskonen, 2006; Lundqvist et al., 2007). Since then there have been no clear distinction between selective and selection felling systems in the Swedish debate (Paper I in this thesis). This is interesting since the main problem was that selective systems were used with no efforts to safeguard or monitor regeneration and growth. It is hard to give an exact year for the transfer to sustained yield forest management since it was a gradual process that occurred at different times in different parts of the country.

However, already in the 1970s a reaction from the society came. Due to large clear cuttings, scarification, cleaning, drainage and the use of herbicides to control deciduous tree species and protect plants, the forests were used so intensively so they started to change in appearance. In the north there was a big increase in clear cuttings with the biggest being 100-500 ha large (Enander, 2007). People saw the changes and several reports supported their worries (Palmstierna, 1967; Gillberg, 1973; Ekelund & Hamilton, 2001; Enander, 2007). In the 1970s there was an intensive debate about clear cuts, scarification and the use of chemicals in forestry (Anon., 1974; Enander, 2003). This was also reinforced by several international reports and books that pointed out that human activity had affected the environment negatively, that the carriage capacity of earth was harmed, and that human use of natural resources were not sustainable (Carson, 1962; Erlich, 1968; Dubos and Ward, 1971; Club of Rome, 1972; Molina and Rowland, 1974).

In 1974 environmental considerations were included in the forest law (Ekelund and Hamilton, 2001; Boström, 2002). In the 1979 Forestry Act several issues to support productivity were included but also a strengthening of the supervision of environmental considerations. The continued stream of reports on unsustainable practises and the growing public worries pushed policy-makers to action. In 1980 the Brandt commission presented its North–South: A programme for survival report (Brandt Commission, 1980) and the IUCN/UNEP/WWF presented the World Conservation Strategy: Living Resource Conservation for Sustainable Development (IUCN/UNEP/WWF, 1980). In the late 1970s an intensive debate on the use of herbicides to control competitive deciduous tree species resulted in regulations against it (Enander, 2007). In 1987 sustainable development was made the overall goal for environmental policy globally with the Brundtland report (WCED, 1987). Sustainable forest management (MCPFE, 1993; Burton et al., 2003; Rametsteiner and Mayer, 2004) is to manage and use forests according to the principles of sustainable development and the ecosystem approach (Wilkie et al., 2003) and it has its roots in the forest principles and Agenda 21 that were adopted at the World summit in Rio (1992) and the Helsinki declaration (MCPFE, 1993; FAO/ITTO, 2004). Following the world summit the new Swedish Foretsry Act of 1993 stated that economical and environmental goals are equally important and that there is a need for a more diverse set of silvicultural systems (Anon., 1993; Anon., 2002b; Enander, 2007; Appelstrand, 2007). More recently also social goals have been included in the Swedish forest policy in line with the principles of sustainable forest management (MCPFE, 1998; 2003, Anon., 2001; 2002a). This was further reinforced by the 2001 and 2006 evaluations of the Swedish forest policy (Anon. 2002b; Mikaelsson, et al., 2006).

To realise the vision stated in international, EU and Swedish policies on sustainable forest management there is a need for a diverse set of forest management methods, aims and systems for governance, planning and management at local to regional and national scales. A recent evaluation of Swedish forestry showed that 96 % of all final fellings were done by the clear cutting system (Anon., 2002b). Paper I showed that alternatives to clear cutting were not correlated to specific site types. This shows that there are no, very limited or only recent efforts to adapt forestry operations to emulate natural disturbance regimes, i.e. consistent with close to nature-forestry and similar concepts.

The aims of this thesis are to (1) propose a definition of continuous tree cover forest i.e. forest on sites that naturally were dominated by forests with gap phase and cohort dynamic and pre-industrial agricultural woodland disturbance regimes, estimate the amount continuous tree cover forest sites in the Swedish boreal forest, how much of it that holds old forest and how it is managed, (2) explore local forestry stakeholders' ability to use and prerequisites for, attitudes towards and knowledge about alternatives to the clear cutting system. In addition to the main research questions I review the Swedish forest policy development, discuss related terminology on continuous cover forestry, and provide some different perspectives. Hopefully this thesis could contribute to a constructive discussion on pros and cons of uneven-aged forest management, i.e. silvicultural systems that aim for a continuous tree cover forest, by answering questions like: What is a continuous tree cover forest? What is continuous cover forestry? Where could it be used and why? The research approach in this thesis is interdisciplinary and terminology from Myrdal (2005) has been used.

## Terminology and definitions

### SELECTION FELLING SYSTEMS AND SELECTIVE CUTTINGS

In Sweden the use and usefulness of uneven-aged forest management has been and is still contested (Karlsson & Lönnstedt, 2006a; b). To be able to discuss the pros and cons of uneven-aged selection felling systems for economic, ecological and social dimensions of sustainable forest management there is a need to clarify the terminology regarding what uneven-aged forest management is. There is also a need to specify on what site types and for what dimensions of sustainable forest management alternatives to clear cutting systems are beneficial (e.g., Angelstam, 2003). In particular, it is important to understand the definitions of selection harvesting and selective cutting. The selection felling system means felling of scattered single trees and/or small groups of trees selected over the whole harvesting area (Matthews, 1989). The size and age of remaining trees should be maintained so that all age classes are represented. A suitable mixture of species should be maintained. Young saplings should be freed from suppression, and defective stems should be removed if they hamper the development of better ones. Proper management to secure regeneration is as important as for any silvicultural system. These recommendations may be adjusted if the aim of management is other than timber and pulpwood production. By contrast, selective cutting means high-grading or high-dimension felling. All valuable large dimension trees are felled and no management is carried out to secure regeneration and to improve the growth and quality of the remaining trees (Anon, 1999b). While this is not a silvicultural system (Matthews, 1999), it is still practised in many areas around the world. Selective methods used in Sweden pre-1950 were often termed selection felling and this confusion contributed to giving uneven-aged forest management its poor reputation (Schutz, 1994; O'Hara, 2002; Enander, 2005; Siiskonen, 2006; Lundqvist et al., 2007). Selection felling systems qualify as a form of uneven-aged forest management.

### CONTINUOUS TREE COVER FOREST

The Swedish Forest Agency has proposed the following definition of forests with a continuous tree cover (CTC) (Anon., 2004). ”The extent of individual stands should be at least 0.25 ha and they should have had a continuous forest cover with no major changes in tree species during at least 300 years. In addition, the forest should have held a minimum of 30 m3 ha-1 of living trees during this period. In mixed forests there should be at least one species with over 10 m3 ha-1”. In principle, this is similar to the concept of ancient and semi-natural woodlands (Watkins, 1990; Schuck et al., 1994; Peterken, 1999).

However, to make the concept of CTC acceptable, useful and understandable it is important to connect it to ecological theories and empirical data about forest ecosystems. It is today commonly accepted that disturbances are an important part of forest ecosystems. Previous researchers thought a forest developed through several steps of succession to a final steady state called the climax (Clements, 1936). Clements and his colleagues probably noted disturbances but overemphasized the steady state or climax in old forests (Kuuluvainen, 2002a). However, over the years scientists noticed that there was no steady state in natural forests, and the theory on natural disturbance regimes started to develop. Since the 1970s the ideas has developed into commonly accepted theories on natural disturbance regimes (Pickett and White 1985; Falinski, 1986; Oliver and Larsson, 1996; Attiwill 1994; Rülcker et al., 1994; Fries et al., 1997; Bergeron et al. 1998; Engelmark, 1999; Hunter, 1999; Angelstam & Kuuluvainen, 2004).

