Deciduous trees in southern Sweden: Relevance, occurrence and future perspectives

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MSc thesis in forest management
30 ECTS, advanced level, SLU course code EX0630

Before the following 100 pages will deal very detailed with deciduous trees in southern Sweden, I would like to dedicate the next few lines to some important people who played substantial roles on the way filling these pages.
First and foremost Ola Sallnäs and Renats Trubins, my supervisor-team, who were very patient in answering numerous questions and e-mails, providing advice and encouragement whenever needed.
Furthermore I would like to thank Matts Lindbladh for his support regarding the "ecology questions" and his objective criticism.
Besides I guess all these weeks would have been rather hard without the "Burlöv Community" behind me, especially my dear flatmates who cared for me and made me see something else but my computer screen.
Finally I want to say "thank you" to all those people, among them my family, who believed in me and supported me wherever I was going and made it possible for me to come to Sweden.

Ich danke Euch von Herzen.

Elisabeth Kindler

May 2011

…and now the remaining pages….

Content

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Note: the terms "deciduous" and "broadleaved" trees used in this thesis refer both to the broadleaved and deciduous forest tree species found in Sweden's hemi-boreal region (compare table 1) and do therefore not include e.g. larch species (*Larix spp.*).

Note: the term "species" used in the following pages does often also refer to species groups like e.g. the genus *Quercus* etc.

Abstract

Deciduous trees in Europe's hemi-boreal forests are of major importance considering not only the biodiversity tied to them and therefore their nature conservation values, but also due to their relevance for forest recreation, their role in mixed stands and in risk spreading when it comes to adopting forest ecosystems towards the expected climate change. For these reasons it seems also important to incorporate deciduous trees more into the forest management and its planning to be able to keep track of them as well as of their associated benefits. This thesis introduces the first steps taken into that direction: after summarizing the importance of the deciduous species in Sweden's hemi-boreal region it contains an GIS investigation of deciduous trees in Kronobergs län and finally a simulation illustrating the effects for production and biodiversity when increasing the deciduous share in a forest landscape. The investigation has shown that the vast majority of the total deciduous volume can be found admixed into mixed or conifer dominated stands, while only 13% of it is standing in deciduous dominated forest types, accounting for 5% of the forest area. These stands, where birch is the prevailing species, are furthermore located close to open land types like agricultural areas, urban sites or lakes. Another important result from the study demonstrates moreover that there are huge differences within the county having a deciduous rich south and a comparable poor north-east when it comes to broadleaved trees. Finally the simulation regarding an increased deciduous share following the criteria concerned with deciduous trees in the new FSC standard resulted in only minor differences in the forest production: the harvest possibilities and the standing volume in the coming decades. The state of the indicators for biodiversity on the other hand was generally able to improve remarkably also pointing at deviations caused by the different approaches taken to reach the FSC target.

1 Introduction

Deciduous trees in Europe's hemi-boreal region are of great ecological importance and a significant natural feature of this forest ecosystem. Many authors have discussed and explained this from different points of views regarding for instance forest living insects, lichen species or the forest's resilience. But today's hemi-boreal forests e.g. in Sweden are not very rich in deciduous trees anymore. They are rather dominated by spruce and pine often managed in monocultures for production purposes. During the last decades this has been subject of many discussions stressing the need to change the current situation. So for example the Forestry act gave special attention to several deciduous tree species. Furthermore the FSC standard emphasizes the importance of deciduous trees aiming at increasing their share.

Despite this, a detailed knowledge about the deciduous trees in the forest landscape is still lacking. But since it is rather difficult to define targets without knowing about the current situation, these information are urgently needed if forest policy wants to take deciduous tree related decisions or if they should be accounted in the forest management. However the FSC has reacted towards the lack of deciduous trees already some time ago and a number of their criteria regard their area and volume share within an estate setting minimum thresholds. But even with defined targets, disregarding how they were derived, there are several ways how those can be achieved and although they might all fulfill the same FSC goal they can differ substantially e.g. in the allocation of deciduous trees, or regarding the forest production, composition of the harvest volume etc.

This thesis aims at providing a starting point, a scientific base for increasing the deciduous share in Sweden's hemi-boreal forests. Therefore it deals with the investigation of some of these "gaps" in the knowledge like the current deciduous state and compares different approaches of how this increase can be achieved.

If we regard the deciduous trees and the aim of increasing their share as a forest management planning problem we can follow the approach of the forest planning cycle, illustrated in figure 1. Our objectives are based on the relevance of deciduous trees outlined in the first thesis chapter and very general they can be described as aiming at an increased deciduous share. In a next step the cycle indicates a data collection important for formulating management alternatives later on. Here realized as an investigation regarding deciduous trees within the hemi-boreal forest in Kronobergs län described in the second chapter, whereby all results are listed in detail in the appendix. The following three points "Management alternatives" their projection and evaluation as they occur in the planning cycle are outlined in the last thesis chapter: comparing different ways how to fulfill the new FSC standard.

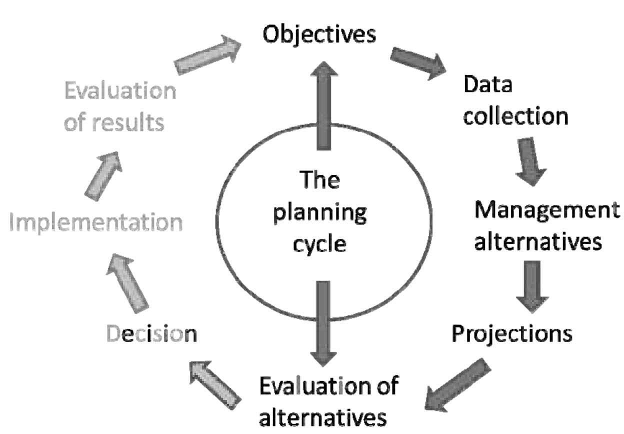

Figure 1: The forest management planning cycle

In that way this thesis can contribute to our current knowledge and serve as a decision support, possibly helping to improve the sustainable management of forests in the hemi-boreal region.

2 The relevance of deciduous trees and stands

As a first step the following chapter will outline the relevance of deciduous trees in Sweden's heim-boreal region. Therefore it is primarily important to know the deciduous species range occurring in this region. Widén (2002) describes the wild growing tree and shrub species in Sweden, out of these about 100 species table 1 lists the deciduous trees which occur in Swedish forests or can be found in forest margins. This allows a rough impression about the species which could be included talking about deciduous or broadleaved trees in southern Sweden. The classification into "forest" and "forest margin" species indicates only a general trend.

Table 1: List of wild growing broadleaved trees in Sweden (adapted from Widén, 2002), forest margin indicates that those species are rarely found in forest stands, species marked with* are found on the National Forest Inventory's (NFI) standing volume list of Kronobergs län period 2005 – 2009 (SLU, 2010), n means noble broadleaves according to the Swedish Forestry Act (Paltto et al., 2006)

Scientific name	English name	Occurrence
Acer campestre	field maple	forest margin[n]
Acer platanoides	norway maple	forest *[n]
Acer pseudoplatanus	sycamore	forest*
Alnus glutinosa	alder	forest *
Alnus incana	grey alder	forest*
Betula pendula		forest*
Betula pubescens	downy birch	forest*
Carpinus betulus	hornbeam	forest[n]
Coryllus avellana	hazel	forest
Fagus sylvatica	beech	forest*[n]
Fraxinus excelsior	ash	forest*[n]
Populus tremula	aspen	forest*
Prunus avium	wild cherry	forest*[n]
Prunus padus	bird cherry	forest margin
Quercus petraea	sessile oak	forest*[n]
Quercus robur	pedunculate oak	forest*[n]
Salix caprea	goat willow	forest*
Salix fragilis	crack-willow	forest margin
Salix pentandra	bay willow	forest margin
Salix viminalis	osier	forest margin
Sorbus aria		forest margin
Sorbus aucuparia	rowan	forest*
Sorbus hybrida	Swedish service-tree	forest margin
Sorbus intermedia	Swedish whitebeam	forest margin
Sorbus norvegica		forest margin
Sorbus teodori		forest margin
Tilia cordata	small-leaved lime	forest[n]
Tilia platyphyllos	large-leaved lime	forest[n]
Ulmus glabra	wych elm	forest[n]
Ulmus laevis		forest margin[n]
Ulmus minor		forest[n]

In Kronobergs län the county which will be investigated in more detail later on only the species birch, oak, alder, aspen, beech, rowan, goat willow, wild cherry, ash and maple/sycamore occur in descending order with a volume share of at least 0.1% considering data from the National Forest Inventory (NFI) 2005 to 2009. So it can be concluded that the forest relevance of the remaining species listed above is rather small in Kronobergs län.

2.1 Ecology

Forests in the European hemi-boreal region, a zone representing the transition between the temperate and boreal biome, where Kronobergs län is located are naturally characterized by a mixture of coniferous and deciduous trees forming various different forest types coined by a diverse disturbance regime (Lõhmus and Kraut, 2010). Next to forest fires which are very likely to account for medium scale disturbances in the dryer areas of the region, small scale windfalls followed by gap regeneration present probably the dominating natural disturbances (Nilsson, 1997). As this ecotone incorporates elements from both temperate as well as boreal forests it hosts therefore a comparable species rich flora and fauna (Lõhmus and Kraut, 2010) whereby many species occur here in their northern most range (Berg et al., 1994). On the other hand the ecological specifics of this transition region, which accounts for a 600 km wide zone in Sweden, are not as well studied as ecological features in the main biome types (Nilsson, 1997).

Intensive exploitation in the past has resulted in substantial modification of the hemi-boreal forest. The anthropogenic influence on the forest landscape in southern Sweden lasts for more than the past 1,000 years and has slowly altered e.g. forest structure or species composition (Nilsson, 1997 and Gärdenfors, 2010).

The forest area in southern Sweden centuries ago was covered by deciduous dominated stands, for instance in Kronobergs län dominated by alder, birch, hazel, oak and lime as common species in its western and central parts and high abundance of pine (*Pinus sylvestris)* in the eastern parts. Beech gained more importance about 1,500 years ago while spruce (*Picea abies*) was playing a minor role (Lindbladh et al., 2000). The German federal office of nature conservation defines mixed spruce and deciduous forests with an emphasis on oak in the majority of Kronobergs län and hemiboreal pine forests with admixed broadleaves in the eastern part to be the potential natural vegetation, which could be expected excluding direct anthropogenic influences (Bundesamt für Naturschutz, 2004).

Contrasting today the hemi-boreal zone is dominated by plantation forests, often spruce monocultures (Felton et al., 2010a) at the expense of deciduous woodlands which have dramatically decreased since the mid 20th century (Gärdenfors, 2010), implying the loss of the natural habitat for many species, reduction of the habitat patch size and an increasing isolation of these patches (Andrén, 1994). Many indigenous wood-living species are now restricted to remaining habitats often located in areas not suitable for agriculture or forestry (Fries et al., 1997, Nilsson, 1997 and Gustafsson et al,. 1992) as the average Swedish forest stand does not fulfil their biotope requirements anymore (Gärdenfors, 2010).

In addition to the biodiversity threats arising from fragmentation the rate of change represents a problem. Paltto et al. (2006) found a reaction time delay of 120 years for some vascular plants and wood-living fungi in southern Sweden, which could imply that many of the species associated with deciduous forest are actually in “extinction debt” and it is just a matter of time until they will finally disappear (Lindbladh and Foster, 2010).

Considering Sweden on a country scale, reaching from the temperate zone in the very south to the boreal biome with its harsh climate conditions in the north, it is not surprising that the general species richness in the southern part of the country is higher (Gärdenfors, 2010). Also higher is the proportion of threatened forest species in the temperate and hemi-boreal areas and most of these species are dedicated to southern deciduous forests (Berg et al., 1994). In 2010 52% of the threatened species were found to be associated with forests (Gärdenfors, 2010) emphasizing the forest’s immense role in hosting Sweden’s biodiversity.

Deciduous trees gain special importance regarding for instance the attendant insect fauna; 26% of the red-listed forest insects can be found on oak and 29% out of these are monophagus and so are exclusively dependent on oak trees. Beech has turned out to be of similar importance (Jonsell et al.,

1998) and each of those two species represents one of Sweden's few foundation species (Lindblahd and Foster, 2010). Comparing the tree genera and their insect fauna shows that certain groups of genera attract a similar pool of species. It also indicates that the *Fraxinus* and *Tilia* species, but first and foremost the *Salix* species support a rather dissimilar assortment of associated insect species compared to the others stressing their importance in the forest ecosystem.

Besides their relevance for insects deciduous trees also play an important role for bats and birds. There is a clear distinction between bird species being dependent on conifers and those relying on deciduous trees (Nilsson, 1997), in this case mixed forests often host the highest bird densities (Berg et al., 1994) whereby a deciduous dominance with an admixture of 10 to 30% of conifers is probably optimal (Nilsson, 1997). The existence of deciduous trees within a stand's over storey also affects the composition and diversity of the ground flora, differing light regimes and litter substance change terms and conditions for the under storey and soil organisms. Generally higher floral species richness can be expected under deciduous forest (Nilsson, 1997 and Barbier et al., 2008).

Frequently investigated is also the linkage between bryophytes or lichens and deciduous trees, here beech is again a species of particular importance hosting the majority of red-listed lichen species in southern Sweden (Fritz and Brunet, 2010). Felton et al. (2010a) studied the effects of admixing deciduous trees, in this case birch, into spruce monocultures and concluded that this relatively small diversification in the stand led to increased biodiversity, although it is unlikely to improve the situation for most red-listed species. Nilsson (1997) showed a similar result: already small amounts of deciduous trees can play a substantial role; this time regarding small patches of old deciduous forest serving as refuges and dispersal sources for insect species.

Deciduous trees can occur in the forest as single trees or small groups admixed into the conifer matrix or as stands. Depending on the species relying on them, those trees are of importance either because they represent habitat patches to support populations and sub-populations or as stepping stones for organisms crossing the matrix (Fischer et al., 2006).

Besides these direct impacts of deciduous trees on biodiversity in the forest they also influence for example the water household of a region. For soil and water protection for instance mixed stands are preferable to pure conifer stands. The runoff in coniferous stands is higher than in hardwood forests accounting for potentially more erosion on slope sites. Here thick and deep roots are most desirable which tie the soil layer to the bed rock (Fujimori, 2001).

The lack of deciduous trees in today's hemi-boreal forests is an important feature nature conservationists criticize besides the need for especially old deciduous trees and dead wood in form of snags and logs etc. is often emphasized (Berg et al., 1994 or Jonsell et al., 1998).

Another important issue raised e.g. by Andrén (1994) is that the arrangement of habitat patches gains more and more importance with increasing habitat fragmentation, so the connection to similar habitat types nearby is for instance important for saproxylic beetles feeding on oak trees (Franc et al., 2007).

Some forest species, often those of low mobility, are furthermore dependent on continuity, for some bryophyte species this is even more important than the stand age (Gustafsson et al., 1992). Unfortunately Eriksson et al. (2010) did not find the distribution of older deciduous stands to be associated with forest continuity emphasizing the importance of knowledge about the past land use of an area in question when evaluating its nature conservation values.

Concluding it can be stated that deciduous trees in the hemi-boreal forests are of major importance: their high natural relevance in this region for biodiversity and forest ecology has been enormously intensified by the past rapid, large-scale reduction of deciduous trees and stands in the transition zone.

2.2 Recreation

Forest recreation has a rather long tradition in the Nordic countries and is linked to the right of public access, allowing everybody to enter any forest independent of the owner. Research in forest recreation regarding visiting patterns or preferences has been done intensely since the 1970s (Søndergaard Jensen, 1995). Among many other things it showed that preferences concerning the favourite recreation forest type differ for instance between countries. Popular are often mixtures incorporating different tree species and ages (Axelsson Lindgren, 1995). Carlén et al. (1999) found out that leaving deciduous trees on clear cut sites had a clear positive effect on recreation, while others concluded that an increased broadleaf share of the forest landscape in Sweden would enhance its recreational value (Bostedt and Mattson, 1995 and Norman et al., 2010). Kardell (1980 and 1985a in Rydberg and Falck, 2000) on the other hand regards this as a limited correlation and recommends a deciduous volume share of about 30% giving priority to ever-green conifers which are more pleasant during the winter time.

Forest visitors like visual variations which can be achieved in different ways and are also dependent on the dominating forest type (Axelsson Lindgren, 1995). Deciduous trees offer that in a special way as the appearance of the tree itself changes during the year: flushing trees in the spring differ from those in the summer, or from those in the fall. Annerstedt et al. (2010) investigated the stress relieving effect of broadleaved forest and concluded that there might be such an impact as well as important experience values to humans for evolutionary reasons.

Furthermore it needs to be considered that the silvicultural system has also huge influence on the aesthetics of a woodland (Holgén et al., 2000).

2.3 Economics

2.3.1 Production

The forests that can be found today in Sweden's hemi-boreal region are coined by conifer dominated production forests. Compared to most native broadleaves spruce shows a higher productivity and presents a rather safe investment due to good opportunities to sell the timber, availability of seed material and the great experience regarding its silviculture.
Hogén and Bostedt (2004) compared the land expectation values (LEV) of establishing a beech or a spruce stand on a bare piece of land in southern Sweden and reason that at an interest rate of 3% the LEV for beech is negative and much lower than that for spruce, although high prices can be expected for high quality hardwood logs (Woxblom and Nylinder, 2010).

Generally pure deciduous stands are of only low economic importance in Sweden's hemi-boreal forestry. However in the agricultural sector there is an increasing interest in growing willow, hybrid aspen or other fast growing poplar species on short rotations in so called "energy forests". Such plantations exist in Sweden since the 1930s and energy crises in the past and in the course of the current debate regarding renewable energy they will probably gain more and more importance (Christersson, 2010, and Mola-Yudego and González-Olabarria, 2010).

Much more discussed than the economics of pure deciduous stands are the effects of admixed broadleaf trees in conifer forest and possible benefits from mixed stands.
Different authors list numerous possible benefits and also disadvantages from mixing tree species, heavily depending on the mixture type in question. Agestam et al. (2006) mention the possibly higher costs of establishment and stand management, like others (e.g. Lindén, 2003) they expect the effect on volume productivity to be minor although benefits could arise from the more efficient site use possibilities or the decreased damage level e.g. from root and bud rot. Mixtures in form of shelterwoods can prevent the nursed species from frost while there is no clear result for the effect on wind caused damages.
Problems might arise from browsing or whipping but generally mixed stands show greater resilience capacities compared to monocultures and can therefore significantly reduce the financial risk (Knoke et al. 2008, Knoke and Seifert, 2008) e.g. by diversifying the forest owner's production range, being able to serve different markets (Waxblom and Nylinder, 2010).
Even though there is quite some literature available on the performance of mixed stands, comprehensive economical analysis incorporating also the admixture's effect on resistance, productivity or timber quality are still rare (Knoke et al., 2008).

Although neglected in the forest management the deciduous trees play a certain role in the pulp wood industry where about 20% of the consumed wood accounts for hardwoods. Due to their higher energy conversion rate per volume hardwoods are on the other hand also of importance regarding fuel wood – considering one and two-household dwellings the hardwood share of fuel wood accounts for about 50%.
Wood properties vary among the tree species and so each species shows different main applications. This is reflected in the consumption patterns; while birch, beech and aspen for instance are mainly used for pulp production the saw mills show more interest in oak and ash wood.
Generally the demand for hardwood is increasing and exceeds the national supply: today for example about 50% of the imported round wood is hardwood. On the other hand many of the desired high quality logs are not delivered to the saw mills but end up in pulp or fuel wood. This is due to their dispersal and the associated logistical costs when extracting and delivering only few logs. Regarding this and the increasing demand supports the idea to invest in more deciduous stands (Woxblom and Nylidner, 2010).

2.3.2 Value of recreation and biodiversity

Forests are not only valued because of their timber and other production values (e.g. berries and mushrooms), they are also of economic interest regarding their recreational and biodiversity values. Biodiversity values contain for example the value of endangered or threatened species: existence and bequest values, which are often investigated using the society's willingness-to-pay (Richardson and Loomis, 2009). Due to the ecological importance of broadleaf trees the value assigned to a deciduous stand in the hemi-boreal region should therefore be substantially higher than that of a conifer dominated plantation forest.

The same counts for recreational values: the high worthiness of broadleaved trees, exceeding the recreational value of conifers, is often stressed even though according to some authors only in certain limits, as mentioned above. Generally the recreation value represents a substantial component of the total amenity value of southern Swedish forests (Norman et al., 2010).

Another activity, which could be considered as recreational as well, is since centuries closely related to forests: hunting. The game species have not only been affected by the profoundly changes of their forest environment, outlined before, but also by fluctuating hunting regimes (Nilsson, 1997). As the ungulate species are browsing among others on deciduous trees they influence the tree growth and are themselves vice versa influenced by the deciduous quantity and distribution.
Selective browsing on deciduous trees is a problem from a forest management point of view: Gärdenfors (2010) appraises the forest restoration and first and foremost the increase of the broadleaf share to be endangered by the high deer populations. From the hunter's perspective broadleaves on the other hand might be a very welcome forest feature which increases the hunting values as it attracts the game no matter if those sapling will grow to trees or not.

Both, the assessment of use- as well as of non-use values in forestry especially regarding deciduous trees and stands in the hemi-boreal region has shown to be rather challenging. Therefore studies following an overall investigation, incorporating all those different economic approaches are hardly undertaken and most authors indicate the need for further research.

2.4 Trends and situation in Sweden

During the last decades beginning back in the 1960s the nature conservation movement began to raise its voice in forestry debates and the threats of biodiversity in the Swedish forests came into public awareness (Jong et al., 1999 and Gärdenfors, 2010). As a result environmental concerns gained more importance, so in 1964 for instance beech stands got protected by the Forestry Act (Jong et al., 1999) and two years later the use of herbicides in forestry was banned (Hägglund, 1991). The consideration of conservational issues reached the practical forest management as well and the introduction of retention trees and high stumps to be left on clear cut sites, increased broadleaf share within the stands especially close to open water surfaces and set aside areas developed to be part of the every-day management (SLU Department of Ecology, 2010 and Jong et al., 1999).
Also increased has the scientific interest in deciduous trees, so e.g. the Swedish University of Agricultural Science (SLU) started a research project back in 2003 called "The broadleaf program" investigating production, nature conservation, welfare and wood of the noble broadleaf species (SLU, 2009). Public associations like the Swedish deciduous trees association (Svenska Lövträdförenigen) indicate the present interest of the society in nature conservation and forestry.

2.4.1 Forestry act & Environmental targets

Since 1994 the Swedish Forestry Act sets two equal targets of forest management: production and biodiversity (Jong et al., 1999 and Skogsstyrelsen, 2007) broadleaves are considered in a special way as the conversion of stands dominated by the so called "noble broadleaves": elm, ash, hornbeam, beech, oak, wild cherry, linden/lime and maple (compare table 1) is not allowed. The Forestry Act defines such stands as forest areas of at least 0.5 ha size with a total deciduous share of at least 70% whereby noble broadleaves should account for at least half of the total volume (Skogsstyrelsen, 2007). Furthermore subsidies may be paid to assure the regeneration with these deciduous tree species (Skogsstyrelsen, 2007).

In 2004 the Ministry of Sustainable Development Sweden (2006) published the so called "Environmental Quality Objectives", whereby it set environmental targets to be met until a defined point of time in future. In the chapter "Sustainable Forests" it formulates the goal to increase the area regenerated with deciduous trees until 2010. The Swedish Forest Agency (Skogsstyrelsen), which was in charge of the implementation judged this specific target, like most of the forest related goals, to be met (Skogsstyrelsen, 2010).

2.4.2 FSC

In Sweden currently about 11 million ha of forest land are certified under the Forest Stewardship Council (FSC) certification system (FSC, 2010a). The certification is tied to the fulfilment of numerous criteria regarding an estate's forest management. They are listed in the "Swedish FSC Standard for forest certification" and here as well special attention is given to deciduous trees.
So deciduous trees should dominate throughout the whole rotation in forest areas which are neighbouring non-forested cultural land and at least 5% of the mesic and moist land suitable for deciduous trees should be covered with deciduous rich stands. Furthermore the management should maintain or establish deciduous stands adjacent to water surfaces, in sediment ravines and on other wet land which would naturally be dominated by deciduous trees. The latest standard also asks for a minimum share of 10% deciduous volume in the final felling stands (FSC, 2010b).

2.5 Climate change and bioenergy

Finally deciduous trees and the role they could play in the hemi-boreal region regarding the expected climate change are discussed broadly.
Generally forests are of particular concern when it comes to climate change since they fulfil different roles at the same time: their deforestation and degradation on a global scale has substantially contributed to the rising CO_2 level, they are regarded as important carbon sinks, they are potentially huge sources for CO_2-neutral renewable energy carriers and in turn they are themselves ecosystems threatened by climate change (Bravo et al. 2008).
These points are also of importance focusing on hemi-boreal forests and its deciduous trees in southern Sweden. Besides probable increased occurrence of extreme weather events like storms or forest fires, droughts and changes in frost regimes, the growth conditions in southern Sweden are estimated to improve (Chapin, 2007) for instance due to the expected prolonged vegetation period (SCCV, 2007). The deviating growth conditions allow a northerly migration of species (Chapin, 2007) and whole vegetation regions will probably shift further north (SCCV, 2007).
The changes will not only affect the tree species but also the conditions for their natural antagonists: the new settings are expected to be beneficial e.g. for many fungi species or bark beetles which might reproduce and swarm more often during the summer, as well as the deer populations are expected to increase further (SCCV, 2007).

Broadleaved trees seem of particular interest as they are not expected to be as vulnerable to this probably increased damage level as spruces is and they are also important considering the expected higher deer populations (SCCV, 2007).
To reduce the vulnerability of the forest to climate change associated threats risk spreading has been suggested (Felton et al., 2010b). This strategy should ensure productivity and at the same time help restoring species and landscape diversity, whereby enhancing the ecological diversity has been regarded as the greatest challenge (Chapin et al., 2007). Risk spreading can be implemented by increasing the forest heterogeneity taking the specifics of the forest site into account (Felton et al., 2010b) like for instance focussing on pine and oak on sites with higher risk for drought damages (SCCV, 2007). Generally mixed stands and an increased share of native deciduous trees is recognized as a good strategy to face climate change.
Götmark et al. (2005) investigated the deciduous saplings in coniferous stands and concluded that the establishment of mixed stands using the existing advanced deciduous regeneration is rather promising. Other ideas focus on the introduction of new tree species or hardy provenances which furthermore offer possibilities for increased productivity (Felton et al., 2010 and SCCV, 2007).

