Natural forest and cultural woodland with continuous tree cover in Sweden- how much remain and how is it managed?

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Abstract

Swedish forestry has a long and successful history of developing sustained production of wood. Consequently silviculture is dominated by clear-felling approaches, despite the fact that Swedish forests are ecologically and culturally diverse. A considerable proportion of our naturally dynamic forests were Continuous Cover Forests (CCF). CCFs were also a part of the pre-industrial cultural landscape. Both the natural and the cultural landscape CCFs are today threatened and their area extent does not satisfy the new dimensions of sustainable forest management as biodiversity conservation and socio-cultural values.

In this study I estimate the past and present amount of two natural and one cultural CCF types in two study areas using several different approaches at two different spatial scales. The results are compared with the silvicultural practices in the two areas located around two important biophysical and socio-cultural transition zones in northwest and south-central Sweden.

My results show that in our present landscape 9 to 10% of our forested land is potential wet and dry CCF sites. In addition to this there is a portion of high altitude CCF with moist oceanic climate in the Scandinavian Mountains. However, of all potential CCF sites in the southern study area only 0 to 6% remains. In the northern study area the proportion left was slightly higher at 0 to 17% of the potential, except for the high altitude CCF where the decline was less. It is clear that this difference between the study areas is due to the later arrival of the timber frontier in the north. Present management practices on different site types indicates that the situation will be the same as in the south in a few decades since Swedish forest management exercises limited consideration in different site types to maintain CCFs. To match the natural diversity of forests and to satisfy all three dimensions of sustainable forest management there is a clear need for developing alternative forest management methods in Sweden.

Key words

continuous cover forest, continuous cover forestry, forest dynamics, forest management

Introduction

In most developed countries the historical use of forests has evolved through several more or less distinct phases (Björklund, 1984; Angelstam and Arnold, 1993; Drushka, 2003; Williams, 2003; Burton et al., 2003). In general three historical phases can be identified, (Östlund and Zackrisson, 2000): (1) The pre-industrial agricultural phase with a low intensity use of the forests, often including animal husbandry with cattle grazing the forests. (2) The “diverse uses” phase where the usage of a range of different resources was diversified and intensified. This phase included local and regional small-scale production of for example potash, tar and charcoal together with extraction of larger trees. (3) The industrial phase, where the use of the forest was even further intensified and often less diverse. This phase initially often resulted in an unsustainable exploitation of the wood resources. The realisation that harvesting rates were larger than the regeneration and growth rates in the forest was an important driver towards the development of a sustainable timber yield (Schuler, 1998; Drushka, 2003; Kardell, 2004).

As forestry in Sweden developed after WW2, there was a need for improved and more economic efficient management regime. Large forest tracts were in poor condition due to ineffective regeneration and poor forest management during the exploitative phase. In the 1948 forestry act the importance of industrial forestry for the country was emphasised. Measures of existing knowledge on how to optimise production levels to improve and optimise production to ensure a long-term sustainable yield timber and pulpwood were taken. Clear-felling is an economically efficient method that is quite simple to practice using mechanised methods (Matthews, 1989). As a consequence this method became the main silvicultural approach in Sweden since about 1950 (Ekelund and Hamilton, 2001). An important part of the development of economic sustainable forestry has also been the implementation of effective means of regeneration of forest after harvesting.

Around 1970 a discussion of ecological issues began in society, which also affected the forest sector. In Sweden, intensive clear-felling methods (Anon., 1974) triggered increased environmental considerations (Anon., 2002b; Angelstam, 2003a). In 1983 the United Nations (UN) appointed the so called Brundtland commission to propose strategies on how to improve human well-being in the short term without threatening the local and global environment in the long term (WCED, 1987). This report triggered several forest-related events such as the development of the Forest principles and the UNFF (UN, 1992; 2000).

In Sweden's forest policy from 1993 it is clearly stated that economic and environmental-ecological aspects of forestry are of equal importance (Anon., 2001a, 2002a). The environmental quality goals of Sweden have reinforced this (Anon., 2001b). Finally, during the last few years, also socio-cultural values have been acknowledged (Anon., 2002a). This is a trend also in the rest of Europe (Malcolm et al., 2001; Mason, 2003). Thus, all three pillars of the concept sustainable development are now included in the national policies related to the management of forests in Sweden. The development of the concept sustainable forest management (SFM) has thus entered a fourth phase representing post-modern values (Bolshakov, 2000).

As a consequence, the selection and combination of silvicultural methods and landscape planning is widely discussed (e.g., Angelstam and Pettersson, 1997; Fries et al., 1997, 1998; Raivio et al., 2001). Forestry has since the 19th century reduced many elements and structures as well as simplified the dynamics of natural Swedish forests to a minimum (Östlund et al., 1997). An evaluation of the contemporary Swedish forest policy was established in 1993, and in the subsequent 1994 Forestry Act it was concluded that there is a need for developing alternatives to the clear-felling approaches (Anon., 2002b), such as different kinds of selection felling systems. Initially the focus was on emulating natural disturbance regimes for the maintenance of biodiversity (Rülcker et al., 1994; Angelstam, 1998). Alternative forest management approaches has also been advocated to satisfy socio-cultural values such as recreation and tourism both in Sweden (Lindhagen, 1996; Rydberg and Falck, 2000; Rydberg, 2001) and internationally (Konijnendijk, 1997, 1999, 2003; Wenner, 2000). Management recommendations related to climate change, storm and other new risks include similar conclusions (Anon., 1999; Blennow, 2004; Chao et al., 2005).