As the new theories on natural disturbance regimes spread there was a need to adapt this new knowledge to conservation and forestry. As a response to this need the ASIO-model was developed (Rülcker et al., 1994; Angelstam, 1998). It divides the forest into different types depending on the relative frequency of fire disturbance in different site types; A – absent or almost never, S- seldom, I – infrequently and O – often; representing a gradient from wet tall herb to dry lichen. It offers a simple and robust way to emulate some of the features of the fire disturbance regime with a landscape perspective. The aim was to offer a model for forest management that was easy to use and understand (e.g., Fries et al. 1997). This does not mean that a forest management unit or protected area where the ASIO-model is applied should look exactly like a boreal forest landscape affected by a natural fire disturbance regime. Rather forest management should be inspired by the natural disturbance regimes. For the implementation of the ASIO-model in the context of biodiversity conservation (i.e., to maintain species, habitats and ecological processes) a critical challenge is to identify sufficient amounts of different disturbance regimes on a landscape level. Focal species is one approach that can be used to provide quantitative estimates (e.g., Roberge 2006 PhD).

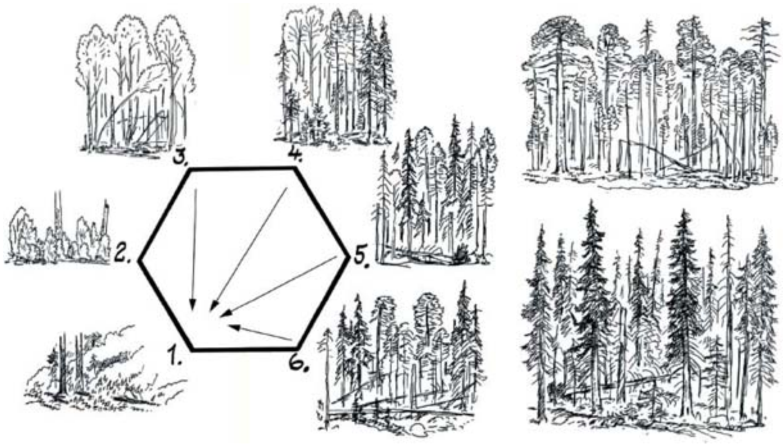


*Figure 1. Drawing illustrating six developmental stages during the succession after stand-replacing disturbances such as fire or strong wind. In the boreal forest of Fennoscandia and Russia an early deciduous and a late coniferous phase is typical. Most developmental stages can return to the first stage following disturbance, resulting in a multitude of successional pathways (left). Cohort dynamics in a dry Scots pine forest is shown in the upper right corner, and gap dynamics in a wet Norway spruce stand in the lower right corner (Angelstam and Kuuluvainen, 2006; drawing by Martin Holmer).*

Inspired by the natural disturbance regime paradigm, the ASIO-model and site adapted forestry (Lundmark, 1986) I propose a definition of a continuous tree cover forest as a forest where stand-replacing events were very rare in the naturally dynamic and pre-industrial cultural landscape. Such forests and woodlands were dominated by old and large trees, standing and lying dead wood and often held a diverse horizontal and vertical stand structure, and with trees in different age classes. This was a result of different natural (forest) and antropogenic (cultural woodland) disturbance regimes, climate, site conditions, and landscape topography. My proposed ecological definition is based on the forest disturbance regime paradigm. A continuous tree cover forest belongs to either the multi-cohort or gap phase dynamics groups (Falinski, 1986; Rülcker et al., 1994; Fries et al., 1997; Angelstam & Kuuluvainen, 2004), or the wooded grasslands of the pre-industrial cultural landscape (e.g., Peterken, 1999).

In a naturally dynamic boreal forest landscape the multi-cohort and gap phase dynamics groups is found mainly on dry pine and wet spruce sites, respectively (Falinski, 1986; Rülcker et al., 1994; Fries et al., 1997; Angelstam & Kuuluvainen, 2004). A cultural woodland continuous tree cover forest is defined as wooded grassland since this is the main culturally caused woodland type in Sweden (e.g., Ihse, 1995). Here I follow the FAO definition of forest, i.e. with a minimum of 10 % crown cover (Anon., 1999a). When trees grows in the open Swedish cultural landscape they develop more and larger branches as well as crowns many times bigger than in a forest and will thus provide quite large and important habitat structures for birds, insects and sedentary organism even at low tree densities. During the 20th century, as forest management practices generally encouraged removal of deciduous trees, the cultural woodlands provided refuges for many threatened species (Tucker & Evans, 1997; Kirby & Watkins, 1998; Mikusinski et al., 2003). All continuous tree cover forests vary in structure, composition, density, and tree species, in both time and space.

It should be noted that the definition proposed here does not exclude forests that fit under the Swedish Forest Agency's definition, i.e. old forests on mesic sites. A part of the CTC forest in the naturally dynamic and pre-industrial cultural landscape became old by chance or because of landscape topography. However, the majority of CTC forest is to be found on dry and wet sites and sites with humid climate.

In the future this definition might need to be revised to include also new types of production forests and cultural CTC forests that implementation of the principles of sustainable forest management will give rise to. Here I mainly think of protective forests along and around streams, lakes, roads and urban areas, forests that provide pleasant scenery, recreational forests in the vicinity of urban centres and larger areas in more remote areas (see Innes and Hoen, 2005). In addition to this the safeguarding of ecosystem services vital to human survival might also give rise to new continuous cover forests in the future.

# Some perspectives on continuous cover forestry

## AN ECONOMIC PERSPECTIVE

It is often claimed that continuous cover forestry is negative for economical reasons. Probably that is true if the clear cutting management system is compared with uneven-aged continuous cover forestry, no other values than timber production are considered, and the fact that logistic systems and industries in Sweden are adapted to clear cutting systems. There are reports on how much money that would be lost on the national level if continuous cover forestry would replace the clear cutting management system in Sweden (Karlsson, B. & Lönnstedt, L., 2006b). In paper I we showed that about 10 % of the forest in Sweden was of site types were alternatives to the clear cutting system could be considered for biodiversity conservation reasons. In addition management for recreation, energy, carbon sequestration, adaptation to climate change and other ecosystem services might require alternatives to the present forest management system (Costanza et al., 1997; Daly, 1997; Tahvanainen et al, 2001; Linder, 2000; Noss, 2001; Kraxner et al, 2002).