On the other hand the adaption rate, especially of species with long generations, like trees, is thought to be too slow to cope with the rapid climatic change (Bravo et al., 2008). Moreover the current forest ecosystem in its rather artificial state, regarding species composition and forest structure, cannot be expected to show a great resilience potential, stressing the need for prompt actions. Other authors discuss the possible benefits from climate change, driving the lost diversity back into the hemi-boreal region (Chapin et al., 2007).

At the same time there is a debate concerning the potential, CO_2-neutral and therefore climate-friendly energetic use of admixed deciduous trees in conifer stands (Johansson, 2003) and the use of fast growing deciduous species planted in Sweden for energy purposes (e.g. Johansson 2008 or Mola-Yudego and González-Olabarria, 2010). Some authors regard this as a small chance for the forestry sector while others discuss the impact of bioenergy harvesting on the environment critically whereby there are large differences depending on the species used in short rotation plantations: genetic modified clones or fast growing native species like willows (Perttu, 1998).
Generally the production for energy purposes has gained more importance and the relevance of biofuels from the forest can be expected to increase further (SCCV, 2007).

2.6 Conclusions and Discussion

The results from the literature review presented above outline the importance of deciduous trees in Sweden’s hemi-boreal region. Deciduous trees as well as deciduous dominated stands play a key role in hosting the forest biodiversity and are a substantial part of the natural ecosystem.
Besides they have a large influence on the recreational value of the forest and are preferred by many forest visitors.
Regarding wood production deciduous trees in Sweden are generally of minor importance but improved logistics and the increasing demand also in the biofuel sector might offer new chances in hardwood applications.

Finally deciduous trees have gained attention when it comes to the climate change debate; one of the main ideas regarding risk spreading is the increased use of mixed stands with a higher deciduous share.
Generally it can be concluded that deciduous trees and stands are not only of major importance for the sustainability of the forest ecosystem but also offer numerous new chances.

Bergeron and Harvey (1997) stress the importance to mimic natural disturbance regimes in forestry operations to ensure an ecological sustainable management while other authors emphasize the relevance of the knowledge about the regimes for successful conservation (Eriksson et al., 2010). This is rather problematic in the European hemi-boreal region, since the separation of manmade features in the forest history is difficult (Nilsson, 1997) and typical natural forest processes can only be estimated due to the lack of reference areas (Sjödberg and Lennartsson, 1995).
So when it comes to nature conservation issues which are closely related to deciduous trees we cannot be entirely sure about an appropriate forest management.
Finally the possibility that numerous species might be in extinction debt stresses the urgent need to restore the forest ecosystems as soon as possible (Paltto et al., 2006).

But besides problems arising from the past management, some present developments are also counter steering nature conservation goals. The high browsing pressure in the forests makes a further decline of deciduous trees probably and the occurrence of large scale fungi diseases in broadleaf species during the last decades contributes to this trend.

The review has also shown that there are still many uncertainties and lacking knowledge e.g. regarding how many deciduous trees are needed to support the forest biodiversity. But even with this knowledge it would take quite some time until it would arrive in practical forest management and finally have an effect in the forest itself. Forest ecosystems react rather slowly, consequences of the negative impacts of past management regimes are still apparent and so it will also take some time until the effects of the recent changes can be evaluated (Gärdenfors, 2010).
Still it is of urgent importance to react now as we should not risk losing more forest living species and with them the function they fulfil in the whole ecosystem.

On the other hand the public awareness of the pressure threatening forest biodiversity has increased in the past years (Gärdenfors, 2010) and led to adaption in forest management like the duty to replant noble broadleaf stands with the same species, leaving retention trees, high stumps and small groups of trees on clear cut sites (Jong et al., 1999). And the first positive developments have been recorded e.g. when comparing the recent Red List to its earlier version: more species linked to forests were able to improve their situation in terms of red list classification, than have declined (Gärdenfors, 2010).

3 Investigation of deciduous volume and stands

The previous chapter summarizes the importance and relevance of deciduous trees in Sweden's hemi-boreal region discussed by many authors. Besides it also describes the vast reduction of deciduous trees within the forest landscape in the transition zone during the last centuries and explains the need for forest ecosystem restoration.

But the way from this theoretic knowledge to actions taken in practical forest management is rather long. If deciduous trees should gain more importance in that field they need to be included into planning processes and the next step in the planning cycle, assuming the need for an increased deciduous share to be an objective, would be a more detailed investigation regarding the deciduous trees in the forest since it is necessary to know the current state for further planning.

The National Forest Inventory (NFI) for instance provides annual estimations of the volume of the most common tree species on a county scale but does not allow any conclusions in terms of e.g. deciduous dominated stands like their size or distribution.

Information considering the dispersal of the deciduous trees; whether they are mainly mixed into the conifer dominated areas or rather in deciduous stands exist but are based on the inventory plots' size and not on stand level.

However such knowledge is essential for management planning when it comes to choosing suitable alternatives, to decisions regarding for example an increased broadleaf share or when evaluating the habitat suitability of the forest landscape for certain species.

Therefore the following chapter tries to answer some of these questions using satellite data exemplary for the county Kronobergs län in the hemi-boreal region of southern Sweden providing detailed information about the deciduous volume and the deciduous dominated stands especially.

3.2 Materials and methods

3.2.1 The study area

3.2.1.1 Cornerstone data

Kronobergs län is a southern county of Sweden located between the 56th and 57th latitude, surrounded by the counties Skåne, Halland, Jönköping, Kalmar and Blekinge (Google, 2011). The county, covering a total area of 8,468 km² supports a population of about 183,000 people or approximately 22 inhabitants per square kilometre (Statistics Sweden, 2009).

Numerous lakes, like the lake Åsnen in the south or the lake Bolmen in the north-west contribute to the county's landscape (Google maps, 2011), while first and foremost forests dominate the land cover classes followed by mires, as figure 2 illustrates (Skogsstyrelsen, 2010).

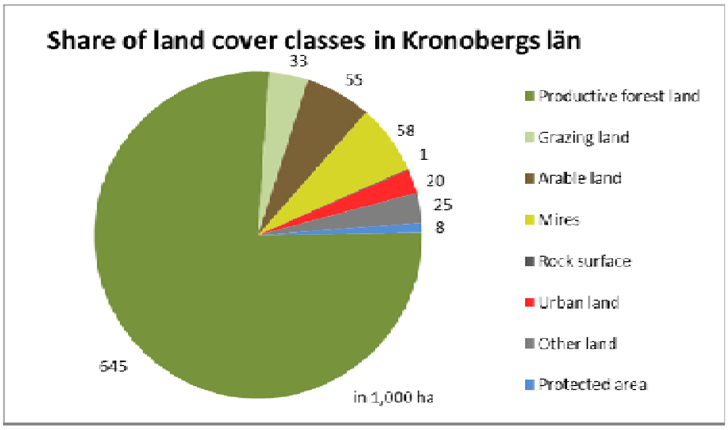

Figure 2: Area share of land cover classes in Kronobergs län during the period 2005-2009 (Skogsstyrelsen, 2010)

3.2.1.2 Climate, geology and elevation

The predominating climate in Kronobergs län is maritime and the annual precipitation varies between 600 mm to 800 mm in most of the county while the very west receives with 800 mm to 1,000 mm more water (Arnberg, 2010). The growing season in this hemi-boreal region lasts for about 190 to 200 days per year.

Kronobergs län shows two main types of bed rocks; while gneisses dominate in the west, granite takes over in the eastern half interrupted by areas of porphyry (Helmfrid, 1996).

The county ranges in terms of elevation from 100 m above sea level up to 350 m while the west is mainly flat a plateau and the highest elevations shape the county's north east.

Climatic, geological and topographical factors all together create heterogeneous conditions for forest growth, resulting in varying site productivities from 4.5 to 12 m^3/ha/year as figure 3 illustrates.

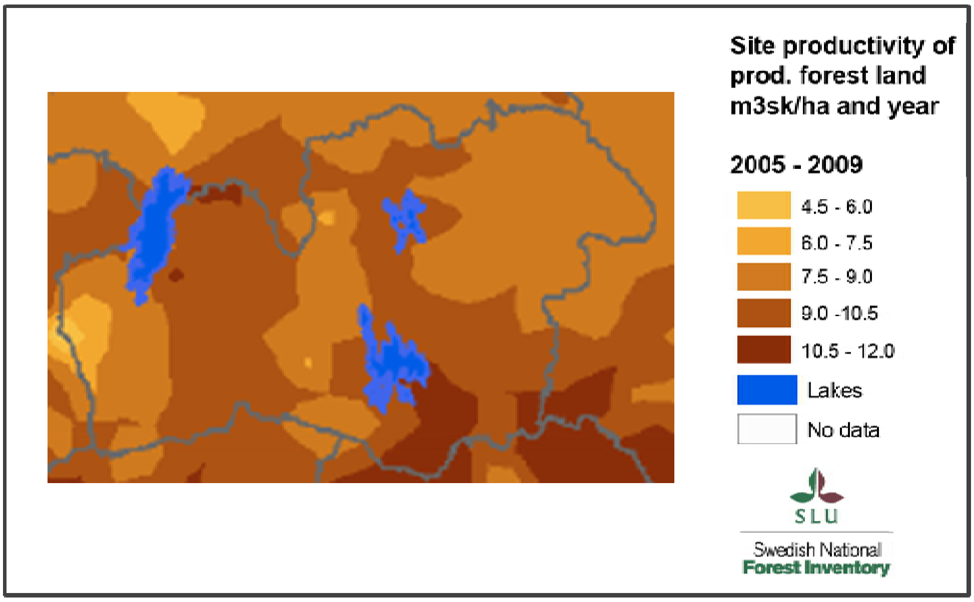

Figure 3: Site productivity of forest land in Kronobergs län (adapted from: SLU, 2010)

3.2.1.3 Forest data according to the forest statistics

Table 2: Forest benchmark data for Kronobergs län (Skogsstyrelsen, 2010)

Benchmark data	Value
Productive forest area [ha]	645,000
Unproductive forest area [ha]	45,000
Total forest area [ha]	690,000
Growing stock [million m³]	112.9
Mean site productivity [m³/ha/year]	8.8
Growing stock per hectare [m³/ha]	146

According to the Swedish Statistical Yearbook of Forestry Kronobergs län is covered by productive forest land of about 645,000 ha, which accounts for 76% of the county's land area exceeding the total Swedish average. The term productive forest land refers to the mean site productivity of a forest site of at least 1 m³/ha/year, for Kronobergs län the mean site productivity found is about 8.8 m³/ha/year.

In Kronobergs län the vast majority of forest land is kept privately and only 18% belong to different ownership types. Private forest owners others than companies hold 80% of the forest area while the remaining 2% refer to companies.

The species share of growing stock in the county's forests has been quite stable during the last decades. As figure 4 illustrates spruce was already the dominating species in 1946 but has gained even more importance since then at the expense of pine.
Today (period 2005 to 2009) the total growing stock on productive areas in Kronobergs län is estimated to be 112.9 million m³, respectively 146 m³/ha on average, clearly dominated by spruce and pine as shown in figure 4.

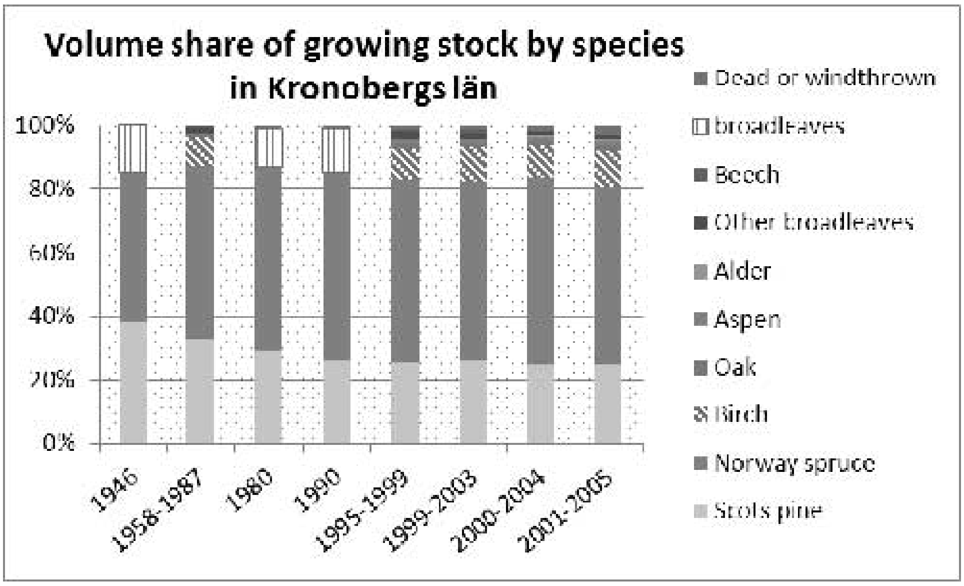

Figure 4: Species share of growing stock on productive forest land during the last decades in Kronobergs län (Skogsstyrelsen, 1953, 1962, 1971, 1982, 1990, 2010)

3.2.2 The data

The analysis regarding deciduous volume and deciduous stands in Kronobergs län is based on data derived from the “k-NN-Sweden 2005”and from the *Svenska Marktäcke Data* (SMD) data sets which have been combined to create a source for the investigation.

Data procession and analysis was done using the programs ArcGIS, Fragstats and Microsoft Office’s Exel. The handling of the *k*-NN raw data, the derivation of the deciduous stands and the volume analysis was undertaken with the software ArcMap , version 9.3, within the ArcGIS package by Esri. For the investigation of different class metrics the freeware Fragstats was applied (University of Massachusetts Amherst, 2000).

3.2.1.1 k-NN

The *k*-NN method has been used to produce continuous estimates of forest variables, for instance timber volume, height or age (Reese et al., 2002) in Sweden. Such a countrywide mapping process, creating a wall-to-wall pixel-based raster database (Tomppo et al., 2008) was initially applied in Finland. First approaches in Sweden at the Swedish University for Agricultural Science (SLU) followed around 1992 (Reese et al., 2003). The core of the *k*-NN, or *k*-nearest neighbour, method is the interpretation of satellite data in combination with information from forest inventory plots and support from digital maps. Its main application can be seen in planning and habitat studies (Reese et al., 2002).

The “*k*NN-Sweden 2005”project applies SPOT4 and SPOT5 (Anonymous, 2010) satellite images, field plots from the National Forest Inventory (Reese et al., 2003) and digital topographic as well as vegetation maps (Reese et al., 2002) generating a raster resolution of 25 x 25 m, projected using the Swedish geographical projection RT90 (Anonymous, 2010). The estimations of forest variables are based on a forest mask which exclusively takes productive forest land into account, so only forest land with a productivity of at least 1 m^3/ha/year is considered (Reese et al., 2002).
For each satellite scene ground truthing is based on a selection of GPS (Global Positioning system) positioned NFI plots (Tomppo et al., 2008) all over the image’s geographic extent. To increase the amount of reference data, plot data are generally taken from the last six years, whereat the older estimations of forest variables were updated with the help of a growth simulator (Reese et al., 2003).

To homogenize the satellite scenes they are first altered in terms of illumination and haze (Tomppo et al., 2008). Thereupon the *k*-NN method can be applied to estimate forest variables.
“*k*NN-Sweden 2005” asses the total wood volume, the wood volume of Norway spruce, Scots pine, birch (*Betula pendula* and *Betula pubescens*), oak, beech, the sum of other, remaining deciduous tree species, the age and the tree height (Reese et al., 2003) per 25 x 25 m pixel (Anonymous, 2010). The estimates are based on a comparison between the satellite data of pixel which have been inventoried, the references, and the satellite data of unknown pixel. After outliners have been removed from the reference set, using regression analysis, each variable is estimated as the weighted mean value of the 15 (*k*=15) nearest reference plots, which have a similar appearance according to the satellite data. The weights are chosen to be proportional to the inverse squared Euclidean distance; uprating closer pixel (Reese et al., 2003).

$$\hat{v}_{p} = \sum_{j=1}^{k} w_{j,p} \times v_{j,p}$$

Formula 1
with: $\hat{v}$ the estimated variable for the pixel (p) and $w_{j,p}$ the weight of the value (v) of the reference plot j

where:

$$w_{j,p} = \frac{1}{d_{j,p}^{2}} \Big/ \sum_{i=1}^{k} \frac{1}{d_{i,p}^{2}}$$

Formula 2
with: $d_{j,p}$ the distance between the pixel p and the reference plot j and i to k the reference plots

(Reese et al., 2002)

The forest variable estimates, assessed using the *k*-NN method, generally provide only low accuracy on pixel level. Furthermore the accuracy is limited for stands with high volume, there is a trend to overestimate lower values while higher values are underestimated (Reese et al., 2003) and the root mean squared error (RMSE) derived from cross validating is particular high for the volume estimations of the deciduous trees. This can be due to their low total volume and the lower number of sample plots they can be referred to. The general advice regarding these problems is to use the data on an aggregated level (Reese et al., 2002).

Displaying the data with a geographic information system (GIS) software furthermore reveals some clear borderlines crossing e.g. the county Kronobergs län. For example the visualization of deciduous dominated pixel results in a map, illustrated in figure 6, which allows the identification of different satellite scenes applied for the county analysis.

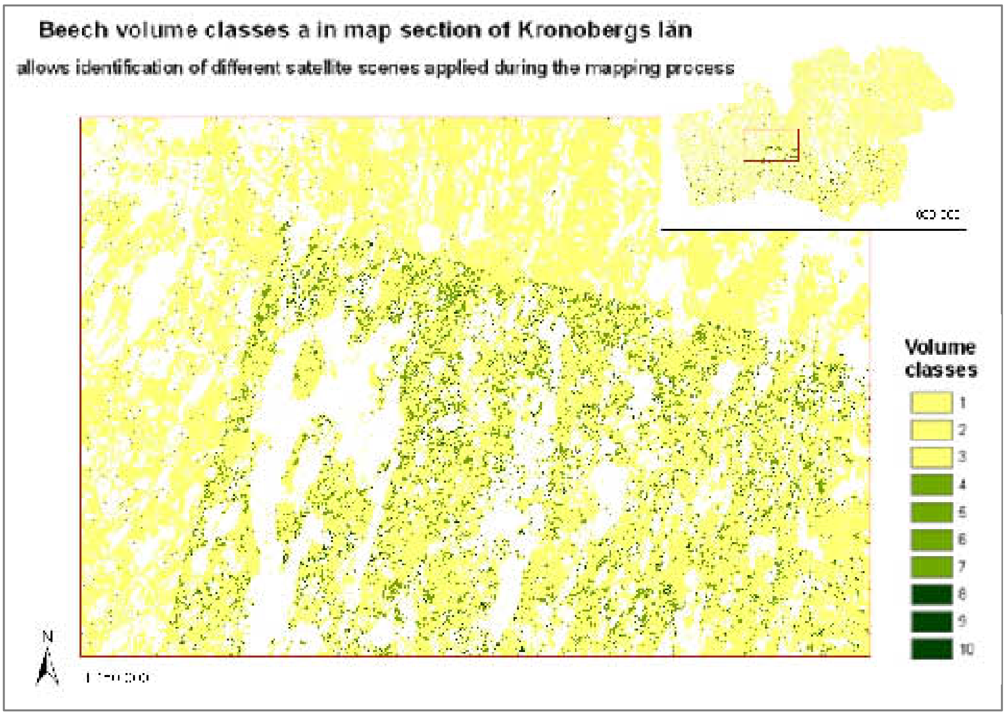

Figure 5: Beech volume classes mapped in the centre of Kronobergs län to illustrate the sharp borderlines due to different satellite scenes applied in the *k*-NN mapping process. Volume classes refer to the volume share, e.g. volume class 1 contains up to 10% beech volume, class 2 contains 10% to 20% etc.

3.2.1.2 SMD

The second data set used additionally to the *k*-NN data are the *Svenska Marktäcke Data* (SMD) which provide a nationwide raster based map of land cover types with a 25 m resolution (Engberg, 2002). They were produced as part of the Corine (Coordinated Information on the European Environment) land cover project in 2000 by the Swedish National Land Survey (NLS) (Ahlcrona, 2003), whereby the classification of forest was contracted out to SLU (Hagner et al., 2005).

The data, also projected within the geographic projection RT90, breaks into all together 59 different land cover classes of which 57 have a minimum mapping unit of 1 ha. Non-forest data are derived mainly from Landsat TM satellite scenes with a resolution of 30 m in combination with road, terrain, vegetation and community maps and information from the County Boards' environmental departments (Engberg, 2002).

Areas with a tree cover exceeding 30% are classified as "forest" regarding the SMD. Those areas are declared as "deciduous" or "conifer forests" as soon as the canopy cover is dominated by more than 75% of deciduous or coniferous trees respectively, otherwise the patch will be referred to as "mixed forest".
The mapping process of the forest area is based on the analysis of Landsat TM satellite scenes (1999-2002), primarily Landsat7 ETMx together with the interpretation of sample plots from the NFI, using plots from the last five to ten-year period. The derived raster data differentiate on a 25 x 25 m level between seven general forest classes.

Before processing the satellite scenes were corrected for haze as well as illumination and matched to the plot data. After classifying the reference pixel according to the NFI data into the forest classes, each remaining pixel is compared to those and sorted into the class of greatest similarity. Finally the results were cross validated to evaluate their quality.

The seven forest classes list clear felled areas, young forest, conifer forest lower than 15 m, higher than 15 m, deciduous forest and mixed forest. The last four categories fall into further subcategories derived by the combination of the forest pixel with data, mainly indicating forest on bare rock and mires, undertaken by the NLS (Hagner et al., 2005).

The results from the cross validation show here again a lower accuracy for deciduous forest pixel (Hagner et al., 2005).

3.2.1.3 Combining the data sets

To allow the incorporation of the *k*-NN volume information into the SMD land use data it was first necessary to compare both data sets. The SMD data assigns every single pixel a code representing a certain land use class. The *k*-NN data on the other hand contain only elements which are forest according to the forest mask that was used during the mapping process and provide e.g. volume information for each pixel, but do not give any classification of the forest itself. Comparing both forest pixel sets, considering "clear felled" and "young forest" (code 54 and 55 or SMD codes 3.2.4.2 and 3.2.4.3) (Stockholms Universitet, n.d.) as SMD forest too, reveals some deviations shown in table 3.

Table 3: Comparison *k*-NN forest and SMD forest (pixel codes 40-52; 54-56) raster data. "Pure area" indicates the area that is only classified as forest according to one of the sources, e.g. 14,100 ha of the *k*-NN forest are not classified as forest regarding the SMD source

	***k*-NN forest**	**SMD forest,** codes 40-52; 54-56	**Overlapping** (forest according to *k*-NN and SMD)	**total** (forest according to *k*-NN or SMD)
Pixel counts	9,807,000	11,096,700	9,580,700	11,323,000
Forest area [ha]	612,900	693,500	598,800	707,700
Pure area [ha]	14,100	94,700	-	-
Area share of total area	87%	98%	85%	-

So both investigations resulted e.g. in different forest areas: according to *k*-NN Kronobergs län is covered by about 612,900 ha of forest, while SMD mapped about 80,000 ha more whereby the actual pixel they define as forest deviate as well.

There are numerous possible explanations for the deviations in questions. First of all: both approaches work with varied forest definitions. Then the underlying data is not the same for the two analyses: they used different satellite scenes and dates and refer to different ranges of NFI plots. Finally the mapping methodologies themselves deviate in both approaches. Therefore it appears quite reasonable that they did not result in exactly the same forest area.

Switching the level and considering SMD forest sub-classes and pixel based volume information of the *k*-NN data (table 4) it has to be kept in mind that the technical differentiation here is not as easily done as between forest and non-forest. The error-rate is probably much higher distinguishing e.g. between "mixed forest" pixel and deciduous dominated forest or even indicating the age or volume associated with different species. So the increasing deviation on a finer level, shown later on, comparing both data sets is not unexpected as well.

3.2.1.4 Other sources

The two basic data sets presented above have furthermore been compared to a digital elevation and a digital road map. Both maps are provided by the the Swedish mapping, cadastral and land registration authority, Lantmäteriet, to the Swedish University of Agricultural Sciences (SLU) and have been cut focusing on Kronobergs län.

The digital elevation map is a raster based file with a resolution of 50 m again using the Swedish geographical projection RT90. While the road map applying SWEREF99_TM on the other hand is vector based displaying all public as well as private roads and streets as line features.

3.2.3 Deriving deciduous stands

The deciduous stands investigated in this thesis were derived using both the *k*-NN and SMD data sets. In an initial step a raster file was created for each source, containing only pixel representing deciduous forest.

For the *k*-NN data it was therefore first necessary to create this information from the given raw data. The raster data for birch, beech, oak, other deciduous and total volume was used to calculate the total deciduous volume and its proportion of total volume for each pixel. After excluding all pixel with a total volume of 5 m^3/ha total volume and less, deciduous pixel have been defined as pixel with a total deciduous volume share of at least 70%.

Regarding the SMD source for Kronobergs län only two out of the three existing deciduous classes appear in the county's data: "broadleaf forest on mires" and "broadleaf forest neither on mires nor on bare rock". For further investigations of broadleaf stands only the forest type with code 40 (or SMD code 3.1.1.1) (Stockholms Universitet, n.d.) "broadleaf forest neither on mires nor on bare rock" have been considered and extracted into a single file, excluding broadleaf forest on mires.

As indicated above the comparison of deciduous pixel in both data sources resulted in only small analogy. Merely 13% of the total number of *k*-NN and SMD deciduous pixel coincides (table 4).