From an ecological perspective, scientists agree that forests are formed by different kinds of disturbance dynamics (Sprugel, 1991; Kuuluvainen, 1994, 2002; Angelstam , 1998; Bergeron et al., 2002; Korpilahti and Kuuluvainen, 2002; Angelstam and

Kuuluvainen, 2004). This means that, depending on local and regional factors, a natural forest landscape may contain several types of dynamic systems (Angelstam, 1998). The result is a very diverse forest landscape when it comes to tree age distribution, structures and species (Kuuluvainen et al., 1998, 2002; Pennanen, 2002). Following the disturbance regime paradigm Swedish boreal and temperate natural forests can be divided into three main groups (for details see 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 where low-intensity fires often kill younger trees and leave some older and larger trees. Typically these sites are dominated by Scots pine *Pinus silvestris* or Oak *Quercus robur.* The stands often contain trees of several age classes. (3) Gap phase dynamics with small-scale disturbances, but as a rule not fire, on wet sites, in humid climates or where the landscape configuration protected against large scale disturbance regimes (Angelstam and Kuuluvainen, 2004). Typically Norway spruce *Picea abies* and other shade tolerant species dominate. Here some trees die of age, disease or because they are weak and can not stand strong winds or other kinds of biotic and abiotic stress. Eventually a few trees fall and create small gaps. In the naturally dynamic landscape continuous cover forests dominated in multi-cohort and gap phase dynamics, and occurred in parts of landscape's mesic sites by chance not subject to stand-replacing disturbances. Our definition is thus that a natural continuous cover forest is a forest with either a multi-cohort and gap phase dynamics.

In analogy with natural forest disturbances, human use of the landscape often gave rise to cultural continuous cover forests when tree covered grasslands were either mowed or used as grazing grounds for domestic cattle. In addition, people collecting winter fodder used trees from a range of species in the cultural landscape. This often resulted in large and old slow growing deciduous trees (Nolbrant, 1998; Ekstam and Forshed, 1996). During the 20th century, with forest management practices including cleaning of deciduous trees, the cultural continuous forests provided rescue habitats for many species and have thus been vital for their survival (Tucker and Evans, 1997; Kirby and Watkins, 1998; Mikusinski et al., 2003). Our definition of a cultural continuous cover forest is that it is a wooded grassland with a minimum of 10% tree cover where the trees are large, old and marked by cultural use.

The evolution of the sustainable forest management concept implies a need to evaluate the extent to which the silvicultural methods used match the different management objectives including forest production, biodiversity conservation and socio-cultural functions (Angelstam, 2003b). In Sweden today about 96% of forests are managed by clear-felling methods (variable retention and seed tree) (Anon., 2002b). By contrast, estimates of the amount of forest land hosting continuous cover forests in boreal forest range from 10% (Anon., 2005c) to 30% (Rülcker et al., 1994) and as high as more than 50% (Pennanen, 2002). In addition a proportion of natural succession forests also had continuous cover characteristics probably due to landscape configuration and chance (Pennanen, 2002). The lower end of this range refers to today's situation with anthropogenic landscape alterations due to for example forest drainage, accumulation of nutrients and non-natural forest dynamics, while the upper end is an estimate of the natural situation. In addition a portion of especially southern Sweden's forests consisted of cultural continuous cover forests in the form of wooded grasslands. Finally, alternatives to clear-felling are desired to satisfy recreational needs (Konijnendijk, 1997, 1999, 2003; Lindhagen, 1996; Rydberg and Falck, 2000; Wenner, 2000; Rydberg, 2001). In countries of economic transition also livelihood issues require alternative to clear-felling (Antrop, 2005).

There is thus overwhelming evidence that the current low diversity in silvicultural approaches is unlikely to match the current ecological and socio-cultural dimensions of SFM. Countries having developed the current broad view on the SFM concept earlier than Sweden have also initiated the development of new silvicultural approaches. To mitigate problems with natural hazards countries in the Alps developed continuous cover methods already several hundred years ago (Dengler, 1944, 1990). In much of Western Europe such methods are advocated for forests dominated by shade-tolerant trees. Similarly, in Great Britain, recent forest policy statements envisage a much greater us of selection systems forest methods (Mason, 2003).

The aim of this paper is (a) to improve the understanding of the extent to which there is a mismatch between the natural and cultural dynamics of forests on the one hand, and today's management practices on the other; (b) to estimate the remaining amount of continuous cover forest in two study areas. We estimate the potential amount of cultural and natural continuous cover forest land at different spatial scales using different methods. Four kinds of continuous cover forests, namely multi-cohort, gap phase due to ground wetness or due to high altitude humid oceanic climate and cultural wooded grasslands are studied (see also Anon., 2004). To cover the range of boreal forest conditions in Sweden I focus on two regions located in the major transition zones in northern and south-central Sweden, "the cultivation line" (Swedish: odlingsgränsen) the northern and high altitude border for cultivation of land (Hahn, 1998; Lundmark, pers. com.) and ”Limes Norrlandicus" (Swedish: norrlandsgränsen) (Selander, 1955; Fransson, 1965) the natural south border of the boreal forest biome (Sjörs, 1956; Aldentun, 1997) in Sweden. Landscapes located in these regions represent a wide range of ecological properties, history of forest use, and types of governance found in the boreal forest region. At this landscape scale both sampling plot data and spatially explicit coarse-grained analyses were used. Secondly, I evaluate the extent to which continuous cover stand level characteristics are found at present on sites of different types and on land managed by different forest owner categories in these two regions. Finally, trends, potential gaps between ecological and socio-cultural on the one hand, and management dimensions of continuous cover forests on the other, are discussed.

