Spatial Allocation of Forest Production – Aspects on multiple-use forestry in Sweden

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Abstract

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The question of how production of different services and goods should be combined or allocated spatially is an issue that often have been discussed during the evolution of the concept multiple-use forestry. Basically there are two different approaches: the first, that of joint production of several goods and services from the same area, and the second, that of specialized production of single outputs from different areas. As forestry is an activity that ranges over a long time period and as values of forests changes over time there are temporal aspects on this spatial allocation problem that have to be considered. The objective of the thesis is to analyse some important factors for spatial allocation of forest production and the temporal aspects on spatial allocation of forest production. The thesis is based on four studies.

In the first paper it is concluded that habitat protection for nature conservation purposes, in areas dominated by non-industrial private forestry, will have socio-economic implications, since there is a variation in habitat occurrence between estates. The second paper results show that there is a significant potential to increase biomass production in Sweden through the use of nutrient optimisation. The potential could be used for increasing the production of forest fuels and/or raw materials for the forest industries. It could also be utilized in order to provide opportunities for setting aside more areas for nature conservation purposes, without the potential harvest levels being reduced. In the third paper, the implications of two different strategies for increasing the fraction of deciduous trees in a forest landscape are studied. The study shows, it takes a long time to change the forest composition in a landscape and if a major increase in deciduous fraction should be reached, drastic management measures are needed. The last paper presents a method for the analysis of production allocation problems. The method is used to evaluate two different strategies for the spatial allocation of wood production and production of nature conservation values. The results reported show that the use of specialized production leads to a higher production of the two outputs as compared to the use of joint production. However, if the goals of forestry change in the future, the use of specialized production could imply a more restricted future planning space.

Keywords: non-industrial private forestry, habitat protection, monte carlo simulation, nutrient optimisation, biomass production, landscape, deciduous trees, projection model, differentiation, zoning.

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Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals

I. Carlsson, M., Andersson, M., Dahlin, B. & Sallnäs, O. 1998. Spatial patterns of habitat protection in areas with non-industrial private forestry-hypotheses and implications. *Forest Ecology and Management 107*, 203-211.

II. Andersson, M., Bergh, J., Börjesson, P. & Dahlin, B. Potential to increase biomass production in Swedish forestry by using nutrient optimisation. (Submitted manuscript).

III. Ask, P. & Andersson, M. Strategies for increasing theproportion of deciduous trees. A landscape study from southern Sweden. (Submitted manuscript).

IV. Andersson, M., Sallnäs, O., and Carlsson, M. A landscape perspective on differentiated management for production of timber and nature conservation values.

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Introduction

Forest ecosystems are a resource able to produce a wide variety of goods and services or values, both consumptive and non-consumptive. The values people associate with forests differ form one society to another and change over time, leading to changes in the use of forests (Kennedy 1985; Koch & Kennedy 1991). Values can be seen here as representing relatively stable beliefs that a person or a society has that a particular way of doing things or a particular end-state is preferable to some other way or end-state (Rokeach 1973). These beliefs serve as a basis for judging such matters as the way forests are used and the end-states associated with their use, involving both short- and long-term considerations (Kennedy 1985).

In agrarian, pre-industrial societies the forests were used to provide a wide range of goods and services such as shifting cultivation, grazing, hunting, harvesting of berries and of mushrooms, as well as wood products such as timber, firewood, charcoal, tar and potash (Stridsberg 1984; Fritzbøger & Søndergaard 1995). When the Industrial Revolution in the 19th century, started in western Europe, it led to a specialization of land use in which the forest land was assigned to the dominant use of producing wood which differ markedly from the multiple-use of forests practised earlier (Stridsberg 1984, Eliasson 1997). The values focused upon, at the cost of those of biodiversity, for example, were those of efficient wood production as expressed in terms of market values. Due to the scarcity of wood that had been experienced in earlier centuries, considerable value was also put upon the sustained yield of wood products. In practise, the increased value of wood production led to, forest grazing being stopped and to management efforts such as draining and planting being increased (Koch & Kennedy 1991). During the 20th Century there was a shift towards a broader spectrum of values being assigned to forests, values of recreation, wildlife, the beauty of a landscape and the like, appreciation of these being at the cost of wood production (Kennedy 1985; Koch & Kennedy 1991; Eckerberg 1995). Not only have there been a change in forest values, also the way values are expressed has changed from that of emphasizing market values to legislation within the political system and arguments presented by different interest groups. Along with changes of this sort, forestry has shifted more and more towards the multiple-use of the forest resources, sometimes referred to as *new* multiple-use in contrast to the *old* multiple-use practised in the agrarian society.

In the production of goods and services within the framework of multiple-use forestry, a balance with regard to local conditions and forest values is aimed at. Since the conditions for forest production and forest values vary from one location to another, there are spatial aspects of forest production. A problem in multiple-use forestry is to decide how the different uses should be spatially combined or, expressed differently, how forest production should be spatially allocated. Forestry is an activity that continues over a long period of time, there are also temporal aspects of forest production. The major topic of the present thesis is that of the spatial allocation of forest production and the temporal considerations linked with this. The thesis deals with various basic approaches for spatially combining various uses of forests, whereas more specific aspects of spatial allocation such as the relations and interactions between different stands or between areas of other types are not included (see Dahlin & Sallnäs 1993; Öhman 2001). The term forest production is in the thesis interpreted in a broad sense, as including all the goods and services, both consumptive and non-consumptive that forests can provide society with.

Historical aspects on forest production in Sweden

The use of forests has in Sweden, as in many other European countries, has long been a subject of legislation, and the legislation has changed as changes in values and structural changes in society have occurred (Kennedy 1985). These legislative changes thus provide insight into the changes in value that have occurred. The first Swedish Forestry Act, enacted in 1903, concerned only privately owned forests. It was passed after decades of discussions concerning the future expected scarcity of wood and property rights (Eliasson 1997; Enander 2000; Ekelund & Hamilton 2001). Nevertheless, the use of forest land had been the subject of legislation in Sweden for several centuries prior to that. During the 16th Century; for example, beech and oak forests were protected from timber harvesting since the acorns and nuts were considered important resources for the raising of pigs. Oak trees were also protected, since the state considered them an important timber resource for the building of warships (Eliasson 1997; 2002). Other regulations aimed at securing resources for the wood consuming mining industry. During the time since the first Forestry Act was passed until today, it has undergone four major revisions. Until the last few decades the focus has been on the production of spruce (*Picea abies*) and pine (*Pinus sylvestris*) timber. The most important section of the Forestry Act of 1903 concerned the regeneration after final felling (Enander 2000; Ekelund & Hamilton 2001). The act also recognized forest land being an important resource for agriculture, however, since it stated that the use of forest land for agricultural purposes could not be blocked by use of the Act (Eliasson 1997). Two years after the Forestry Act was passed, a new forest administration was established, having Regional Boards of Forestry (RBF). Two of the main tasks for these RBFs were to supervise application of the Forestry Act and serving as an extension service to promote better silvicultural practices. In the instructions to the RBFs it was stated that legal disputes with forest owners should be settled if possible outside of court by means of voluntary agreements (Ekelund & Hamilton 2001).

The first revision of the Forestry Act took place in 1923 (Anon. 1923). In that new Act it was stated that forest lands should be used for forest production. More detailed regulations concerning regeneration were also included, the final felling of young stands being prohibited and it being made possible to stop the cutting on estates with a low standing volume (Ekelund & Hamilton 2001; Enander 2001). In 1941 a new central body of the forest administration was established, the National Board of Forestry (NBF). One reason for its establishment was to achieve a more uniform implementation of the forest policy.

In 1948 the Forestry Act was revised a second time (Anon. 1948). Since the use of selective-cutting had resulted in large areas which were low in standing volume or in which regeneration was insufficient, the restoration of forests was emphasized. The first section of the Act stated that forest lands should be managed so to provide a satisfactory economic return at a sustained level. Included in the Act too was sharper regulation concerning the final felling of young stands and regulations of maximum harvest levels, aiming at achieving an even age-class distribution on the estate level (Ekelund & Hamilton 2001; Enander 2001). The Act led to a shift in management from a selective cutting to a clear cutting system (Bäckström 2001). In the 1960s and early 70s the use of the forest resources was discussed. It was suggested that the prevailing sustained yield concept be given up and that the money generated in the forestry sector be invested in other sectors of society that could yield a higher return (Anon. 1973). In the end, suggestions of this sort were rejected. In 1974, regulations of nature protection were introduced by the passing of a special act on the preservation of beech (*Fagus sylvatica*) forests and by the introduction of a section of the Forestry Act dealing with general considerations regarding nature conservation and recreation. The special act on beech forests stated, in short, that beech stands should be replaced by new beech stands after final felling (Anon. 1974; Ekelund & Hamilton 2001).

The third major revision of the Forestry Act took place in 1979, in the first section of which a stronger concern for wood production was expressed. After this revision, the Act also concerns publicly owned forest land. The new regulations that were included placed demands on pre-commercial thinning, prohibited selective-cutting and demanded of forest owner that they replace stands that produced appreciably less wood than was indicated by site productivity. The scope of the section concerning nature conservation and recreation was also widened, by including considerations regarding the safeguard of cultural heritage. In 1984, a section regarding minimum harvest levels was added with the intention of securing raw material for the forest industry. The same year, the special act on the preservation of beech forests was revised to also include ash (*Fraxinus excelsior*), cherry (*Prunus avium*), elm (*Ulmus spp*), hornbeam (*Carpinus betulus*), lime (*Tilia spp*), maple (*Acer platanoides*) and oak (*Quercus spp*) (Anon. 1984; Ekelund & Hamilton 2001).

The latest major revision of the Forestry Act in 1993 marked a change in Swedish forest policy (Anon. 1993a). The focus was no longer simply on wood production. This is expressed in the first section, where it is stated: “The forest is a National resource. It shall be managed in such a way as to provide a valuable yield and at the same time preserve biodiversity.
Forest management shall also take into account other public interests” (Anon. 1993a; Skogsstyrelsen 1994). Many of the restrictions and regulations were removed or relaxed, the individual forest owner being given more responsibility and freedom of choice. The Forest Administration’s role as an extension service in the implementation of the new policy was also stressed (Hallerstig 1998).

Multiple-use Forestry

The basic ideas upon which multiple-use forestry as it is understood today is based date back to the previous turn of the century and to the USA. In the Forest Administration Act of 1897 the reason given for the establishment of National Forests is to “improve and protect” forests and “for the purpose of securing favourable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of the citizens of the United States” (quoted from Cliff 1962). In 1905, the first head of the newly established U.S. Forest Service received a letter from the Secretary of Agriculture, James Wilson who stated: “where conflicting interest must be reconciled the question will always be decided from the standpoint of the greatest good of the greatest number in the long run”. Since then the management of the National Forests in USA has involved recognition of the different functions forests have.

Due its unclear meaning, the idea of multiple-use was debated and criticized during the decades that followed. One of the issues discussed was how one could spatially combine the production of different outputs (Gregory 1955). Conflicts arising between timber production and conservation interests also arose. This eventually led to the passing of the Multiple Use Sustained Yield Act (MUSY-Act) in 1960. In the Act, multiple-use forestry is defined, its being stated that the national forests should be managed with due consideration to non-wood products such as recreation, water, wildlife, range and fisheries. The Act defines multiple-use as follows: "Multiple use means the management of all the various renewable surface resources of the national forests so that they are utilized in the combination that will best meet the needs of the American people, making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide latitude for periodic adjustments in the use to conform to changing needs and conditions; that some land will be used for less than all of the resources; and harmonious and coordinated management of the various resources, each with the other, without impairment of the productivity of the land, with considerations being given to the relative values of the resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output" (Gregory 1987). In this definition, account is taken of the two main topics of the thesis, namely the spatial and temporal aspects of forest production.