Table 4: Comparison *k*-NN deciduous (more than 5 m^3/ha total volume and of this at least 70% deciduous) and SMD deciduous (pixel code 40) raster data. "Pure area" indicates the area that is only classified as deciduous according to one of the sources, e.g. 32,500 ha of the *k*-NN deciduous forest are not classified as deciduous regarding the SMD source

Deciduous	*k*-NN deciduous	SMD deciduous code 40	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or SMD)
Pixel counts	677,400	720,700	157,500	1,240,600
Area [ha]	42,300	45,000	9,800	77,500
Pure area [ha]	32,500	35,200	-	-
Area share of total area	55%	58%	13%	-

The remaining deviating forest areas can mainly be found in other forest categories: so e.g. another 50% of the *k*-NN deciduous forest is classified as "young forest" or "clear felled" according to the SMD data set (codes 54, 55 or SMD codes 3.2.4.2 or 3.2.4.3) (Stockholms Universitet, n.d.) and only 7% are not considered as forest at all regarding SMD.

Vice versa 40% of the lacking SMD deciduous forest can be found for instance in *k*-NN pixel with 30% to 70% deciduous volume while in this case 11% are not defined as k-NN forest at all (see Appendix for more details).

The overlapping pixel indicating deciduous forest according to the definitions above in both raster files are most likely to represent a patch of deciduous forest in reality, as two independent investigations classified them that way. But the area itself of about 10,000 ha, representing 1% of the unified forest area of *k*-NN and SMD, appears too small considering the share of deciduous forest of 6% or 7% respectively regarding each source separately.

To derive a shape file containing the actual deciduous stands to be analysed the overlapping pixel serve as core elements. In addition the stands are based on a file containing all deciduous areas, *k*-NN as well as SMD derived.

As illustrated in figure 6 the file with the merged deciduous forest areas (b) is overlaid with the overlapping areas (c), from the resulting file (d) all those deciduous forest areas according to *k*-NN or SMD are extracted (4) which contain overlapping pixel, classified as deciduous according to both sources (e). In a last step polygons below a certain size are removed from the remaining pool (5) and the result is a file showing the deciduous stands to be analysed (f).

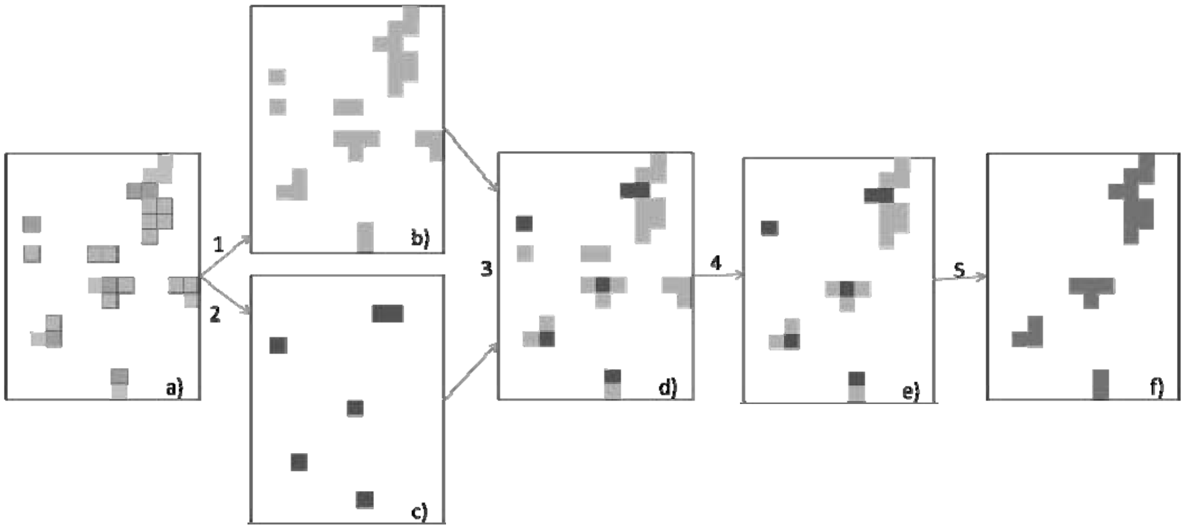

Figure 6: Scheme illustrating how the deciduous stands were derived from *k*-NN and SMD data sets. Section a) shows the comparison of SMD and *k*-NN deciduous pixel, one in red and blue respectively. Based on this file, b) and c) are created; b) representing the areas that are deciduous forest according to any source and c) outlining only those areas where both sources indicate deciduous forest. In step 3 both files are put on top of each other and in step 4 all pixel-polygons which do not contain any overlapping elements are removed. Finally patches which are too small to count as "stands" are removed from set e) in step 5 and the resulting file f) contains the deciduous stands to be analysed.

As the investigation aims at evaluating deciduous stands it does not seem reasonable to include single pixel in the analysis which happen to be deciduous dominated. Regarding the area loss by excluding small patches, falling below 0.25 ha or 0.5 ha respectively (table 5) it has been decided to include only stands of at least 0.5 ha size, as the area loss of the excluded pixel is not much bigger compared to investigating stands from a minimum size of 0.25 ha. Furthermore this is in line with the size the Forestry Act applies for defining noble broadleaf stands (Skogsstyrelsen, 2007). The remaining bigger pixel-polygons present the deciduous stands which are finally analysed and will be referred to as "deciduous stands" in the following text.

Table 5: Areas and area shares of the derived deciduous stands, intermediate steps as illustrated in figure 6 and total forest area

	Area [ha]	% of total forest area
Total forest area (***k*-NN or SMD based**)	707,700	-
Merged deciduous forest b) (***k*-NN or SMD based**)	77,500	11%
Overlapping deciduous forest c) (***k*-NN and SMD based**)	9,800	1%
Merged deciduous polygons containing overlapping e)	40,400	6%
Derived decid. stands >= 0.25 ha	38,700	5%
Derived decid. stands >= 0.5 ha	36,000	5%

The total deciduous stand area derived by this method has a size of about 36,000 ha and accounts for 5% of the unified *k*-NN and SMD forest area.

Comparing these stands back to the input data sets shows that the majority of the stand area has underlying k-NN (92%) as well as SMD (97%) data. When considering only the deciduous data its 49% of the stand pixel being deciduous according to *k*-NN and 74% regarding SMD.

3.2.4 Stratification

As the investigation of deciduous data in Kronobergs län shows later on the county is quite heterogeneous regarding for instance the density of deciduous pixel, or stands in a later analysis stage. Therefore it has been decided to create more homogeneous sub-units, e.g. for analysing spatial relationships, to achieve a reasonable scaling, as the heterogeneity of a landscape is to a certain extent scale-dependent (Ramezani, 2010) and investigating too large areas might fade out interesting regional differences. Furthermore the quality of the input data, showing clear borderlines between single satellite scenes used, suggests such a subdivision.

The stratification used in this thesis, illustrated in figure 7, is based on the mapped deciduous stands compared to the *k*-NN input files indicating the satellite scenes' borderlines. The idea was to achieve more homogeneous sub-areas with similar stand densities, incorporating the borderlines similar accuracy of *k*-NN input data within the strata and bigger differences between them can be expected.

Following this approach Kronobergs län falls into four strata: the West, obviously covering the western part of the county, the South in the southern central part followed in the north by the Center north which is in the north-east adjoined to the last stratum, the so called North-east.

The strata vary in their total size between 177,800 ha in the North-east and 272,900 ha in the West accounting for 19% to 29% respectively of the total county's area.

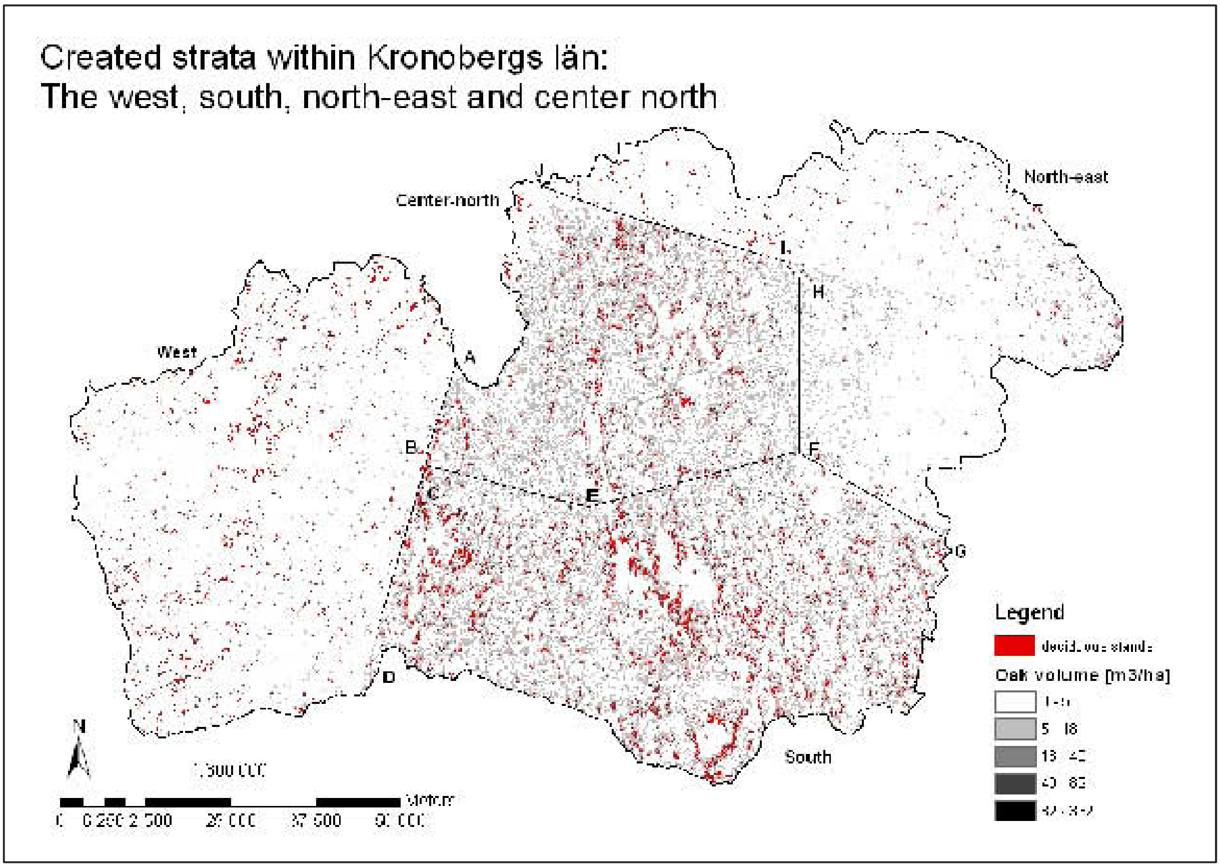

Figure 7: Stratification of Kronobergs län, illustrating the four strata: West, South, North-east and Center north. To get an idea of how the stratification has been done the oak volume is displayed in the background with the deciduous stands on top of it.

Table 6: Position of stratification corner points

Point	X value [m]	Y value [m]
A	1403800	6310425
B	1392330	6271522
C	1399227	6295368
D	1392381	6266275
E	1423275	6289285
F	1454283	6297498
G	1475875	6284619
H	1454283	6322853
I	1451927	6325488
J	1416550	6336388

3.2.5 Investigation

After deriving the deciduous stands they were analysed according to their area, deciduous volume, stand density, distance between them, distances regarding other land use classes, stand aggregation and age. Besides the total deciduous volume disregarding its location within the stand types has been studied for the whole county and its strata. Furthermore a brief investigation of the stands shape and their location compared to the county's topography has been undertaken.

To gain information about the deciduous stand area, number of stands, average stand sizes and age of the stand pixel ArcGIS has been used.

The deciduous volume was examined employing the *k*-NN volume information, processed in ArcGIS. For the total deciduous volume in the whole county only those pixel were accessed which hold a total volume of more than 5 m^3/ha, while the deciduous stand volume and the volume by strata is based on all available *k*-NN volume data.

Next to the stand density, the distances between deciduous stands and other land use classes have been studied using the tool "select by location" in ArcGIS, to identify stands in a certain distance to the land use types in question.
Regarding the distance between the stands the simple mean stand distance assuming regular distribution of the stands in the stratum in question has been calculated as illustrated in formula 3.

$$mean\ stand\ distance_i = \sqrt{\frac{A_i}{n_i}}$$

Formula 3
with: A the total land area of the stratum i in m^2 and n the number of deciduous stands located in the stratum i

To get another idea of the distances between the stands, the deciduous stand information has also been processed with Fragstats to derive data regarding the distance to the nearest neighbouring deciduous stand.
Unfortunately the Fragstats outcomes e.g. regarding number of deciduous stands differ from the ArcGIS results so they should not be compared directly. For that reason and due to the long processing time the mean nearest neighbour distance has only been calculated exemplary for the South and the North-east, where the biggest differences can be expected regarding the other results. Fragstats calculates the nearest neighbour distance as shortest Euclidean straight line distance "[...] based on patch edge-to-edge distance, computed from cell center to cell center." (University of Massachusetts Amherst, 2000).

As the polygons representing the deciduous stands are derived from raster files, their shape allows the identification of single pixel within them. Therefore the stand shapes are unnaturally jagged. For that reason the shape has been simply analysed by measuring the angle of the main polygon axis, the so called "polygon mean angle" to check for directional trends as it returns only the values "-90", "0" and "90" for these kind of polygons. Stand polygons with a value of either "-90" or "90" can be identified as having a north-south bearing while the stands with the value "0" are more aligned in east-west direction. Squared polygons are also classified as "0".
Another simple measure of a polygon's shape is the perimeter-area ratio, indicating if a stand is rather compact or more drawn-out (University of Massachusetts Amherst, 2000).
As the possible results of this measure cannot be compared between different polygon shapes and sizes the perimeter-area ratio for each polygon has been compared to the minimal possible perimeter-area ratio a given the stand size - a circle. This minimum-ratio allows the comparison of stands of the same size and has been investigated for the five largest size-groups of stands measured according to the number of stands they contain.

$$PerimeterArea\ ratio_i = R_i = \frac{p_i}{A_i}$$

Formula 4:
with: p the perimeter in meters of a polygon i and A the corresponding area in square meters

$$Minimum\ ratio_i = \frac{2}{R_i\sqrt{\frac{A_i}{\pi}}}$$

Formula 5:
with R the Perimeter-Area ratio of a polygon i and A the corresponding polygon area in square meters

To get an idea about the distribution of deciduous stands compared to the county's topography the stands have been linked to a digital elevation map in ArcGIS but due to the grid size of the elevation map of 50 m only very general conclusions can be drawn from this investigation.

3.3 Results – for whole Kronobergs län and the strata

The following chapter presents the outcomes of the investigation of deciduous stands in Kronobergs län and the created strata.

3.3.1 Area

The deciduous stands in Kronobergs län account for 5% of the total forest area, representing about 36,000 ha, following the definitions presented above (table 7). Comparing this share among the different strata shows some deviations from the average value: while the South comes with the highest deciduous stand cover of 9% of the forest area the North-east shows a contrasting trend with only 2% deciduous stands despite its high forest cover.

Noticeable is also how the deciduous stand area falls into the four strata, the North-east holds only 8% of the total deciduous stand area, while almost 50% are located in the South.

Table 7: Land area, forest area, deciduous stand area and their proportions, referring to total county and strata areas; forest areas are derived as joined SMD and *k*-NN forest data.

	Total area [ha]	**% share among the strata**	**Forest area [ha]**	**% share among the strata**	**% of forest cover**	**Decid. stand area [ha]**	**% share among strata**	**% of decid. stand area of total area**
West	272,900	29%	197,400	28%	72%	8,300	23%	4%
South	272,600	29%	197,400	28%	72%	17,900	49%	9%
North-east	219,400	23%	185,900	26%	85%	2,900	8%	2%
Center north	177,800	19%	126,200	18%	71%	7,300	20%	6%
Kronobergs län	942,600	100%	707,700	100%	75%	36,400	100%	5%

The applied definition of deciduous stands resulted in about 15,000 stands with an average size of 2.3 ha for the whole county. By definition the smallest stands have a size of 0.5 ha and the biggest stand examined located on the lakefront of the lake Mien in the south (Google Maps, 2011) exceeded 180 ha.

As table 8 shows in more detail, these values vary again among the strata: the South is richest regarding both, number and area of deciduous stands. Furthermore the average stand size of 2.8 ha in the South overtops the others and the biggest deciduous stands in absolute terms are located in this stratum. Contrasting fewest stands can be found in the North-east accounting for the smallest area, with the lowest stand sizes.

Table 8: Number and area of deciduous stands, their mean and maximal size in Kronobergs län and the strata

	Number of decid. stands	Decid. stand area [ha]	Mean stand size	Maximal stand size
West	4,000	8,300	2.1	71
South	6,400	17,900	2.8	181
North-east	1,900	2,900	1.5	35
Center north	3,300	7,300	2.2	98
Kronobergs län	15,600	36,000	2.3	181

Considering the size class distribution shown in figure 8 there is a clear dominance of small stands up to a size of five hectares, the stands exceeding 5 ha account only for 9% of the total stand number. Looking at the deciduous stand area illustrates that a large proportion, about 41%, is accumulated in stands of 1 to 5 hectare size, followed by 16% in the next size class: five to ten hectares.

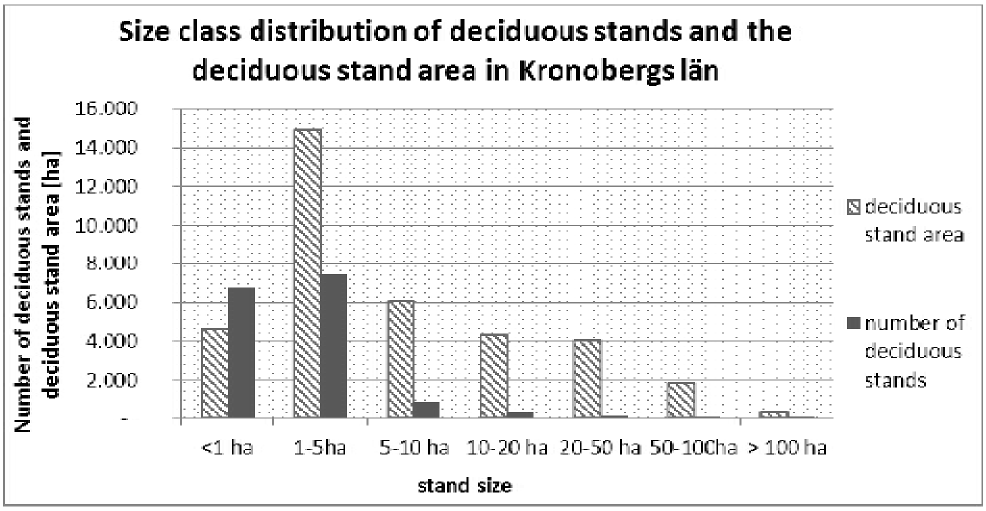

Figure 8: Size class distribution of deciduous stands and the deciduous stand area in Kronobergs län

These trends illustrated above for the whole county are quite similar among the different strata. Small deviations occur again in the South with a higher area share of the bigger stands and in the North-east demonstrating a complementary trend.

Using the *k*-NN volume information for the deciduous stand pixel on *k*-NN forest land gives an idea of the species composition to be found in the deciduous stands. Depending on the stratum 90% - 96% of the deciduous stand pixel have underlying *k*-NN data.

In a first step these deciduous stand pixel have been investigated regarding simply the presence of the different deciduous species in their total pixel volume.
As illustrated in below 99% of the whole stand area contain at least some birch volume, regardless of the stratum in question.
For the other species there are quite some variations among the strata. For instance pixel with beech volume account in the whole county, the West and in Center north for 36% to 48%. Contrasting, in the North-east only 4% of the pixel come with some beech wood, while there are 61% in the South having a beech volume proportion.
As figure 9 shows in most cases two species or more are present in at least 60% of the deciduous stand pixel, showing that there are almost no "pure pixel" with only one species present, in the whole county

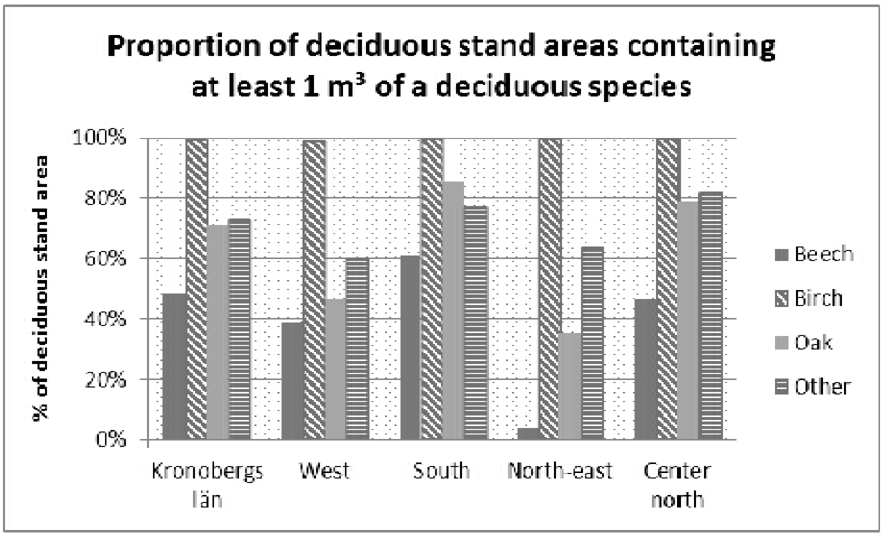

Figure 9: Proportion of deciduous stand pixel with *k*-NN data containing at least 1 m³ of beech, birch, oak and other deciduous volume respectively

In a second step the deciduous stand pixel have been analyzed regarding the prevailing species, according to their share of the deciduous pixel volume (>70%). As figure 10 illustrates 55% of the deciduous stand area can therefore be described as "mixed deciduous" as no species accounts for more than 70% of the deciduous volume in these pixel.
Another 41% of the stand area is birch dominated, 3% fall under beech control while other deciduous species as well as oak are dominating only 1% of the area each.
Again there are deviations among the four strata although mixed and birch dominated areas account consequently for more than 90% of the stand area.
Conspicuous is the highest share of 5% of beech dominated areas in the South contrasting the North-east with hardly any beech dominated patches but the highest proportion of areas under birch control and also the Center north where mixed stands with an area share of 66% are prevailing.

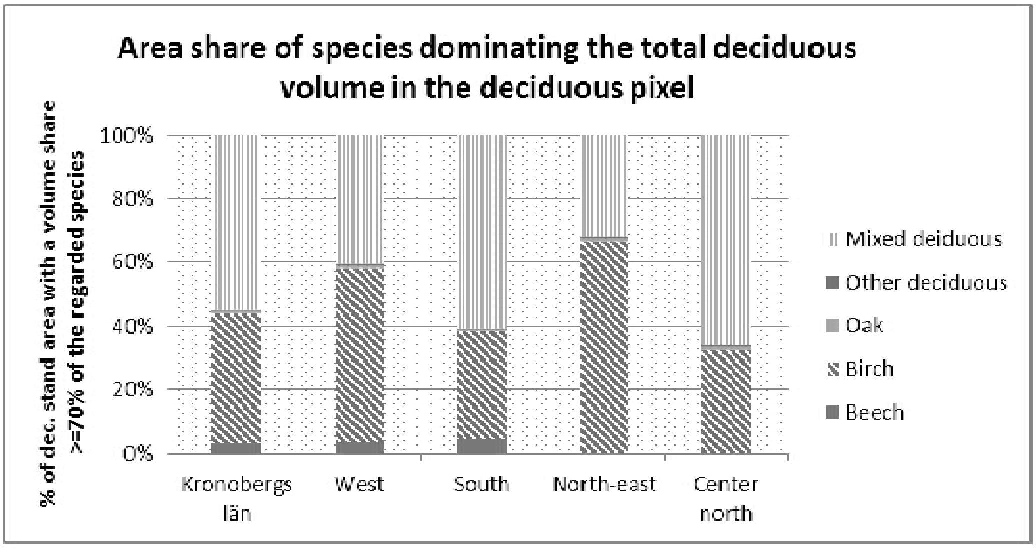

Figure 10: Proportion of deciduous stand pixel with *k*-NN data being dominated by one species, accounting for at least 70% of the deciduous volume

Locating the beech and oak dominated pixel shows that they are rather spread out among different stands than being aggregated in few. So this pixel wise investigation does not allow drawing conclusions concerning the actual species composition of stands.

3.3.2.1 Deciduous volume in Kronobergs län and strata

The investigation of deciduous volume in Kronobergs län's forests resulted in a total deciduous volume estimation of 15,476,000 m³ which represents about 15% of the total wood volume.
This is comparable to the estimations the Swedish Forest Agency published in 2010 of 18,200,000 m³ deciduous volume accounting for 16% of the total volume (Skogsstyrelsen, 2010).
According to the *k*-NN information incorporating only pixel with more than 5 m³/ha total volume 66% of this deciduous volume represents birch , 16% other deciduous species while 11% and 7% account for oak and beech respectively.

Looking into the different strata figure 11 shows quite a large proportion of the deciduous volume, representing a share of 36% can be found in the South, while the remaining amount is about equally distributed, 20% to 23%, among the other strata. Easily noticeable is also the importance of birch throughout the county.

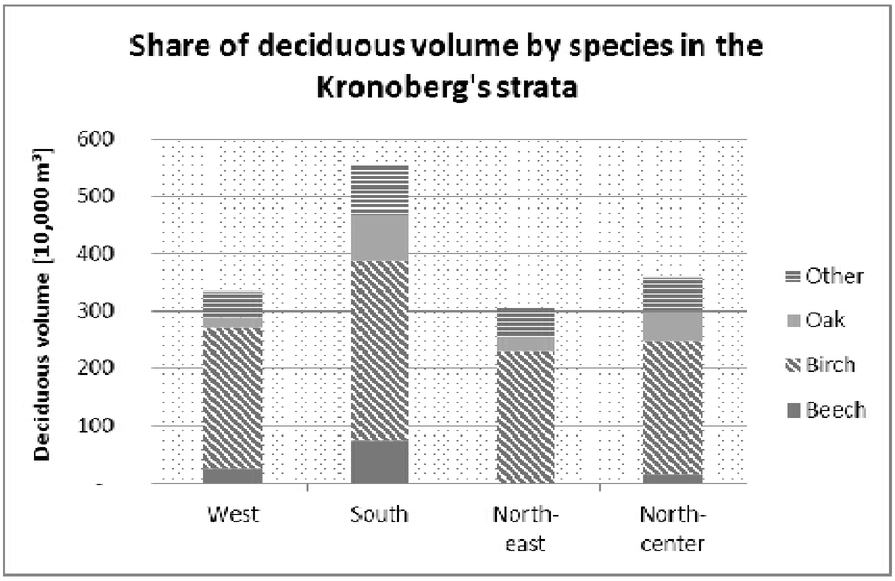

Figure 11: Share of total deciduous volume by species in the Kronoberg's strata, according to *k*-NN data

Most stable is the proportion of other deciduous volume ranging from 14% to 17%. In contrast beech and oak volume show a more heterogeneous distribution comparing the strata: While the share of beech volume varies between only 1% in the North-east and 13% in the South, the oak proportion ranges from 5% in the western part of the county up to 15% as well in the South.