Study areas

Landscape scale analyses

There are large regional differences in the history of development of silvicultural systems (Eliasson, 2002; Angelstam, 2003b; Kardell, 2004; Holmberg, 2005). This means that different forest history phases can often be found at the same time in different regions (Angelstam et al., 1997). As illustrated by my two study areas. Sweden is a good example of this.

The southern study area in Bergslagen located around the "Limes Norrlandicus" (Selander, 1955; Fransson, 1965) include both upland areas with a long land use history and lowland areas where considerable areas have been cleared for agricultural purposes. In the Bergslagen region in south-central Sweden forestry started several hundred years ago, driven by the mining industry (Wieslander, 1936) . During the 17th and 18th centuries, large parts of the world's iron production originated from Bergslagen. Due to intensive produce charcoal for the iron industry the forest rotation time was short and stands were often harvested at less than 50 years of age (Ek, 1995). During the same time period the forest resource was also heavily exploited for timber. First the large dimension trees were harvested and then smaller and smaller trees (Enander, 2005). When the iron industry declined in the late 19th century the practice of clear-felling with high costs for regeneration was questioned (Wallmo, 1897). After WW1 the criticism grow stronger and resulted in a period of single and group tree selection before the breakthrough of mechanised forestry with clear-felling as the main harvesting method in the 1950s (Ekelund and Hamilton, 2001). The long history of development with industry, forestry and farming in Bergslagen resulted also in a cultural landscape with continuous cover forests. Land owners in Bergslagen range from non-industrial private to forest commons, the Swedish church and large companies. The ownership pattern in Bergslagen is fragmented with about 70% owned by owners with properties less than 1000 hectares in size. Only a few percent of the land is owned by the government.

The northern study area was located in western Västerbotten and south-west Norrbotten in the northern part of Sweden around the "Cultivation Line" (Hahn, 1998; Lundmark, pers. com.). The area covers a gradient from north boreal to sub-alpine mountain forest. In this area the history of industrial forestry is relatively short. 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., 2004b). In fact, large parts of the forests close to the mountains have still not been subject to intensive forest management (Forsell and Axelsson, 1990; see Table 2). As in Bergslagen the forest resource was initially heavily exploited both on government and privately owned land. The main way of harvesting was dimensions cutting. This unsustainable forestry practice was supported by instructions for forestry on government owned land (ref xx) and regional laws on dimension cutting in the coastal parts of Västerbotten and Norrbotten countys as well as by a special law (Swedish: utsyningslagen) regarding private land further away from the coast (Enander, 2005). Landowner patterns are different in this study area with less fragmentation and only about 25% owned by owners with properties less than 1000 hectares in size. In this study area land is to a large extent owned by the government and large forest companies. Included in this study area is the Vilhelmina Model Forest (Svensson et al., 2004).

Cultural landscapes

The county of Västmanland is a central part of the southern study area in Bergslagen and was thus chosen for estimating the present amount of cultural landscape continuous cover forest. These kinds of culturally created wooded grasslands were never a characteristic feature in western Västerbotten county.

Stand scale analyses

For the stand scale analysis of the extent to which forest stand characteristics differ among site types (dry, mesic, moist/wet) a sample of local landscapes represented by stands or properties with the full range of site types was collected. Additionally, for the northern study area, were gap phase dynamics may be due to both ground wetness and humid oceanic climate, estates with oceanic climate were included.

Methods

Landscape scale analyses

Sample plot analyses

All sample plots from a 100-km wide band centred on the southernmost 350 km of the cultivation line and the Limes Norrlandicus (Figure 1) were extracted from the national forest inventory database (Anon., 2002c). In the northern study area it was assumed that continuous cover forests should be present at higher altitudes due to the moist oceanic climate. Data on precipitation was used to extract sample plots in this climatic zone (Ångström, 1958). In this analysis only meteorological data on precipitation was used to identify the wet sites. The age distributions of the forest on different potential continuous cover sites and mesic sites were compared. An estimate of the present amount of continuous cover forest was made by using the oldest age class i.e. forest stand 140 years old or older.

Coarse-grained spatially explicit analyses

Within the study areas two squares of 50x100 km were chosen for a coarse-grained spatially explicit analysis. 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 to estimate the area proportion of naturally moist and wet areas. Soil moisture is a result of several factors such as precipitation, evaporation, topography, lateral flow, soil types and vegetation (Moore et al., 1991; Wilson et al., 2004). In a limited area like the two 50x100 km squares precipitation and evaporation is assumed to be spatially uniform over a longer time scale. The model used was based on the wetness index developed by Beven and Kirby (1979). The TWI has been further developed and verified towards identification of wetter areas. Results from the TWI modelling are typically digital thematic maps with land classified in different wetness indices ranging from wet to dry. From the distribution of wetness classes I chose an amount of moist and wet areas, and combined them with digital map data on rich soil types (sediment type soils) to obtain an estimate of the potential areas for wet-rich continuous cover forests. The estimates were conservative to make sure I did not overestimate the proportion of this forest type. To identify the dry and poor sites only soil type information (sand-gravel and rocks with absent or very thin soil layer) were used. In the northern study area data on yearly average precipitation was used to identify areas with high altitude humid oceanic climate. All remaining forest land was classified as being mesic sites. Finally, forest age distributions on the different site types were estimated using nearest neighbour (kNN) classified satellite image data (Tomppo, 1991; Franco-Lopez et al., 2001; McRoberts et al. 2002, Reese et al. 2003, 2005).