## AN ENVIRONMENTAL PERSPECTIVE

There is wide agreement that the structure and composition of natural forests are formed by its disturbance dynamics (e.g., Sprugel, 1991; Kuuluvainen, 1994, 2002b; Angelstam , 1998; Bergeron et al., 2002; Korpilahti and Kuuluvainen, 2002; Angelstam and Kuuluvainen, 2004). Natural disturbance regimes results in a diverse forest landscape with respect to tree age distribution, structures and tree species (Kuuluvainen et al., 1998, Angelstam, 1998; 2002; Pennanen, 2002). To make site adaptive forestry easier to implement the disturbance regime paradigm for boreal and temperate natural forests was used with its division of the forest into three main groups (e.g., Falinski, 1986; Rülcker et al., 1994; Fries et al., 1997; Angelstam and Kuuluvainen, 2004): (1) Succession dynamics on mesic sites with large-scale disturbance regimes, resulting in largely even-aged stands with successions of young to old-growth deciduous, coniferous and mixed stands. (2) Multi-cohort dynamics on dry and poor sites, normally dominated by Scots pine (*Pinus silvestris*) or in the south Oak (*Quercus robur*) in several age classes, where low-intensity ground fires often killed younger trees and left most of the older and larger trees intact. (3) Gap phase dynamics with small-scale disturbances, but rarely fire, on moist to wet sites, in humid climates or where landscape topography protects against large scale disturbances. Norway spruce (*Picea abies*) and other shade tolerant species dominate. The forest is multi layered with smaller gaps due to trees that die of age, biotic and abiotic stress. To mimic a natural disturbance regime there is a need to use a diverse set of silvicultural systems (Angelstam, 2003). Uneven-aged selection felling systems would be one of several important tools. However, here we need to understand that there are large differences within the uneven-aged forest management concept ranging from intensive industrial to close-to-nature. Management using intensive industrial uneven-aged forestry does not promote biodiversity while a well managed network of close-to-nature managed forest stands will.

## A SOCIAL PERSPECTIVE

The word social refers to the society, its organisation and people. A development that is sustainable to the society, its organisation and people is proposed by Thin (2002) to include 1) social justice, 2) solidarity, 3) participation, and 4) security. In addition to this the Swedish National Institute of Public Health has pointed out human wellbeing as a major goal for sustainable development (Kjellström et al., 2005). This is well in line with international policy (MCPFE, 1998; Innes and Hoen, 2005) and the Swedish Forest Agency's interpretation of sustainable forest management (Nordanstig, 2004).

Alternative forest management approaches have been advocated to satisfy social values such as recreation and tourism, both in Sweden (Lindhagen, 1996; Rydberg & Falck, 2000; Rydberg, 2001) and internationally (Kimmins, 1991; Wenner, 2000; Konijnendijk, 2003; Tabbush, 2004; O'Brien, 2005). However, social dimensions of sustainable forest management change over time and are thus different in countries with different levels of social development (MCPFE, 2003). In Sweden today human wellbeing and parts of the solidarity, participation and security points above qualifies as important parts of the social dimension of sustainable forest management. However, only security aspects and human wellbeing applies to the continuous cover forestry concept specifically. Under security I like to divide the different aspects in three groups of threats that could be avoided or decreased with continuous cover forestry at four spatial scales. Locally: noise and air pollution, land slides, wind caused damage, local climate, and flooding; regionally: flooding, and degradation of ecosystem services; and nationally: accusations of unsustainable forestry, degradation of ecosystem services, and climate change; and internationally: climate change and degradation of ecosystem services. Climate change and continuous cover forestry will be further elaborated in a separate paragraph in this thesis. Some of these aspects are also valid for human wellbeing. Other aspects that are of importance to human wellbeing are accessible forest of good quality for recreation and tourism (Koch och Kennedy, 1991; Bolshakov, 2000; Rydberg, 2001; ), to maintain the cultural landscape and provide nice views and the perception of a sustainable landscape to local people (Anon., 2000). This is important for rural communities' potential to attract entrepreneurs and qualified manpower. Many rural communities have been dependent on the forest resource and some still are. The livelihood aspect of sustainable forest management is pointed out in European level forest policy (MCPFE, 1998). Social dimensions of sustainable forest management are complex and often hard to grasp. Hence there is a need for an adaptive and learning management process and wide cooperation to address these issues (MCPFE, 1998; MCPFE, 2003; Campbell and Sayer, 2003; Innes and Hoen, 2005).

### Continuous cover forestry and climate change

The forest sector can play a significant role for the accumulation of greenhouse gases (Makundi, 1997). A climate change perspective on forestry could be divided into two parts, namely mitigation and adaptation. It should also be noted that climate change impact locally could be both positive and negative but implies a great uncertainty. Both mitigation and adaptation relate to costs. A successful mitigation of climate change implies efforts from all over the world, not only from negatively affected areas (Pacala and Sokolow, 2004).

Mitigation of climate change means to take actions to control or reverse the climate change process. From a forestry perspective this can be done by; 1) increasing the capacity of forests to store carbon; 2) replace fossil fuel use by the use of bioenergy; 3) increasing the forested area (Pacala and Sokolow, 2004). From a continuous cover forestry perspective mainly the first alternative to increase the capacity of forests to store carbon is valid. This implies an increase in standing volume, a change to other or mixed tree species or both (Karjalainen et al., 2002). Close to nature management using uneven-aged forest management might be the best way to multiple use forestry and mitigation of climate change (Kraxner et al., 2003). According to Newell and Stavins (2000) mitigation of carbon is more cost effective if trees are not periodically harvested. Here continuous cover forestry could potentially play a role. In contradiction Taverna et al. (2007) found that the optimal forestry climate change mitigation is to maximise the annual increment on a sustainable level, harvest, develop systems for cascade use of forest products and to use rest wood for energy production. Cascade use means that the wood should have one or several use cycles before it finally is used for energy production. The cascade use concept is in line with the production of slower growing wood qualities and wood products with longer life cycles that have been discussed (Kraxner, 2002). However, it has been estimated that only 5 % of the forest sector carbon is in forest products and 95 % is in the forest ecosystem. In some European countries, including Sweden were harvesting is less then the annual increment the carbon storage is increasing with present management systems (Karjalainen et al., 2002).

Adaptation to climate change implies activities to counteract the negative effects and to reduce vulnerability of socio-ecological systems to experienced and expected effects (Scheraga & Grambsch, 1998). This means mainly to secure ecosystem services needed for the survival and wellbeing of humans and nature (Daly, 1997). Ecosystem services are very costly to replace if functions are lost (Costanza et al., 1997). Noss (2000) lists a series of forest management practices that are likely to support the maintenance of biodiversity and ecological functions during climate change. Here follows the management practices from the list that could need the use of continuous cover forestry; 1) representing forest types across environmental gradients in reserves i.e. to include all different forest types in the network of formally protected areas; 2) protecting climatic refugia at multiple scales; 3) avoiding fragmentation and providing connectivity, especially parallel to climatic gradients i.e. to provide dispersal and migration corridors for organisms that need to move to survive climate change; 4) providing buffer zones for adjustment of reserve boundaries; 5) practicing low-intensity forestry and preventing conversion of natural forests to plantations. According to Krankina et al. (1997) fast adaptation of long-lived boreal forests is a less likely scenario.

When it comes to factors affecting timber production adaptation might be supported through a more diverse forest that could be managed with continuous cover forestry methods (Spittlehouse and Stewart, 2003). Most probably a more diverse forest is more adaptable to the new disturbance situation that climate change might result in (Dale et al., 2001). To be able to maintain the production of also traditional forest products alternatives to the even-aged clear cutting system are needed. Here continuous cover forestry can play a role (Makundi, 1997).