3.3.2.2 Total deciduous volume in Kronobergs län in volume classes

To investigate in what kind of stands the deciduous volume can be found the *k*-NN volume data has been classified into ten volume classes (1 - 10) indicating an increasing share of deciduous volume in 10% steps (compare table 9).

The results show that most of the deciduous volume is actually not standing in deciduous dominated areas. Almost half of the deciduous volume can be found in coniferous dominated volume classes (classes 1 - 3) covering more than 70% of the forest area.
Only 19% of the deciduous volume is located in areas dominated by deciduous trees (volume classes 8 - 10) representing merely 8% of the forest land.
The remaining "mixed" volume classes (classes 4 - 7) contain 32% of the deciduous volume and cover the residual 13% of the area (Table 9, figure 12).

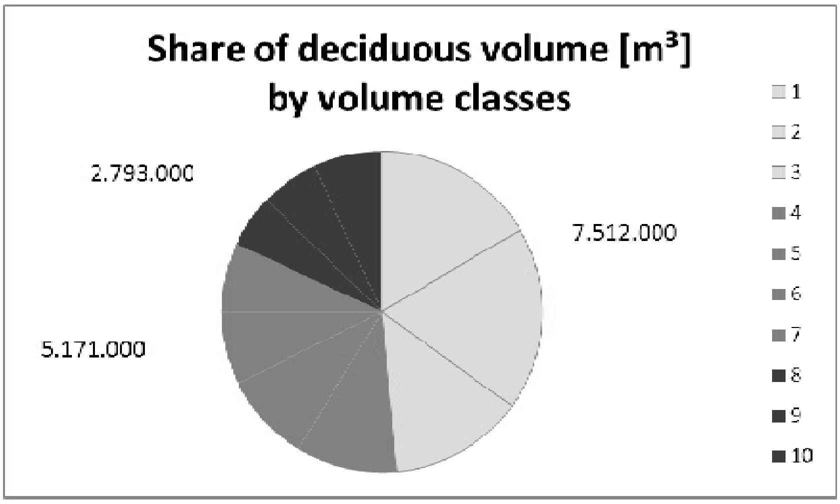

Figure 12: Share of total deciduous volume by volume classes in Kronobergs län according to *k*-NN data, excluding information from pixel with 5 m³/ha total volume or less. Light green presents conifer dominated classes, green mixed classes and dark green stands for the deciduous dominated volume classes.

Table 9: Deciduous volume according to *k*-NN data in Kronobergs län: explanation of volume classes, associated areas and volume. Excluding information from pixel with 5 m³/ha total volume and less

Volume class	Deciduous volume share	Term	Area		Deciduous volume	
			Area [ha]	Relative	total deciduous volume [m³]	Relative
1	- 10%	conifer dominated	248,380	43%	2,552,000	16%
2	11 - 20%		114,610	20%	2,864,000	19%
3	21 - 30%		58,150	10%	2,096,000	14%
4	31 - 40%	mixed	39,630	7%	1,573,000	10%
5	41 - 50%		30,850	5%	1,384,000	9%
6	51 - 60%		22,810	4%	1,138,000	7%
7	61 - 70%		17,250	3%	1,076,000	7%
8	71 - 80%	deciduous dominated	12,640	2%	821,000	5%
9	81 - 90%		13,470	2%	905,000	6%
10	91 - 100%		18,470	3%	1,067,000	7%
1-3	- 30%	conifer dom.	421,140	73%	7,512,000	49%
4-7	31 - 70%	mixed	110,540	19%	5,171,000	33%
8-10	71 - 100%	decid. dom.	44,580	8%	2,793,000	18%
Total			576,260	100%	15,476,000	100%

Here as well, birch has consequently the biggest share in all volume classes, but it is less represented in the deciduous dominated areas. Therefore beech, oak and the other deciduous species show a general trend the other way round; their volume proportions tend to increase with the volume class as illustrated in figure 13.

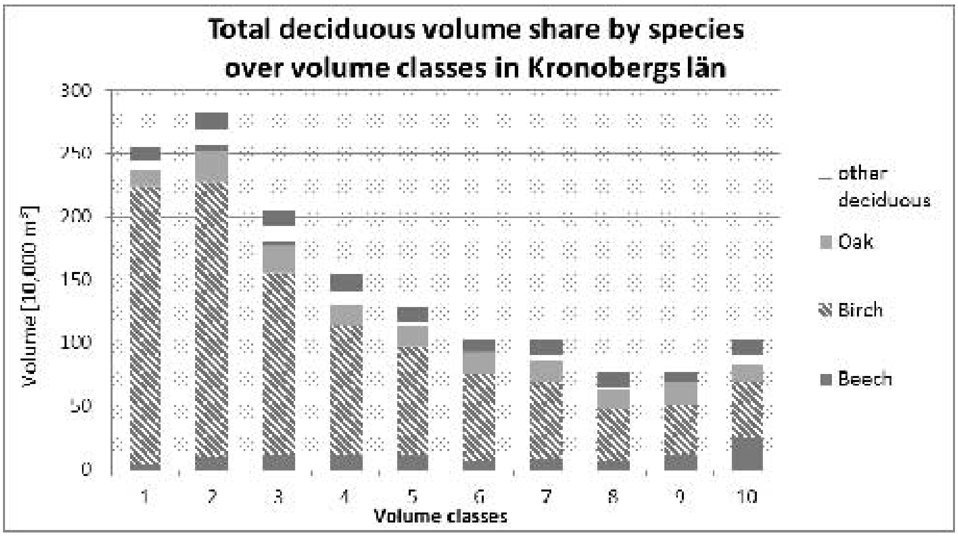

Figure 13: Total deciduous volume share by species, according to *k*-NN data within the volume classes 1 - 10

Regarding the volume ratio between the different classes within a species reveals quite different patterns comparing the species. Figure 14 shows e.g. for birch, that only a minority of its volume is accumulated in the deciduous dominated areas, while almost 60% can be found in the volume classes 1 to 3.

Beech wood on the other hand is not very common in coniferous dominated parts and 40% is standing in the classes 8 to 10.

Finally oak and other deciduous species' volumes show a fairly equal distribution among the volume classes; 27% and 26% respectively is accumulated in the deciduous dominated classes.

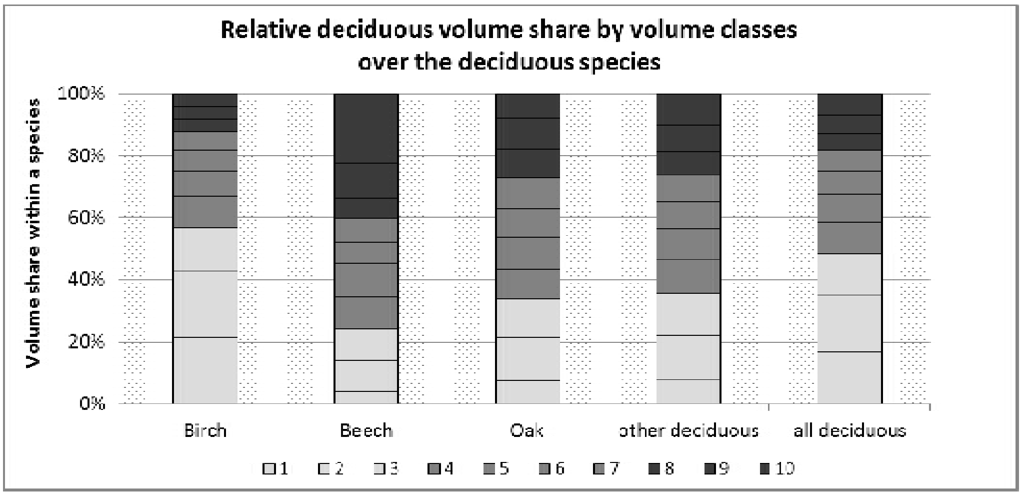

Figure 14: Relative share of the total deciduous volume according to *k*-NN data in Kronobergs län in volume classes. Light green presents conifer dominated classes, green mixed classes and dark green stands for the deciduous dominated volume classes.

Applying species dependent volume classes (figure 15) depicts that there is only little volume stored in the classes dominated by a single species.

For instance only 2% of the birch volume is to be found in areas dominated by birch. Oak dominated classes contain less than 1% of the total oak volume. The only exception are the other deciduous species where more than 20% of their volume stands in areas dominated by them.

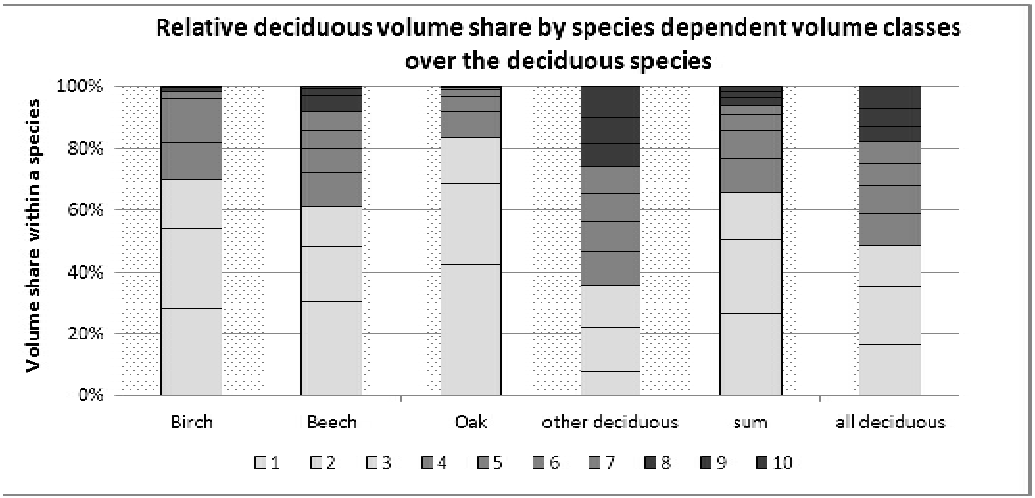

Figure 15: Relative share of the total deciduous volume according to *k*-NN data in Kronobergs län in species dependent volume classes. E.g. birch volume class 1 comprising a birch volume share up to 10%. Light green presents conifer dominated classes, green mixed classes and dark green stands for the deciduous dominated volume classes.

3.3.2.3 Deciduous volume in the deciduous stands in Kronobergs län and strata

After examining the total deciduous volume this sub-chapter focuses on deciduous volume standing in the defined deciduous stands in Kronobergs län and its strata. Since volume information can only be derived from *k*-NN pixel, the following results cover only the 90% - 96% of pixel, depending on the stratum, which contain underlying *k*-NN volume information.

As table 10 illustrate the proportion of deciduous volume standing in the deciduous stands compared to all the deciduous volume in the forest varies depending on the species in question.
On average 13% of all the deciduous volume is located in deciduous stands, while e.g. only 10% of the total birch volume can be found in deciduous stands or one fourth of all beech wood is standing there.

Table 10: Deciduous volume in deciduous stands and its proportion of total deciduous volume, according to *k*-NN data

Species	Deciduous volume in deciduous stands [m³]	Share of total deciduous volume
Beech	288,000	25%
Birch	1,040,000	10%
Oak	345,000	20%
Other deciduous	398,000	16%
All deciduous	2,071,000	13%

Noticeable are also the differences found comparing the four strata shown in figure 16. While the South shows once more the highest presence of deciduous volume in deciduous stands as well for all species as for each species individually (16% to 27%) only 4% of the deciduous volume can be found in deciduous stands in the North-east. Trends among the species' representation in the stands is generally quite similar: apart from the North-east where oak takes to role of beech, beech is always the species with the highest volume share within the stands, ranging from 21% to 27% and for birch it is always the smallest with 3% to 16% including the North-east in this case.

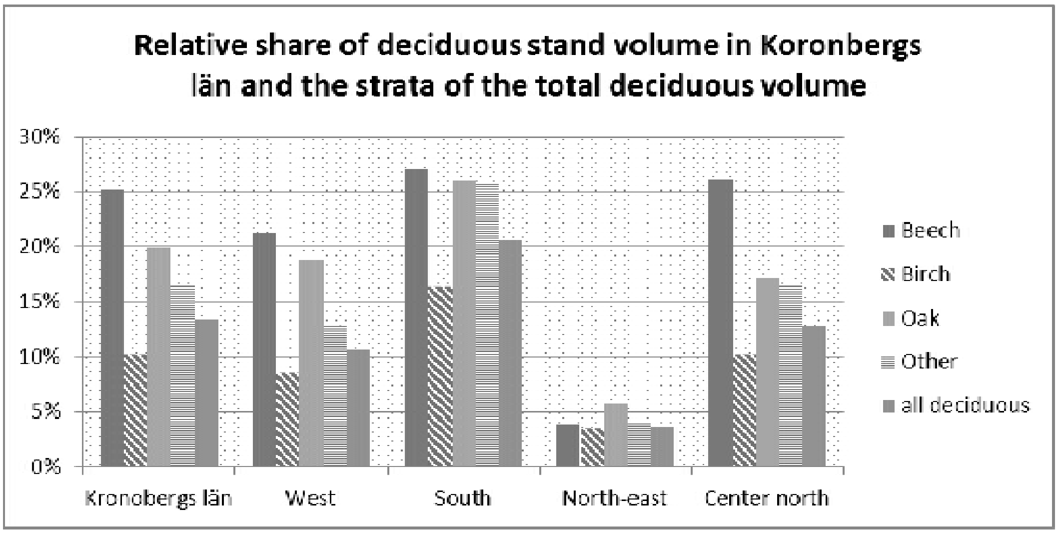

Figure 16: Relative share of deciduous volume by species presented in decidous stands in Kronbergs län and the strata, according to *k*-NN data

Regarding the share of the 2 million m³ deciduous volume in deciduous stands among the strata, table 11 shows that it is much more heterogeneously distributed than the total deciduous volume. While for the latter each stratum accounts for a share of 20% to 36%, the ratios for the stand volume vary between 5% of deciduous volume standing in deciduous stands the North-east and 55% located in the South.

Table 11: Distribution of deciduous volume and deciduous volume in deciduous stands among Kronobergs län and the strata

	Deciduous volume [m³]	% share among strata	Deciduous volume in decid. stands	% share among strata	% decid. stand volume of total decid. volume
West	3,335,000	22%	353,000	17%	11%
South	5,551,000	36%	1,145,000	55%	21%
North-East	3,038,000	20%	112,000	5%	4%
Center north	3,577,000	23%	460,000	22%	13%
Kronobergs län	15,502,000	100%	2,071,000	100%	13%

These 55% accounting for 1,145,000 m³ deciduous volume contain furthermore the highest total volume of each species compared to the other strata. Moreover the South is the stratum with the highest relative share of beech and oak volume and the smallest proportion of birch volume, as it was also the case for the total deciduous volume.

Considering the deciduous volume share of species in the deciduous stands in the whole county (Figure 17) it is remarkable that birch still accounts for 50% although the vast majority of the birch volume is actually standing outside those areas. The proportion of the remaining species is quite equal: 14% beech volume, 17% oak volume and 19% volume of other deciduous trees.

Compared to the total deciduous volume the ratio of beech, oak and other deciduous volume in the stands has increased not only on a county scale but also in each stratum at the expense of birch. The only exception here is the beech volume in the North-east, beech accounts for 1% of the total deciduous volume in this stratum and has the same share within the deciduous stands. The North-east also holds the largest relative share of birch volume, accounting for 69% of the deciduous stand volume.

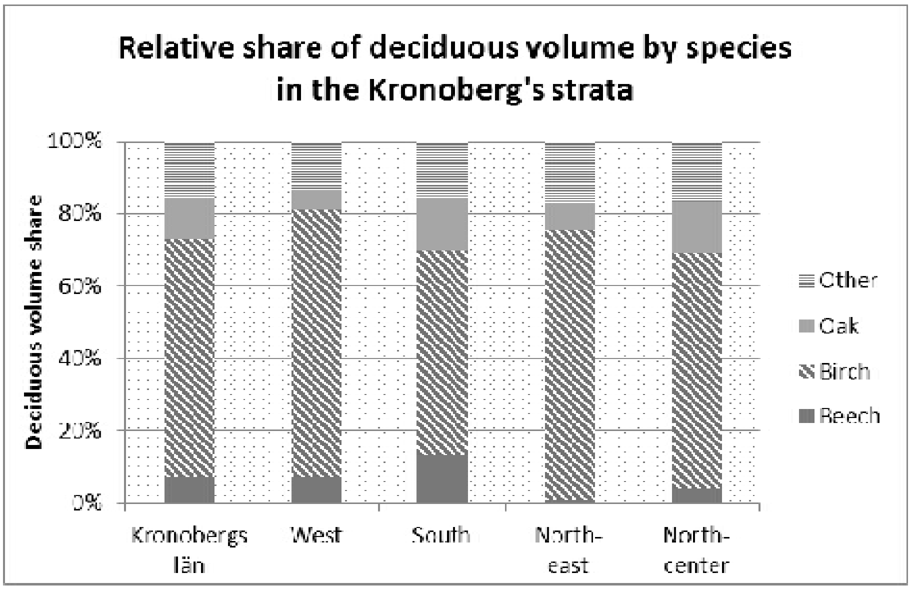

Figure 17: Relative deciduous volume share in deciduous stands within the Kronobergs län's strata by species, according to *k*-NN volume data of the defined deciduous stands

3.3.3 Shape and elevation

The rough shape investigation by examining the stand polygons mean angle resulted in a majority of stands being drawn-out northwards.
About 63% of stands have their main axis in north-south bearing rather than in east-west direction or without directional trend.

The minimum-ratios, comparing the minimal possible perimeter-area ratio for a given stand polygon to its actual perimeter-ratio has been studied for the stands with the most frequently occurring stand sizes. The comparison shows that only few stands are compact, 68% of the stands have a minimum-ratio value falling below their minimum-ratio 's mean and can therefore be regarded as drawn-out.

Investigating deciduous stands regarding the county's elevation illustrated in figure 18 indicates first of all that most of the stands can be found on an elevation between 175 and 250 meters height above sea level (table 12).
Taking into account the differing areas belonging to a certain elevation range shows on the other hand that the stand number tends to decrease in frequency with increasing elevation. While 3% of the lower areas (100-175 m .a.s.l.) are covered by deciduous stands distributed in about 16 deciduous stands per 1,000 ha, only 1% of the high elevation areas (> 250 m a.s.l.) account for deciduous stands with about 7 stands per 1,000 ha.

Table 12: Deciduous stand distribution depending on different elevations

Elevation [m above sea level]	Area share of elevation group	Share of decid. stand number	Share of decid. stand area	Share of decid. stand area of the total group land area	Stand density per 1,000 ha
100 – 175 m	35%	42%	46%	3%	16
175 – 250 m	54%	52%	50%	2%	12
> 250 m	11%	6%	4%	1%	7

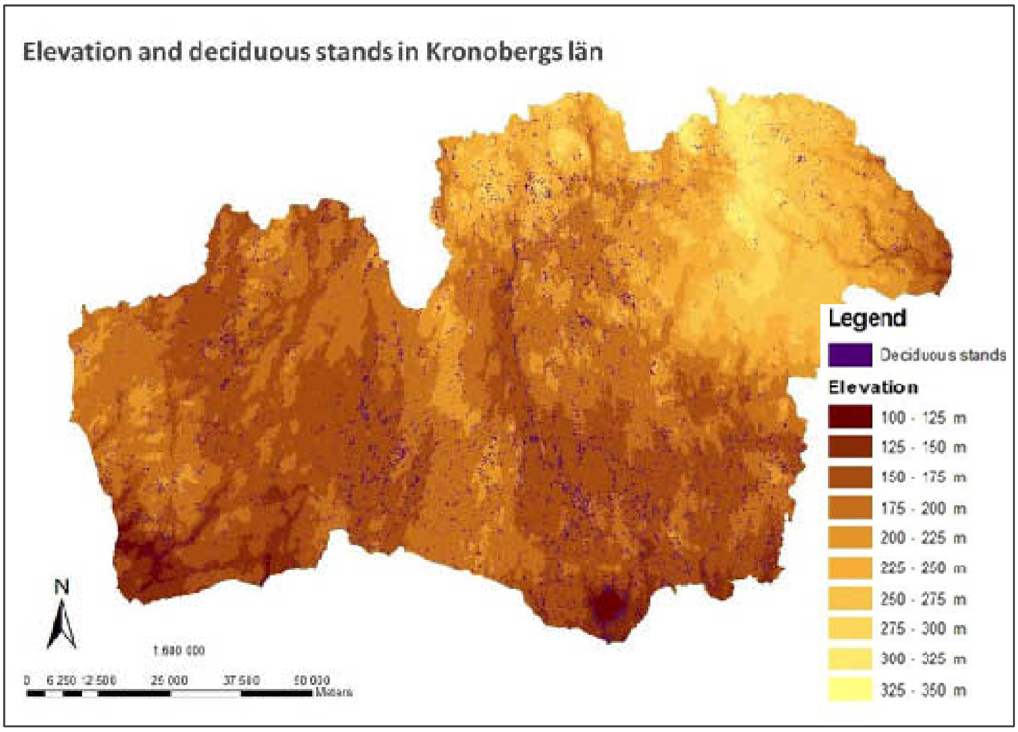

Figure 18: Elevation and deciduous stands in Kronobergs län

3.3.4 Density and Distances

After examining the deciduous stands' area and volume, the following sub-chapter focuses on stand density, distances between the stands themselves and the stands and other land cover.

Recalling the results from the deciduous stands and their areas the outcome of the investigation of the stand densities is not surprising. Regarding an example area of 1,000 ha the average number of deciduous stands which can be found in the different strata varies between 9 in the North-east and 24 in the South. For the whole county the deciduous stands occur with a density of 17 stands per 1,000 ha also presented in table 13.

Using the strata's area and the number of deciduous stands within there the average distance between the stand centres assuming a regular distribution has been calculated. The results (table 13) show that following this approach the deciduous stands in the North-east are more than one kilometre away from each other, while the average value for the whole county indicates a distance of 780 m and 650 m for the deciduous rich South.

To receive an impression regarding a stands closest neighbouring deciduous stand the program Fragstats has been applied to derive data about the South and the North-east with the difficulties explained in chapter "Investigation”. It resulted in a mean nearest neighbour distance of 150 m for the South and almost twice that distance for the North-east.

Although the mean distance assuming a regular distribution and the nearest neighbour distance are not directly comparable as they have been processed in different programs the big difference between them allows the conclusion that the deciduous stands occur rather clumped than regularly distributed.

Table 13: Deciduous stand densities and mean distances between stands and nearest neighbours. Mean distance is derived assuming a regular distribution of stands, measured from plot centre to plot centre, mean distance to the nearest neighbour is derived from Fragstats and therefore not directly comparable to the other results exemplary for the South and the North-east, due to differences

Stratum	Total area [ha]	No. of decid. stands	Decid. stand density per 1,000 ha	Mean distance between decid. stands [m]	*Mean distance to nearest neighbour [m]*
West	272,900	4,000	15	830	
South	272,600	6,400	24	650	*150*
North-east	219,400	1,900	9	1.070	*290*
Center north	177,800	3,300	19	730	
Kronobergs län	942,600	15,600	17	780	

To compare the deciduous stand distribution also concerning other land cover classes: the distances to urban areas, agricultural areas and water surfaces according to SMD were investigated. Under urban areas the codes 1 to 9 and 13 to 20 (or SMD codes 1.1.1, 1.1.2.1.1, 1.1.2.1.2, 1.1.2.2, 1.1.2.3, 1.2.1 - 1.2.4, 1.3.3, 1.4.1 and 1.4.2.1 - 1.4.2.6) were considered, agricultural areas include codes 30, 31 and 32 (or SMD codes 2.1.1, 2.2.2 and 2.3.1) and lakes and water courses (code 80 and 81 or SMD codes 5.1.1 and 5.1.2.1) account for water surfaces (Stockholms Universitet, n.d.).

Paying attention to all those classes at the same time reveals that 77% of all the deciduous stands are adjoined directly to some extend with these areas, illustrated by figure 19.

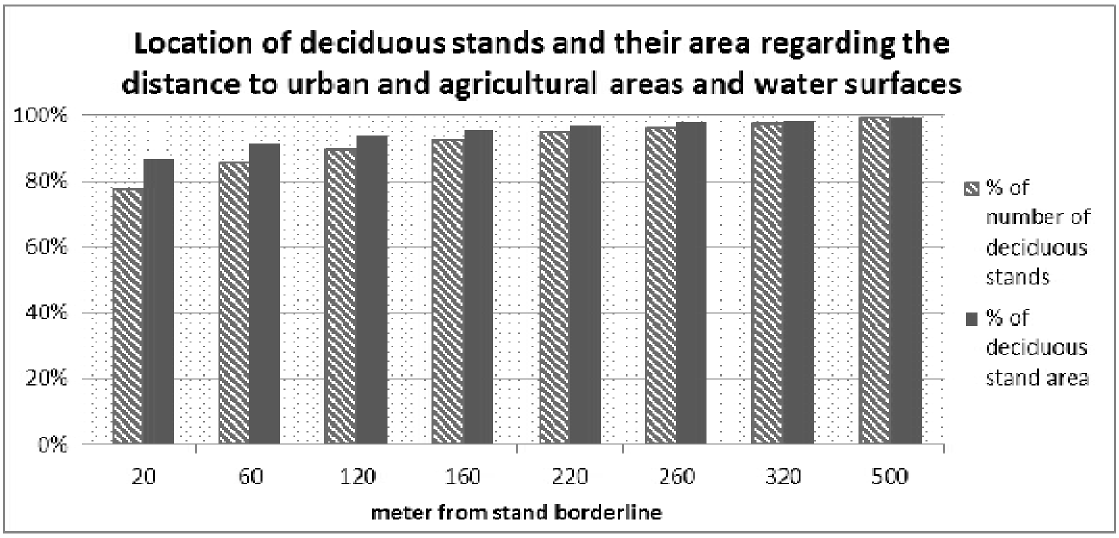

Figure 19: Location of all deciduous stands and their area regarding the distance to urban and agricultural areas and water surfaces in relative terms. The scale shows the distribution regarding the total number of deciduous stands in each case. The distance in meters is chosen regarding the background of the polygons as pixel based data, each step includes the next two pixel rows or columns.