Cultural landscapes

The present amount of the cultural type of continuous cover forest was extracted as all cultural grasslands with a tree cover of 10% (Anon., 2005b) or more from a recent Swedish national inventory (Anon., 2005a).

Stand scale analyses

For stand scale analysis data was extracted from forest management plans (Swedish: skogsbruksplan, grön skogsbruksplan). I contacted personally and requested data from all large forest owners and some private forest owners in each study area. I asked the forest companies for data from 5 test areas containing a large sample of each continuous cover forest type. The private forest owners were identified by combining soil type and property maps at the National Board of Forestry or by just getting a list of forest owners from their staff working in the field. All private forest owners were asked if they had a forest management plan and if they were willing to let us use the data in it for my study. Often forest owners also advised us where I could find other private properties with these forest types. The collected data sets were very diverse both in size and quality in terms of variables allowing site type classification. The diversity in variables forced us to use different approaches to identify the site types having a potential to host continuous cover forests. Where ground moisture or ground layer vegetation was present in the data sets this was used. In other cases combinations of ground carriage capacity and site type index (SI), in some cases only the SI was used and in a few cases the forest owner provided a list of the stands with the searched characteristics (Anon., 1985a, 1985b, 1985c; Hägglund and Lundmark, 1987, 1999, 2003). Large parts of the collected datasets were not used since the variables presented were not sufficient to identify the site types.

Results

Landscape scale

The owner categories in the two study areas were diverse (Table 1). There was a clear difference in amount land owned by small owners (less than 1000 ha) and large forest owners between the two study areas.

The analysis based on sample plot data from the Swedish national forest inventory data shows that the potential amount of continuous cover forest land with old forest was very small (Table 2). There was more old forest left on all site types in the northern study area than in the southern. The result from the analysis of National Forest Inventory indicated less forest in the youngest age class for wet sites compared to mesic and dry sites (Table 2). Potential remaining CCF on dry and wet sites was 9-10% in the southern study area and about 22% in the northern with an additional 31-32% of high altitude oceanic climate forest (Table 2).

According to the Topographic Wetness Index the southern study area was slightly drier then the northern study area (Figure 2). As indicated by the amount of younger forests the recent management of the different site types has been very similar in both study areas. For older age classes the results indicate lower amounts in the southern study area than in the northern. For sites located at high altitudes with moist oceanic climate it can be noted that there are larger parts with old production forest and old forests remaining than for any other forest type (see Table 3). The results from the coarse-grained spatially explicit analysis show only the age distribution on the different site types since the amount of the different site types has been chose from a calculated topographic wetness index (see Figure 2). As a consequence this analysis says nothing about the proportion of the different site types in the landscape.

Cultural landscape

The present amount of wooded grasslands with 10% or more tree cover (Anon., 2005b) in the county of Västmanland was estimated to 0.4-0.5% (about 2000 hectares) of today's forested land.

Stand scale

The forest management data from Non Industrial Private Forest (NIPF) owners and from large forest owners is very diverse in size (see Table 4). The stand scale analysis shows that there was more old forest left in the northern study area (see Table 5a and b).

Discussion

Continuous cover forests are rare

In Sweden continuous cover forests and forestry have recently been discussed by the National Forest Administration (Anon., 2004). The proposed definition is that the area extent of individual stands should be at least 0.25 ha and should have had a continuous forest cover with no major changes of tree species for at least 300 years. Further, the forest should have held a minimum of 30 m^3/ha of living trees. In mixed deciduous forests there should be at least one species with over 10 m^3/ha. The exception is cultural forests where the definition is not as strict.

The results from this study, together with the assumption that most of the wettest and driest sites were dominated by continuous cover forests, suggest that these forest types have declined sharply, and are still declining. The remaining amount of such forests in the southern study area today is somewhere between 0 and 6% of the potential. In the northern study area the proportion left was slightly higher at 0 to 17 % of the potential, except for the high altitude continuous forest where the decline was even less. For the county of Västmanland we estimated the past (about 1910) amount of cultural continuous cover forests to be 2-3% (> 10 000 hectares) of the presently forested area using old agricultural statistics (Anon., 1898; Anon., 1916) to be able get a rough estimate of the decline. Our estimate shows a decline of 80% for this forest type. The present management as seen by looking at the amount of forest in the youngest age class shows that continuous cover forest sites to a large degree are managed in the same way as mesic sites (Table 8).

A main difference between the two regions studied is that the timber frontier arrived later in Västerbotten than in south-central Sweden, and especially in Bergslagen (Angelstam et al., 2004b). This is also clearly visible in the sample-plot and coarse-grained spatially explicit analyses (Table 2 and 3). However, because today's management seems to be similar among site types and owners, given enough time, the age distributions on different site types will probably look very similar in the two areas within a few decades.