Passage of the Act did not succeed in resolving the conflicts between different interest groups, due to the definition of multiple-use forestry being somewhat vague and to a lack of guidelines on how the different uses should be balanced. Since then, new legislation has been passed to resolve the conflicts, such as the National Environmental Protection Act passed in 1969, which introduced the use of a more open and democratic decision-making process and also required that interdisciplinary professionals take part in the process when different planning and management alternatives were to be considered (Koch & Kennedy 1991). There are a number of different reasons for the conflicts concerning multiple-use, which have occurred. Koch & Kristiansen (1991) note that the concept of multiple-use has been well received by all the interest groups involved and that this may due to the different groups interpreting the concept in their favour at the cost of the interests of other groups. Kennedy (1985) also claims that foresters were not prepared to understand and respond to the changes either in forest values or the way they were expressed, the importance assigned to the non-consumptive values of forests having increased. Some claims that the inability of foresters to respond to and understand the changes is related to traditions in the training and education of foresters (Kennedy 1985; Behan 1966; Behan 1990; Hugosson 1999).

The conflicts between wood production and nature conservation in the U.S. led to the emergence of various management concepts concerning the multiple uses of forest land, such as “New Forestry” (Franklin 1989), which focuses on the maintenance of complex ecosystems and recognizes the importance of a landscape perspective, of natural disturbances and of riparian zones in a forest management. Another management concept is ecosystem management or ecosystem-based management (Grumbine 1994; Wood 1994; Thomas & Huke 1996; Schlaepfer & Elliot 2000), which aims at safeguarding the ecological sustainability of landscapes within a socio-economic context. The focus on maintenance of ecosystem contrasts the earlier multiple-use policies, for example the MUSY-Act, that focused on the outputs.

One event that led to an increased interest in multiple-use forestry was publication of the “Brundtland Report” on Environment and Development (Anon. 1987), which was followed in 1992 by the Rio Conference on Environment and Development, where the multiple functions of forest were recognized as a key feature of sustainable forestry. The conference initiated a process of defining and implementing sustainable forestry (e.g Anon. 1993b; 1998). Another process that has emphasized the multiple functions of forests is the development of different forest certification standards during the last decade (Erikers 2001). For example, both the Swedish standards issued by the Forest Stewardship Council (FSC) and those issued by Pan-European Forest Certification (PEFC) include components on environmental, social and economic aspects of forestry (FSC 2000: PEFC 2002). The Swedish FSC-standard also states “Multiple use is a feature of the utilization of forests” (FSC 2000).

The concept of multiple-use forestry that had evolved in the USA was spread over the world. An important occasion for the promotion of the concept was The Fifth World Forestry Congress in 1960, which had the theme "Multiple Use of Forest Land". It was held in Seattle two months after the passing of the MUSY-Act. Swedish foresters who visited the congress brought the concept back to Sweden, but according to Hultman (1984) it had little impact here, foresters claiming that in Sweden multiple-use already existed. The basis for these claims was the idea that existing legislation would take care of any conflicts between uses that might arise. Hultman (1984) opposed this, claiming that multiple-use forestry is non-existent in Sweden since forest policy here fails to “recognize other uses than wood production as having the same basic right to exist on forest land”. For example, no objectives were set for the other uses of forests. Furthermore, he argued that in order to be called multiple-use, forestry had to meet the following criteria (derived from King, 1980):

- a clear statement of objectives for each use
- equal considerations of all uses (whether they can be measured in economic terms or not)
- careful coordination of uses and explicit description of conflicts
- a planning procedure that is logical, rational and open to inspection
- that planning must carried out at several levels, including the local level.

The need of careful the coordination of uses which Hultman stressed is of importance, since the different forest values are mutually related, so that when efforts are made to increase a certain value, for example, this affects the other values (Fernand 1995).

Hultman (1984) concluded that forestry in Sweden would eventually have to change, since the pressure to promote other values than those of wood production was increasing. His conclusion was correct, forestry in Sweden having changed in very fundamental ways since then, today his criteria of multiple-use being far better met. The major mark of this change is the revised Forestry Act of 1993 (cf. above). Many forest owners, including forest companies, public owners and non-industrial private forest owners, have also adopted the rules of forest certification standards issued by FSC (FSC 2000) or by PEFC (PEFC 2002). It is of interest that the term multiple-use is not mentioned in the Swedish Forestry Act today. It is, however, mentioned in “Goals for a sustainable forestry” (Skogsstyrelsen 1998) published by the National Board of Forestry, in which it is stated that possibilities for multiple-use should be utilized in management of the forests, although no definition of the concept is provided. A committee set up by the Department of Agriculture in 1990 to revise the Swedish forest policy gives a definition of multiple-use (Anon. 1992) that includes the recognition of different uses and states that attention should be paid to all uses at all forested land, the balance between the different uses depending on the natural conditions present and the needs both of people generally and of the forestry sector (cf. Hytönen 1995).

Spatial aspects on forest production

The question of how the different uses should be spatially combined in multiple-use forestry is an issue that has often been discussed during the evolution of the concept. There are basically two opposing approaches. The first, that of the joint production of several outputs from the same land, is advocated by Dana (1943), McArdle (1953, 1962) and Franklin (1989), for example, the latter author stating: "Protection of biodiversity must be incorporated into everything we do every day on every acre". The second approach, that of the specialized production of single outputs from different areas, has Pearson (1944) and to some extent Vincent and Binkley (1993) and McNeely (1994) as proponents. Gregory (1955) has discussed the two approaches from an economic standpoint, declaring that either of the two approaches could result in the highest level of production, its all depending on the conditions under which production in a particular area takes place. Vincent and Binkley (1993) have discussed why multiple-use forestry could require specialization of production to be effective. They also noted that even if the conditions in two forest stands are identical, management tends towards specialized production as long as one of the two products appears more responsive to management efforts. Gustavsson (1979) has noted that most persons do not interpret the concept as meaning the use of a given area for several purposes simultaneously, instead they think in terms of small-scale zoning in which one use dominates in a certain area and some other use dominates in an adjacent area. He notes further that scale is a key concept in multiple-use, that is, not letting any one use be the exclusive one in a large area (a region or a part of a municipality), but rather seeing to it that several different uses can exist in an area of small size and that changes in the dominant use are facilitated.

Before the Swedish Forestry Act was revised in 1993, three alternative lines of action for how biodiversity should best be maintained in the Swedish forests were discussed (Anon. 1992). These were: (i) the separation spatially of wood production and environmental protection, (ii) the differentiation of management in accordance with site productivity and with distance to industry and to markets, and (iii) a modified form of management aimed at high wood production and considerations regarding environmental protection on all forest land. Included in this last alternative was also an increase in the area of protected reserves and in areas voluntary set aside for environmental protection by forest owners, for which the latter could in some cases receive subsidies (Lämås & Fries 1995; Skogsstyrelsen 1997). The approach suggested was that of the last alternative, the revision of the Forestry Act in 1993 being based on this alternative. Several reasons for discarding the other two alternatives were stated, such as the shortage of natural forests suitable for serving as reserves due to a long history of management focusing on wood production, to a low degree of acceptance by the general public because of the right of common access to forest land, to the structure of ownership involving there being a large fraction of non-industrial private forest (NIPF) owners, and to the need of increasing the protection of forests in areas located close to industry and in areas of high population density (Anon. 1992; Lämås & Fries 1995). The alternative that was selected can be described as a combination of there being joint production on a large part of forest lands and specialized production on a much smaller part on which specialized production is for the purpose of environmental protection and not for that of wood production. This principle has also been incorporated into the different forestry certification standards that have been adopted in Sweden (FSC 2000, PEFC 2002).

Spatial scale

As Gustavsson (1979) and Hultman (1984) have noted, one needs to include several different levels of scale in the planning of multiple-use forestry. The different levels of importance for forest production can be identified by using both a nature conservation and a socio-economic perspective as a point of departure.

During the last two decades, forestry has come to a consensus regarding the landscape level being an appropriate level in the planning for preservation of biodiversity, since it is a level at which processes important for the diversity of species such as those of population dynamics and of natural disturbances, are acting (Clark 1991; Oliver 1992). The basis for this consensus is to be found within in the field of landscape ecology, which in short can be defined as the study of the spatial and temporal dynamics of a heterogeneous landscape (Forman & Gordon 1986). In landscape ecology a landscape is defined as a mosaic structure with a cluster of ecosystems repeated in similar form over an area extending for several kilometres at least (Forman 1995). In landscape ecology, the different levels of scale is seen as a hierarchy in which the higher level provides the setting for the subordinate level. The landscape level is subordinate to the regional level, in which a mosaic of different landscapes is found, and is higher than ecosystem level (Forman 1995; Jasinski 2002).

Similar hierarchies of socio-economic character can be identified. If the Swedish national forest policy is taken as an example, on can say that the state represents the highest level, legislation being passed there and the National Board of Forestry being responsible for implementing the policy. A region would be at a subordinate level, the national policy having regulations adapted to regional conditions and the Regional Boards of

Forestry being responsible for matters of implementation. The subsequent levels are the estate or forest holding level and the stand level. There are sections of the current Forestry Act (Anon. 1993a) such as Section 11, which concerns age-class distribution that pertain to management at the estate level, but most sections concern management at the stand level. This hierarchy can be seen as representing a top-down perspective on forest policy, legislation with its regional adaptations providing the setting for forest owners to make decisions concerning their estates, this together with conditions at the estate level providing the setting for decisions on stand management. This hierarchy is somewhat ambiguous since many of the levels have an overlapping distribution in space (Fig. 1), and since in industrial forestry the estate/forest holding level can concern, in an individual case, parts of several different regions.

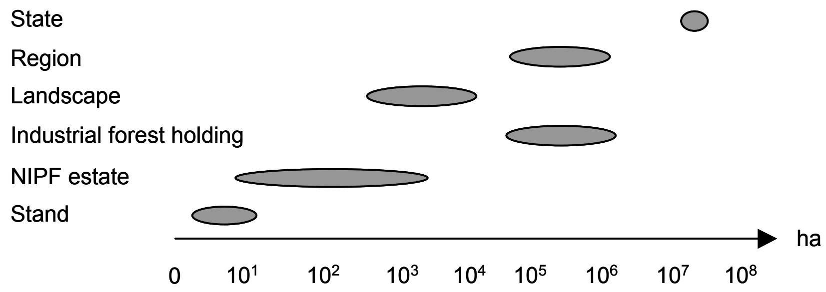

Figure 1. Spatial distribution of different levels important for forestry planning in Sweden.

The region to stand levels can also be identified from the perspective of forest recreation. At a regional level the population density affects the recreational use of forests, whereas at a stand level the properties of a stand affect its recreational value (Hultman 1983; Ribe 1989). However, the recreational value of a forest area is based not only on the sum of individual stands it contains, since the variation in forest types involved is also important (Axelsson-Lindgren & Sorte 1987). Hence, a level higher than the stand is needed in planning for the recreational use of forest.