The diagram also shows a trend we can find consequently in all strata: that the share of the deciduous stand area is always exceeding the share of stand quantity, so it can be concluded that the average stand close to urban and agricultural areas or water surfaces is bigger than the once further away.

Noticeable here is particularly the average size of stands neighbouring lakes and water courses which is more than twice as big as the average stand.

Table 14: Average stand sizes of deciduous stands directly adjoined (20 m distance) to urban, agricultural areas and water surfaces. Also compared to the mean stand size of 2.3 ha in the whole county.

	Urban areas	Agricultural areas	Water surfaces	All
Average stand size of adjoined deciduous stands [ha]	4.1	2.6	5.9	2.6
% of mean stand size	177%	113%	257%	112%

Splitting the information into the different land cover types points at the differences between the these : while 73% of the number of deciduous stands, accounting for 83% of the stand area (figure 20) are adjoined to agricultural areas and additional 45% are furthermore neighbouring urban areas, only 25% of all deciduous stands are located directly next to water surfaces.

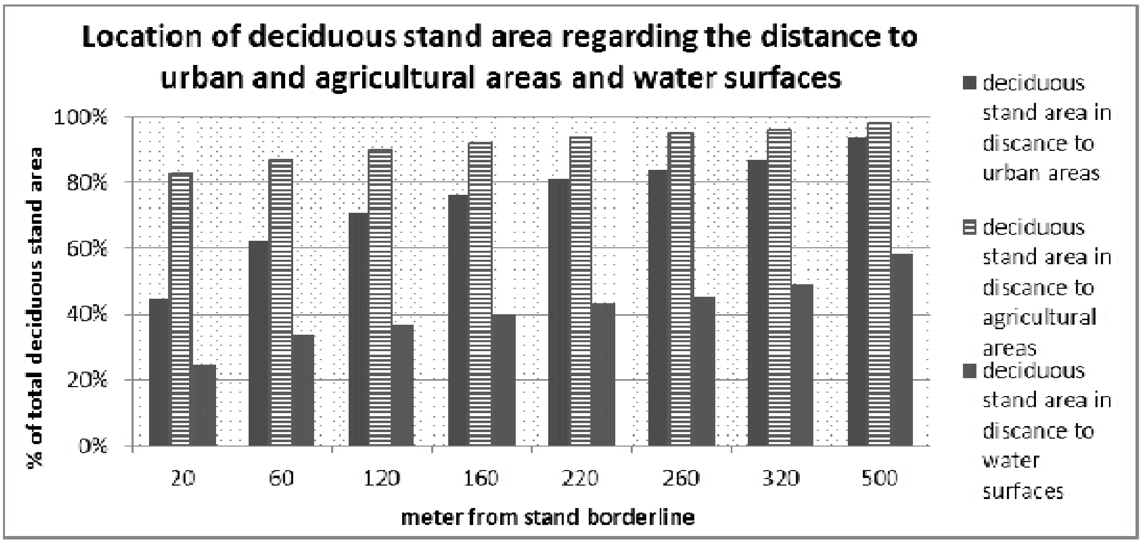

Figure 20: Location of the area of deciduous stands regarding the distance to urban and agriculutural areas and water surfaces.

Besides the distribution of deciduous stands with regard of their distances to roads has been investigated. The results show a big similarity with the patterns found for urban areas, 51% of the stands are neighbouring road sites, accounting for 71% of the stand area.

3.3.5 Age

Finally the deciduous stands have been analysed regarding their age based on underlying *k*-NN data. Figure 21 shows a clear trend of decreasing deciduous forest area with increasing stand age; almost 50% of the deciduous stand pixel is younger than 30 years.

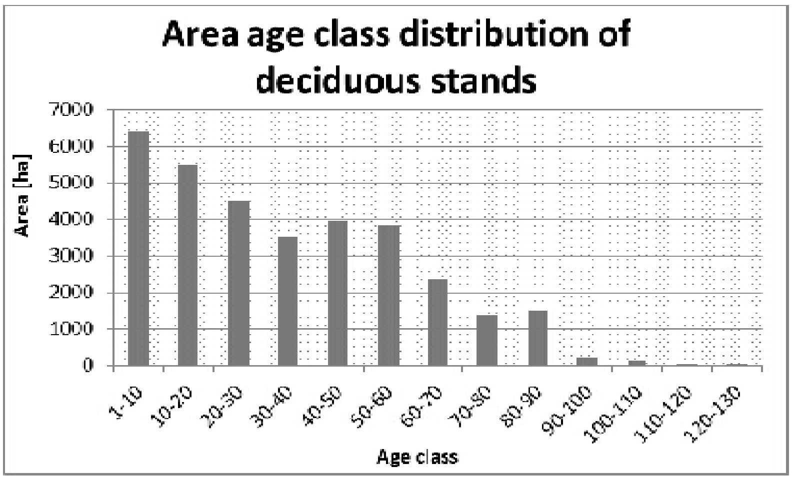

Figure 21: Age class distribution of deciduous stand area pixel, according *k*-NN data

Comparing this to the age class distribution of all deciduous pixel in Kronobergs län shows a deviating pattern. Here the first three age classes contain a higher area share covering more than 60% of all the deciduous pixel. So, while the deciduous stand pixel are on average 30 to 40 years old the deciduous pixel in general are about ten years younger. Therefore deciduous trees in deciduous stands tend do be older than the once growing e.g. within a coniferous production stands.

Displaying the stands' age resulted in hardly any neighboring deciduous pixel to be the same age. Figure 22 illustrates these differences to be still apparent even after grouping the ages into three age classes.

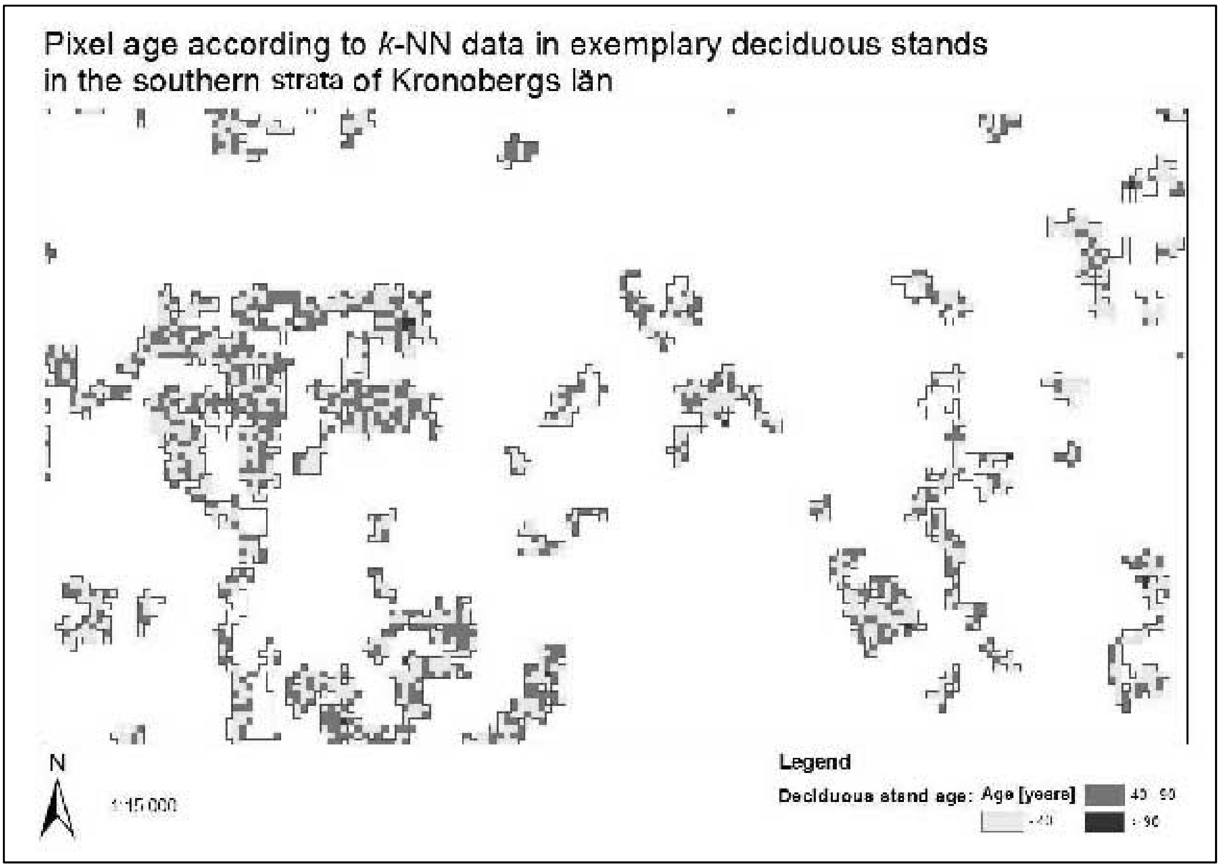

Figure 22: Pixel age according to k-NN data in exemplary deciduous stands in the southern stratum of Kronobergs län, outlined: deciduous stands

3.4 Discussion

Looking back on the results presented above it is important to keep in mind on what kind of information they are based on. The deviations between the two underlying data sets and the inconsistency within the *k*-NN data which have been discussed in the beginning might not seem very encouraging to serve as background for an investigation of deciduous stands.

On the other hand these are the "best" data accessible at the moment and the derivation of the deciduous stands as well as the stratification of Kronobergs län has been designed to reduce misinterpretations and hopefully improved the final results.
Regarding the inaccuracy of the input data these results can hardly present the exact true values for the "real" deciduous stands out there in Kronobergs län, but they can give us an idea about trends and circumstances and serve as reference point for more detailed future investigations or inventories.

One of the most important and therefore most questionable steps taken is the derivation of the stands themselves. A stand, often defined as silvicultural treatment unit is not too easy to derive from volume proportions and species information.
One could argue that the incorporation of the stands' heights or age would have been a useful step, but this would have probably led to even more deviations between the data sets on the one hand and furthermore I think that the importance of deciduous stands is based first of all on the associated ecological values.
A stand under these circumstances represents in my opinion therefore more an ecological - than a management unit. Following this approach I judge species and volume information to be most important to derive deciduous stands regarding the *k*-NN source.

The chosen way of deriving the deciduous stands was done taking into account the deviations in the data sets assuming an equal reliability of both sources. The core of the applied method represent those areas which both investigations defined independently as deciduous dominated. In these cases it is most likely that the digital pixel really refers to some deciduous forest. Furthermore the finally derived deciduous stand area is quite similar to the area share the two input data sets result in. For these reasons I think that the undertaken steps are reasonable, effectively incorporating both sources.

The previous pages present numerous tables and diagrams regarding the volume distribution among the deciduous species or to be more accurate species groups between which the *k*-NN data differentiate.
The division into birch, beech and oak seems useful and reasonable but concerning the group of all remaining species referred to as “other deciduous” seems to me unsatisfactory. The main problem I see is that all other ecologically valuable forest tree species like lime or goat willow are grouped together with deciduous trees grown for energy purposes like hybrid aspen or other fast growing poplar species.
With the increasing interest in bioenergy these species, playing a minor role today, are likely to gain importance as well and although today mainly found on agricultural areas might influence forestry in future (Johansson, 2003). In that case I think it is of interest to be able to distinguish between them as energy forests differ in their silviculture, appearance and ecology substantially from the "usual” deciduous stands.

Recalling the results for the deciduous stand area the first remarkable figure was 5%: 5% of the forest area account for deciduous stands, at least following the assumptions and definitions applied in this thesis.
According to the recent Swedish National FSC Standard this is the minimum area share a forest holding has to have on "mesic and moist” forest land (FSC, 2009).
This would mean, that Kronobergs län as whole is scarcely able to meet the FSC standard regarding this criterion. For the North-east it looks even worse: even if it is able to double its deciduous stand area it would still fall under the threshold value of 5% - as it is now.

After examining the total stand area the analysis' outcome showed that the average stand has a size of 2.3 ha, more than 90% of all the stands cover 5 ha and less.
This leads to the question regarding the effect of such a stand size: following an ecological approach and regarding the deciduous stands as islands in a coniferous dominated matrix, as the island ecology

does, stresses their importance of supporting populations of organisms depending on deciduous trees.
There are of course big differences within the plant, animal or fungi species relying on the deciduous forest trees but knowing the stands' size class distribution we can focus on the question: Are 2.3 ha or more general less than 5 ha enough to support the majority of those species and are the others able to overcome the distances between the stands?
Also interesting might be the effect of such a stand size on the forest management ,for a large scale forest owner such patches might be too small to be considered separately and become therefore neglected. Contrasting for a small private owner it might be just the right size to be managed by him or herself and maybe of special interest.
In connection to this it would furthermore be good to know the ownership structure of the deciduous stands also regarding target groups for forest policy when it comes to deciduous forest.

The volume analysis in the next step has shown: when talking about Kronobergs län's deciduous volume in general we mainly talk about birch, even when focussing on volume in deciduous stands still half of it accounts for birch and a large share of the deciduous stand area is dominated by this genus.
A rather big proportion of birch is actually not surprising regarding its biology; the light demanding pioneer species produces enormous amounts of wind dispersed seeds which are quite far reaching. Fast growing in the beginning birch is one of the typical colonizers of clear cut areas or abundant field sites. As a pioneer it does on the other hand not grow very old, cannot stand shady conditions and would therefore not appear in following successional stages (Evans, 1984).
This allows the conclusion that many of the broadleaf stands we can find were not continuously covered by forest for more than one tree generation and are neither very old compared for instance to an oak's life span.

Considering the volume distribution in general it is remarkable that most of the deciduous volume can be found within coniferous and mixed stands.
From an ecological point of view these trees are important for biodiversity and can serve as partial habitats or stepping stones depending on the species in question (Felton et al., 2010a, Fischer et al., 2006). Taking this perspective it would be important to keep these trees within the conifer stands - especially old trees with typical features occurring only with a certain age - but therefore they require a certain management attention. To develop big and healthy crowns oak and birch for instance cannot tolerate much competition for light and competitors need to be taken away more often than a standardized spruce thinning program would allow.
This demand for a more selective forest management is quite contrasting to the recently applied large scale silviculture, although it obviously results in quite some quantity of deciduous trees in the conifer dominated stands it lacks the quality required.

When investigating the stand distribution with regard to other land cover classes I thought it was quite surprising that 77% of the stands are to some extend adjoined directly to one of the land use classes considered.
A possible explanation for this trend could be the recreational value of deciduous stands and therefore their importance close to urban areas and lake sites.

Interesting is also the trend of the stand size to be biggest close to water surfaces. Besides the forest aesthetics this could be naturally due to the water level that has been observed during the last decades, creating areas of primary succession promoting wet deciduous forest types (Sallnäs, 2011).
The stand distribution has been analysed up to a distance of 500 m by this stage most of the stands, often exceeding 95%, were covered. So we can conclude the other way round that only very few and on average comparable smaller stands are far away from urban and agricultural areas and water surfaces. Those stands are again of certain importance regarding nature conservation values, embedded in a coniferous matrix they present small biodiversity hotspots and would therefore need special attention from a management point of view.

The investigation of the pixel's age first of all illustrates again problems with the *k*-NN data. Hardly any neighbouring pixel have been detailed the same age and in many cases not even a similar one. Still the overall trend, a decreasing deciduous area with age is not unexpected. Interesting is also that deciduous pixel in general compared to those in the deciduous stands, are on average younger and the proportion of older pixel is much smaller. It seems that deciduous trees grouped in bigger stands have a greater chance to grow old than small groups or single trees admixed into conifer stands.
On the other hand the comparable small share of very young pixel regarding all deciduous pixel in the age of 1 to 10 was surprising. I thought this proportion to be bigger as the recently regenerated stands, before the first pre-commercial thinning usually have a substantial share of naturally regenerated birch.

Among the trends found for the deciduous stands in Kronobergs län the differences between the four strata, especially the South and the always contrasting North-east are furthermore remarkable. Possible explanations for this pattern can be for example due to deviating climate, topography, residential densities or differences in the forest management. But the information itself can play an important role for forest policy regarding e.g. possible promotions of an increased share of deciduous stands: now we know it would be more important to implement it in the North-east rather than in the South.

Partly based on the character of the input information, partly due to the temporal limitations a thesis work implicates some of the deciduous stand properties were investigated only in a simple way and hold probably much more interesting and also important details, like the for instance the analysis of the stand shape or the stand aggregation. Therefore I hope that these first rough results lead to further research into these directions.

4 Simulation

The investigation of the deciduous volume and especially the deciduous stands in Kronobergs län has resulted in numerous numbers and figures presented in the previous chapter. Assuming these figures to be not too far from the reality and knowing about the importance of deciduous trees first and foremost for biodiversity and nature conservation leads almost automatically to the question regarding the situation's evaluation: is the deciduous share big enough, is the stand size sufficient, or are the stands close enough together to anticipate a further decrease of biodiversity?

Although we are able to describe our forest landscape in a rather detailed way, science is still lacking tools to evaluate this information on a general level regarding its quality for biodiversity. For single species such analysis have been undertaken (e.g. Carlson, 2000) but this implies detailed knowledge about the species in question and reference data, e.g. from undisturbed ecosystems. However the results indicated by such studies not very promising, authors have stressed before that our current forest ecosystems are too hostile for many forest living species (Gärdenfors, 2010). But the question how much we need to change and what would be the best way to do it remains unanswered.

The forest planning cycle, introduced in the beginning, identifies the point "management alternatives" as the step following the data collection to approach general planning problems.
Due to the rather undefined target of increasing the deciduous share the new FSC standard will serve as reference point. It also acknowledges the insufficiency of the current deciduous state and aims at stricter standards for the Swedish forests. Since June 2010 they request a 10% share of deciduous volume in final felling stands which can be lower either if 10% of the forest area set aside for nature conservation or 20% of the production forest area are stocked with deciduous stands.
For the forest owner this is not an easy task, there are now three opportunities between which he has to choose and there are many ways how these targets can be met. Therefore the following chapter tries to compare some of these possibilities as indicated in the planning cycle via projections and evaluates them both from a production as well as from the nature conservational perspective.

4.1 Materials and methods

The comparison between different cases illustrating different ways how the new FSC standard can be met uses a small forest landscape and simulates the forest development for the next 75 years according to the current forest state and chosen management alternatives.

4.1.1 Simulation square data

The simulations are based on a 5 km x 5 km square located in northern Kronobergs län, in the west of the lake Helgasjön (table 16). These 25 km² illustrated in figure 23 vary in its elevation from about 150 m above sea level to about 205 m.

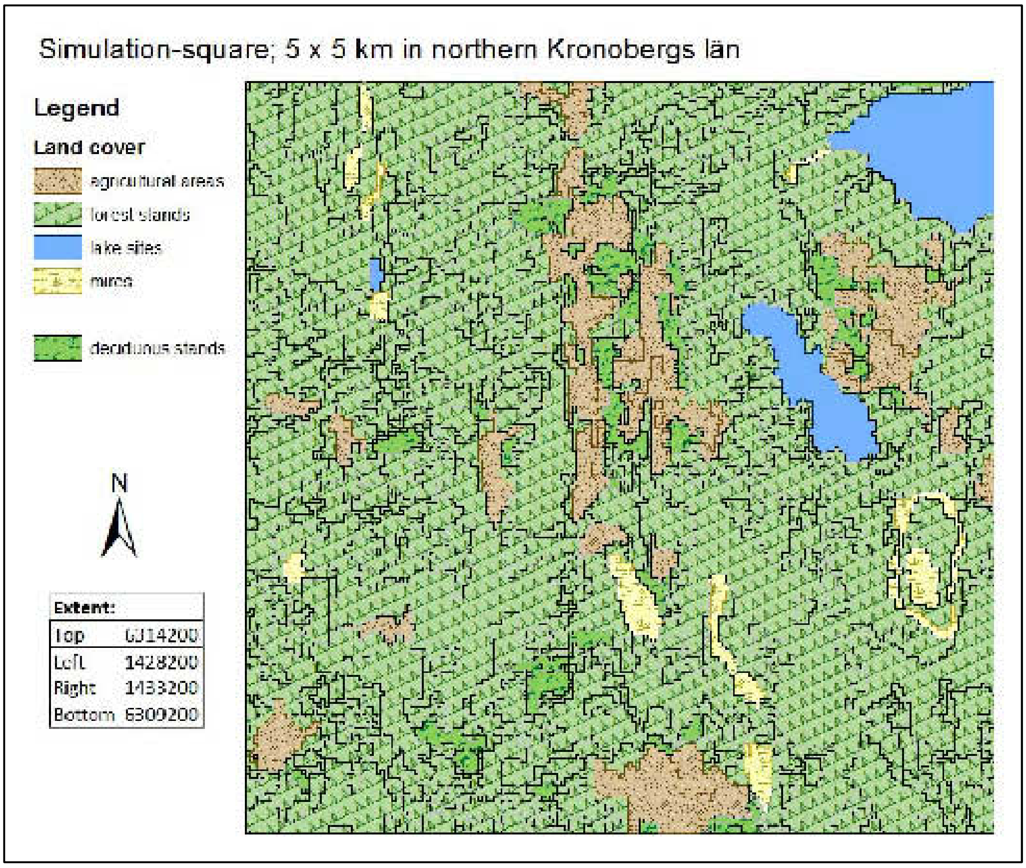

Figure 23: Simulation square in northern Kronobergs län

Table 15: Position of the simulation square in northern Kronobergs län

Point	Value [m]
top	6314200
left	1428200
right	1433200
bottom	6309200

The square's landscape is dominated by forests: according to the SMD land cover classes 83% of the total area is covered by forest, while the *k*-NN investigation offers volume data for 75% of the square area accounting for 1,877 ha. The remaining land is covered by 10% agricultural areas and lakes.

Table 16: Benchmark data of the simulation square

Benchmark data	Value
Square size [ha]	2,500
Productive *k*-NN forest area [ha]	1,877
Forest cover [%]	84%
Volume per hectare [m^3/ha]	196

Figure 24 shows a map of the simulation square indicating site productivity classes, it can be seen that most of the forest land is rather productive and sites of very low productivity are quite rare. The map also shows that the deciduous stands are often to be found either on very low productive sites or close to open, mostly agricultural areas.

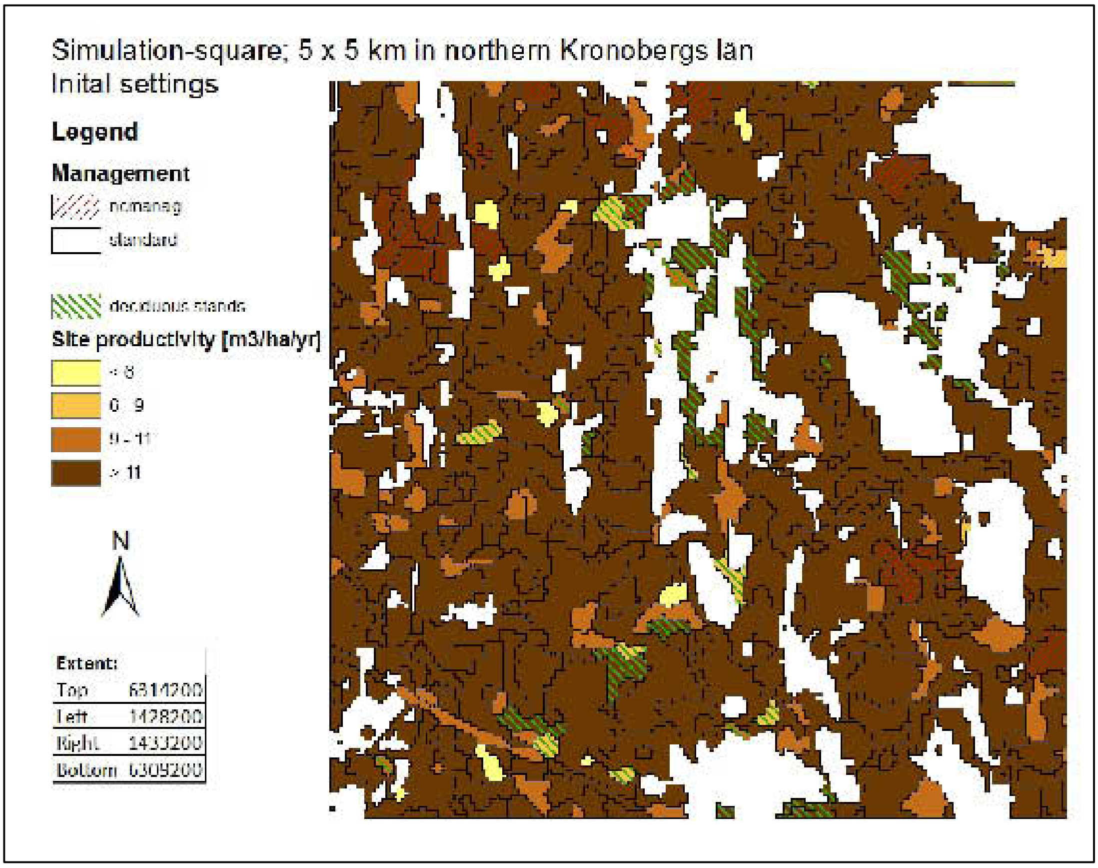

Figure 24: Simulation square site productivity and initial settings

According to the Swedish forest agency (no date) the cut landscape contains four key habitats and seven additional areas with natural values (*naturvärde*) out of which two are not located on forest land.

Considering the forest age, there are no stands of remarkable age, according to the *k*-NN data the oldest stand in the square does not exceed 90 years.