Remote sensing as a tool to estimate and identify remaining continuous cover forests

One consequence of the paucity of continuous cover forests today is that they are hard to identify using remote sensing techniques. This is clearly shown if results from the sample-plot and coarse-grained spatially explicit analyses are compared (Table 2 and 3). The large differences in the oldest age classes in the sample-plot and coarse-grained spatially explicit analysis are a result of the rarity of continuous cover forests and differences in the two landscapes. In the southern study area the remaining amount of old forest is smaller and more fragmented while in the northern study area the landscape consists of larger homogenous elements. Small fragments of old forest stands are hard or impossible to detect using the kNN analyzing method. In Bergslagen the forest is denser and the canopy closes at an earlier age. After the canopy has closed it is hard to see any differences between stands using remote sensing methods. Other methods like multispectral analyses of satellite images might be better options for identifying the last remaining biologically old forests.

Gap between policy, forest management and continuous cover forests

While contacting private forest owners to obtain forest management data a clear majority reacted negatively when they heard the words "continuous cover forestry". This seemed to be due to a misconception that the current forest policy trend would force them to use continuous cover forestry on all their land. Continuous cover forestry is a concept that could be used in stands and areas where for some reason the desired values would not be maintained if all trees were cut. This could be due to ecological reasons like hosting species adapted to a continuous cover forest on the site types described in this study. It could also be since the forest has other functions than timber production such as protecting a water resource, protecting infrastructures such as roads and residential areas, reducing air and noise pollution, providing opportunities for recreation and tourism. Continuous cover forestry methods that retain more or less of the forests natural characteristics should be used on these sites.

Several forest companies in this study have expressed a clear interest in continuous cover forestry. Why is that? Is it because they want methods that mean they can produce some timber on sites that would else not be suited for forestry? Or is the reason to develop new silvicultural regimes? During the study we had contacts with forest managers that did not understand the difference between selection (Swe: blädning) and selective cutting (Swe: dimensionsavverkning) and its implication for the forests ecological values. Hence, if forest managers due to poor knowledge use alternatives to clear-felling whereby they select and cut all the most valuable trees the result will be more or less as bad as if all trees were cut, thus resorting to high-grading approaches commonly used in the mid 19th century.

We use the definition of selection cutting from Matthews (1989). The Selection felling system means a felling of scattered single trees and/or small groups of trees selected from a large area. The size/age of remaining trees should be maintained in a proper proportion where all age classes should be represented. A suitable mixture of species should be maintained if needed. Young saplings should be freed from suppression and defective stems should be removed if they hamper the development of better ones. Off course this might be slightly adjusted if the aim of the forest is other than timber production. With selective cutting we mean high-grading or dimension felling. All valuable high dimension trees are felled and no management to improve the remaining trees is done (ref xx). This is not a silvicultural method but still practised in many areas around the world (Matthews, 1989).

The Swedish national forest statistics indicates that 96% of our forests are managed by clear-felling methods (variable retention and seed tree) (Anon., 2002b). This could mean that at the most 4% of the forests are managed with methods that attempt to mimic natural disturbance regimes. However, my study shows no sign that this is the case. Instead it shows that forestry methods are not as diverse as our forests and that our last remaining continuous cover forests will soon disappear or be small isolated patches in the landscape if management methods will not change. The change might already have started on wet sites. One forest manager in a large forest company told us that management has changed on some of the wet sites the last 15 years. This change might also be indicated in the results from the sample-plot analysis (Table 2.).

Conservation of continuous cover forests

If I like to conserve a sufficient amount of continuous cover forests and the connected biodiversity there is clearly a need for alternative management methods. For most habitats it is assumed to be critical when an 80% loss is reached (Andrén, 1994; Farig, 1997; Angelstam et al., 2004a). However, for continuous cover forests the critical number might be different since they more or less by definition are very fragmented also in a natural landscape. The very small areas with remaining old forest will need urgent protection with appropriate management if they are not protected already. For at least a part of the remaining areas with these site types restoration is needed. It will make a big difference for restoration purposes if the last remaining continuous cover forests could be used as core areas in the restorative process. The restoration can be achieved by protecting some areas. In other areas forestry methods that are based on the idea to emulate natural dynamic and thus maintain the characteristic structures of different forest types should be used. Both rich and wet sites as well as forests in humid macroclimate will sooner or later recover if left, even if the right management probably could speed up the process. If the management method could mimic natural processes some timber harvesting could take place.

By contrast, the conservation of cultural and poor-dry site continuous cover forests usually requires special management to maintain their biodiversity values. The cultural continuous cover forest needs to be kept open and cleaned from most of the coniferous growth. Ideally most of this could be done with grazing domestic animals. It is for ecological reasons very important that we maintain this forest type at least until the remaining part of our forests will hold natural amounts of deciduous trees (Mikusinski et al., 2003). Scandinavian forests suffer from nitrogen deposition and the production capacity has clearly increased during the last 50 years (Binkley and Högberg, 1997; Solberg et al., 2004). Along with the fact that we have had a long time period without forest fires this means an accumulation of organic material that adds to making sites richer, which is a threat to the poor-dry continuous cover forest type. Naturally frequent low intensity forest fires burnt the dry lichens covering the ground. Most pioneer plants were kept away by this kind of low intensity disturbance and nutrients in the shape of soot particles often left the sites with wind and rain. The sites were thus maintained as poor-dry, to the benefit of specialised species (Berglind, 2004). Today forest fires are more or less absent, and thus this kind of continuous cover forest type is severely threatened. To conserve this dry site continuous cover forests some kind of selection cutting combined with burning could be used. Despite the results in this study this might be our most threatened continuous cover forest type since it does need active management to be maintained.