Although the levels considered most in the planning of forest production in Sweden today are the stand, the estate or forest holding and the landscape level, there are differences between non-industrial and industrial forestry. For a small forest estate, the most important levels are those affected by the decisions the owner takes, that is the estate and stand level. However, higher levels than these influence the decisions made, for example when decisions are taken concerning the preservation of biodiversity, information is needed regarding higher levels such as those of the landscape and the region (Ask 2002; Jasinski 2002). The landscape can also be an arena for cooperation between owners, for example in coordination of the management efforts to promote biodiversity (Ask & Fredman 2002; Ask & Carlsson 2000) or to assist each other in forest operations.

In industrial forestry the levels from forest holding to stand are of importance, the fact that a holding can cover up to millions of hectares leads to its often being sub-divided into one or more levels that are the subject of planning. As opposed to conditions in non-industrial private forestry, the landscape level is a subject of planning in industrial forestry as regards planning for biodiversity. Forest owners with a holding greater than 5000 ha who have adopted the FSC certification standard (FSC 2000), are required to implement what in the standard is called "landscape ecology planning". On smaller estates or holdings the standard simply states that the forest management practised should be based on a of landscape ecological perspective, this perspective also being stressed in policy documents from the National Board of Forestry (Skogsstyrelsen 1998). In the 1990s several conceptual models for the landscape planning of multiple-use oriented forest management were developed in Sweden (Fries et al. 1998). In most of these models, the focus is on wood production and biodiversity, such as in the ASIO-model, which is based on the natural fire dynamics present in boreal regions of Sweden (Angelstam & Rosenberg 1993; Angelstam 1997).

Most activities in forestry concern the management of trees, which is a level that in most cases is not a subject of planning, since treatments are planned and are applied at a stand level. The stand is the traditional unit for describing the properties of a forest and they are delineated with the aim of forming as homogeneous units as possible. Since forestry has turned to a broader spectrum of forest values, it has been questioned whether stands are the proper level for describing forests, as more variables are needed to describe important forest properties and in many cases these show variation on a scale smaller than the stand. An alternative suggested for describing forests is to use a continuous description of a forest based on pixels (e.g. Holmgren & Thuresson 1997; Dahlin et. al. 1997).

There of course are other, levels of importance than those discussed above which could be identified by using some other perspective as a point of departure. For example, in considering an investment to increase the production capacity in a wood-consuming mill of some sort, there is a need for information regarding future supply of wood at some regional level.

Spatial variation in conditions for forest production

The conditions for forest production are affected by a large number of abiotic, biotic and socio-economic factors that show variation in space. As Cliff (1962) and others (e.g. Anon. 1992) have noted, the specific conditions in an area need to be considered in achieving a balance of different uses in multiple-use forestry. The variation at different levels for a number of important factors are given here as examples, some of which are further examined in this thesis.

Abiotic factors, such as bedrock, soils, temperature, solar radiation and the availability of nutrients and of water, form the basis for the biological processes involved. From a wood production perspective these factors can be expressed in terms of site productivity. In Sweden site productivity ranges from 1-14 m^3 ha^{-1} and yr^{-1} (Skogsstyrelsen 2002). Although for most regions in southern Sweden the range is similar, there are differences in distribution of site productivity classes, the range of these decreasing to the north (Fig. 2 and 3b). The mean site productivity in Sweden is 5.3 m^3 ha^{-1} and yr^{-1}, yet there is large regional variation, involving a decreasing gradient from south to north (Fig 3a). The variation in site productivity can be of the same range at the landscape level as at the regional level, the first of these exemplified by the forest landscapes of Asa and Stenbrohult, both situated in region G (Fig. 4). Each of the two landscapes covers 3000-4000 ha of forest land and has a mean site productivity of 8.5 m^3 ha^{-1} and yr^{-1}, its being 8.9 m^3 ha^{-1} and yr^{-1} for region G as a whole. The main factor that limits forest growth in Sweden is that of nutrient availability, although in the southern, and particularly the southeastern, part of Sweden also the water availability is a limiting factor of importance (Bergh et al. 1999). Nutrient availability can be eliminated as a limiting factor by the use of nutrient optimisation, that is supplying trees repeatedly with nutrient during stand rotation, already on an early stage, using a balanced mixture of nutrients, the mixture depending on foliar analyses of the nutrient status of the trees. On the basis of fertilisation experiments, Bergh & Linder (2000) have derived a map showing that stemwood production can be increased by a factor of 2-4 if management according to the principles of nutrient optimisation is employed (Fig 3c).

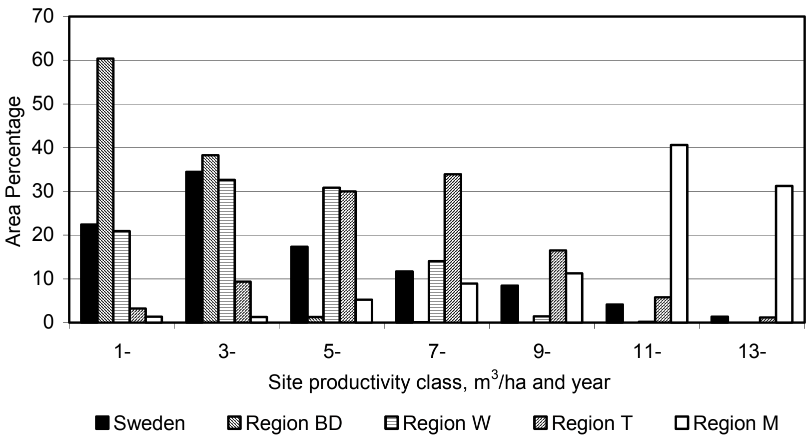

Figure 2. Distribution of site productivity classes in Sweden and in region BD, W, T and M (Skogsstyrelsen 2002). For map representing regions and regional codes see figure 3b.

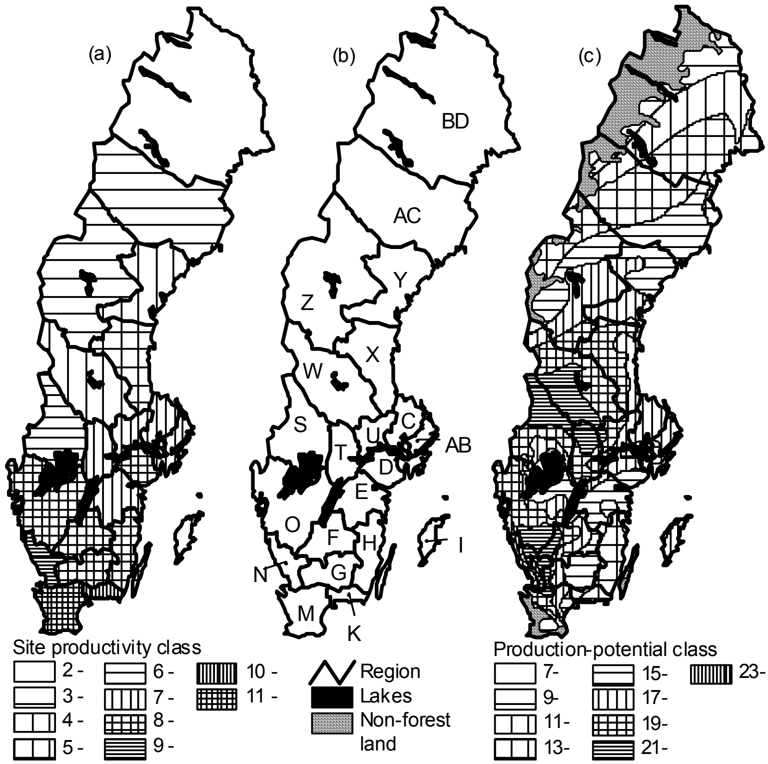

Figure 3. a) Regional mean site productivity (m^3 ha^{-1} and yr^{-1}) in Sweden (Skogsstyrelsen 2002), b) regions with regional codes and c) potential stemwood production by use of nutrient optimisation, a map derived by Bergh and Linder 2000.

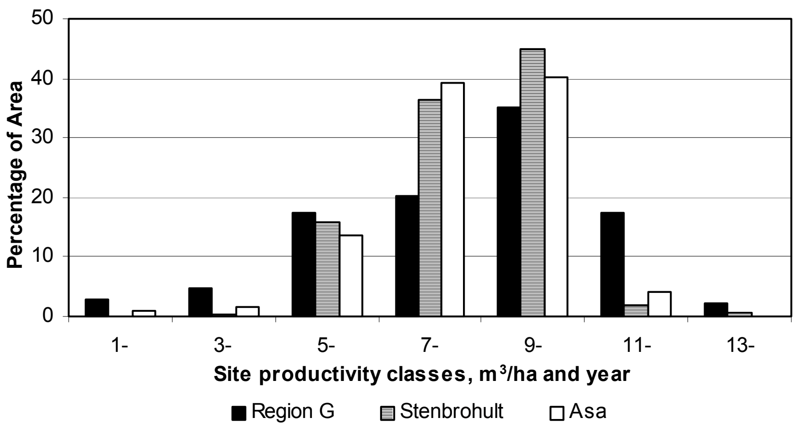

Figure 4. Area distribution of site productivity classes in Region G and in the landscapes of Asa and Stenbrohult (for map representing regions and regional codes see figure 3b).

Biotic factors that affect the conditions for forest production are numerous and involve characteristics of the different populations and communities involved. One example of a biotic factor is that of the species composition of the tree cover. In Sweden the fraction of deciduous trees ranges from 9-40% at a regional level. (Tab. 1). There is also a regional variation in the occurrence of deciduous tree species, the species that are protected specially by legislation (cf. above) mainly being found to the south of region S, W and X (Fig. 3b). The landscapes of Asa and Stenbrohult have a deciduous fraction of 5 and 20% and in region G it is 15%. Even if there is a difference in fraction of 15% between the two landscapes they both show a similar pattern of how the deciduous trees are distributed in the landscape (Fig 5). Another biotic factor that has a regional variation in both size and occurrence is that of key habitats (Tab. 1). A key habitat is defined as a forest area that is colonized by any red-listed species (i.e. an organism included in the official lists of nationally endangered species), or has abiotic and biotic conditions favoured by red-listed species (Nitare & Norden 1992; Skogstyrelsen 1995). The certification standards of FSC and PEFC (FSC 2000; PEFC 2002) require a forest owner to voluntarily protect key habitats.

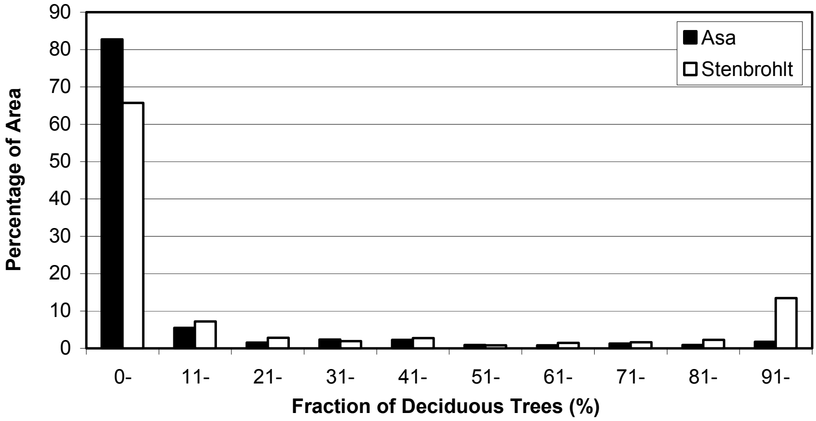

Figure 5. Area distribution of deciduous trees in the landscapes of Asa and Stenbrohult, the fractions being specified in classes.