The ownership structure in the landscape extract on the other hand shows more variation: the forest area falls into 144 different estates ranging from 0.063 ha to 703 ha with a mean estate size of about 17 ha illustrated in figure 36, showing the estate borderlines within the simulation square. The estate data are provided by the the Swedish mapping, cadastral and land registration authority, Lantmäteriet, to the Swedish University of Agricultural Sciences (SLU).

Considering the square's *k*-NN volume data shows a clear conifer dominance as it can be found for the whole county. 86% of the volume accounts for spruce and pine, while spruce with 238,400 m³ is the most abundant species.

The deciduous volume share is smaller than the counties average: birch, beech, oak and other deciduous tree species account for only 13% of the total volume. Figure 25 shows how the total 367,500 m³ are distributed among the species.

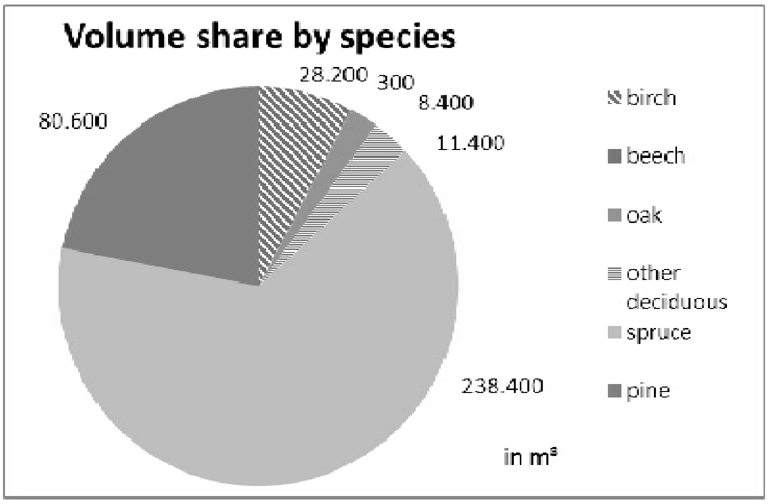

Figure 25: Volume share by species in the simulation square

Focussing on the deciduous volume figure 26 illustrates that most of this volume can be found in coniferous dominated and mixed stands and only 16% are accumulated in deciduous dominated stands.

As it has been shown before for the whole county this distribution varies according to the species in question. This is similar regarding the simulation square. Again birch shows its highest abundance in the coniferous dominated stands while for instance about 50% of the total beech volume can be found in deciduous dominated areas.

Generally the volume share of oak, beech and the remaining other species increases from 25% in the first deciduous volume class (to 10% deciduous volume) constantly to almost 70% in the 10th deciduous volume class (90-100% deciduous volume) at the expense of birch which shows a contrasting trend

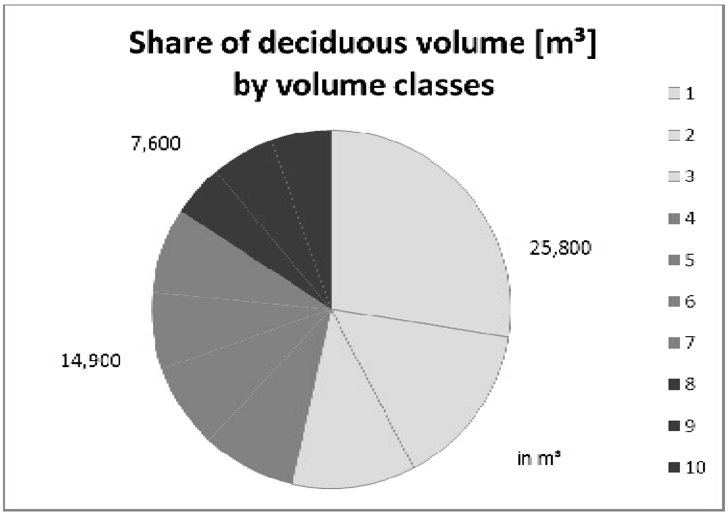

Figure 26: Share of deciduous volume by volume classes (class 1: 0-10% decid. vol. etc.) in the simulation square

The area stocked with deciduous dominated stands presents 6% of the total forest area in the simulation square. 51 deciduous stands of 2.1 ha average size contribute to a total deciduous forest area of 107 ha. Figure 27 illustrates the stand's size class distribution and it can be seen that stands ranging from 5 to 10 ha gain the most importance both regarding the stand number as well as the summed area.

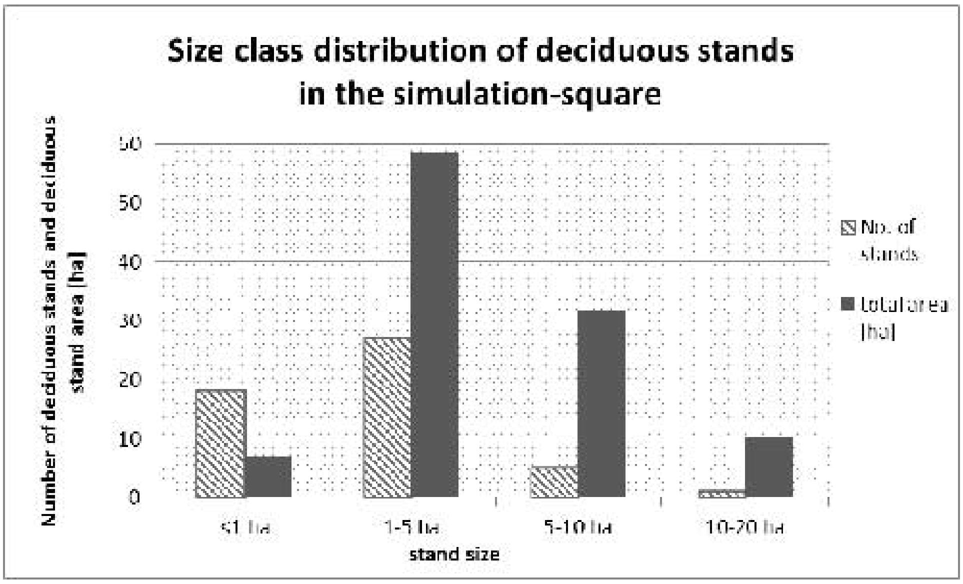

Figure 27: Size class distribution of deciduous stands in the simulation square

Compared to the deciduous stands' mean distance assuming a regular distribution of 606 m the stands have an average distance to its nearest neighbour of only 106 m indicating a clumped distribution of the stands which can also be seen on the square's maps (Figure 23).

Table 17: Benchmark data about deciduous stands and volume in the simulation square

Current state	Value
Forest area share of deciduous stands [%]	6%
Mean deciduous stand size [ha]	2.1
Number of deciduous stands	51
Mean deciduous stand distance [m]	606
Nearest neighbour distance [m]	106
Share of decid. volume not in decid. stands [%]	84%

4.1.2 The data

The analysis and investigations of the initial square and the simulated cases are as well based on *k*-NN and SMD data. But this time the segmented version of the 2005 records was used. The data and their specific background are described in detail in the previous chapter.

The stand borderlines within the square were generally derived following the given segmentation using species composition, volume and age. Therefore each pixel was classified according to its volume class regarding the deciduous proportion of the volume, the total volume and according to its age class.
Pixel with the same classes in all three categories were grouped together in stands. Further subdivisions occurred if the stand was very large and spread out into different arms which were only connected by the width of a few pixel and if a big stand contained a small area of nature values or key habitats.

Deciduous stands in this context are areas in deciduous volume class 8 to 10: containing 70% of deciduous volume or more. The approach applied in the previous chapter was not used here to simplify the process and because the simulator cannot process pixel without underlying *k*-NN data.

4.1.3 Approaches and assumptions

The latest version of the Swedish FSC standard changed its requirements regarding deciduous trees: Criterion 6.3.8 asks the forest manager now to manage the stands in a way keeping at least 10% of deciduous volume in the final felling stands. This share on the other hand can be smaller either if the 10% of the forest area that should be set aside for nature conservation purposes according to another FSC criterion (5% in the former standard) are deciduous dominated or if at least 20% of the production forest area account for deciduous stands (FSC, 2010b).
So the forest owner has basically three different opportunities how to fulfil this criterion which will be simulated and compared later on.
In the course of these simulations it is aimed at meeting the targets by proper management activities and not e.g. by removing coniferous growing stock until the required deciduous share has been reached. Furthermore the simulations are based on the same input forest area and no afforestation activities or conversions of forest into agricultural or urban lands occur.

4.1.4 The simulation

The simulations have been processed and evaluated using the Landscape simulator LANDSIM, developed by Ola Sallnäs, ArcGIS in the version 9.3 from Esri and Mircosoft Office's Excel.

4.1.4.1 The simulator

The forest development has been simulated with LANDSIM which projects timber production like harvest volume in final fellings or thinnings and changes in the forest state like age class distributions or area share of species groups in five year time-periods and displays a pixel based 2D map for the actual state.

Each pixel is simulated individually applying a specified management instruction that is assigned to the corresponding stand and volume, species, age and site index input data. These are then processed by a growth simulator from the SMAC-model (Sallnäs, 1990), a matrix-based model of Markov chain type. The single pixel is moved in the simulated time period between different predefined forest types according to certain probabilities, regarding forest development and the chosen management alternative.

To handle the different species compositions that occur in forests the simulator offers the distinction of eight different species groups, which can be defined according to volume shares e.g. more than 70% spruce, pine or conifers in general, birch dominated etc. Before processing each pixel is classified according to these groups and if the chosen management instruction does not aim at a species class change, e.g. convert a certain stand to deciduous forest, it will stay in this class.

4.2.4.2 The management instructions

Possible management instructions that can be assigned to the stands and then fed into the simulator are e.g. “standard” management, short or long rotation, conversion to broadleaves, focus on nature conservation applying treatments or allowing free development and furthermore a function for afforestation of agricultural areas.

During the simulated cases described later on only the management instructions “standard”, the conversion to deciduous forest tool “speckonv”, the active management for nature conservation “ncmanag” and an instruction only designed for the need of this thesis called “incrmix” are applied. “Standard” management in this context means that the stand is final felled as soon as it is 30% beyond the minimum age for final felling according to the Forestry Act. Apart from the application of the conversion tool stands are automatically regenerated into the same stand type after it has regularly been clear felled.

If the chosen management instruction is the conversion to broadleaves (“speckonv”) the stand will be regenerated with deciduous species as soon as the recent stand has regularly been clear felled at the end of its rotation. Therefore it might take some time before changes can be noted in the simulation.

Stands which should be managed for nature conservational purposes will be assigned to the management instruction “ncmanag”, this instruction does not set a date for final felling, stands are continuously thinned, comparable to selective cuttings. For nature conservation purposes the tool incorporating management actions has been chosen and not the free development tool since it can not be assured that the stands are in such conditions to support a beneficial natural development without any interactions, e.g. old oaks in the over storey and spruce underneath.

For the special simulation purposes needed in this thesis the simulator has been modified and a new tool called “incrmix” for increase mixture was created to deal with stands which have a deciduous share of less than 10%. These stands will be regenerated after regular final felling with a stand aiming at a deciduous share of 10% to 30%.

4.2.4.3 The cases

In the way described above eight different cases have been analysed and compared, illustrated in figure 28. Seven of the cases regard the whole square as one estate, while the eighth case deals with the real estates within the square.

The first case for the whole suare is to illustrate a reference (R) with no adaptions in the management regime regarding the new FSC standard.

The next five cases try to fulfil the deciduous criterion in question, following the three different approaches; A having 10% deciduous volume in the final felling stands, B having a 20% area share of deciduous prodction stands and C having a 10% share of deciduous areas set aside, whereby three cases have been modeled in case B (B_{con}, B_{hom} and $B_{low\ prod}$).

Finally one case has been simulated (Case D) assuming a nature conservational concern of the forest owner aiming at the required deciduous volume share within the final felling stands and a 20% area share of deciduous stands at the same time.

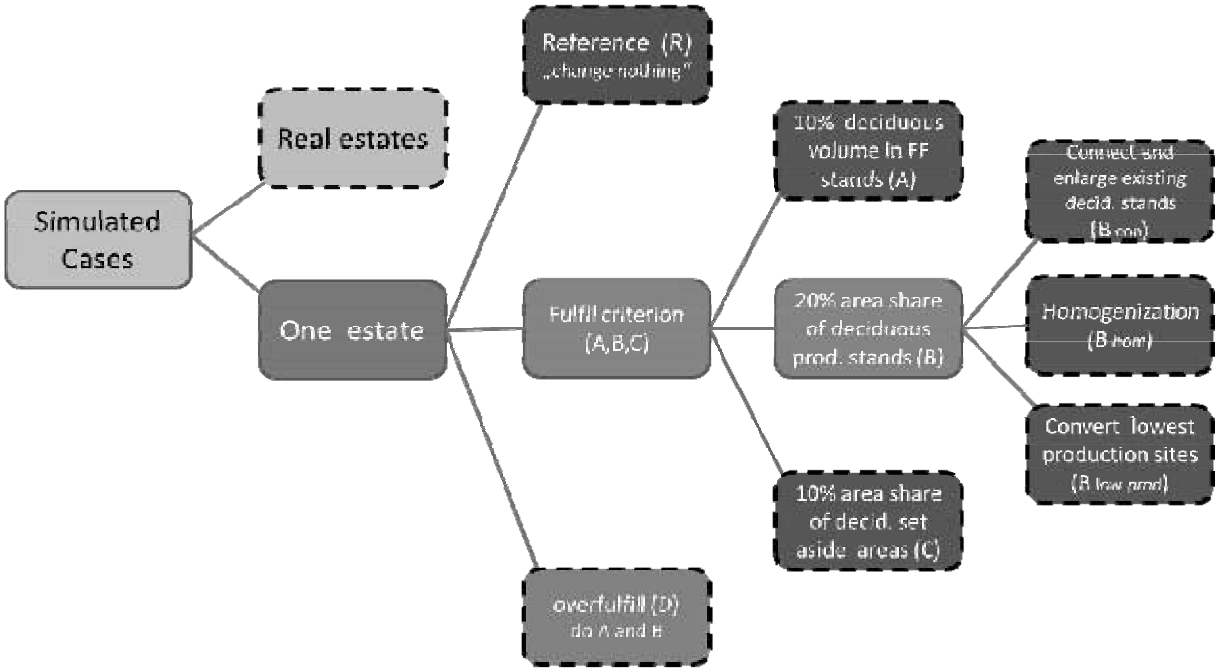

Figure 28: Illustration of the simulated cases A, B_{con}, B_{hom}, $B_{low\ prod}$, C, D and R

4.2.4.4 Implementation

In a first step the square has been investigated for its basic forest and volume data again using ArcGIS. To run the simulations it was then necessary to assign a management instruction to each stand depending on the simulated case.

Therefore first of all 5% of the forest area needed to be "set aside"; consequently all stands containing key habitats or other nature values were chosen to be managed for nature conservation (ncmanag). But as these areas add up to only 2.6% in a next step all stands exceeding the age of 80 years were set aside accounting for an additional percentage. Then stands older than 70 years adjacent to the existing patches were also selected for conservational purposes and finally such stands were chosen connecting the existing nature conservation areas until 5% were reached, as it was required for the old FSC standard. This area has been defined identically for all simulations apart from the case O where the real estates have been used.

Then the cases A, B, C and D needed an additional area of 5% to be reserved for nature conservation to reach the now required 10% set asides. Therefore further stands of old forest have been chosen similarly for these cases.

Finally according to the case in question the remaining stands were appointed other management instructions (standard, speckonv or incrmix).

These data were then fed into the simulator which was run in the following step for the next 75 years, approximately one forest rotation.

The Reference case, case R, is simulated applying the standard management instruction to all stands except those 5% of the forest area set aside for nature conservation which are managed under ncmanag. It should illustrate the development which can be expected disregarding the new FSC standard. In comparison to the other cases it is then possible to see the differences between getting out of and keeping the certification.

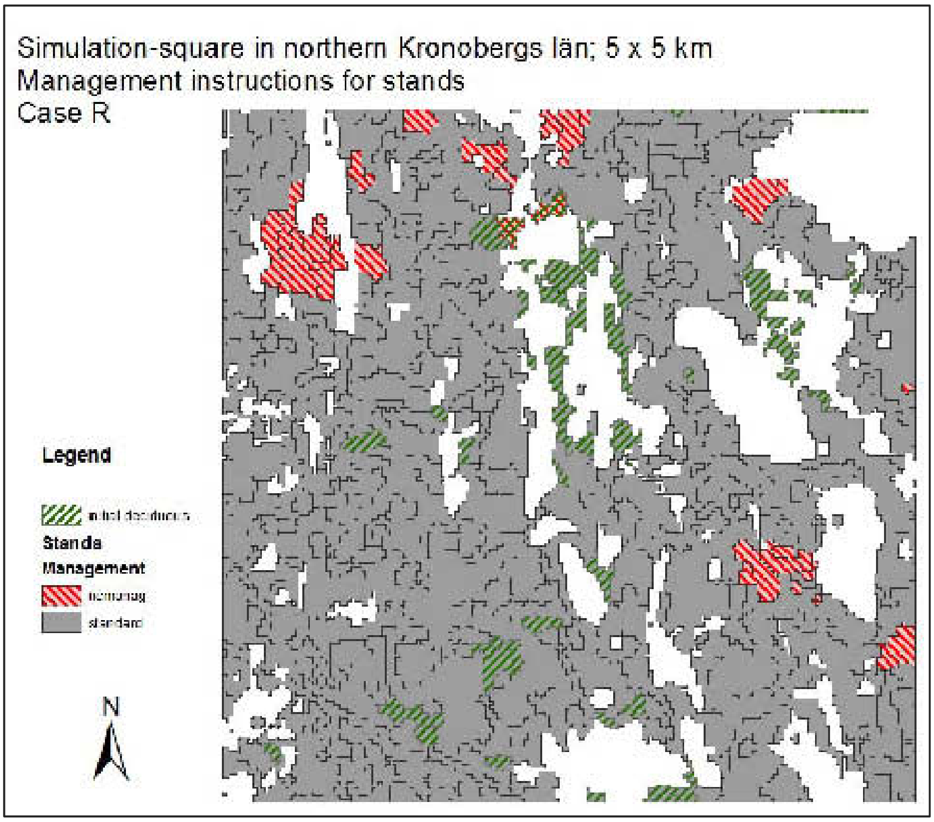

Figure 29: Map illustrating the Reference case

The first case aiming at the fulfilment of the deciduous criterion for the whole square, case A, follows the approach having at least 10% deciduous volume in the final felling stand. Therefore all stands in the deciduous volume class 1, having less than 10% deciduous volume, need to be managed with the target to increase the volume share up to 10%. Beside the areas set aside for nature conservation management all remaining stands stay under the standard management regime.

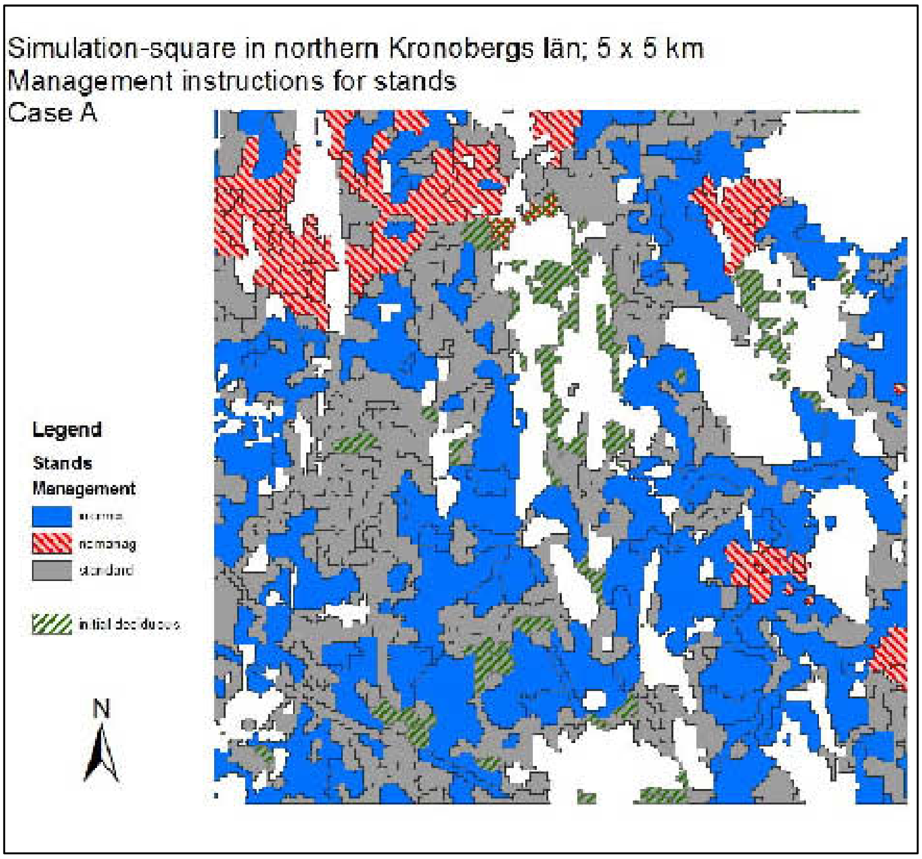

Figure 30: Map illustrating case A

FSC states that the share of deciduous trees in the final felling stands can be smaller if 20% of the forest area for production is covered by deciduous stands. But there are various options how these 20% can be distributed. Therefore three different cases are simulated illustrating this opportunity.

B_{con}, the first variation, aims at connecting and enlarging the existing deciduous stands until a 20% share is reached. These stands are manually chosen and assigned to the conversion instruction while the remaining stands, besides the 5% set aside for nature conservation, are managed according to the standard regime. For a forest manager the aggregation of the deciduous stands might be beneficial as e.g. the logistics for silvicultural treatments are easier to coordinate.

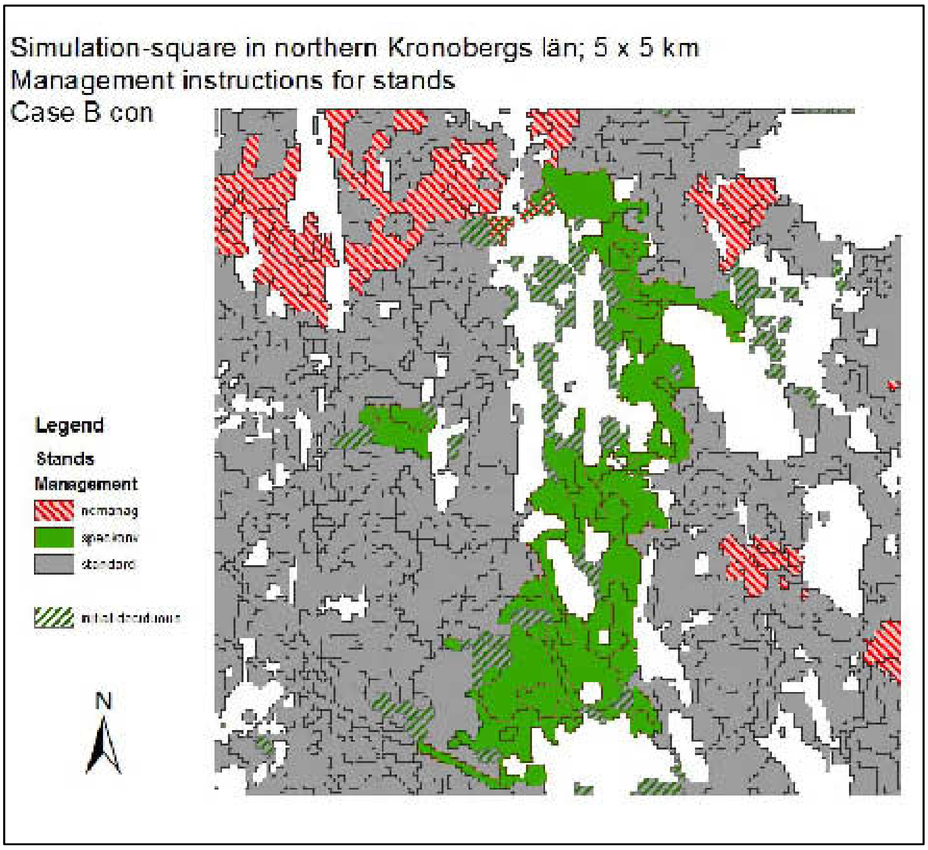

Figure 31: Map illustrating case B con

B_{hom} on the other hand follows a very different approach distributing the conversion stands regularly covering the whole production range. In this case the stands to be converted into deciduous areas are also chosen manually until the threshold is reached while the other stands are treated as mentioned above.

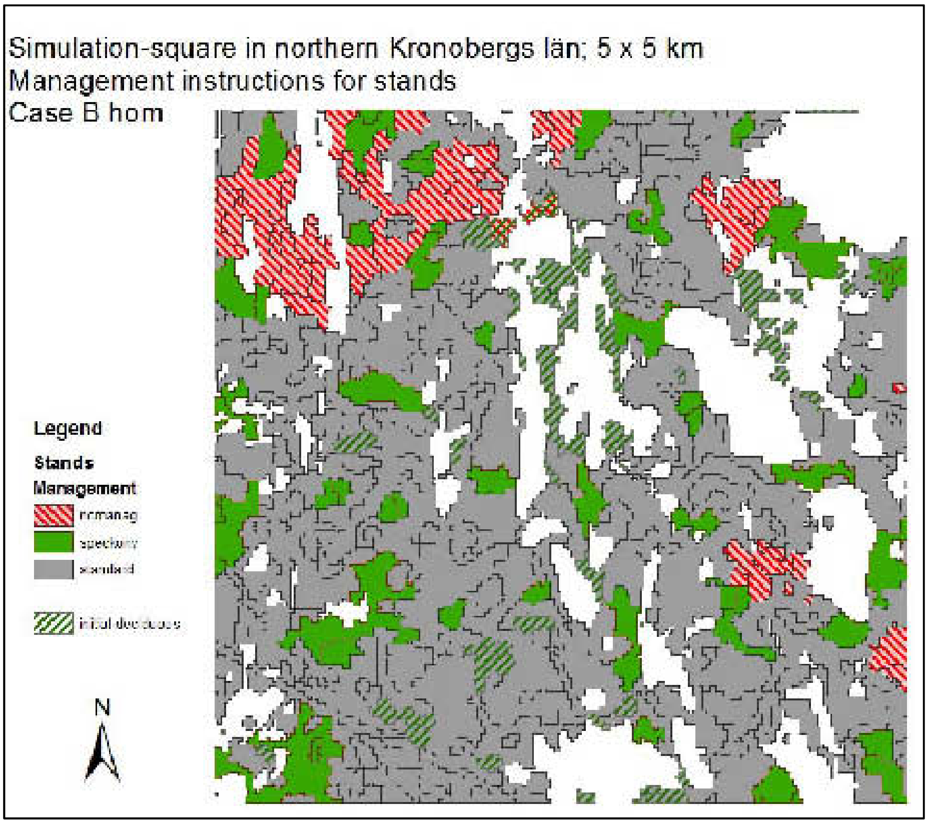

Figure 32: Map illustrating case B hom

The third variation B_{low} focuses on establishing new deciduous stands on the sites of low productivity. So all stands with an average site productivity below class 4, which means less than 11 m^3/ha/year are chosen to be converted into broadleaves. As these do not add up to the required area share additional stands connecting the existing deciduous stands and those chosen for conversion were furthermore selected for “speckonv”.