## Study areas

There are large regional differences in the history of forest use and the development of silvicultural systems in Europe (Eliasson, 2002; Angelstam, 2003; Kardell, 2004; Holmberg, 2005). This means that different forest historical phases can often be found at the same time in different regions as illustrated by our study areas (Angelstam et al., 1997). The two study areas were selected to exemplify regional differences with respect to land-use and forest management history in Sweden's boreal forest region (Figure 2). In addition to the description of the forest policy development in Sweden presented in the introduction some differences between the study areas will be pointed out here.

*Figure 2. Location of the two study areas. The grey areas are 50-km wide bands around the "Limes norrlandicus" in the south and the "Cultivation limit" in the north used for the sample plot estimates. The darker grey squares are 50x100 km squares used for the mixed spatially explicit methods estimate, and the dots represent the forest management plans collected for the stand scale estimate. Interviews with local forestry actors were made in the same areas as where forest management plans were collected.*

The southern study area located around the “Limes norrlandicus” (Figure 2; Selander, 1955; Fransson, 1965) includes both upland areas with a long forest and land use history and lowland areas that were cleared for agricultural purposes more than 1000 years ago. Eventually the iron industry in south-central Sweden’s Bergslagen region grew big and replaced the local saw mills as the main user of wood. The wood was used to produce charcoal that was needed for the iron production. In Bergslagen intensive harvesting started several hundred years ago, driven by the mining industry (Wieslander, 1936). During the 17th and 18th centuries, a large part of the world’s iron production originated from the Bergslagen region (Eriksson, 1955). Due to the strong demand for charcoal to the iron industry the forest rotation time was short and stands younger than 50 years of age were often harvested (Ek, 1995). Starting prior to this period and continuing through it, the forest resource was also heavily exploited for timber. First the large dimension trees were harvested and then smaller and smaller trees (Enander, 2004; 2005).

The long history of land use and development with industry, forestry and farming in Bergslagen resulted also in a cultural landscape with continuous tree cover forests i.e. the wooded grasslands.

Today land ownership in Bergslagen is fragmented with about 65 % of the properties smaller than 1000 hectares in size. Only 11 % of the land is owned by the government, whereas large companies owns about 18 % and the rest is shared among municipalities, the Swedish church, commons and private companies (Paper I).

The northern study area is located in north-western Sweden (Västerbotten and Norrbotten counties) around the “Cultivation limit” in western Lapland (Figure 2; Lundmark, 2005). The study area covers a gradient from north boreal to sub-alpine mountain forest. In this area the history of industrial forestry is relatively short (Borgegård, 1973). In Västerbotten County the main force affecting forests and forestry was the arrival of the timber frontier in the late 19th century associated with the export of wood to markets abroad (Angelstam et al., 2004). In fact, large parts of the forests close to the mountains have still today not been subject to intensive forest management (Forsell and Axelsson, 1990; Paper I). As in Bergslagen the forest resource in accessible areas was initially heavily exploited both on government and privately owned land. The main way of harvesting was using selective cuttings. This unsustainable forestry practice was supported by government instructions for forestry on government owned land and regional laws on selective cuttings in the coastal parts of Västerbotten and Norrbotten counties as well as by a special law (Swedish: utsyningslagen) regarding private land further away from the coast (Enander, 2005).

Land ownership patterns are different in the northern study area with less fragmentation and about 23 % of properties less than 1000 hectares in size. In the northern study area land was to a large extent owned by the government (58 %). Large forest companies owned about 13 %, commons 5 % and the rest was shared by owners like municipalities, the church, and private companies (Paper I).

# Methods

## NATURAL SCIENCES

For the landscape scale estimates all sample plots from a 100-km wide band centred on the southernmost 350 km of the "cultivation line" in the north and the "Limes Norrlandicus" in south-central Sweden (Figure 2) were extracted from the National Forest Inventory (NFI) database (Anon., 2002c). Several variables and parameter values were used together with ground moisture to identify continuous tree cover forest sites. In the northern study area it was assumed that continuous tree cover forests are also present at higher altitudes due to the moist oceanic climate. Modelled data on precipitation from the Swedish Meteorological Institute and digital elevation model (DEM) data was used to extract sample plots in this climatic zone (Ångström, 1958; Anon., 1999c). The age distributions of forest on different potential continuous tree cover sites and mesic sites, as identified in the NFI, were compared. Since it is hard to identify very old forest using remote sensing methods the approach was instead to remove forest younger than 140 years and to estimate what was left. In addition an estimate of the management was done by comparing the amount forest in the youngest age class (0-40 year) on the different continuous tree cover forest site types and mesic sites.

For the landscape scale coarse-grained spatially explicit estimates two squares of 50x100 km were placed on the "cultivation limit" and the "limes Norrlandicus". A topographic wetness index (TWI) (Beven and Kirby, 1979; Rodhe and Seibert, 1999; Zinko, 2004; Güntner et al., 1999; Zinko et al., 2005) was used together with soil type data to estimate the amount of naturally moist and wet sites. In a limited area such as the two 50x100 km squares precipitation and evaporation are assumed to be spatially uniform over a longer time scale. To identify the dry and nutrient poor sites only soil data (sand-gravel and rocks with absent or very thin soil layer) were used. In the northern study area modelled data on precipitation from the Swedish Meteorological Institute and DEM data was used to identify areas with high altitude moist climate. All remaining forest land was classified as being mesic sites. Finally, forest age distributions on the different site types were estimated using k nearest neighbour (kNN) classified satellite image data from the Swedish University of Agricultural Sciences (Tomppo, 1991; Franco-Lopez et al., 2001; McRoberts et al. 2002, Reese et al. 2003, 2005).

For the stand scale estimates data was extracted from forest management plans from non-industrial private forest owners, private companies and government owned forests. The forest companies and government made available data from 5 areas containing a sample of stands for each continuous tree cover forest site type and mesic sites. Private estates were identified by combining soil type and property maps at the Swedish Forest Agency and 5 forest management plans from private forest owners were collected for each continuous tree cover forest site type and mesic site types. All forest owners volunteered to make the data available. The collected data sets were diverse both in size and quality but also in terms of variables allowing site type classification, which required a multiple set of approaches to identify the site types having a potential to host continuous tree cover forests. Ground moisture or ground layer vegetation data was used when available. In other cases combinations of ground carriage capacity and site type index (SI), in some cases only the SI was used together with information from the forest owner (Anon., 1985a, 1985b, 1985c; Hägglund and Lundmark, 1987, 1999, 2003). Large parts of the collected data sets were not used since the variables presented were not sufficient to identify the site types.

In addition to wet and dry sites there were sites at high altitudes with moist climate that rarely experienced stand replacing disturbance events. To identify this area the zonation of Ångström (1958), was used together with modelled data on precipitation from SMHI (calculations made for the National atlas of Sweden (Anon, 1999c). An estimate was done that forest 550 m a.s.l. belonged to this climate zone. Since only parts of the northern study area was located at these higher altitudes it was not possible to estimate how much of the total forest area that consists of this forest type. All three of the above mentioned methods were applied in these areas.

The present amount of the cultural type of continuous cover forest was extracted as all cultural grasslands with a crown cover of 10 % (Anon., 2005b) or more from a recent Swedish national inventory for the Västmanland county in the south-central part of Sweden (Anon., 2005a). To get an estimate of the loss of culturally caused wooded grasslands during the 20th century the data was compared with about 100 year old agricultural statistics (Anon., 1898; Anon., 1916).