A socio-economic factor of importance for forest production in Sweden is the structure of forest ownership, which for example has affected the way in which the Forestry Act is formulated (cf. above; Anon. 1992). In Sweden there are about 250 000 non-industrial private forest (NIPF) estates or holdings and about 350 000 NIPF owners, who represent some 4% of the total population of the country (Skogstyrelsen 2002). Although a variety of reasons have been given for the NIPF owners owning forest land, certain common features can be identified (Törnqvist 1995). One common feature is the comprehensive objective of preserving the estate (Lönnstedt & Törnqvist 1990). The interest in preserving the estate is connected with the owner's social relationship to the estate, the owner's view concerning the future of the estate during his/her ownership, and the transfer of the estate to the next generation. At a national level, NIPF owners own 51% of forest the land (Skogsstyrelsen 2002). In southern Sweden NIPF ownership is dominant, whereas in the north industrial forest companies and the state are dominant (Tab. 1). The size of NIPF estates also increases from south to north (Tab 1). Asa and Stenbrohult are good examples of the variation in ownership structure, both being of a similar size, but NIPF ownership being dominant in Stenbrohult, which is divided up into 90 estates (Fig. 6), whereas Asa is a single estate owned by the state. Population density is another important socio-economic factor, since it is related, for example, to the use of forests for recreational purposes (Tab. 1). Hörnsten (2000) studied how the distance to the forest affects the frequency of forest visits, concluding that distance can be seen as a barrier, visiting frequency decreasing with an increase in distance. The recreational value forests and use of them are also affected by the qualities different types of forests are experienced as having. For example, large trees are found to be attractive, more open and moderately stocked stands tend to be preferred, whereas logging residues and other evidence of harvesting are disliked (Hultman 1983; Ribe 1989). However, there are differences between different groups of forest users in how they perceive forests, especially between foresters and the public generally (Hultman 1983). The location of sawmills and pulp industries (Fig. 7) is also a factor of importance. In most parts of Sweden, for example, the price for pulpwood is dependent on the distance to the pulp mill.

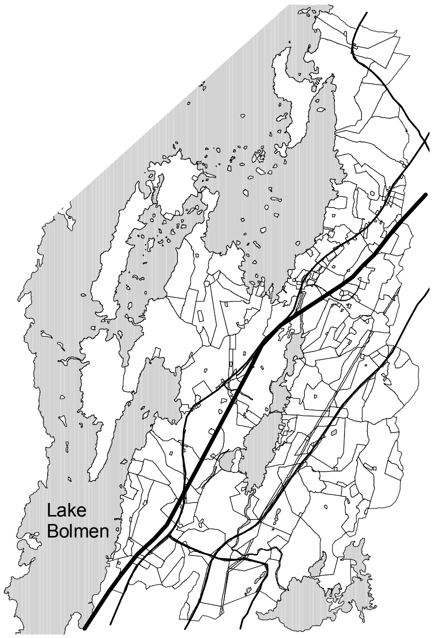

Figure 6. Spatial distribution of forest estates in the landscape of Stenbrohult.

Table 1. Regional distribution of some biotic and socio-economic factors affecting the conditions for forest production in Sweden (for map representing regions and regional codes see figure 3b)

Region	Fraction of deci-duous trees[1]	Mean size of key ha-bitats[1, 2]	Fraction of forest representing key habitats [1, 2]	Pop-ulation land density[3]	Fraction of NIPF ownership[1]	Fraction of NIPF estates with forest land area < 50 ha[4]
	%	ha	%	km^{-2}	%	%
BD	17.0	5.4	0.7	2.6	32.9	27.9
AC	15.2	7.7	0.8	4.6	41.8	41.6
Z	12.7	4.4	0.9	2.6	44.0	32.6
Y	15.1	3.4	0.5	11.3	44.4	39.7
X	11.8	3.1	0.7	15.3	43.9	35.9
W	9.0	5.8	1.7	9.8	45.3	50.2
S	13.1	2.6	1.5	15.6	61.7	55.3
T	14.7	2.9	1.4	32.1	46.5	67.5
U	14.0	2.5	1.1	40.9	53.1	54.2
C	17.0	3.9	2.3	42.4	39.2	67.3
AB	23.2	4.4	6.7	283.3	61.6	61.7
D	19.5	2.4	2.2	42.4	67.0	62.6
E	14.8	2.2	2.2	39.0	60.0	55.9
O	19.5	2.2	0.9	62.7	78.7	75.9
F	12.7	1.5	0.7	31.3	80.6	55.6
G	14.8	2.2	0.9	20.9	79.4	54.8
H	17.2	2.8	1.4	21.0	74.5	46.5
I	12.3	2.1	3.8	18.3	82.7	67.2
N	19.4	2.6	1.6	50.7	83.7	72.1
K	26.2	2.3	1.3	51.0	86.2	59.7
M	39.7	1.5	0.9	103.1	82.2	76.9
Total	15.5	3.1	1.2	21.7	51.0	58.1

[1] Skogsstyrelsen, 2002.
[2] Only non-industrial forest land is included.
[3] SCB, 2002.
[4] Jorbruksverket, 2001.

The examples just given of spatial variation in the conditions for forest production at different levels of scale stress the importance of including several different levels of scale in the planning of multiple-use forestry.

Temporal aspects on forest production

A feature of the forestry sector that makes it different from most other sectors of society is the long-term perspective used in planning. This is because of the long rotation periods employed, in Sweden periods of 60-150 years, which implies management activities to have a long-term impact on future forest conditions. The long-term perspective is also a central part of the concept of sustained yield management, which has prevailed in Swedish forestry and elsewhere during the past hundred years. Implicit in the long-term perspective and the concept of sustained yield is a concern for future generations. In the USA this concern was expressed in the Multiple Use Sustained Yield Act's (MUSY-Act) definition of multiple-use forestry, and is further emphasized in declarations and definitions of sustainable forestry (Anon. 1987; 1993; 1998). The concern both about the future and about the long-term effects of forest management activities will always be troublesome, in the sense that future options for forest use will always be a function of the forest management carried out in the distant past, which in turn is linked with the forest values of the past, history telling us that forest values change (cf. above). Gustavsson (1979) argues that, to deal with this problem adequately, management needs to facilitate changes in the uses that dominate. The problem is also recognized in the MUSY-Act's definition of multiple-use, which states that management needs to "provide latitude for periodic adjustments in the use to conform to changing needs and conditions" (Gregory 1987). The increasing concern for biodiversity and the associated increase in planning efforts for the preservation of biodiversity have led to the temporal aspects of forest production becoming increasingly important, since the temporal changes in the occurrence of different types of habitats needs to be considered in the planning process.

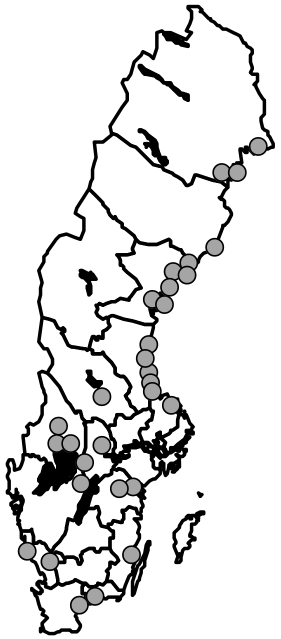

Figure 7. Location of pulp mills with a production capacity over 100 000 tonnes per year in Sweden (Skogsstyrelsen 2002).

Not only forest values have changed, but also the conditions for forest production have changed and will probably continue doing so. Such socio-economic factors as the structure of the pulp and sawmill industries have changed, and changes in the of sawmill industry still continuing, the number of large mills becoming greater, these in turn being owned by a smaller and smaller number of sawmill companies (Lönner & Libäck 1990; Staland, Navren & Nylinder 2002). There have also been changes in the ownership structure of non-industrial private forest estates, a decreasing number of estates being involved in the agriculture sector and there being an increasing number of forest owners who get most of their incomes from other sectors of society (Törnqvist 1995).

Biotic factors have in some cases changed dramatically since the industrial revolution of the 19th Century. Logging activities have altered the forest structure by replacing the heterogeneous natural forests once found by homogeneous forest stands. The landscape mosaic created by variations in topography, in soil types, in soil moisture and in natural disturbances has been transformed into a mosaic in which stands are more uniform in size and boundaries are more distinct (Forman 19995; Axelsson 2001). The transformation of forests in this way has resulted in a more than 35% increase in the standing volume of forest since the 1950s (Skogstyrelsen 2001). Although the species composition during this period has in general been stable, structural changes in the forests has led to most of the deciduous trees today being found in younger stands. A change in predominant tree species not readily discerned in the general picture of forest conditions is that of the beech forests of southern Sweden. Before the special act on the preservation of beech forests (Anon. 1974) was passed, the area of beech forests had been reduced by 15-20% in the three most southern regions of Sweden. The fraction of the total standing volume that was beech was reduced during this period by 5% (Anon. 1971). It is estimated that if the management practises of the 1990s are continued, the total standing volume of all tree species will increase during the next hundred years by 50% and the deciduous fraction by 10% (Skogsstyrelsen 1999).

Abiotic factors have also undergone change, for example, site productivity has increased due to the atmospheric deposition of nitrogen (Gustavsson et al. 2002). Abiotic factors are also expected to change in the future, the climate, for example, changing through an increase in both temperature and precipitation, which will clearly affect the conditions for forest production (IPCC 2001; Rummukainen 2001). It has also been questioned whether the high level of production of coniferous tree species is sustainable, since there is a risk of soil acidification and nutrient imbalance (Sverdrup & Rosen 1998).

Objective

The objective of the thesis is to analyse various aspects of the spatial allocation of wood production and production of nature conservation values, within the context of multiple-use forestry, to provide support for decision at the policy and management level. The analyses concerns the following:

- two factors of importance for spatial allocation, namely the distribution of habitats and the regional distribution of land suitable for intensive management by use of nutrient optimisation
- temporal aspects of the spatial production allocation of deciduous and coniferous trees, partly in the light of the inherent uncertainties regarding future forest use.

Results

Spatial aspects on forest production

Implications for non-industrial private forestry by the employment of a standardized policy on habitat protection

In the process of developing a certification standard for Swedish forestry it was suggested that a number of types of habitats should be protected. The employment of such a standardized policy for habitat protection has socio-economic implications, since forest estates are likely to differ in how they are affected, due to variation between estates in the occurrence of different habitats. In paper I the spatial patterns of five types of habitats – key habitats, riparian zones, young broad-leaved forest, old broad-leaved forest and old forest – are analysed by use of empirical data from four landscapes dominated by non-industrial private forestry. A conceptual model for understanding these patterns is also presented. The model is derived from the results of Monte Carlo simulations. In the paper it is argued that the variation between estates in habitat occurrence, expressed as the standard deviation of the area fraction between estates, is dependent upon the average size of habitat type, the abundance of the habitat type in the landscape and the average shape of the habitat type. This line of argument is based on results of the Monte Carlo simulations, which show that (i) the larger in size and the more compact in shape a habitat type is, the greater the variation in occurrence is between estates and (ii) the less abundant a habitat type is, the less the variation is in its occurrence.

Analysis of patterns found in the four landscapes, which consists of 194 forest estates and cover an area of 11,700 ha, showed there to be various differences in size and shape between the habitat types. For example, old forest was significantly larger in size than the other habitat types, and key habitats and old forest were significantly more compact in shape than the other habitat types. These differences in shape and size resulted in differences in the variation of habitat occurrence, which accorded with the pattern shown by the Monte Carlo simulations. It could thus be concluded that the variation in habitat occurrence found depends on the habitat type chosen for protection. These results suggest that the habitat type chosen for protection not only is of importance for nature conservation, but also has socio-economic implications.