A need to improve the thematic resolution of forest management plans

My contacts with large forest companies showed that not all of them have the needed knowledge about continuous cover forests and forestry. Here I can see the need for more information. The thematic information in most forest management plans were also not enough for proper planning of the management of continuous cover forest sites. Given the current definition of sustainable forest management this is not acceptable. Most of the data have been collected once to calculate production oriented parameters. To meet society’s current sets of values forest management plans need to be standardised and become more complete so they could be used as important tools for planning of ecological considerations and used to reach sustainable forest management. Ultimately they should develop into landscape management plans, including both terrestrial and aquatic dimensions.

To meet the current definition of SFM there is clearly a need for a broader set of management approaches than have been applied so far (Sayer and Maginnis, 2005). To specify the relative ambitions in terms of wood production and biodiversity management in forest stands with different site conditions in Sweden, the National Board of Forestry, forest owners' associations and Sveaskog Co. use a system for management ambition attributes to be used in addition to the traditional site and wood production information in forest management plans (Anon., 2003; Ingemarsson, 2001). Currently four management attributes imply a gradient in the relative importance of wood production and biodiversity management: PG (production goal with general environmental considerations); PF (production goal with reinforced environmental considerations); NS (nature conservation goal with management); NO (nature conservation goal based on no management). One problem is that a forest management plan contains information on one property only while planning for ecological values need to consider a larger scale and where actual values are present or could be restored. The management ambition attributes system used by the National Board of Forestry, forest owners' association and Sveaskog Co. might be proper for very large properties or forest companies. For smaller properties this is however not an optimal approach (Ask and Nilsson, 2005).

Conclusion

The way forward

The multiple approaches employed in this study need to be developed further. First, I propose an extensive analysis of the potential amount of continuous cover forests using the available Swedish national forest inventory data and other relevant data. By combining several variables the definition of different forest types could be more specific than in this pilot study. The Swedish national kNN dataset (Reese et al., 2003, 2005) covers most parts of our country and a new data set will be available in a year or two. It is possible to use the data set as in this study with a modelled topographic wetness index with expanded study areas. Even a full country analysis is possible. Another interesting approach would be to use vegetation maps for areas where they are available. Several counties have produced these kinds of maps. Here one problem might be the diverse origin of these vegetation maps and thus potentially different quality. On the other hand the dry-poor and wet-rich sites should be quite easy to detect.

A second important thing to look at is the long-term trend for these kinds of forests. For at least a few different areas (were data is available) older datasets should be used to describe past trends over time, and estimate the trajectory into the future. This information will be very useful when making decisions on how to conserve the remaining continuous cover forests, and to develop new.

For the cultural continuous cover forest data on the present situation as well as data on areas that could be restored is available for the whole country. Here it would be useful with some new approaches to estimate the past amount.

For forest management plans it is more or less impossible to collect large amounts of high quality data from non industrial private forest owners. Instead an enhanced co-operation with the larger forest companies, other large forest owners and the National Property Board should be the way forward. The aim should be to use their full forest management datasets to identify all stands on the different site types and compare the age distributions. One problem could possibly be that different forest companies have different parameters in their stand descriptions. The problem could be minimised be combining several parameters for a successful identification of the site types.

The future for our continuous cover forests and forestry

To fulfil the present forest policy the combination of different forest management methods used should allow the naturally occurring forest organisms to maintain viable populations. This means that sites naturally having large-scale disturbance regimes potentially could be managed using intensive methods like clear-felling combined with variable retention. However, the different continuous cover forest sites naturally were dominated by small-scale disturbance regimes. Most organisms in these forest types are adapted to this and would suffer from large stand replacing disturbances. Here new management approaches need to be implemented (Fries et al., 1997).

One problem appears to be that forest managers generally do not understand the differences between selection and selective cutting and its implications to continuous cover forests. The result is that these sites are managed for short-term economic gains instead of aiming to reach sustainable forest management. Long-term effective forestry with sustainable management of our forests all values can only be reached if owners and land managers collaborate according to their ability, and apply a diversity of management approaches (protection, management and restoration) at multiple spatial and temporal scales. Here I see a need for learning about how continuous cover forestry is applied in regions with different forest ecosystems, land use history and systems for governance such as in Russia and the Alps.

Another challenge is limited knowledge on what kind of disturbances our flora and fauna needs and/or can manage. Some organisms need the disturbance or secondary effects from the disturbance, and for other organisms the same disturbance is a problem. Additionally we need better knowledge about thresholds for many species habitat requirements in terms of quality, quantity and configuration of habitats. Too much ecological care is costly and too little means that we loose some of our forests values. The same argument can be made for socio-cultural values.

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Table 1. Size of study areas and distribution of land among different landowners. See figure 1 for an overview of the areas. Data from Markägarkartan (Landowner map) produced by Metria for the Swedish Environmental Protection Agency (Anon., 2005d).