### HUMAN SCIENCES

In the two study areas groups of local forest owners, users and actors were identified for the interviews. The idea was to only include people that directly affected forest management. This resulted in a group of 28 interviewees representing forest owners, planners, wood buyers, forest consultants, forest owner association representatives, forest commons representatives, the Swedish church, the Swedish Property Board, municipalities and the Swedish Forest Agency.

Data were collected through qualitative interviews with open-ended questions (Kvale, 1996; Kvale, 2007). An interview manual was used to direct the interview towards issues of interest. The interviewees where given full freedom to express their thoughts and to reason about the questions. The interviews were carried out in the interviewee's office or home and the interviewer tried to be as neutral as possible to not affect the interviewee. The interviews took 30 to 90 minutes. A total of 14 local forestry actors were interviewed in each study area. Actors with similar profiles were chosen in the two study areas. While we do provide statistical analyses of our data, we stress the qualitative aspect to different stakeholder's ability to use and prerequisites for, attitudes towards and knowledge about uneven-aged forest management presented in paper II were we made an effort to present the full spectrum of opinions.

All relevant parts of the interviews were transcribed. Everything that the interviewees said that was connected to the research questions was extracted from the transcriptions and concentrated. The concentration of the sentences means that opinions stressed by the interviewees were shortened and re-written as clearly as possible. A number of specific issues that was included in all interviews were chosen to make it easier to compare the opinions of different interviewees. For all interviewees their opinions on each issue were classified on a 3-step scale as follows; 1) agree completely, 2) agree partly, and 3) do not agree.

# Results

## CONTINUOUS TREE COVER FORESTS AND THEIR MANAGEMENT

*Potential and present amount CTC*

The two study areas representing the Swedish boreal forest landscape held about 10 % CTC site types (See Table 1.).

*Table 1. Table showing amount of site types (%) in the two study areas based on data from the national forets inventory*

| | Southern (Bergslagen) | | | Northern (Västerbotten) | | |
|---|---|---|---|---|---|---|
| Site type | Dry | Mesic | Wet | Dry | Mesic | Wet |
| Amount site type (all forest, %) | 5.5 | 91 | 3.8 | 5.8 | 90 | 3.8 |

Out of the 10 % CTC site types (See Table 1, dry + wet sites) 88-97 % did not hold old forest according to data from the Swedish National Forest Inventory. There was more old forest remaining in the northern study area (10-12 %) and less in the southern (3-6 %) on these site types.

However, in the northern study area 32 % of the high altitude forest held old forest. The other two study methods confirmed these results and even showed values somewhat lower for remaining old CTC forest (Paper I, Table 2.).

*Table 2. Percent of area with no old forest on potential continuous tree cover forest sites with different analyses, scales and data sets in the southern and northern boreal forest study area.*

| | Southern (Bergslagen) | | | Northern (Västerbotten) | | |
|---|---|---|---|---|---|---|
| Site type | Dry | Wet | Cultural | Dry | Wet | Climate |
| National Forest Inventory | 94 | 96 | - | 90 | 88 | 68 |
| Remote sensing | 100 | 100 | - | 100 | 100 | 98 |
| Agricultural statistics | - | - | 81 | - | - | - |
| Stand scale | 98 | 99 | - | 84 | 82 | 53 |

The estimates for the wooded grasslands CTC forest type in the southern study area showed that about 80 % had disappeared during the 20th century (See Table 2.) and that the remaining area was about 0.5 % of the forested area.

*Future amount CTC*

Forests management and harvesting seem to be similar on wet, mesic and dry site types seemed. The percentage young forest (0 - 40 years) on CTC site types compared to mesic sites did not show that CTC sites were managed differently. According to data from the National Forest Inventory there were similar amounts or higher of young forest on dry sites and slightly lower on wet sites.

*Table 3. Young forests (0-40 years) (%) on different site types with different analysis methods in the southern and northern boreal forest study areas. For the stand scale analysis the mean values from the different owners/owner categories has been used*

| | Southern (Bergslagen) | | | Northern (Västerbotten) | | | |
|---|---|---|---|---|---|---|---|
| | Dry | Mesic | Wet | Dry | Mesic | Wet | Climate |
| National Forest Inventory | 50 | 48 | 33 | 47 | 38 | 25 | 22 |
| Remote sensing | 37 | 41 | 55 | 41 | 45 | 51 | 58 |
| Stand scale | 47 | 49 | 49 | 44 | 38 | 24 | 9.4 |

## PERCEPTIONS ABOUT UNEVEN-AGED FOREST MANAGEMENT

### *Ability to use and attitudes about uneven-aged forest management*

Most respondents agreed fully or partly with the statement that the technology (89 %) and knowledge (79 %) needed for uneven-aged forestry is available today. Nevertheless, many respondents saw difficulties in uneven-aged forestry since this was a practise of the past. A clear majority (86 %) claimed it is fully or partly impossible to use selection felling systems for economical reasons. This was partly due to selection felling systems not being efficient and partly due to logistical and infrastructure being adapted to the clear cutting management system. The influence from the Swedish forest policy was commented: *"The forest policy is rigid. In forestry it has always been like that…but the new forest policy is better, you are not as much steered today. Earlier you could be forced to fellings. Today you are free to test different methods, so it is better"*.

More than half of the respondents were clear in their opinion that there is a need for a more diverse set of silvicultural systems then what is used in Sweden today. Only 4 out of 28 thought that the clear cutting system was enough. A clear majority also expressed the opinion that different forest actors and stakeholders affect each others' use of forest resources, but they did not see it as a problem. Many thought that the present environmental considerations were good enough to satisfy the intentions of the forest sector policies. They had experienced a clear improvement when it came to mainly environmental considerations. Several respondents expressed the view that alternatives to the clear felling system are needed to meet the needs from other forest stakeholders and in areas where social use of the forest is high. A clear majority (75 %) thought fully or partly that it is possible to even out the differences between natural and managed forests.

Most of the respondents were dissatisfied with the Swedish forest policy. Half of the respondents were very negative and another 30 % were partly negative. Only 21 % expressed that they were positive to the Swedish forest policy. This applied to both production and conservation oriented respondents. Most respondents wanted clearer directives and a stronger enforcement of the forest policy. With the present policy many were not sure if either of the production or environmental goals could be reached. Several of the respondents thought it was hard to understand what an equal importance of production and environmental goals means practically. Several reacted negatively to the term continuous cover forestry. They related the term to different conservation measures that earlier had limited the freedom of forest owners. However, on specific sites or on land important for social purposes they could see the usefulness of continuous cover forestry.

Half of the respondents (46 %) believed they have no responsibility to implement the goals of the Swedish forest policy. They thought it is the responsibility of the politicians to realize the forest policy through clear laws and by reimbursements for economical losses. A large part of the respondents wanted the local forest agencies to charge forest owners that do not manage their forests in a socially, economically and ecologically sustainable way. Many had a strong trust to the local forest agency offices when it came to providing appropriate advice. This was expressed by one respondent: *"Even if there is not a law for everything the forest agency should be able to force forest owners to do things. They are competent, that's enough. It can be controversial but if you like to keep the freedom you can not regulate details"*. Some respondents expressed contempt towards knowledgeable instances without experience, for example one respondent: *"It was in the 1960s we started with clear cuts here, and now it is only cleared areas. The people who know, the educated, say we are supposed to do like this"*.