Regional potentials to increase biomass production by intensive management using fertilizers

The increasing concern for the preservation of biodiversity in Sweden can be expected to lead to a long-term reduction in potential gross fellings, at the same time as the demand for renewable energy such as forest fuels can be expected to increase, due to political decisions regarding reduction in the use of nuclear energy and fossil fuels (Anon. 1997a, b, c). If forests are to be able to meet the increasing interest in nature conservation and the increasing demands for forest fuels that can be expected, and at the same time provide raw materials for the forest industries, wood production needs to become more efficient, that is the per hectare yield needs to be increased. A suggested solution for solving this conflict is the implementation of specialized production in which some areas are managed for biodiversity purposes, others are managed intensively for wood production purposes and still others are managed by use of joint production for several purposes (cf. Vincent & Binkley 1993; McNeely 1994).

In paper II the regional potentials for increasing biomass production in Sweden by use of nutrient optimisation is assessed (cf. Fig. 3a-c). The study includes an assessment of the forest land area suitable for management involving nutrient optimisation. On the basis of this assessment the potential production of biomass with and without the use of nutrient optimisation is calculated. In the calculations no considerations is given to economic, environmental and technical constraints on the harvest of biomass. The biomass production potential in terms of forest fuel and raw materials for industry is calculated for two alternative ways of utilizing the biomass from nutrient-optimised areas: (A) the harvesting of tree-sections from thinning for use as forest fuel, and the harvesting in the final felling of the stemwood for industrial purposes and of logging residues for use as forest fuel, and (B) the harvesting of stemwood for industrial purposes, both in thinning and in the final felling and of logging residues in the final felling for use as forest fuel. The harvesting of biomass at sites managed without nutrient optimisation was assumed to be in accordance with alternative (B). From the assessed potential for the production of forest fuel, the level of production when economic, environmental and technical constraints have been taken into account is derived. This level of production is then compared with the present and the potential future consumption of wood fuel in district heating (Börjesson 2001).

At a national level 62% of the forest land in Sweden is suitable for nutrient optimisation, the fraction at a regional level ranging from 48 to 69%. If the requirement for an increase in production by 4 m^3/ha and year using nutrient optimisation is imposed, the fraction of suitable land drops to 56%. The regional pattern is that of the fractions being highest in central and in northern Sweden and lowest in the southeastern part of Sweden. If the requirement of 4 m^3/ha and year is imposed, the potential production of forest fuel at a national level is increased by 280% and 70% for harvest alternative A and B, respectively, as compared with management without nutrient optimisation, the potential production of industrial raw material being increased by 60 and 90%. The regional pattern of a potential increase in production accords with the pattern of suitable forest land. In comparing the present and future use of forest fuel with the potential production of it, the following restrictions were employed: (i) areas used for nutrient optimisation had to have a growth response of 4 m^3/ha and year or higher, (ii) no more than of 10% of the forest land could be used for nutrient optimisation and (iii) harvest levels on areas not managed by nutrient optimisation were to be at the same level as today. Production at a national level without use of nutrient optimisation is sufficient to cover both the present demand of forest fuel and the potential future increase in heat production (Tab. 2). To cover the increase in demand that an increase in electricity production can bring about, it is necessary to employ nutrient optimisation and to use harvest alternative A (Tab. 2). At a regional level, the correspondence between supply and demand is rather low, there being an excess of supply in the northern regions, whereas in the densely populated regions AB and M the situation is the opposite.

In paper II it is concluded that a significant potential exists for increasing biomass production through use of nutrient optimisation. The increase in production by use of nutrient optimisation can be achieved with only a low input of energy, since the ratio of output to input is about 25 to 1. The increase in production potential can be utilized to increase the production of forest fuels and/or of raw material for industry. It can be used to provide opportunities for setting aside larger amounts of forest land for other purposes without reducing the harvest levels. How much of the potential increase in production is utilised will depend on the economic viability of nutrient optimisation.

Table 2. Present use of forest fuels in district heating systems (DHS), potential increase in demand and level of production of forest fuels with and without use of nutrient optimisation, in PJ/yr. Production without use of nutrient optimisation is given for a harvest level of 75 millions m^3sk/yr. Production with use of nutrient optimisation is calculated for sites with a growth response of at least 4 m^3sk/ha and yr, and where a maximum of 10% of the forest land is fertilised. Production is given for harvest alternatives A and B (for map representing regions and regional codes see figure 3b)

Region	Production of forest fuel			Demand for forest fuel		
	Without use of nutrient optimisation	With use of nutrient optimisation on max 10% of the forest land		Present use[1]	Potential increased use for heat production in present DHS[1]	Potential increased use for electricity by use of cogeneration in DHS[1]
		Alt. A	Alt. B			
BD	12.6	24.1	17.6	1.1	0.0	1.8
AC	12.2	24.1	17.6	2.2	0.7	3.2
Z	10.4	21.6	15.8	1.8	0.0	2.2
Y	8.3	15.8	11.5	0.7	1.4	1.8
X	8.6	16.2	12.2	1.4	0.0	0.7
W	10.1	20.5	15.1	1.1	0.7	1.1
S	8.3	15.1	11.5	1.4	0.0	1.1
T	4.3	7.2	5.4	3.2	0.4	5.4
U	2.9	4.7	3.6	1.1	4.7	6.5
C	2.9	4.7	3.6	5.0	0.0	5.4
AB	2.2	3.6	2.9	9.0	16.2	32.0
D	2.5	4.0	3.2	2.5	0.7	4.3
E	4.7	7.2	5.8	7.6	0.0	7.6
F	5.8	9.0	7.2	3.2	0.7	2.2
G	5.4	8.3	6.5	1.8	0.0	1.4
H	5.8	6.8	6.1	1.4	0.4	1.1
I	0.7	1.1	0.7	0.0	0.0	0.4
O	10.4	16.6	13.0	6.1	2.5	11.5
N	2.5	4.0	3.2	0.4	0.4	0.4
K	1.8	2.2	2.2	0.4	0.0	0.0
M	4.0	5.8	4.7	5.4	8.3	13.0
Total	126.0	221.4	169.2	57.6	37.1	103.0

[1] Börjesson 2001.

Temporal aspects on spatial allocation of forest production

Increasing the fraction of deciduous trees

In recent decades there has been an increasing interest in deciduous tree species on the part of forest owners and of various other groups in society. A wide range of forest values are involved in this. Today the majority of red–listed forest species belonging to different groups of organism are associated with deciduous trees (Berg et al. 1994). The recreational value of forests of deciduous trees is usually higher than that of dense spruce forests. The economic value of deciduous forest has increased during the last 30 years, timber prices for hardwoods having increased in real terms, whereas softwood timber prices have remained unchanged or have decreased (Lohmander 1992; Spiecker 2000). There can also be economic risks in relying on only one product such as spruce wood in a changing timber market (Lohmander 1992). Another value of deciduous trees is that they are more resistant than spruce to calamities such as windthrow (Persson 1975; Peltola et al. 2000; Jørgensen & Nielsen 2001) and root rot (Bendz-Hellgren et al. 1998; Korhonen & Stenlid 1998). Deciduous trees affect the soil differently than coniferous tree do and it has been questioned whether a high level of production of spruce is sustainable (Sverdrup & Rosen 1998).

Several policy documents on forestry published by the National Board of Forestry recognize the need for increasing the deciduous fraction in Swedish forests generally (Skogsstyrelsen 1994, 1998). The Swedish Environmental Protection Agency also recommends that there be a higher fraction of deciduous trees, seeing this as a means of preserving biodiversity (cf. Anon. 1999).

In paper III the implications of ten different strategies for increasing the fraction of deciduous trees in forests are studied, the strategies being applied to the landscapes of Asa and Stenbrohult. Two main landscape strategies – dispersed and concentrated – were involved. In the dispersed strategy the increase is accomplished through joint production, the deciduous fraction being increased in every stand. In contrast, in the concentrated strategy the increase is accomplished through specialized production, some mixed or coniferous stands being converted into pure deciduous stands. The stands that were to be converted were also concentrated around the five spots in each landscape with the highest concentration of deciduous trees. Each of the two landscapes strategies was combined with five retention tree strategies aimed at setting aside deciduous trees. Three levels of retention trees were employed, 0, 5 or 15 trees per hectare being set aside in the landscape in question. At levels of 5 and 15 trees per hectare, trees were retained either in every stand or only in stands with deciduous trees.

Development of the forest over a period of 155 years was simulated by use of a projection model, one described by Agestam et al. (in press). Each of the ten strategies was tested against two goal levels, those of 25% and 50% deciduous trees, for standing volume in the landscape. The management used in the simulations accorded with the present management practise, involving neither premature final felling for the coniferous stands nor extended rotation periods for the deciduous stands. For the deciduous trees only natural regeneration was used and in all the strategies at poor sites, birch was given the highest priority so as to increase the deciduous fraction there, whereas at fertile sites oak was given the highest priority.

The results of the simulations show it to take a long time (85 to 120 years) to reach either of the two goal levels by use of any of the strategies (Fig. 8), although with use the concentrated strategy the times involved were somewhat shorter. Since no adjustment of the rotation periods was made the increase was gradual, its taking about one rotation period for the goal levels to reached, although it would be possible to obtain a high fraction of deciduous trees in a shorter period of time, for example by regenerating all stands that are up for final felling during the first 20 years with deciduous trees only. Management of this sort would produce an uneven age-class distribution of the deciduous trees, however, which would have long-term implications for management if a stable level were aimed at. The fact that regardless of strategy a long-term perspective is needed, demonstrates how slow a system a forest represents. By setting aside retention trees in stands of deciduous trees the goal levels could be reached somewhat earlier. The use of retention trees, which can be regarded as an extension of the rotation period for such trees, could be an effective way of increasing the fraction of deciduous trees. Since the retention trees are not harvested, the deciduous retention trees can be of considerable importance for biodiversity, although they also reduce the per-hectare growth and thus the volume that can be harvested.

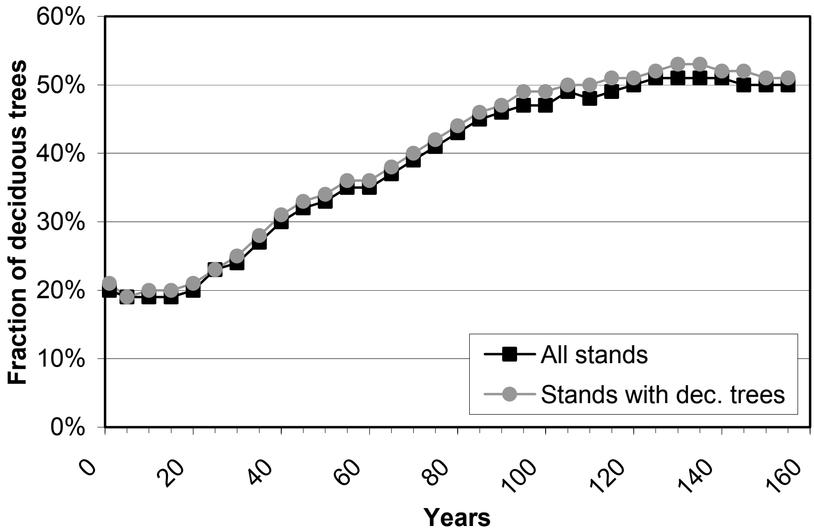

Figure 8. An example of the simulated increase in fraction of deciduous trees in Stenbrohult by use of the dispersed strategy and 15 retention trees per hectare in all stands or only in stands with deciduous trees. The goal here was a stable fraction over 50%.