	Bergslagen	**Västerbotten**
Total study area (ha)	5 105 001	4 757 969
Government (%)	2.3	37.7
Municipalities (%)	1.2	0.3
The Swedish church (%)	1.9	0.1
Commons (%)	0.6	5.4
Sveaskog	8.6	20.2
Bergvik skog väst AB (%)	15.7	-
Holmen skog AB (%)	0	0.8
Korsnäs AB (%)	2.5	-
SCA (%)	-	12.1
Other Corporations (%)	1.5	0.6
Other companies and commonly owned (%)	0.3	0.1
Landowners with less than 1000 ha (%)	65.4	22.7

Table 2. Landscape scale forest age distribution (%) on different site types based on national forest inventory data in study areas Bergslagen and Västerbotten. Note that the "Amount site type" shows numbers in percent of all forest land and that the following lines show the age distribution of the different site types. The site types dry, mesic and wet (moist-wet) include all forest land (100%) and are based on the National Forest Inventory parameter "ground moisture" while climate is overlapping. Climate can thus include dry, mesic and wet land. Here climate means areas with a yearly precipitation of more than 800 mm in the Swedish mountain range. Other land is land were the national forest inventory variable could not be measured or estimated. The national forest inventory has different sample densities in the two areas.

	Bergslagen			**Västerbotten**			
Site type	dry	mesic	wet	dry	mesic	wet	climate
Amount of site type	5.5	90.7	3.8	5.8	90.5	3.8	3.2
Young Forest (age 0-40 years)	49.5	48.5	32.9	46.6	38.1	24.8	22.3
Growing Forest (41-80)	17.6	25.5	29.7	18.3	16.7	28.5	3.6
Production Forest (81-110)	19.8	15.6	24.3	10.0	12.4	9.7	12.3
Old prod. Forest (111-140)	6.4	6.4	6.4	14.6	17.8	23.2	29.4
Old Forest (141-)	5.9	1.1	3.5	10.4	12.8	11.7	31.5
Other forest land	0.7	2.9	3.1	0.0	2.2	2.2	0.9
SUM	100	100	100	100	100	100	100

Table 3. Forest age distribution on different site types in Bergslagen and Västerbotten based on mixed spatially explicit methods from two 50x100 km squares in the study areas (see figure 1). All numbers are given in percent (%). Note that the "Amount site type" shows the age distribution of the different site types. The category dry is based on soil type only and the category wet is based on a wetness index and the soil type. The site types dry, mesic and wet (moist-wet) include all forest land (100%) while climate is overlapping. Climate land can thus include dry, mesic and wet land. Here climate means areas with a yearly precipitation of more than 800 mm in the Swedish mountain range.

	Bergslagen			**Västerbotten**			
Site type	dry	mesic	wet	dry	mesic	wet	climate
Amount site type	12.9	81.6	0.3	5.8	88.9	0.4	2.4
Young Forest (age 0-40 years)	36.7	40.9	54.8	40.6	44.9	50.6	57.8
Growing Forest (41-80)	42.3	41.1	32.7	22.1	24.5	25.0	7.5
Production Forest (81-110)	20.6	17.7	12.2	24.0	20.5	18.0	12.6
Old prod. Forest (111-140)	0.3	0.3	0.3	13.0	9.9	6.3	20.0
Old Forest (141-)	0.01	0.01	0.00	0.4	0.4	0.2	2.0
SUM	100	100	100	100	100	100	100

Table 4. The number of stands and size of the total sample of different site/CCF types included in the stand scale study for different forest owners in the two study areas. All numbers in hectares (ha).

Site type	Poor-Dry		Mesic		Moist/Wet		Climate	
Bergslagen	stands	ha	stands	ha	stands	ha	stands	ha
Forest owner A	79	382	101	627	96	400	-	-
Forest owner B	665	3824	951	3298	263	1160	-	-
Private	66	44	267	486	49	143	-	-
Västerbotten	stands	ha	stands	ha	stands	ha	stands	ha
Forest ownerA	132	1801	1458	19945	-	-	501	5552
Forest owner B	-	3020	-	51751	-	13576	-	-
Forest owner C	34	172	481	2888	43	144	-	-
Private	29	193	226	1648	31	132	76	544

Table 5a. Stand scale forest age distribution (%) estimates based on forest management plans for large forest owners and private forest owners. A and B are two large forest owners and Priv. is a group of private forest owners.

Bergslagen									
Site type	dry			mesic			wet		
	A	B	Priv.	A	B	Priv.	A	B	Priv.
Young Forest (age 0-40 years)	67.9	42.2	31.9	73.5	22.4	52.1	43.7	46.4	56.8
Growing Forest (41-80)	16.1	9.3	18.4	17.2	26.9	15.7	12.9	50.7	38.9
Production Forest (81-110)	8.1	16.9	44.0	5.0	27.9	31.6	32.1	2.8	4.3
Old production Forest (111-140)	7.9	24.1	5.8	4.3	18.2	0.6	8.2	-	-
Old Forest (141-)	-	7.5	-	-	4.6	-	3.0	-	-

Table 5b. Stand scale forest age distribution estimates based on forest management plans for large forest owners and private forest owners. A and B are two large forest owners and Priv. is a group of private forest owners.