Almost all respondents agreed that a landscape approach of some kind is important, to plan forest use over larger areas. However, many expressed worries that this landscape approach is not yet operational and they saw a lot of difficulties. Respondents in the northern study area were more hesitant to landscape approaches than respondents in the southern. What seemed to be lacking was a function to facilitate different actor's activities over a larger area. It was often mentioned that neighbours sometimes do co-operate when they harvest forest to increase the profit. Forest companies often had a working co-ordination internally for their own work, but saw large problems if a landscape approach to governance and planning of the use of different silvicultural systems on different site types in cooperation with neighbouring land owners should become a reality.

A clear difference between the southern and northern study areas was that fewer in the northern had other than economic goals with their forestry. In the southern study area a majority expressed the importance of other goals than economy (71 %). In the northern study area fewer expressed that they had other goals than economical (43 %) instead a majority (57 %) claimed that economy was their only goal. This is maybe due to the larger estates in the north and that no one of the private forest owners in the south claimed that they needed income from their forest. In the north people were more dependent on the economic use of their forest.

A few respondents witnessed about the difficulties for uneven-aged forestry to be accepted as a forest management principle in Sweden. One reason for this is probably the clear cutting only direction of Swedish forestry educations here expressed by a Swedish forester: *"Partly this is a question about attitudes. We are educated in the same school everyone, moulded in the same cast. You can imagine what happens if you put a bunch of 20-year-olds in the same school. It is the conventional forest management principles that most, despite specialization have learned."*

Another respondent working for the forest owner association had experienced the unwillingness to discuss alternatives to the dominant clear cutting system: *"When I go to meetings and we will discuss thinning, then they say- you can leave since you do not do this anyway! They almost bully me for this. At the same time I can show 1000s of harvested cubic metres with happy farmers instead. I do not care since I do not have too long time to retirement also. During my last years I can support this, it is harder for the younger guys and girls that are coming with a message like this."* According to the same respondent there is a large potential, mainly with private forest owners with multiple goals for their forest, in having forest standing and at the same time get a smaller profit at several occasions. This respondent mentioned the importance of not forcing a forest owner to use a new method but letting the forest owner chose on his own.

*Knowledge about uneven-aged forest management*

Foresters were generally negative to using selection felling system as alternatives for sustained-yield wood production. However, they were positive to them as a complement to satisfy social and to some extent ecological values. About 60 % of the respondents claimed that they know what selection felling systems are. However, when asked about what it is, answers ranged from associations with early industrial high-grading, special management related to social considerations in areas were people live and in cultural wooded grasslands to harvesting in high altitude harsh conditions were regeneration after clear cutting would be hard or impossible, and the Liberich system (Hagner, 2006). Most respondents considered uneven-aged forest management something for forest owners with other interests than purely timber production and economic profit, or in areas where forestry would otherwise not be possible.

Very few respondents associated uneven-aged forest management as a method for intensive production of timber. Very few respondents (11 %) thought that uneven-aged selection systems could favour economy, more thought that it could partly benefit the economy (39 %), and the remaining half of the respondents (50 %) thought this was not the case.

Several respondents associated continuous cover forestry to high-grading and unsustainable selective harvesting that was common before the 1950s. An example was the following statement: *"I do not know too much about continuous cover forestry, but I know how many "5:3" forests*[1] *that were restored in the 1970s, a result from high-grading in low productive and sparse areas. This is the risk you get if you use that kind of harvesting".* One respondent expressed his opinion about the Liberich selection system approach (Hagner, 2006): *"I am taking a course were we have discussed Mats Hagners Liberich method, and I do not believe anything of this. This is how to create degraded forests (Swedish: rest- och trasskogar) and 5:3 forests. They were present on my fathers land. I removed*

*[1] 5:3 is the number of the law paragraph that handled restoration of pre-1950s exploited forests in Sweden. It is often used to name the poor condition of forest stands that remained after the exploitation phase.*

*them the first years and planted a new forest. They had been selectively harvested, they were allowed to grow as they liked. The best method is clear cutting, take away what is harvested and then you should scarify and plant"*. By contrast, another respondent said: *"I think you should use Liberich. Clear cutting is on its way out both because of environmental concerns and cultural remains. It is said that Liberich works only if your forest is layered, but it becomes layered if you optimize the present value. You can harvest large dimension timber early, and you create quality for the future."*

Thus, continuous cover forestry associated to many different things and the there was confusion about the terminology. The respondents that remembered how things were done before the clear cutting era had a hard time to place selection felling systems in a modern context *"Selection felling is a thing of the past with the technology you had, you never thought of large clear cuts"*.

Most respondents claimed that that uneven-aged forest management would support ecological values in the forest to some degree but had a hard time to specify how.

Almost all (93 %) respondents agreed, fully or partly that social values would be favoured by uneven-aged forest management in some areas. In the southern study area this was fully supported by a clear majority (86 %), compared to only a few (14 %) in the northern. Many respondents thought of social values as more important than ecological ones. It was easier for them to relate to other peoples' use of the forest compared to conservation. The connection between multiple values in the forest and the number of jobs was brought up by many respondents. A majority believed that job opportunities are threatened by continuous cover forestry. A few saw an unused opportunity in hunting and nature tourism.

# Discussion

## THE PRESENT SITUATION IN SWEDEN

Uneven-aged forest management continues to be surrounded by strong feelings in Sweden. The situation has its roots long back in time when selection felling systems were blamed for the early unsustainable exploitation of the Swedish forest resource as described earlier in this thesis. In contrast, the clear cutting system is associated with modern and profitable sustained yield forestry.

A recent evaluation of Swedish forestry showed that 96 % of all final fellings are done by the clear cutting system with or without seed trees. According to the polytax inventories 1999 and 2000 69 % of the harvested areas are left with no seed trees, 27 % are left with seed trees and on the remaining areas (4 %) other harvesting methods are used, like shelterwood, and different selection systems (Anon., 2002b, Anon., 2002d). Paper I) showed that alternatives to the clear cutting system were not used on specific site types and adapted to mimic natural disturbances. Policy development, evaluations of the Swedish forest policy and the principles of sustainable forest management implicate that uneven-aged management should be used as a complement to even-aged management on suitable site types and in urban forests (Anon., 1993; Anon., 2002b; MCPFE, 1998; 2003; Anon. 2002b; Mikaelsson et al., 2006).

The final report of the Swedish Forest Agency's 3-year long project named *Continuous forests and continuous cover forestry* it is concluded that continuous cover forestry is a complement to the clear cutting system and should be used in suitable areas. The report provides an estimate that 5-10 % of the productive Swedish forest area is suitable for uneven-aged forest management (Cedergren, 2008). In addition to forests that could be managed with uneven-aged forest management for ecological reasons there are also forest where uneven-aged forest management could be considered to satisfy social dimensions of sustainable forest management. The Swedish Forest Agency has estimated the amount of urban forests to 300 000 hectares, and aims for about half of this to be considered for management with selection felling systems (Anon., 2005c; 2007). This equals about 0.6 % of the total forest area in Sweden.