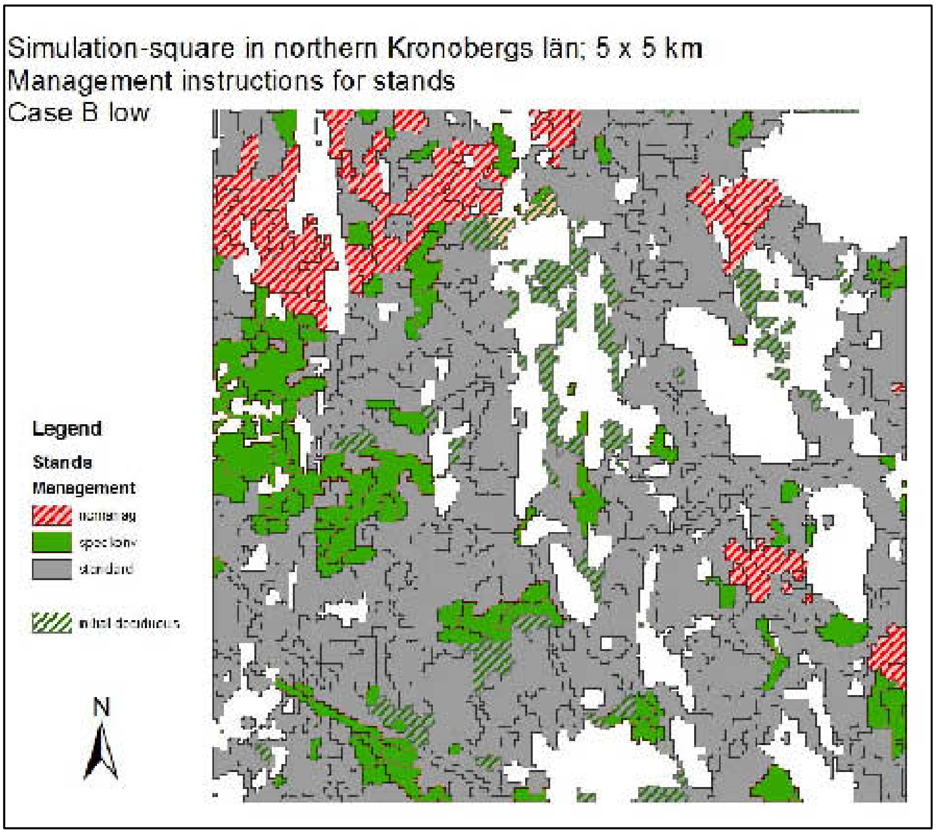

Figure 33: Map illustrating case B low

Case C aims at fulfilling the remaining opportunity to achieve the FSC criterion 6.3.8: the deciduous volume share in the final felling stands can be smaller if the 10% set aside area is deciduous dominated. As for the simulations the stands chosen for nature conservational purposes are based on real nature values it has been decided not to take those out of the “ncmanag” instruction but to add deciduous stands until 10% deciduous set aside was reached. Therefore the total set aside area exceeds the required value, it is now 15%.

To achieve these 10% deciduous set asides all existing deciduous stands were selected for this management alternative and since this was not sufficient additionally stands from the deciduous volume classes 7 and 6 were assigned to nature conservational management.

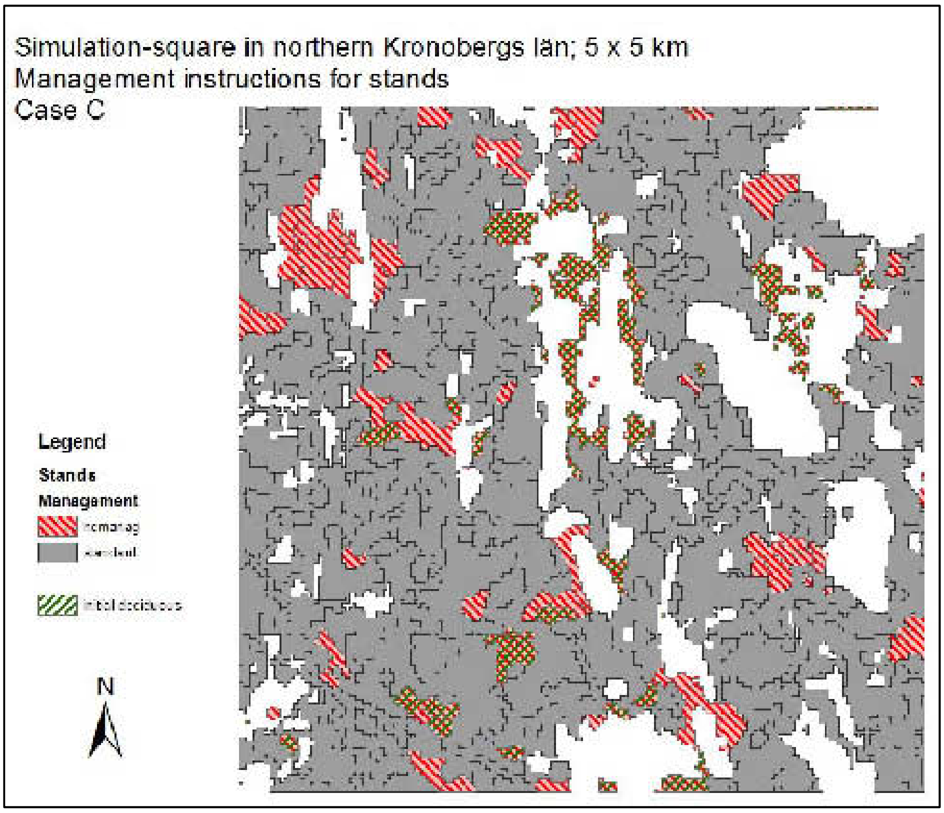

Figure 34: Map illustrating case C

In case D the FSC standard is not understood as a list of restricting instructions but as an advisory tool regarding nature conservational improvements of forest management. Here both approaches of the cases A and B are followed at the same time: production stands will be converted into deciduous forest types until they account for 20% of the forest area, using the same scheme as in case B con and furthermore all remaining production stands are managed to keep a minimum share of 10% deciduous volume in the final felling stands. This case will over-fulfil the FSC requirements and is therefore not really comparable with the previous introduced cases but it will be interesting to see how big the differences are regarding the production and nature conservation case evaluation

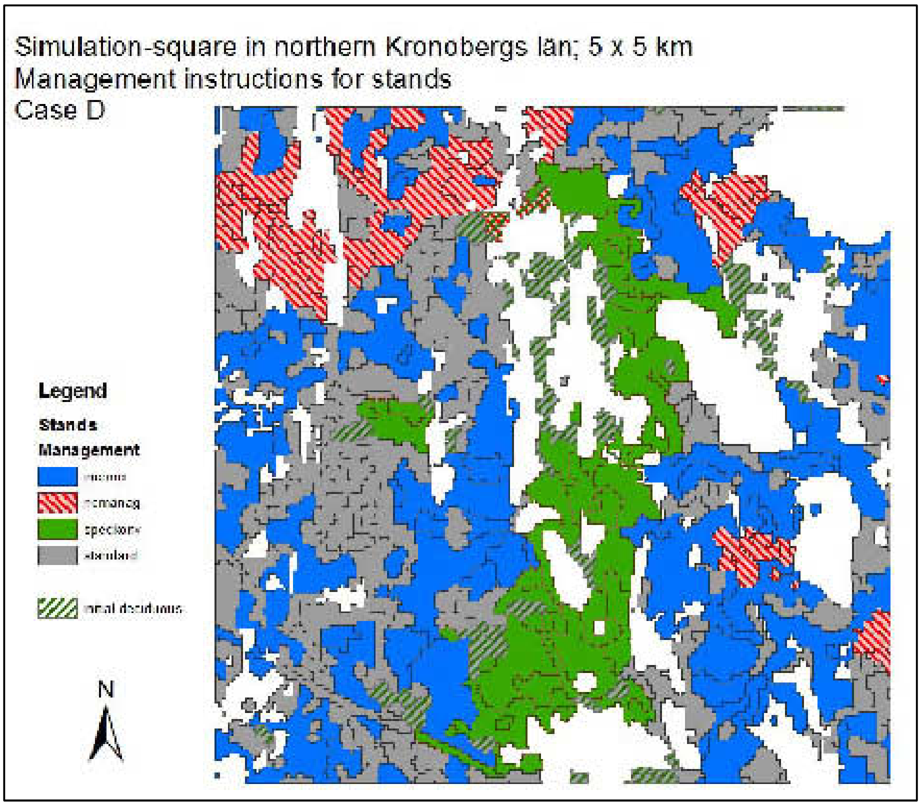

Figure 35: Map illustrating case D

Finally the last case, again not directly comparable to the A, B and C, focusses on the real estates within the simulation square.
For each estate exceeding 5 ha it has been tried to imply the easiest way towards the fulfillment of the FSC criterion in question. Smaller estaes were initially set to “standard” management assuming that forest owners of such areas are not interested in putting much effort in getting certified.
The other properties have been investigated as follows: if the estate contains stands with natural values or key habitats these stands have been set aside until 10% were reached as most of such stands are not deciduous these estates additionally have to fulfill the 10% volume share in the final felling stands and so all stands in decdiuous volume class 1 need to be converted to a higher class.
If the estate has no natural values or not enough the second priority to be set aside are deciduous areas as in that case the 10% decdiduous area share and the set aside share can be fulfilled at the same time on the same area. In most cases the estates had neither any natuaral values nor enough deciduous areas so the easiest approach is to convert an area of 10% to broadleaves and set it aside. Here the management alternative “speckonv” is applied and no adaption of the remaining stands is necessary. No estate contains such a high deciduous stand proportion that approach B would be attractive; having 20% of the production area under deciduous stands.

Due to the incorporation of the estate borderlines some of the initial stands were subdivided, so the total number of stands is higher compared to the other cases. Still most estates consist of only a few stands and as it was decided not to split the existing units further the management instructions are assigned to a stand mainly depending on its size regarding e.g. the 10% to be set aside.

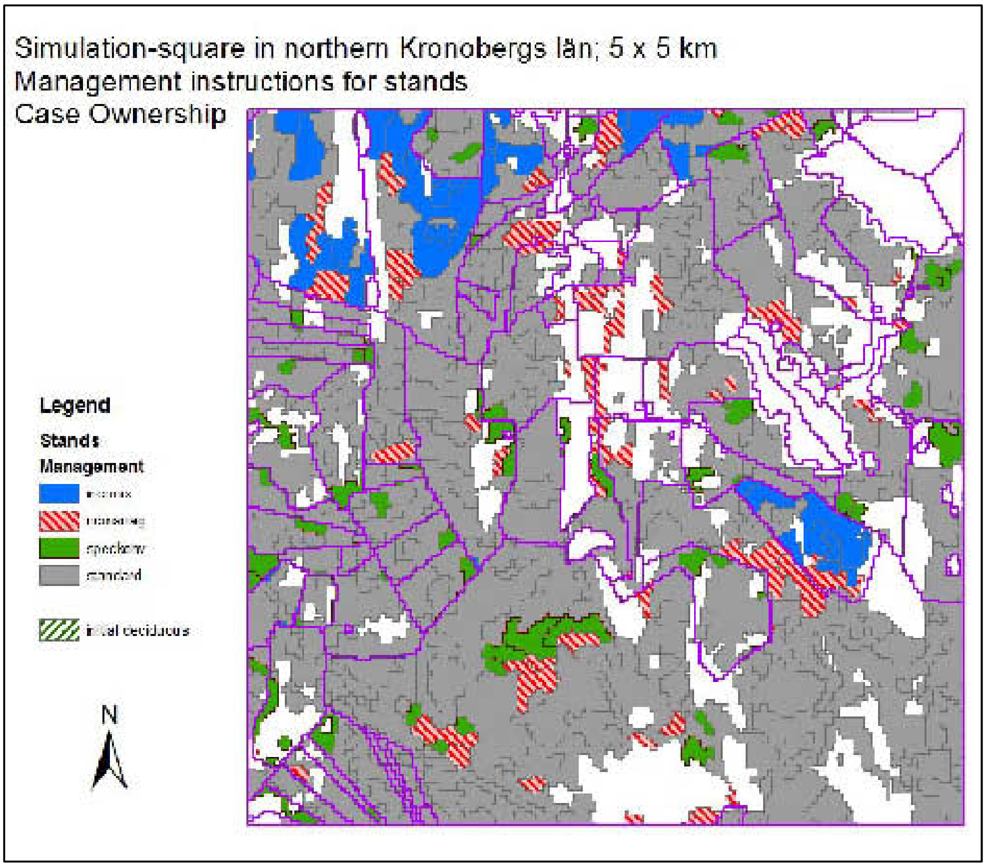

Figure 36: Map illustrating case O

Table 18: Summary of the simulated cases and short description. Production stands refer in each case to those stands which are neither set aside nor converted for nature conservation puposes.

	standard		**ncmanag**		**speckonv**		**incrmix**		**Production stands**	
	No. of stands	Area [ha]	No. of stands	Area [ha]	No. of stands	Area [ha]	No. of stands	Area [ha]		Area [ha]
Refer.	395	1,782	29	95	-	-	-	-	st	1,780
A	267	835	40	188	-	-	117	853	st+incr	1,690
B_{con}	337	1,415	40	188	47	274	-	-	st+sp	1,690
B_{hom}	326	1,414	40	188	58	274	-	-	st+sp	1,690
B_{low}	293	1,414	40	188	91	275	-	-	st+sp	1,690
C	314	1,599	110	277	-	-	-	-	st	1,600
D	233	680	40	188	47	274	104	734	st+sp+incr	1,690
O	588	1,515	65	130	78	108	42	124	st+incr	1,640

4.1.5 Evaluation

After the cases have been simulated they were evaluated and compared regarding wood production and nature conservational values.

For the production perspective the total harvest volume, the standing volume after 75 years in all stands as well as only in the production stands and the increment have been investigated.
As the simulator works with species groups depending on volume proportions, e.g. one group for 70% to 100% pine volume, and presents its results in these groups it is not possible to extract the exact deciduous volume share after the simulated time period. Therefore the initial deciduous volume share within each group has been calculated before the simulation and afterwards the same ratio has been used to recalculate the deciduous share from the simulated group volume.

On the other hand nature conservation values are hard to estimate therefore indicators have been used: the deciduous volume, its share compared to the total volume, the area share of the deciduous stands, the area of stands with a deciduous volume share exceeding 10%, the size of deciduous patches and the distance between them.
Apart from the deciduous volume and its share these indicators are derived from ArcGIS after the management instructions were assigned to each stand, assuming that after the simulation period years all stands initially identified for conversion or an increased mixture will have developed towards this state at the end of the simulation time.

The results of the cases A, B, C and D will be compared directly for each of the criteria separately, whereas an overall evaluation is difficult as it depends very much on the forest owner's or forest manager's personal objectives and how he or she weights the different criteria.
Still it would be interesting to see how the cases "perform" regarding production and conservation not separately but at the same time. Therefore it has been decided to follow a very simple approach to get at least a rough idea about an overall evaluation. As the Swedish Forestry Act sets production and biodiversity values equal to each other they will be evaluated using the same weight later on as well. To avoid the problem regarding the weights of the different criteria discussed before only one criterion is chosen for production: the total harvest volume and one for nature conservation: the deciduous volume share.

Case O dealing with the real estates is discussed individually as it is not designed for the same purpose as the other cases but to illustrate differences between managing on landscape and on estate level.

4.2 Results

4.2.1 Production

4.2.1.1 Harvest volume

After the forest development has been simulated for the next 75 years for all the cases the estimated harvest volume has been compared. As table 19 indicates the total harvest from final felling operations and thinnings ranges between 735,300 m^3 in case C and 773,200 m^3 in the Reference case or 392 m^3/ha and 412 m^3/ha respectively. The translation into relative terms, comparing the harvest volume to the reference shows how close the results are together: all harvest results vary between 95% and 97% of the reference value.

Table 19: Simulated total harvested volume of the next 75 years for the cases R, A, B, C and D

Case	m³ harvest	m³/ha	% of Reference
Reference	773,200	412	
Case A	749,700	399	97%
Case B_{con}	745,000	397	96%
Case B_{hom}	747,000	398	97%
Case B_{low}	749,400	399	97%
Case C	735,300	392	95%
Case D	744,300	397	96%

Even when considering a more detailed scale and regarding the distribution of the harvested volume among the species classes; results in a similar correlation. During the last 25 years of the simulation period the share of harvests from the coniferous dominated stands declines from about 80% to between 60% and 75% depending on the case.

4.3.1.2 Standing volume

In a next step the standing volume at the end of the simulation period has been analysed. For all cases the standing volume has increased compared to the current state of 367,500 m³. The Reference case shows here the lowest total standing volume with 372,500 m³ or 198 m³/ha while case C on the other hand which had the lowest harvest amount accounts now for the highest standing volume of 429,000 m³ totally or 229 m³/ha. Again the values are quite similar; all exceeding the reference value by 7% to 15%.

Considering the standing volume only in production stands, stands not under nature conservation management nor converted for protective reasons, results in a slightly different picture, illustrated in figure 37. Most total standing volume in production stands can be found once more in the Reference case accumulating 304,800 m³, while in the case B_{low} with the lowest total value it is only 276,400 m³ - 91% of the reference value. The remaining cases reach maximal 94% of the reference case.

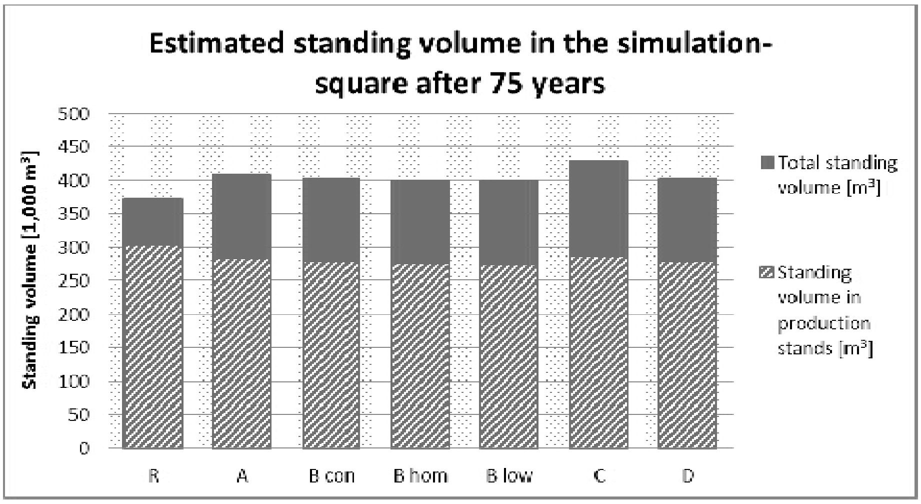

Figure 37: Estimated standing volume and standing volume in production stands in the simulation-square after 75 years

But as the production stands are not the same in every case and add up to different total areas the results per hectare production stand look quite different: here the outcomes range between 164 m³/ha in case B_{low} up to 180 m³/ha in case C or between 96% to 105% compared to the Reference case.

4.3.1.3 Increment

As harvest volume and standing volume influence each other the final indicator chosen to evaluate the production incorporates both of them: the increment.

$$Increment = \frac{\frac{stVol_{t=75} - stVol_{t=0} + harvVol}{tota\ area}}{time}$$

Formula 4:
with: $stVol$ the standing volume in m³, t the time and $harvVol$ the harvested volume in m³ in the 75 years

The calculated increment (formula 4) results in a similar trend shown before: the different cases do not vary a lot. The increment per hectare and year ranges from 5.53 m³ in the Reference case to 5.66 m³ in case C, indicating a total difference of 0.13 m³/ha/year.

To summarize the simulation outcomes from a production point of view it can be stated that the different simulated opportunities to fulfil the new FSC standard result in no remarkable difference, even compared to the Reference case where no further adaptions regarding the latest standard were taken.

4.2.2 Biodiversity

As mentioned before biodiversity itself or nature conservation values are hard to measure and to evaluate so indicators such as the deciduous volume or the size of the deciduous stands have been used to compare the different outcomes of the simulations.

4.2.2.1 Deciduous volume

For all simulated cases the deciduous volume share has increased compared to the current state: even without any additional conversions its estimated proportion in 75 years has doubled its initial deciduous share of 13%.
The highest volume shares of 31% can be found in case D where many stands were converted towards a deciduous dominance and all production stands have a minimum deciduous volume share of 10% and also in case C where all the deciduous stands are under management for nature conservation. Case C has furthermore the largest total amount of standing deciduous volume: more than 130,000 m³. Least deciduous volume totally and relatively can be found in the Reference case where no stands were converted, about 98,000 m³ account for 26% of the total volume in this simulation (table 20).

The deciduous volume has also been investigated using the mean value of the last three simulation periods, here the same trends can be observed although the value of the 15th period exceeds the mean by 6% to 8% depending on the case in question.

Table 20: Simulated deciduous volume for the cases R, A, B, C and D after 75 years

Simulated cases	Total decid. volume [m³]	% decid. of total volume	% area stocked with < 10% decid. volume
Refer.	97,900	26%	52%
A	107,400	26%	7%
B_{con}	120,300	30%	46%
B_{hom}	120,800	30%	45%
B_{low}	112,600	28%	49%
C	131,600	31%	52%
D	123,200	31%	7%

Besides information regarding the square's deciduous volume its distribution is also of interest. First considering the area share of forest with less than 10% deciduous volume it is shown in table 20 that despite an area reduction in all cases from initial 76% the simulations result in very different outcomes. While this area is reduced down to 7% in the cases D and A it ranges between 45% and 52% for the remaining cases.

Second regarding the distribution of the deciduous volume depending on the stand type: compared to the initial state where more than half of the deciduous volume is located in coniferous dominated stands and further 31% in mixed forests the general trend has changed after 75 years, illustrated in figure 38.
The deciduous volume in deciduous stands has increased a lot and varies for all simulated cases between 40% in case A and 54% in the cases B_{con} and B_{hom}. Of similar importance is still the volume in conifer dominated stands accounting for 33% in cases C up to 48% of the total deciduous volume in case A. Therefore the proportion in the mixed stand has generally decreased.

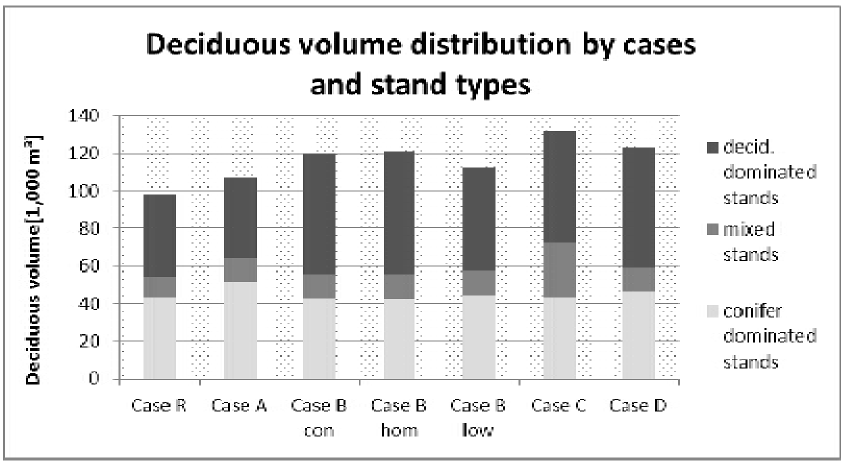

Figure 38: Simulated distribution of deciduous volume in different stand types by cases after 75 years

4.2.2.2 Deciduous patch size and distances

To evaluate the new deciduous areas not the stands themselves but the deciduous patches, meaning neighbouring stands aggregated to bigger connected units are evaluated. Although such deciduous stands might be in the age for different silvicultural treatments, they can still provide the same or similar habitat conditions for many species compared to the coniferous dominated production stands. Furthermore when it comes to crossing from one deciduous area to another one only the aggregated patch data present the real minimum distances that need to be overcome by organisms. Since the total patch area or position was not changed in the Reference case as shown in table 21 it also presents the deciduous patch data for the current state without any simulating.

Table 21: Data concerning the deciduous patches (aggregated stands) for the simulated cases R, A, B, C and D. "NN dist. patches" refers to the mean distance to the nearest neighbouring deciduous patch in meters, while the "mean dist. patches" presents the distance from patch centre to patch centre assuming a regular patch distribution

Simulated cases	No. of decid. patches	Decid. patch area [ha]	% of decid. patch area	Mean patch size [ha]	NN dist. patches [m]	Mean dist. patches [m]
Refer.	45	110	6%	2.4	136	646
A	45	110	6%	2.4	136	646
B_{con}	29	380	20%	13.2	103	805
B_{hom}	77	380	20%	5	118	494
B_{low}	78	380	20%	4.9	118	491
C	64	190	10%	3	116	542
D	29	380	20%	13.2	103	805

The different approaches taken in the cases to fulfil the new FSC standard result in very diverse numbers, sizes and distributions of deciduous patches in the simulation square, also demonstrated in the maps illustrating each case (Figure 29 - 36). Least patches can be found in the cases B_{con} and D, the approach to connect the existing initial stands to bigger units resulted in 29 deciduous patches with a mean size of 13.2 ha, while in the case B_{low}, converting the sites of lowest productivity lead to totally 78 deciduous patches in the simulation square.
The smallest patches with 2.4 ha average size occur in the cases where no additional areas were converted: in the Reference and in case A. Depending on the chosen approach the total area of deciduous patches or stands varies between 110 ha and 380 ha or 6% and 20% of the forest area respectively.