	Västerbotten															
Site type	dry				mesic				wet				Climate			
	A	B	C	Priv.	A	B	C	Priv.	A	B	C	Priv.	A	B	C	Priv.
Young Forest (age 0-40 years)	19.6	31.2	45.1	79.5	30.3	50.9	40.7	30.8	-	42.4	19.9	8.8	15.8	-	-	3,0
Growing Forest (41-80)	1.2	35.3	45.1	16.5	3.6	17.0	12.5	30.7	-	15.8	15.5	11.5	9.1	-	-	8,1
Production Forest (81-110)	32.4	11.7	10.8	0.5	9.0	10.8	4.2	9.2	-	14.7	16.5	11.5	6.2	-	-	4,6
Old production Forest (111-140)	29.4	12.7	0.0	2.1	51.1	13.6	15.2	13.5	-	19.7	14.1	54.9	26.5	-	-	33,6
Old Forest (141-)	17.3	9.2	15.3	1.3	15.0	7.6	27.4	15.8	-	7.3	34.0	13.3	20.4	-	-	50,6

Table 6. Percent of area with no old forest on potential continuous cover forest sites with different analysis, scales and data sets.

	Bergslagen			Västerbotten		
Site type	Dry	Wet	Cultural	Dry	Wet	Climate
National Forest Inventory	94.1	96.5	-	89.6	88.3	68.5
Remote sensing	99.99	99.99	-	99.6	99.8	98.0
Agricultural statistics	-	-	80.9	-	-	-
Stand scale	92.5	97.0	-	89.2	81.8	64.5

Table 7. Young forest (0-40 years) (%) on different site types with different analysis methods. For the stand scale analysis the mean values from the different owners/owner categories has been used.

	Bergslagen			Västerbotten			
	Dry	Mesic	Wet	Dry	Mesic	Wet	Climate
National Forest Inventory	49.9	48.5	32.9	46.6	12.8	28.8	22.3
Remote sensing	36.7	40.9	54.8	40.6	44.9	50.6	57.8
Stand scale	49.6	49.4	49.0	49.6	15.4	8.8	9.4

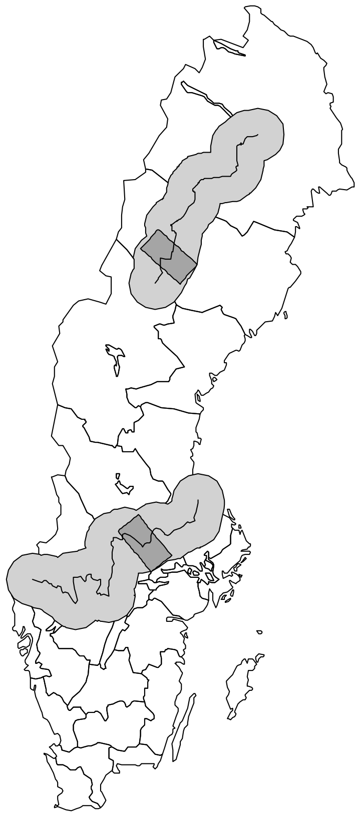

Figure 1. The figure shows the two study areas on a map of Sweden. Bergslagen is located in mid-central Sweden and Västerbotten in northern Sweden. The dark grey squares are the 50x100 km squares used for the mixed spatially explicit methods analysis.

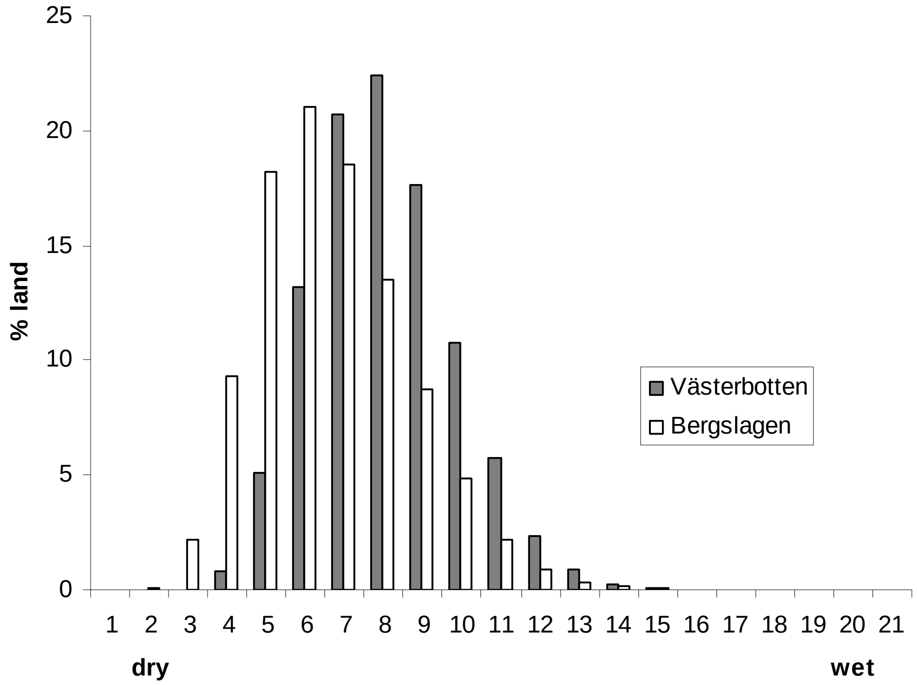

Figure 2. Total Wetness Index (TWI) in the two 50x100 km large squares in the study areas calculated from altitude and water bodies. The graph shows the distribution of land area in different wetness classes. In this graph all land except water bodies is included. The TWI ranges from dry (low numbers) to wet (high numbers).