This thesis shows that in the study areas about 10 % of forest sites are of continuous tree cover type, i.e. hosting gap-phase and cohort dynamics under naturally dynamic conditions. These are the 4 % wettest and the 6 % driest forest sites types (see Figure 2). These numbers were higher in the naturally dynamic boreal forest landscape. Numbers ranging from about 30-50 % are mentioned in the literature (Rülcker et al., 1994; Pennanen, 2002). Indeed, de Jong (2002) noted an increase of the amount mesic sites relative to either extreme. Reasons for reduced areas of CTC site types include clearing of rich and moist site types for agricultural purposes, forest drainage and fire control on dry and poor site types. In addition to this atmospheric deposition of nitrogen and fertilisation make poor site types richer (Högberg and Binkley, 1996; Sohlberg et al., 2004). The expected increase in productivity is confirmed by Elfving and Tegnhammar (1996). For the whole boreal zone (including alpine-northern, mid and southern boreal forests) according to data from the NFI about 9% (4 % wet and 5 % dry) of the forest sites are of continuous tree cover types (NFI on the internet, July 27, 2008). Continuous tree cover forests are or have until very recently been managed with the same methods as other forest types. In addition to the about 9 % continuous tree cover site types there are also high altitude moist climate mountain forest in the North and culturally generated wooded grasslands in the South. Today the diversity of Swedish forest ecosystems and cultural woodlands are not met by a corresponding diversity of forest and woodland management systems (Paper I). Knowledge about efficient selection felling systems is limited due to the long-term dominance of the clear cutting system, even if there is knowledge and technology for the extraction of trees from forest stands. This applies to both the social and ecological dimensions of forest and woodland landscape management.

One approach to define quantitative targets for how much continuous tree cover forests are needed to satisfy sustainable forest management policies a gap analysis should be performed (Scott et al., 1993; Angelstam et al., 2003). Put simply, this should include the following steps. 1) Estimate the amount continuous tree cover sites in the pre-industrial landscape, 2) use performance targets derived from the forest and nature conservation policies to be able to estimate the amounts needed for a particular level of ambition ecological or social sustainability, 3) identify present amounts of CTC forest type (Paper I) and estimate the gap.

According to the interviewees more than half of the continuous tree cover forest sites are not used for forestry due to too poor productivity, inaccessibility and because parts of these areas are under formal protection. This suggests that 4-5 % of the forest land remains as candidates for selection felling systems. Out of this a part is potentially under non-formal protection. Thus a rough estimate is that the aim could be to manage about half of the remaining 3-4 % units using uneven-aged forest management (see Figure 2.). In addition to this there might be areas with a need for uneven-aged forest management to protect humans or economical interests i.e. forests with protective functions.

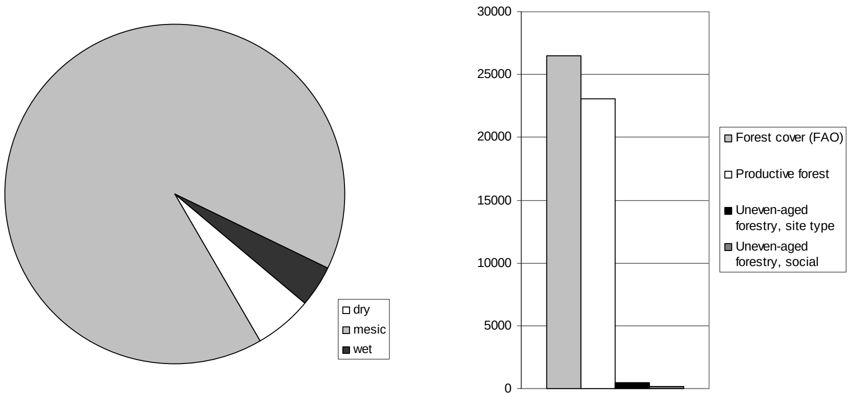


*Figure 2. The pie chart to the left shows a rough division into site types in the two study areas of about 5 million hectares in Sweden's southern and northern boreal forest. According to data from the Swedish National Forest Inventory the present forest landscape include 5.6 % dry and 3.8 % wet sites would have held continuous tree cover forests in a naturally dynamic landscape. The histogram to the right is an effort to translate this information to a graph for the whole country that could be used for discussions about the relative amount of different silvicultural systems needed to satisfy policies advocating alternative management systems to clear cutting. This graph shows forest cover, productive forest, a potential level for continuous cover forestry of ecological reasons (2 %), and for social reasons (0.6 %) in Sweden. Forest cover is the amount of forest in Sweden using international definitions based on crown cover while productive forest is the amount of forest in Sweden using a national definition based on land use and yearly increment. Areas that could potentially be considered for uneven-aged forest management are calculated as percentages of productive forest land.*

A major obstacle for the implementation of sustainable forest management policies by an increased diversity of forest management approaches is the distrust between the environmental, social and the industrial forestry sectors, actors and stakeholders. This results in conflicts instead of co-operation. One example is the conflict about how negative continuous cover forestry would be to the Swedish economy, assuming uneven-aged forestry would be used everywhere and thus replace the clear cutting forest management system (Karlsson and Lönnstedt, 2006a;b). There are both conservationists and foresters debating that uneven-aged forestry or clear cutting management systems are better and should be adapted on all forest land. This debate is unrealistic since there are no forest policies that advocate the use of selection felling systems on all forest land. Instead uneven-aged forestry is proposed as a complement to clear cutting forest management on specific and limited areas to satisfy ecological and social dimensions of sustainable forest management.

## SOME REFLECTIONS ON THE METHODS USED AND THE VALIDITY OF THE RESULTS

Different methods provide different perspectives and have different limitations. It is important to discuss this to make the reader understand the qualities and limitations of the different estimates and analyses regarding the amount of different site types. Using the sample plot method to estimate the natural potential for the amount of different forest disturbance regimes, the area of forest land in today's landscapes was compared on wet, dry and mesic sites, and on sites with humid climate. The data from the National Forest Inventory is of good quality and the method is straightforward. A limitation might be the location of the study areas, i.e. could the results tell anything about the whole boreal zone in Sweden in general? A comparison of the estimates of the amount CTC on dry (i.e. cohort dynamics) and wet sites (i.e. gap phase dynamics) showed that the results were similar (NFI on the internet, 27 July, 2008). The comparison showed that the estimates in paper I are slightly higher then for the entire boreal zone. Paper I estimated dry sites to 5.5 % (Southern study area) and 5.8 % (Northern study area), and wet sites to 3.8 % in both areas (data from 1996-2002). The average according for the entire boreal zone was 4.7% dry sites and 4.2 % wet sites, respectively (data from NFI 1997-2001). Thus, in spite of the study areas location in two transition zones, with the aim to cover large parts of different gradients in the boreal forest but then also includes some extreme conditions, the results in Paper I were indeed representative for the entire boreal region.

The other methods had other potential limitations. For example, the landscape-scale coarse-grained spatially explicit method estimated the amount of potentially old forest and young forest on CTC and mesic sites in a naturally dynamic landscape. This means that there was no consideration of anthropogenic alterations affecting the site type distribution, such as drainage and fire control, factors that tend to increase the amount of mesic sites relative to either extreme (de

Jong, 2002). This method did not give an estimate of the amount of the different site types in the landscape.