The results of the simulations show as well that drastic management measures are needed to achieve a the high fraction of deciduous trees, especially in Asa, where the initial fraction of deciduous trees is only 5%. If the concentrated strategy is employed, as much as 77% of the forest land needs to be converted in order for the 50% goal level to be reached, and for the dispersed strategy the fraction of deciduous trees in each stand needs to be increased by 55 percentage points. The corresponding figures for Stenbrohult, where the initial fraction is 20%, are 58% and 35 percentage points, respectively. Drastic measures are needed since the growth rates of the deciduous tree species are lower and the deciduous stands are managed at lower densities than coniferous or mixed stands, so that a larger area is needed to grow a given volume. The increase in the deciduous fraction results in the standing volume in the landscapes being lower, and the mean annual increment likewise being lower.

In employing the concentrated strategies in Asa, the management measures needed to reach the goal levels were affected not only by the initial deciduous fraction being low, but also by the initial age-class distribution being uneven, over 70% of the area being under 40 years of age. This is due to the deciduous fraction not being allowed to drop below the goal level after it had been reached, so stronger measures thus needing to be taken to keep the deciduous fraction above this level (Fig. 9). The stronger measures taken due to the uneven age class distribution also reduced the time needed to achieve the level aimed at.

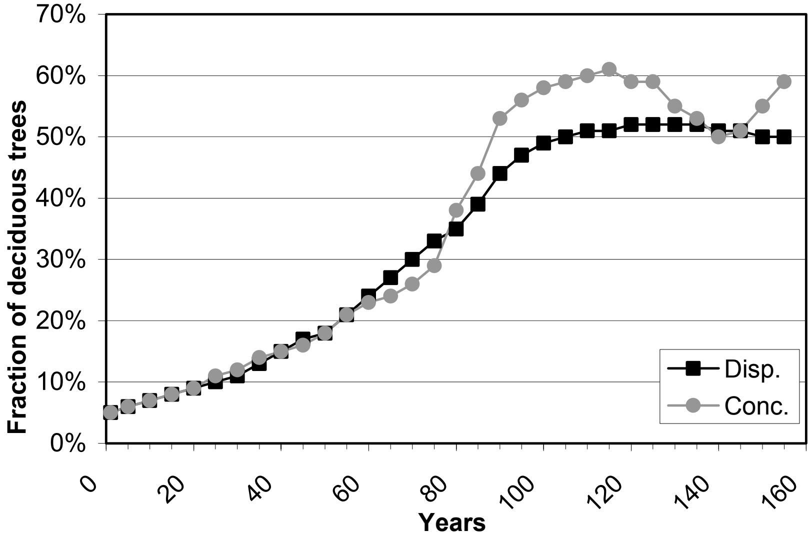

Figure 9. An example of how the simulated increase in deciduous trees in Asa was affected by the uneven age class distribution. Strategies presented are concentrated and dispersed with no retention trees. The goal here is a stable fraction over 50%.

Implications of joint or specialized production for future changes in forest use

The long debated issue in multiple-use forestry of how to spatially combine the production of different outputs (e.g. Gregory 1955; Vincent & Binkley 1993) is analysed and discussed in paper IV. The outputs considered in the analysis are old deciduous trees for nature conservation purposes (D) and timber harvested (T). The paper presents a method making it possible to analyse production allocation problems of this type. The method is applied to the forest landscapes of Asa and Stenbrohult for estimating the production possibilities for D and for T with respect in particular to possibilities for future changes in forest use.

The analysis is based on the assumption that production of D and of T could be carried out either with a strategy of using a single-stand management objective (SO) for all the stands in a landscape or by using a strategy of differentiated stand management objectives (DO), different objectives being set for different stands in a landscape. Five management objectives (i) were used in the analysis, where $i = \{0, 10, 20, 30, 100\}$. Since the single-objective strategy can involve the use of any of the five management objectives (SO_i), SO_{10} means all stands in a landscape being managed to gradually reach the targeted levels of 10 deciduous retention trees and a 10% fraction of deciduous trees, by the time the next rotation period begins. The DO strategy, in turn, means some one of the five different management objectives (i) being selected for each stand. The number of possible combinations of stand management objectives is large, its depending upon the number of stands present.

Two phases were used for analysing the possibilities to change forest use in the future. The phases extend over 100 years, the first starting at year 0 and the second at year 50, and the production possibilities for D and for T are estimated for each phase. For the second phase two different initial forest states are employed. The first is the state that results after the SO strategy using management objective i = 10 (SO_{10}) has been employed for 50 years. The second is the state that results after a corresponding DO strategy has been employed for 50 years. For each stand, the management objective to be employed in the corresponding DO strategy is selected so as to yield the highest utility for each stand, given the restriction that D and T should be produced at the same ratio at landscape level as for SO_{10}.

The results reported in paper IV show that in the first phase the production possibilities for old deciduous trees and for harvested timber are greater in both landscapes if the DO strategies rather than the SO strategies are employed. The management objectives selected for the first phase, using the DO strategy that corresponds to the SO_{10} strategy, is objective $i = 0$ for 80-90% of the area in both landscapes and objective $i = 100$ for 5-7% of the area there.

Results for the second phase are similar to those for the first in that the production possibilities are greater for the DO strategies than for SO strategies, regardless the state of forest in year 50. However, the production possibilities differ as a function of the state of the forest in year 50. For both landscapes, the state of the forest after the SO strategy has been employed for 50 years, is linked with the possibility of producing a greater amount of old deciduous trees during the subsequent 100 years than would have been the case for the state of the forest after use of the DO strategy. The future harvesting potential is somewhat higher for the state of the forest after use of the DO strategy than for that after use of the SO strategy. Thus, the two different states after the use of the SO and the DO strategy for 50 years, feature different production possibilities.

The results for the second phase show that use of the DO strategy could imply less latitude for changes in future forest use. This is not surprising, since most of the stands are managed for the specialized production of timber and some of them for the specialized production of deciduous trees. In the latter stands, the production of deciduous trees cannot be increased, whereas in the former stands it would take a long period of time before the stands could be converted to the production of deciduous trees. One reason the production possibilities being restricted when a DO strategy is employed, could be the way in which the production of D and T is balanced. In considering the wide range of possible combinations of D and T, it can be noted that the one chosen places particular weight on timber production, which involves a large area being allocated to the production of T alone. No conclusions regarding differentiation generally should be drawn on the basis of this particular case, however, since the result depends to a large extent on the allocation of stands to specialized production and not on differentiation per se.

Discussion

The present Swedish forest policy contains clear goals concerning both the preservation of biodiversity and wood production. This policy also expresses to some extent how forest production should be allocated spatially in order for the goals to be reached. In the certification standards this is also expressed in a similar way. The national forest policy and the certification standards do not state what relative weights should be assigned to the production of nature conservation values and of wood. Instead they state the minimum requirements for the production of nature conservation values. The minimum requirements contained in the national policy are stated in section 30 of the Forestry Act, which in short calls for due considerations being given to biodiversity on all forest lands. The policy also takes account of the forest owners needing to voluntarily set aside certain areas of value for nature conservation purposes. In the certification standards, voluntary protection by forest owners are required, the minimum requirement being that of protection of all key habitats or at least 5% of the forest lands at either the estate or the landscape level. If one should describe the spatial allocation of forest production as expressed in both the policy and the standards in terms of the utilization of wood-producing capacity, it could be described as involving specialized production of nature conservation values on a relatively small part of the forest land, that is a low utilization of wood-producing capacity, and joint production of both nature conservation values and wood on the major part of the land, there being some variation in the weights placed on the two products, that is utilization of wood-producing capacity to a rather high degree (Fig 10a). Thus, the policy and the standards call for a differentiation or a zoning of management at both the estate and at the landscape level. There of course are other, alternative ways of differentiating management than the one incorporated into the policy and the certification standards. Before forest policy was changed in 1993, two other alternatives for the spatial allocation of production were discussed but were finally rejected. One alternative was that of the specialized production of nature conservation values and of wood (Fig. 10b), the other being the differentiation of management as a function of site productivity and of distance to industry and to markets.

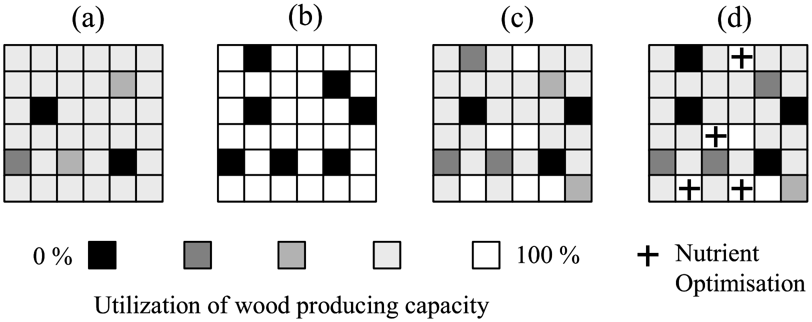

Figure 10. The differentiation of forest production, the production of nature conservation values and of wood being expressed in terms of utilization of the wood producing capacity: (a) differentiation as expressed in terms of the present national forest policy, (b) an alternative manner of differentiation considered before the present policy was adopted, (c and d) two alternatives for increase an in the production of biodiversity wood production being sustained by the use of specialized production of wood.

The results of paper I indicate there to be variation between non-industrial private forest estates in the occurrence of key habitats. This implies that, if the rules of the certification standards regarding the protection of key habitats are employed, some estates are affected to a greater extent than others. The variation in extent to which estates are affected is balanced to a certain extent, however, by the rule in the standards which states that at least 5% of the forest land at the estate or the landscape level should be protected, regardless of whether it represents a key habitat or not. In paper I its is concluded that the variation between estates in the occurrence of key habitats is dependent on the size the of key habitats, larger habitats yielding greater variation. In looking at mean regional size of key habitats as presented in table 1, it can be seen that the largest habitats are found in the most northern regions. This would imply that the variation between estates in the occurrence of key habitats is greater in northern than in southern Sweden. However, since the mean forest estate size is larger and overall occurrence of key habitats is lower and both these factors lead to a reduction in variation, it cannot be concluded that the variation between estates is greater in the northern than in the southern Sweden.

One effect of the occurrence of key habitats being high would be a decrease in the possibilities for wood production. If wood production were to remain at the same level, the per-hectare yield would need to increase.

This could be achieved by use of improved management practises, so that wood-producing capacity, i.e. site productivity, is better utilized. Today, the mean annual increment of wood in Sweden is 79% (Skogsstyreslen 2002) of what the site productivity indicates. There is also the possibility of improving per-hectare yield by use of nutrient optimisation, as discussed in paper II. However, the results show there to be a regional variation in the possibilities of increasing wood production by nutrient optimisation, the potential for increasing production being low in the southeastern part of Sweden and high in the central and northern parts of the country.