For the stand-scale estimate several different indicators were used to identify CTC sites. This was a result of the variability in the collected data sets. Only some forest owners provided data on site moisture, others had instead data on ground vegetation, ground carriage capacity and site index, all of which nevertheless linked to site type. There were also differences in when and how the forest management data had been updated and the quality of the collected data. To estimate what stands that were of CTC type a diverse set of methods was used together with additional information from the landowners. Despite careful specifications of what kind of data and for how large areas that was needed for the study the collected data sets were diverse and a large part was not used. The main problem was to identify CTC stands and when this was not possible the data set was not used. This resulted in a smaller than expected data set with samples of different size and quality. The estimates were nevertheless used since it is an interesting approach with good potential if larger sets of homogenous data could be collected.

The cultural landscape estimates were done by comparing old agricultural statistics and a recent inventory of wooded meadows and pastures for the County of Västmanland in the Southern study area. This estimate was included because we liked to emphasize the importance of a landscape perspective including all kinds of wooded areas, i.e. forests, wooded grasslands and other types of tree covered areas that are not counted as forests, but nevertheless critically important for both ecological and social dimensions of sustainable forest management.

For the qualitative part of this thesis the qualitative results should be emphasized, i.e. what the interviewees said. A qualitative interview study does not provide (usually) enough data for statistical calculations. Still some statistical calculations were provided to assist the understanding of the collected data. Efforts were made to select groups of interviewees with similar profiles in the two study areas. When possible forest owners that had provided forest management data to the study resulting in paper I were selected.

## GAPS RELATED TO CONTINUOUS COVER FORESTRY

This thesis has identified several gaps related to the application of continuous cover forest management systems. The first I call the "terms and definitions" gap. This is a gap that has developed and been maintained over long time. It has its roots in the early exploitation of Swedish forests and the development of well-working sustained-yield forest management using the clear cutting forest management system. This knowledge gap results in mixing up of terminology where selection felling systems are blamed for the early exploitation of Swedish forests.

The second gap is related to improper definitions of what a continuous tree cover forest is and thus on what site type's uneven-aged forest management could be used for ecological and reasons. This thesis and the articles are an effort to bridge these gaps.

The third gap is related to knowledge to perform continuous cover forestry operations. There seem to be knowledge to use continuous cover forestry as a type of environmental or social consideration on sites with other main aims than to earn money. However, there seem to be very little knowledge on how to use continuous cover forestry as a way to produce better quality timber, to meet other management goals and to produce timber industrially. This is outside the scope of this thesis but still an important gap to fill.

The fourth gap I have identified is the policy implementation gap. The Swedish policies advocating sustainable forest management clearly point at the need for alternatives to the clear cutting management system to meet the requirements of the policy. Still there is a massive dominance of the clear cutting management system and no correlation between alternatives to clear cutting and CTC forest site types (Paper I). Studies like this and special efforts like the Swedish Forest Agency's *Continuous forests and continuous cover forestry project* (Cedergen, 2008) are needed for this. Special applied interdisciplinary (=transdisciplinary) (e.g., Tress et al., 2003) projects are, however, needed to deal with the issues of the forest policy and its implementation together with local to national level forest actors and stakeholders to find sustainable solutions towards supporting implementing the vision of the Swedish forest policy and sustainable forest management.

The fifth gap is related to logistics and the streamlining of forestry towards the clear cutting forest management system only. This result in a situation where forest owners that produce higher quality timber in combination with also other management goals are not able to sell their product as a high quality product.

## TOWARDS SUSTAINABLE FOREST MANAGEMENT AND FUTURE RESEARCH

Previously forestry was easier. To produce economic profit and to secure a sustained yield of timber for the industry was good enough. Today forestry is more complex and includes an increased number of actors that desire increased amounts of goods, services and products from the forests (e.g., Innes and Hoen, 2005). Forestry is important to the Swedish economy but its contribution to the GDP is estimated at 3-4 % depending on the source (Johansson Gran and Resvik, 2006; Anon., 2007a). The long-term trend is that the GDP contribution is decreasing. Other sectors depend on a sustainable management of the entire forest landscape. Foresters have to find sustainable solutions to ecological issues and to satisfy socio-economical demands to safeguard their own business long term (Innes and Hoen, 2005).

To implement international and Swedish policy visions of sustainable forest management and to meet new demands from other sectors of society there is a need for innovative interaction and co-operation among stakeholders at multiple levels. A promising approach to deal with the situation is to participate in and to develop multi-level and multi-actor collaborative and communicative governance arrangements such as Model Forest and Adaptive Management Areas (Axelsson and Angelstam, 2006; Shindler at al. 2003). To find sustainable solutions the innovative transdisciplinary knowledge production, where researchers, practitioners and stakeholders together define the problems and produce the knowledge needed to address these problems is one option (Tress et al. 2003, Axelsson and Angelstam, 2006; Elbakidze et al., 2007). In Sweden today there are a few more or less developed local initiatives representing different regions from south to north. Using them as landscape laboratories would support a development towards a more sustainable use of the forest resource in line with the forest policy and the principles of sustainable forest management.

The work with this thesis and earlier experiences has taught me that natural science only is not enough to provide knowledge needed to implement sustainable forest management and sustainable development. There is in addition a need to understand the interface between social and ecological systems and peoples abilities to understand policies, attitudes and knowledge about sustainability issues to be able to implement policies on the ground. I see a huge need to evaluate different approaches to implement sustainability policies i.e. to learn from both success and failure stories. My own continued research will be focused on different approaches to find and implement sustainable solutions locally and regionally. I will concentrate on participatory approaches like the Model Forest, Biosphere Reserve and other similar concepts. If possible I would also like to explore some independent initiatives and approaches from other then the forestry sector since my strong belief is that there is a lot of existing knowledge locally that is just waiting to be found evaluated and disseminated. I believe strongly in the sustainable forest management concept but to realise this requires new ways to build trust and develop frameworks for co-operation and communication (Axelsson et al., submitted ms; Elbakidze et al., 2007). There is a lot of talk about the need for interdisciplinary research but only few good examples. Scholars also claim that academic reward systems do not recognize interdisciplinary research. I think the time has come to explore the opportunities of inter- and transdisciplinary research and to support the integration of disciplinary research i.e. to synthesize applied knowledge from all the already developed pieces in the puzzle.

## Conclusion

Uneven-aged forestry is surrounded by strong feelings in Sweden. The discussion that started more than 100 years ago still continues even if there seem to be an agreement among most forestry actors that continuous cover forestry is a well needed complement to the clear cutting system to be used on specific sites and limited areas. Continuous tree cover forests site types are managed with the same silvicultural system as mesic sites i.e. there are no or few efforts to mimic natural disturbance regimes. Culturally caused wooded grasslands are decreasing due to no or little present use even if there are efforts to restore and increase areas. For forests with moist climate at high altitudes large parts are protected. Proper information, definitions, terminology and applied knowledge on where what forest management principle would fit will prevent unnecessary conflicts. Today policies at multiple levels advocate sustainable forest management and thus the need to satisfy an increasing number of new demands on the goods, services and values provided by forest landscapes. The only way to address this new situation is to develop co-operative and participatory approaches to forest management. With a joint effort long term sustainable solutions for forest management, local communities and other business sectors can be found.

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