One can ask, since there is a spatial variation in the conditions for forest production, how the production should be allocated spatially at estate or landscape level so as to achieve the goals of preserving biodiversity and sustaining valuable yield. In a given landscape or at a given estate in which the total area high in nature conservation values is large, a differentiation of management in accordance with the Swedish forest policy as presented in figure 10a would result in not all valuable areas being protected. If instead the total area of this sort were small, considerable resources would be invested in the protection of areas low in value. In the former case, in which a large fraction of the forest land is to be protected, zoning in accordance with figure 10a might be an inefficient use of the forest resources (cf. Ask & Fredman 2002). In order to facilitate the protection of a large portion of the forest land, the specialized production of wood could serve to maintain a high level of wood production. A differentiation of management so that it includes the specialized production of wood could be accomplished in many different ways. An example is one of the two rejected alternatives discussed above and presented in figure 10b. Another alternative would be one similar to the present policy (Fig. 10a) but involving in increase in the areas protected and to a certain extent the use of specialized production of wood (Fig 10c). If nutrient optimisation were employed in areas in which specialized production of wood took place, this could facilitate the allocation of larger amount of forest land to the production of nature conservation values (Fig. 10d; cf. Vincent & Binkley 1993, McNeely 1994).

The results presented in paper IV show that a differentiation of management in accordance with figure 10b implies the future possibilities to change forest use to be reduced as compared to a differentiation which includes areas of joint production (cf. Fig. 10a, c, d). The reason for joint production providing greater possibilities in this respect is that it results in a condition in which the balance between the two types of uses could be changed more or less immediately in all the stands, whereas specialized production results in conditions in which stands can only change in one direction and the time frame for change is long, such as when a young coniferous stand is to be converted to an old deciduous stand. It is not likely, however, that the spatial distribution of deciduous trees is the only factor that affects the possibilities for change. Another factor is the way forest uses are balanced. If one use of forests is strongly emphasized, then joint production is close to specialized production Thus, even if immediate change in use of the forest is possible, a major change would take a long time under such conditions. Accordingly, the way forest uses are combined spatially and how they are balanced affects the possibilities for changes in forest use. However, the weight that should be placed on each use in multiple-use forestry is determined mainly by the values associated with the different uses, although in the planning of multiple-use forestry due consideration should be given to possibilities for future changes in forest use. In connection with this, a number of questions concerning the possibilities for change need to be addressed, such as on what spatial scale the latitude for change should be provided, within what time frame changes should be achieved, and to which extent changes in forest use should be possible.

In paper III the two basic approaches for the spatial allocation of forest production, that of joint production and that of specialized production at stand level, were used to increase the fraction of deciduous trees in a landscape. The results reported show there to be no great differences in the time it would take to reach the goals stated in terms of fraction of deciduous trees desired at the landscape level. However, the two management approaches differ considerably in the forest conditions they result in, where in one the deciduous trees are more concentrated to pure deciduous stands, whereas in the other they are spread throughout landscape. On basis of the results presented in paper IV, having specialized production is likely to provide fewer possibilities for change in forest use than the use of joint production.

The spatial allocation of forest production, within the context of multiple-use forestry, is a complex problem, complexity increasing as production of more services and goods being included. In the thesis problems concerning mainly the production of nature conservation values and wood have been analysed and discussed. The results of course do not provide a final solution to the problem of spatial allocation of production. However, they highlight some important factors concerning this sort of problems and indicate that assumptions about future changes in forest values are important when decisions on forest management are to be taken.

References

Agestam, E., Blennow, K., Carlsson, M., Niklasson, M., Nilsson, S. G., Nilsson, U., Sallnäs, O., Stjernquist, I. and Sverdrup, H. Assessment of productivity scenarios for the Asa Forest Research Park. In: Sverdrup, H. & Stjernquist, I. (Eds.). *Developing principals and models for sustainable forestry in Sweden.* Kluwer Academic Publishers. In press.

Angelstam, P. 1997. Landscape analysis as a tool for scientific management of biodiversity. In Hansson, L. (ed). *Boreal ecosystems and landscapes.* Ecol. Bull., 46, 140-170. Copenhagen.

Angelstam, P & Rosenberg, P. 1993. Aldrig Sällan Ibland Ofta. In: Skog & Forskning 93(1), 28-33. Danderyd. In Swedish

Anonymous 1923. Skogsvårdslag (SFS 1923:212). Stockholm. In Swedish.
Anonymous 1948. Skogsvårdslag (SFS 1948:237). Stockholm. In Swedish.
Anonymous 1971. Bokskogens bevarande – Betänkande avgivet av Skogsstyrelsen I samråd med Statens Naturvårdsverk. Stockholm. In Swedish.
Anonymous 1973. Mål och medel i skogspolitiken. SOU 1973:14. Stockholm. 354 pp. In Swedish.
Anonymous 1974. Lag om bevarande av bokskog (SFS 1974:434). Stockholm. In Swedish.
Anonymous 1984. Ädellövskogslagen (SFS 1984:119). Stockholm. In Swedish.
Anonymous 1987. Our common future. World commission on environment and development. Oxford University Press, Oxford. 400 pp.
Anonymous 1992. Skogspolitiken inför 2000-talet - Huvudbetänkande. SOU 1992:76. Allmänna förlaget. Stockholm. pp 343. In Swedish. ISSN 0375-250X
Anonymous 1993a. Lag om ändring av skogsvårdslagen (SFS 1979:429), SFS 1993:553. Stockholm. In Swedish.
Anonymous 1993b. General declaration / Ministerial conference on protection of forests in Europe. Helsinki. 28 pp.
Anonymous 1997a. Regeringens proposition 1996/97:84 – En uthållig energiförsörjning [Government Bill 1996/97:84 – A sustainable supply of energy 1996/97:84]. Stockholm. In Swedish.
Anonymous 1997b. Swedish parliamentary standing committee on industry and trade. Näringsutskottets betänkande 1996/97:NU12 – En uthållig energiförsörjning [Committee report 1996/97:NU12 – A sustainable supply of energy]. Stockholm. In Swedish
Anonymous 1997c. Riksdagens skrivelse 1996/97:272 [Written communication from the parliament 1996/97:272]. Stockholm. In Swedish.
Anonymous 1998. General declaration and resolutions adopted / Third ministerial conference on protection of forests in Europe. Lisbon. 64 pp.
Anonymous 1999. En ekologiskt hållbar skogsnäring. Steg på vägen. Rapport 4985. Naturvårdsverkets förlag, Stockholm. In Swedish.
Ask, P. & Carlsson, M. 2000. Nature conservation and timber production in areas with fragmented ownership patterns. *Forest policy and economics 1*, 209-233.
Ask, P. 2002. Biodiversity and deciduous forest in landscape management – Studies in southern Sweden. Diss. Alnarp: Sveriges lantbruksunuversitet.
Ask, P., & Fredman, P. 2002. Efficiency in forest protection in multiple landowner areas. In Ask, P. *Biodiversity and deciduous forest in landscape management – Studies in southern Sweden*. Diss. Alnarp Sveriges lantbruksuniversitet.
Axelsson, A.-L. 2001. Forest landscape change in boreal Sweden 1850-2000 – a multi-scale approach. Diss. Umeå: Sveriges lantbruksuniversitet.
Axelsson-Lindgren, C. & Sorte, G. 1987. Public response to differences between visually distinguishable forest stands in a recreation area. *Landscape and urban planning 14*, 211-217.
Behan, R.W. 1966. The myth of the omnipotent forester. *Journal of forestry 64,* 389-407.
Behan, R.W. 1990. Multiresource forest management: A paradigmatic challenge to professional forestry. *Journal of forestry 88* 12-18.
Bendz-Hellgren, M., Lipponen, K., Solheim, H. & Thomsen, I. M. 1998. The Nordic Countries. In: Woodward, S., Stenlid, J., Karjalainen, R. & Huttermann, A. (Eds.) *Heterobasidion annosum – Biology, Ecology, Impact and Control*. CAB International, Wallingford.
Berg, Å., Ehnström, B., Gustafsson, L., Hallingbäck, T., Jonsell, M., and Weslien, J. 1994. Threatened plant, animal, and fungus species in Swedish forests: distribution and habitat association. *Conservation Biology 8(3)*, 718-731.
Bergh, J., Linder, S., Lundmark, T. & Elfving, B. 1999. The effect of water and nutrient availability on productivity of Norway spruce in northern and southern Sweden. *Forest ecology and management 119*, 51-62.
Bergh J. & Linder, S. 2000. Produktionspotentialen på intensivodlade marker [Potential production on intensively managed forest land]. In: Berg, J. (Ed.) *Fiberskog – a research programme on intensive forestry*, Department for Production Ecology, Swedish University of Agricultural Sciences, Report 6, Uppsala. p 20-32. In Swedish.

Bäckström, P.-O. 2001. Några erfarenheter av svensk skogspolitik. In: *Skogspolitisk historia*, p 132-139. Skogsstyrelsen. Jönköping. In Swedish.
Börjesson, P. 2001. Framtida tillförsel och avsättning av biobränslen i Sverige – Regionala analyser [Future supply and use of biomass in Sweden – Regional analyses] Lund: Lund University, Department of technology and society, Division of Environmental and energy systems studies. Report No. 34 Swedish with abstract in English.
Clark J.S. 1991 Disturbance and population structure on the shifting mosaic landscape. *Ecology 72,* 1119-1137.
Cliff, E.P. 1962. Multiple-use management on the national forests of the United States. In: Fifth World Forestry Congress, Proc:s., Vol. I, p 173-181.
Dahlin, B. & Sallnäs, O. 1993. Harvest scheduling under adjacency constraints - a case study from the Swedish sub-alpine region. *Scandinavian Journal of Forest Research 8(2)*, 281-290.
Dahlin, B., Ekö, P.-M., Holmgren, P. Lämås, T. &Thuresson, T. 1997. Herureka – en model för skogshushållning. Uppsala: Sveriges lantruksuniversitet, Skogsvetenskapliga fakulteten. Rapport 17. 115 pp. In Swedish with summary in English.
Dana, S.T. 1943. Editorial – Multiple use, biology and economics. *Journal of forestry 41*, 625-626.
Eckerberg, K 1995. Multiple-use forestry administration, legislation and interest groups. In: Hytönen, M. (Ed.) *Multiple-use forestry in the nordic countries*. p 357-390. Vaanta: METLA, The Finnish forest research institute.
Eliasson, P. 1997. Från agrart utmarksbruk till industriellt skogsbruk – en långdragen historia. In Östlund, L. Människan och skogen. Skrifter om skogs- och lantbrukshistoria 11. Nordiska museets förlag. Stockholm, Sweden. p 46-70. In Swedish.
Eliasson, P. 2002. Skog, makt och människor – En miljöhistoria om svensk skog 1800-1875. Skogs- och lantbrukshistoriska meddelanden nr 25. Kungliga skogs- och lantbruksakademien. Stockholm. 455 pp. In Swedish.
Enander, K.-G. 2000.Skogsvårdslagen 1903 – dess förhistoria och några huvuddrag i utvecklingen. Umeå: Sveriges lantbruksuniversitet, Institutionenför skogsskötsel. Rapporter 46. 73 pp. In Swedsih with summary in English.
Enander, K.-G. 2001. Skogsbrukssätt och skogspolitik 1900-1950. Umeå: Sveriges lantbruksuniversitet, Institutionen för skogsskötsel. Rapporter 48. 125 pp. In Swedsih with summary in English.
Ekelund, H. & Hamilton, G. 2001. Skogspolitisk historia. Jönköping: Skogsstyrelsen. Rapport 2001-8A. In Swedish.
Erikers, C. 2001. A model for comparison of forest certification standards. Alnarp: Sveriges lantbruksuniversitet, Institutionen för sydsvensk skogsvetenskap. Examensarbete nr 24. 53 pp.
Fernand, J. 1995. Multiple-use forestry - a concept of communication. In: Hytönen, M. (Ed.) *Multiple-use forestry in the nordic countries*. P 67-80. Vaanta: METLA, The Finnish forest research institute.
Franklin, J.F. 1989. Towards a new forestry. *American forestry 95*, 37-44.
Fritzbøger, B. & Søndergaard, P. 1995. A short history of forest uses. In: Hytönen, M. (Ed.) *Multiple-use forestry in the nordic countries*. p 11-42. Vaanta: METLA, The Finnish forest research institute.
Forman, R.T.T. & Gordon, M. 1986. Landscape ecology. John Wiley & Sons, New York 619 pp.
Forman, R.T.T. 1995. Land mosaics – The ecology of landscapes and regions. Cambridge University Press, Cambridge. 632 pp.
Fries, C., Carlsson, M., Dahlin, B., Lämås, T. & Sallnäs, O. 1998. A review of conceptual landscape planning models for multiobjective forestry in Sweden. *Canadian journal of forest research 28*, 159-167.
FSC 2000. Svensk FSC-standard för certifiering av skogsbruk. Accessible in May 2002 at www.fsc-sverige.org. 37 pp. In Swedish.
Gregory, G.R. 1955. An economic approach to multiple use. *Forest Science 1*, 6-13.
Gregory, G.R. 1987. *Resource economics for foresters*. John Wiley & Sons, New York. 477 pp.

Grumbine, R.E. 1994. What is ecosystem management? *Conservation Biology 8*, 27-38.
Gustavsson, R. 1979. Samutnyttjande av tätortsnära jordbruksmark [Multi-purpose use of agricultural land in the urban fringe]. Alnarp: Sveriges lantbruksuniversitet, Konsulentavdelningen. Landskap 52. 161 pp. In Swedish with summary in English.
Gustavsson, K., Angelstam, P., Eriksson, H., Hultengren, S. &Weibull, S. 2002. Framtidens skog – Några tänkbara konsekvenser för miljö och produktion av 1990-talets skogsbruk. Jönköping: Skogsstyrelsen. Rapport 8G-2001. In Swedish.
Hallersig, P. 1998. Swedish forest policy in an international perspective. Skogsstyrelsen. Jönköping. 12+84 pp.
Holmgren, P. & Thuresson, T. 1997. Applying objectively estimated and spatially continuous forest parameters in tactical planning to obtain dynamic treatment units. *Forest Science 43(3)*, 1-10.
Hugosson, M. 1999. Constructing cultural patterns from actor's views on industrial forestry in Sweden – An interpretive study based on assessments of conceptualisation and definitions on organizatinal culture theory. Diss. Uppsala: Sveriges lantbruksunuversitet.
Hultman S.-G. 1983. Allmänhetens bedömning av skogsmiljöers lämplighet för friluftsliv 2 - En rikstäckande enkät. Uppsala: Sverige lantbruksuniversitet, Avdelningen för landskapsvård. Rapport 28. In Swedish with summary in English.
Hultman, S.-G. 1984. Multiple-use in Sweden: undefined – and non-existing? In: Saastamoinen, O., Hultman, S.-G., Koch, N.E. & Mattson, L. (Eds). *Multiple-use forestry in the scandinavian countries*. p 27-32. Helsinki.
Hytönen, M. 1995. History, evolution and significance of the multiple-use concept. In: Hytönen, M. (Ed.) *Multiple-use forestry in the nordic countries*. P 43-66. Vaanta: METLA, The Finnish forest research institute.
Hörnsten, L. 2000. Outdoor recreation in Swedish forests - Implications for society and forestry. Diss. Uppsala: Sveriges lantbruksuniversitet.
IPCC 2001. Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change (IPCC). Cambridge: Cambridge University Press.
Jasinski 2002. Ecological and landscape considerations in forest management. Diss. Uppsala: Sveriges lantbruksuniversitet.
Jorbruksverket, 2001. Rapporter från lantbrukets företagsregister 2000 – Jordbruksföretag, företagare, och ägoslag den 1 augusti 2000. Jönköping: Jordbruksverket. Statistiska meddelanden, JO 34 SM 0101. In Swedish.
Jørgensen, B. B. & Nielsen, C. N. 2001. Træaarters stormfasthed. Skoven særnummer februar 2001. In Danish.
Kennedy, J.J. 1985. Conceiving forest management as providing current and future social value. *Forest ecology and management 13*,121-132.
King, K.F.S. 1980. Multipe-use research. In: Research on multiple use of forest resouces. IUFRO/MAB Conference, Flagstaff, Arizona. USDA, Forest Service General Technical Report WO-25, p 3-9.
Koch, N.E. & Kennedy, J.J. 1991. Multiple-use forestry for social values. *Ambio 20*, 330-333.
Koch, N.E. & Kristiansen, L. 1991. Flersidigt skovbruk: et idekatalog. (Multiple-use forestry: a handbook of ideas.) Miljöministeriet/Skov- og Naturstyrelsen. Hörsholm. 39 pp. In Danish.
Korhonen, K. & Stenlid, L. 1998. Boilogy of Heterobasidion annosum. In: Woodward, S., Stenlid, J., Karjalainen, R. & Huttermann, A. (Eds.) *Heterobasidion annosum – Biology, Ecology, Impact and Control*. CAB International, Wallingford.
Lohmander, P. 1992. The multi species forest stand, stochastic prices and adaptive selective thinning. *Systems analysis – Modelling – Simulation 9*, 229-250.
Lämås, T. & Fries, Emergence of a biodiversity concept in Swedish forest policy. *Water, air and soil pollution 82*, 57-66.
Lönner, G. & Libäck, K. 1990. Omvärlden och svensk skogsindustri. In: Elmberg, J., Bäcksröm, P.-O. & Lestander, T. (Eds) *Vår skog – vägvalet*. p 149-165. Stockholm: LTs Förlag. In Swedish.

Lönnstedt, L. & Törnqvist, T. 1990. Ägaren, fastigheten och omvärlden. Uppsala: Sveriges lantbruksuniversitet, Institutionen för skog-industri-marknad studier. Rapport 14. 177 pp. In Swedish with summary in English.
McArdle, R.E. 1953. Multiple use – multiple benefits. *Journal of forestry 51*, 323-325.
McArdle, R.E. 1962. The concept of multiple use of forest and associated lands- Its values and limitations. In: Fifth World Forestry Congress, Proc:s., Vol. I, p 143-145.
McNelly, J.A. 1994. Lessons from the past: forests and biodiversity. *Biodiversity and conservation 3*, 3-20.
Nitare, J. & Norden, M. 1992. Nyckelbiotoper kartläggs i nytt projekt vid skogsstyrelsen. *Svensk botanisk tidskrift 86*, 219-226. In Swedish with summary in English.
Oliver, C.D. 1992 A landscape approach . Achieving and maintaining biodiversity and economic productivity. *Journal of forestry 90(9)*, 20-25.
Pearson, G. A. 1944. Multiple use in forestry. *Journal of forestry 42*, 243-249.
PEFC 2002. Tekniskt dokument.System för certifiering av skogsbruk och virkesflöde. Accessible in September 2002 at www.pefc.se. 37 pp. In Swedish.
Peltola, H., Kellomäki, S., Hassinen, A., Granander, M. 2000. Mechanical stability of Scots pine, Norway spruce and birch: an analysis of tree-pulling experiments in Finland. *Forest Ecology and Management 135*, 143-135.
Persson P. 1975. Stormskador på skog – uppkomstbetingelser och inverkan av skogliga åtgärder [Windthrow in forests – it's causes and the effect of forestry measures]. Stockholm: Skoghögskolan, Institutionen för skogsproduktion. Rapporter och uppsatser nr 36. In Swedish with summary in English.
Roekeach, M. 1973. The nature of human values. Prentice-Hall, Englewood Cliffs, NJ. 287 pp.
Ribe, R. G. 1989. The aesthetics of forestry: What have empirical preference research taught us? *Environmental management 13(1)*, 55-74.
Rummukainen, M. 2001. Klimatförändringar i Norden: regional konkretiseringar på 50-100 års sikt. *Terra 113:3*, 153-160.
SCB, 2002. Data accessible in Sept. 2002 at www.scb.se.
Skogsstyrelsen 1994. Skogsvårdslagen: handbok [The Swedish Forestry Act]. Jönköping: Skogsstyrelsen. 66 pp. In Swedish.
Skogsstyrelsen 1995. Datainsamling vid inventering av nyckelbiotoper. Jönköping: Skogsstyrelsen. 88 pp. In Swedish.
Skogsstyrelsen 1997. Naturskydd och naturhänsyn i skogen. Jönköping: Skogsstyrelsen. Meddelande 1997:1, 82 pp. In Swedish.
Skogsstyrelsen 1998. Mål för ett uthålligt skogsbruk – natinella sektorsmål. Jönköping: Skogsstyrelsen. Stencil, 15 pp. In Swedish.
Skogsstyrelsen 1999. Skogliga konsekvensanalyser_ skogens möjligheter på 2000-talet. Jönköping: Skogsstyrelsen.. In Swedish.
Skogsstyrelsen 2001. Skogsvårdsorganisationens utvärdering av skogspolitikens effekter - SUS 2001. Jönköping: Skogsstyrelsen. Meddelande 2002-1. In Swedish.
Skogsstyrelsen 2002. Skogsstatistisk årsbok 2002 [Stastical Year Book of Forestry 2002]. Jönköping: Skogsstyrelsen. 353 pp. In Swedish with summary in English.
Schlaepfer, R. & Elliot, C. 2000. Ecological landscape considerations in forest management: The end of forestry. In: Gadow, K., Pukkala, T. & Tomé, M. (Eds.) *Sustainable forest management*. p 1-68. Dordrecht: Kluwer Academic Publishers.
Spiecker, H. 2000. The growth of Norway spruce (Picea abies [L.] Karst.) in Europe within and beyond its natural range. In: Hasenauer, H. (Ed.): Forest Ecosystem Restoration. Ecological and Economical Impacts of Restoration Processes in Secondary Coniferous Forests. Proceedings from the International Conference held in Vienna, Austria 10 – 12 April 2000. p 246 – 256. Vienna: Institute of Forest Growth Research.
Stridsberg, E. 1984. Multiple-use forestry in former days. In: Saastamoinen, O., Hultman, S.-G., Koch, N.E. & Mattson, L. (Eds). *Multiple-use forestry in the scandinavian countries*. p 27-32. Helsinki.
Sverdrup, H., & Rosén, K. 1998. Long-term base cation mass balances for Swedish forests and the concepts of sustainability. *Forest Ecology and Management 110*, 221-236.

Thomas, J.W. & Huke, S. 1996. The forest service approach to healthy forest ecosystems. *Journal of forestry 94(8)*, 14-18.
Törnqvist, T. 1995. Skogsrikets arvingar – En sociologisk studie av skogsägarskapet inom privat enskilt skogsbruk. Diss. Uppsala: Samhällsvetenskapliga forskningsinstitutet. In Swedish with summary in English.
Vincent, J:R. & Binkley, C.S. 1993. Efficient multiple-use may require land-use specialization. *Land economics 69*, 370-376.
Wood, C.A. 1994. Ecosystem management: Achieving the new land ethic. *Renewable Natural Resources Journal 12*, 6-12.
Öhman, K. 2001. Forest planning with special regard to spatial relationships. Diss. Umeå: Sveriges lantbruksuniversitet.

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