Closely related to the patch number, disregarding the patch size, is the patch density: on an area of 1,000 ha it varies between 15 and 42 deciduous patches in the simulated cases.

The selection of different stands for conversion to deciduous dominated forests also influences the distance between the stands, the shortest possible line from the patch border to the next nearest patch ranges from 103 m in cases B_{low} and D up to 136 m for the Reference and case A. Comparing these values to the mean distance between the patch centres assuming a regular spreading shows that the patches are distributed in a rather clumped way.

4.2.3 Overall evaluation

Looking back on all the results presented above shows that there is no "overall winner" comparing the cases aiming at the fulfilment of the new FSC standard A, B, C and D. Considering the production perspective all cases perform equally; the lowest values reached still account for at least 93% of the maximum value.

The differences increase when it comes to the indicators of nature conservation value; here the case D results most often in the highest values. Figures 39 and 40 demonstrate the performance of the cases always compared to the highest value that was reached by one of the cases and it illustrates once more that it is hard to identify the best alternative as each case has its strengths and weaknesses.

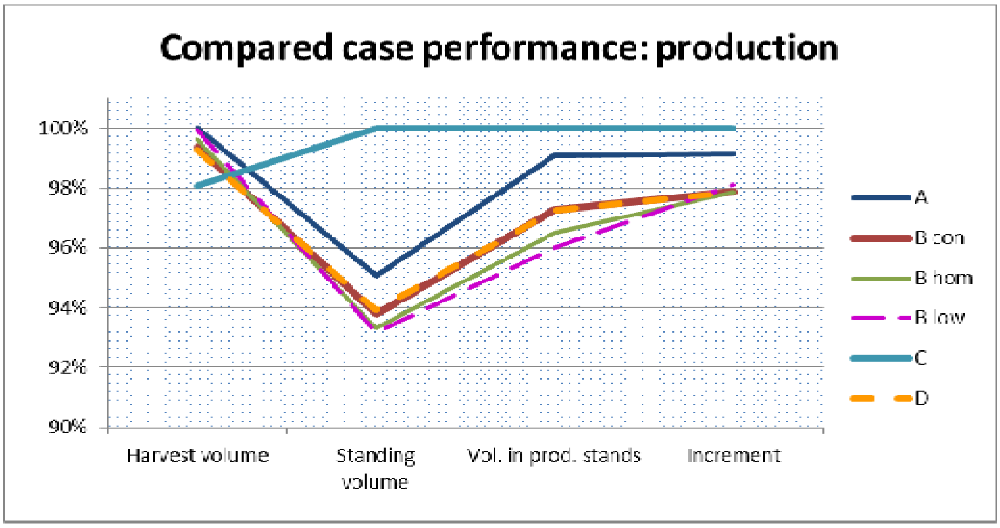

Figure 39: Compared simulated case performance of the production indicators for the cases A, B, C and D

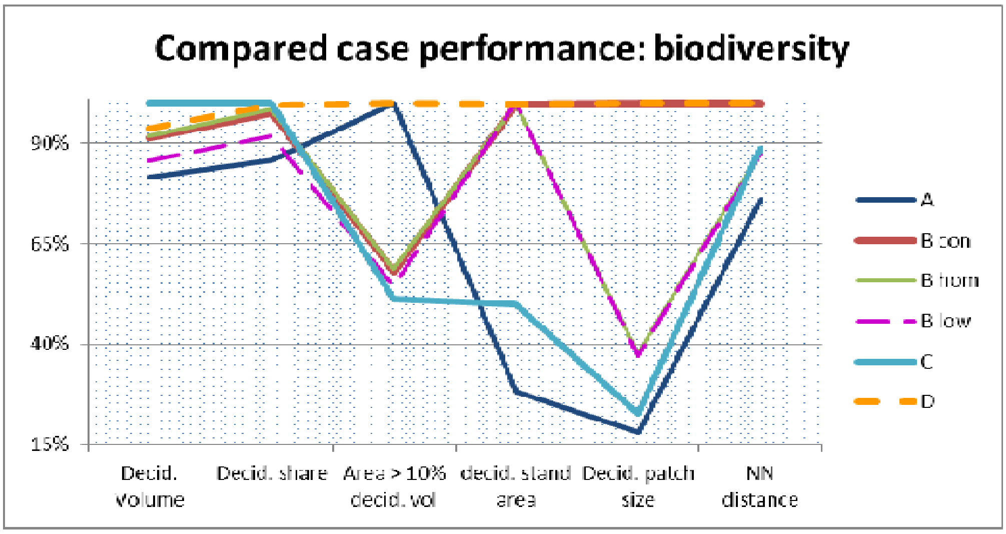

Figure 40: Compared simulated case performance of the nature conservation and biodiversity indicators for the cases A, B, C and D

To allow a simple comparison including production and nature conservation values at the same time the cases A, B, C and D have been compared using the following formula. As explained before the values for harvested volume and total deciduous volume are weighted in the same way referring to the Forestry Act where the same emphasis is given to production and nature conservation.

$$v = 0.5 \cdot \frac{harv.Vol\ Case_i}{harv.Vol\ Case_{max}} + 0.5 \cdot \frac{decid.Vol\ Case_i}{decid.Vol\ Case_{max}}$$

Formula 5:
with: v the evaluation value, $harv.Vol$ the total harvest volume during 75 years, $decid.Vol$ the total deciduous volume after 75 years and $Case_{max}$ the case among A, B, C and D with the highest value

Taking only these two indicators into account leads to the results presented in figure 41: Once more it can be seen that on such a general level the cases are quite close to each other comparing these evaluation values, still case C achieves the best outcome and would be the most suitable alternative if considering only harvest volume and total deciduous volume.

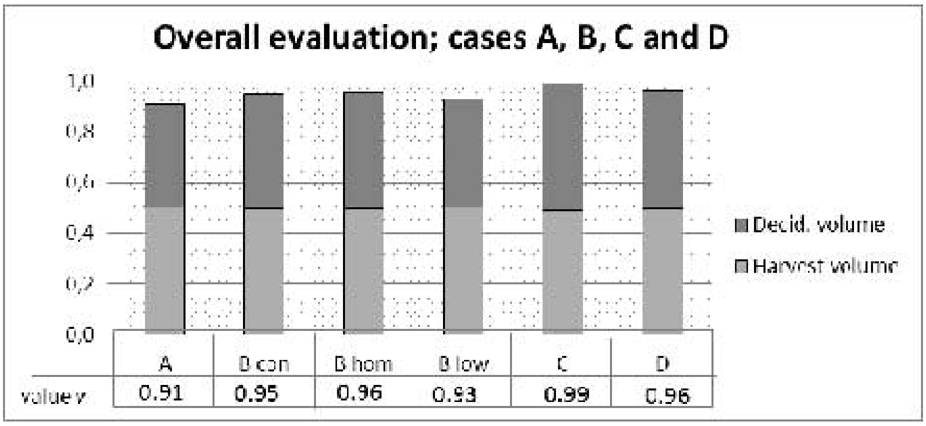

Figure 41: Overall evaluation of the cases A, B, C and D considering harvest volume and total deciduous volume, always comparing to the case with the maximum value (formula 5)

But the results do not allow the identification of the generally best alternative as this is highly dependent on the forest owner's personal objectives.

4.2.2 Case Ownership

In addition to the cases A, B, C and D another case has been simulated considering the real estates within the simulation square. As described above in this simulation it is aimed at fulfilling the new FSC standard for each property exceeding 5 ha separately.

For this case the 75 years of simulating resulted in 772,000 m³ total harvest volume and 372,000 m³ standing volume at the end of the simulation time out of which 77% are standing in production stands; 174 m³/ha. As table 22 shows the outcomes for the production are quite close to the

Reference case. Here all the case O results, except the comparable low increment value, lie in between the outcomes of the other simulated cases.

Table 22: Production results case O compared to the Reference case

	Reference	Case O
Total harvest volume [m³]	773,200	772,100
Total standing volume in period 15 [m³]	372,500	372,100
Standing volume in period 15 [m³/ha]	198	198
Total standing volume in production stands [m³]	304,800	284,700
Standing volume in production stands [m³/ha]	171	174
Increment [m³/ha/year]	5.53	5.52

Table 23 summarizes the results for the biodiversity perspective. The conversion of many small stands among the square led to a high deciduous volume after 75 years of simulating and furthermore to the highest deciduous volume share of 33% considering all the cases. The approach taken in this case resulted with 119 in the highest number of deciduous stands with the smallest mean size of 1.8 ha.

Since there are so many deciduous patches the distance between them is quite short and the distance to the nearest neighbouring deciduous patch accounts for only 73 m. The different approach taken in case O is reflected by its results for biodiversity which often present outliner values compared to the other cases.

Table 23: Biodiversity results case O compared to the Reference case

	Reference	Case O
Total decid. volume [m³]	97,900	121,400
% decid. of total volume	26%	33%
% area stocked with <10% decid. volume	52%	44%
No. of decid. patches	45	119
Decid. patch area [ha]	110	215
% of decid. patch area	6%	11%
Mean patch size [ha]	2.4	1.8
NN dist. patches [m]	136	73
Mean dist. patches [m]	646	397

4.3 Discussion

Before discussing the results presented above it is first necessary to remember where those numbers come from. Since the simulation is based on several models, e.g. a growth model or a regeneration model which generalize and simplify natural processes the results should be referred to as pure estimations and so the general trends that can be observed using the case comparisons should be more reliable then the total numbers.
Furthermore it needs to be kept in mind that the model used in these simulations is a stochastic one and would generate a slightly different result for the same input data every time it is run. For that reason small differences in the results should not be given too much attention as they can be rather due to the effect of the chosen probabilities within the model than due to real differences in the applied forest management.

Those universal difficulties when dealing with models and simulations are accompanied by problems arising from the input data and predefined assumptions. The questionability of the *k*-NN data which form the base for the simulation has been discussed in the previous chapter. But since there is currently no alternative to theses data the only thing that can be done is treating the descriptive data about the square and the simulation output figures with the necessary caution.

For the simulations run in this chapter a time horizon of 75 years was chosen, although this time span might be too short to allow full development e.g. of the conversion effects; since stands are just converted after the regular final felling. Still 75 years cover approximately one forest rotation so areas covered with young stands today will carry such stands again at the end of the simulation period, at least for the coniferous stands, so that independently from the age class distribution the two states in time can be compared more or less directly.
Furthermore related to the characteristics of models the outcomes get less and less reliable the longer the simulation period.
Moreover forests and forestry have to deal with enormous environmental changes driven by the climate change. Site productivities and species competitiveness will adapt and therefore longer simulations would become even less accurate.
Finally the simulation refers to the new FSC standard in effect since June 2010 and until 2086 there will probably be many more standards and other requirements than today, which need to be considered by forest management.

Despite all these possible problems arising from the input data and the simulation itself the results of the different cases can be compared and evaluated since they are all based on the same processes.
For the total volume production it has been shown that all the cases perform more or less equally.
This seems reasonable considering that only one rotation has been evaluated and since in most cases the same areas have been set aside for nature conservation all the stands that can be found in the square right now will be harvested approximately at the same returning a similar volume in most cases.
So differences in the harvested volume should be more or less only based on the second generation stands, regenerated during the simulation time, but those effects are just obvious after a sufficient number of stands was converted or regenerated with a new mixture etc.
Compared to the reference, where only 5% of the forest area have been set aside, all cases show more or less an equal loss of production ranging between 3% to 5%.

Additionally the species composition of the harvested volume changes slightly and the amount of the "safe" spruce timber shrinks while more deciduous volume is harvested.
But we are not dealing with a stable system neither in the forest nor on the market. Climate change effects the growth conditions and for the end of the simulation periods around 20% higher productivities are predicted for pine, spruce and birch (SCCV, 2007). Since the simulator does not take these changes into account there will be probably no production loss that needs to be considered. What remains is the changed species composition, but this is a rather long process and it is hard to predict what will be the demands on the wood market in 50 or 70 years from now.

Differences become more obvious when regarding the standing volume at the end of the simulation period. In figure 37 the case C clearly sticks out with the most total standing volume while its total volume in the production stand is not remarkable different from the other cases. Here we can see the effect of the large areas under nature conservation management where the volume accumulates. Case C also has most standing volume per hectare production stand which seems reasonable too as all production stands are under the standard management and since all deciduous stands are protected most of these stands are actually conifer dominated and therefore more productive. The lowest value on the other hand shows the case B_{low} as a result of all the sites of low productivity being converted to deciduous forest which count as production stands too.

Finally for the production site the increment combines standing volume and harvest amounts, figure 39 nicely illustrates that cases which have a high harvest volume therefore on the other site lack standing volume. The results for the increment incorporating both values lie therefore in between these values on the relative scale of figure 39. Regarding absolute values; the difference from the minimum value in the Reference case of 5.53 m³ and the highest value again in case C with 5.66 m³ accounts for only 0.13 m³/ha/yr. These figures seem pretty low compared to the mean site productivity of about 10 m³/ha/year according to the input data – so what happened to the other 5 m³?
Part of it might be "lost in translation" since the simulator output data is not in gross volume and therefore does not consider any dead wood. Maybe the assumption taking within the standard management method is wrong assuming final fellings to take place after 130% of the lowest legal final felling age and fellings take place earlier. Finally it is possible that the growth model within the simulator underestimates the actual growth and therefore the results present actually too low figures.

The indicators that have been used in this thesis for evaluating the biodiversity or nature conservation values could be subject of long discussions themselves.
Can the amount of deciduous volume in a forest really tell us that it is richer in biodiversity or more valuable from a nature conservation point of view than another forest with less deciduous volume? Of course the indicators used here are just parts of the framework that is needed as basement for a biodiverse forest ecosystem, but the number of red listed beetles, the richness in rare lichen species or the amounts of dead wood and other important structural features are already hard to attain in a real forest – how to do that in a simulated one?
Therefore this thesis follows a very simple approach for the biodiversity values concentrating on the deciduous trees and stands: the more, the bigger, the closer – the better. And since there are no general thresholds that can be referred to these indicators are evaluated on a relative scale compared to the initial state and the results of other cases.

But still it needs to be emphasised that real information e.g. concerning the habitat quality is lacking and when going through the results it is important to keep that in mind; a deciduous stand under nature conservation management where no clear fellings take place is for sure of different importance compared to a deciduous stand managed for production.
Furthermore another important forest characteristic when it comes to nature conservation and biodiversity, the forest age has not been taken into account at all.

The first biodiversity indicator analysed for its simulated development was the deciduous volume and an impressing first result was that the deciduous volume has doubled for all the cases compared to the current state.
Since that also happened for the Reference case where no effort was put at all in an increased deciduous share the main reason for that must be the increment in the mainly young deciduous stands we can find today.
The differences we can see among the simulated cases is not surprising: lowest amounts can be found in the Reference case while the highest volume share occur in case C and D with either large deciduous areas set aside or a big deciduous production share. Interestingly most successful in accumulating deciduous volume totally was one more time case C. It seems that setting aside deciduous stands for nature conservation is a quite effective for building up deciduous stocks. Since in that case also stands were considered under "ncmanag" with a deciduous ratio of 60% to 70% as well as some of 50% to 60% deciduous volume the share of deciduous volume in mixed stands is remarkably higher than in the other cases. Here the importance of the deciduous volume in mixed stands has decreased compared to the current state mainly for the benefit of the volume share stored in deciduous dominated stands. Since this development can also be observed in the Reference case and case A where no conversions took place this is probably once more the effect of the doubled deciduous volume due to the stand age structure.

All simulated cases except the reference and case A had a big influence on the characteristics of the deciduous patches.
Comparing the results it is not surprising that case D, the case where 20% of the production area were converted to deciduous stands and furthermore all stands have a minimum share of 10% deciduous volume, performs best.
But it is quite hard to draw conclusions from it since we do not know if this is enough e.g. to conserve the existing forest biodiversity in the long run. It would be quite interesting to compare these results to the habitat requirements and mobility of well investigated species and to see which cases fulfil their requirements and which cannot support viable populations.

For the forest management all these results allow a simple conclusion; since the differences in the production have shown to be negligible the management can focus on an alternative that is most suitable for nature conservation purposes. How such a management plan looks like would of course vary depending on the landscape in question, its species composition and other characteristics. If no further information is taken into account but the simulation results for choosing an alternative in the simulation square case D seem to be the most promising one.
If we exclude this case from the alternatives, since it aims at over fulfilling the FSC requirements the choice of the most suitable case is much harder but generally the B cases achieve good results as well.

Not only nature conservation and certification are sometimes quite unbalanced; it is the same case for practical forest management. The new FSC standard asks for 10% deciduous volume in the production stand when it is finally felled but the certification does not state how this could be achieved.

There is no real practical experience in keeping deciduous trees within the production stands for such a long time. (Drössler pers. comment, 2011).

So measures taken now have more or less experiment character and it will take one rotation until forest managers and certifiers can see how successful they were in fulfilling this criterion.

5 Conclusions and overall discussion

With the evaluation of the management alternatives at the end of the last chapter we have fulfilled the first round of the planning cycle introduced in the very beginning:

The data collection, the investigating the deciduous volume and deciduous stands in Kronobergs län has resulted in important details regarding the volume composition and distribution, the differences when it comes to volume in deciduous stands and their location compared to other land cover classes.
The high proportion of birch among the 15% volume accounting for deciduous species was known before but birch still accounts for half the deciduous volume when taking into account only deciduous stands.
Furthermore the investigation has illustrated the differences within the county as well as deviations when considering the total deciduous volume or only the deciduous stands.
These stands account for only 5% of the forest area and contain 13% of the total deciduous volume. Corresponding it can be concluded that the vast majority of the deciduous volume is admixed in conifer dominated stands or part of mixed stands.
Besides another interesting outcome shows that the stands are more or less all located close to open areas; agriculture, urban sites and water surfaces.
Finally we have also seen that there are still unanswered questions for example regarding the forest age or the stand aggregation which would be useful to know when it comes to management planning.

Still these new findings offer now many different approaches when it comes to management alternatives dealing with the deciduous volume:
First considering the species composition: if we would like to focus on oak, since it is very important for nature conservation and biodiversity, we know now that only 20% of its volume can be found in deciduous stands. Therefore an effective management of this species would have to incorporate for instance the mixed stands e.g. by generally favouring oak trees in all thinning operations.
Then we can also use this data regarding a more political perspective: as it has been shown Kronobergs län's north-east is quite poor when it comes to deciduous trees and stands so this area could be defined as first priority target region when it comes to increasing the deciduous share.
Another approach would consider the location of the deciduous stands. It has been discussed earlier that the few remaining stands which are not close to these open areas but within a "spruce desert" are of particular importance for to biodiversity. Therefore it would be worth taking these areas into account as well and putting emphasis on keeping them in the forest landscape.
These few examples demonstrate how the information gained from the investigation could be translated into numerous possible management alternatives.

The simulation chapter on the other hand is restricted to a very small area and aims at fulfilling the recent FSC standard regarding its criterion on deciduous trees. Although it does not make too much use of the beforehand gathered information we can also see here that there are very many different ways how to manage the forest even with a much narrower defined target.
This diversity of alternatives is somehow typical for forestry and its management but it is also a threat for its planning, since it is never possible to consider all the opportunities.

After having chosen some alternatives out of this immense pool the next step in the planning cycle was the “projection” – where might those alternatives lead us to? The simulation and basically all projections are based on models, true only for very specific cases with many underlying assumptions. The simulator used for the square cases introduced before does for instance not consider climate change.
However the forecasted production losses when adopting towards the new FSC standard are now contrasting to the expected improvements in tree growth in Kronobergs län. Since these vary between ca. 10% - 20% of the current growth at the end of the simulation period depending on the species in question (SCCV, 2007) the discussion regarding “production losses” has actually lost its base.
Finally when dealing with models and simulations it is important to keep in mind that they are no digital fortune tellers but tools to compare different initial situations.

And this has been done in the “evaluation of the management alternatives” the next point when following the planning cycle.
As discussed before the results of the evaluation allow the simple conclusion to focus on what is best for biodiversity since there is almost no difference regarding the forest production. Here it is important to remember that this outcome is only true for the investigated indicators. For instance there are no information about the timber quality or potential revenues from the harvests and the biodiversity indicators imply only deciduous volume and deciduous dominated areas but no age or other information.

At this point the planning cycle shifts into the practical management where taking a decision would be the next thing to do.
Now we face the problem that the resulted advice to choose the alternative that is best for nature conservation is not so easy to realize. Since there are no general data available regarding for instance the threshold of deciduous volume needed to support most of the threatened species out in the forest landscape, it is not even possible to say whether the suggested approaches would be sufficient. What are we actually aiming at: forests as close to nature as possible or preserving the highest species diversity? And what would be the best way to reach that; by integrating forest functions on the same area or by separating strictly between reserves and stands for production?
Finally the problem of this ambiguity aggravates regarding the urgency to make a decision.

It seems every step in the planning cycle becomes more and more complicated the further we get. The implementation, rather theoretical since we had already problems with the evaluation of the management alternatives, bears many new problems.
For instance the implementation scale: The case O has shown that the consideration of the individual estates leads to a quite different result compared to the landscape level regarding the whole square. Even assuming similar targets of the forest owners, estate and landscape targets deviate from each other: The total protected area might be the same but some estates contain nature values that account for more than 10% of the forest area while others have only conifer dominated production forest without any remarkable values in there.
So the estate wise management is not as effective in protecting sensible areas as the landscape approach. To optimize nature conservation management it would therefore be beneficial to include the landscape level to set first protection priorities.

That would on the other hand lead to the need for compensations for the forest owners who are in the situation to have big areas of conservational importance. But who should pay for this since it is not the fault of the remaining forest owners that they do not have such areas.
Furthermore starting from the landscape level should not minder the importance of measures taken on an estate level; deciduous trees and stands are not only of importance in key habitats but also as patches and trees within the conifer matrix which are hard to get track of considering a whole landscape.
But how realistic is it to assume that all forest owners have similar targets? Ideal would be a landscape wise group-certification with landscape as well as estate targets and a kind of fund system to compensate forest owners in a fair way. But this is probably not marketable as long as it possible to certify a single estate as no forest owner without large natural values in his or her estate would be interested in joining such a landscape-group since he would gain no real benefits.

But stepping from estates to landscapes is just the beginning of the problematic of scales:
The field of national and global policy is so wide that measures taken on one site with good intention might have adverse effects on the other site.
In the course of the EU 20-20 targets Sweden plans to increase its share of renewable energy up to 49% until 2020 (EC, 2010). This will for sure result in a higher pressure on the forest ecosystems and will be pretty hard to get in line with restoring and adapting these systems.
Another example is the FSC certification which does probably improve the sustainable forest management of the certified estate (or landscape), but Eriksson et al. (2007) showed that a country covering certification would result in a substantially reduced production level.
This will undoubtedly lead to an increased import of material for the Swedish wood industry increasing the pressure on other forest ecosystems which might be not certified or less well controlled than the Swedish ones. In that case certification does not solve environmental problems but dislocates them to other countries more difficult to access environmentally, possibly threatening ecosystems which might be closer to its natural state than the heavily modified hemi-boreal region in Sweden.
It could be argued if it is not of more importance to protect existing, still intact ecosystems than restoring others which might be beyond repair anyway. But this disregards the value of every ecosystem and shifts the responsibility to those countries which, for whatever reason, have not exploited their environment as heavily as Europe did for instance. In this case climate change helps arguing as well since measures taken for the adaption of the forest ecosystem are similar to those which should be taken for the restoration.

But the planning process itself has already reached is preliminary end with the evaluation of the management results. It has been shown above that the results from this evaluation cannot yet serve as a base for a political decision and so the arrow in the cycle leads us back to the objectives right to the beginning of the whole process.

To be more successful in the “next round” it is now necessary to delineate more accurate targets, stating in more detail where we want to go with the hemi-boreal forests, its deciduous trees, its forestry and how we want to deal with the scale problem.
I hope that this thesis can therefore contribute to the follow up and that the findings e.g. made in the investigation can help defining such more specific targets to adopt our forest management towards a more sustainable forestry regarding biodiversity as well as timber production at the same time.

6 Literature

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7 Appendix

The following tables give the detailed results from the investigation of deciduous trees in Kronobergs län and its strata as well as the exact outcomes from the simulated cases. Some of these results are not discussed in the previous chapters but since they have been analysed in the course of this thesis and because this is one of the first detailed investigations of deciduous volume and deciduous stands it has been decided to include this information here as well.

7.1 Investigation of deciduous volume and deciduous stands

7.1.1 Total deciduous volume in Kronobergs län

Table Appendix1: Total deciduous volume in Kronobergs län in volume classes [m³], excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	all deciduous
1	2,191,906	46,081	126,984	186,732	2,551,703
2	2,162,901	112,130	241,959	347,363	2,864,352
3	1,437,119	115,675	214,491	328,783	2,096,068
4	1,021,502	118,414	166,319	266,643	1,572,877
5	844,848	127,386	174,201	237,923	1,384,358
6	683,684	74,684	167,206	212,921	1,138,495
7	601,274	87,961	172,534	214,283	1,076,052
8	404,959	76,142	159,704	179,812	820,616
9	396,260	126,902	171,406	210,395	904,963
10	436,253	256,187	134,371	239,837	1,066,648
total	10,180,705	1,141,559	1,729,174	2,424,693	15,476,132
%	66%	7%	11%	16%	

Table Appendix2: Total deciduous volume share in Kronobergs län within species, excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	all deciduous
1	22%	4%	7%	8%	16%
2	21%	10%	14%	14%	19%
3	14%	10%	12%	14%	14%
4	10%	10%	10%	11%	10%
5	8%	11%	10%	10%	9%
6	7%	7%	10%	9%	7%
7	6%	8%	10%	9%	7%
8	4%	7%	9%	7%	5%
9	4%	11%	10%	9%	6%
10	4%	22%	8%	10%	7%
total	100%	100%	100%	100%	100%

Table Appendix3: Total deciduous volume share in Kronobergs län within classes, excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	all deciduous
1	86%	2%	5%	7%	100%
2	76%	4%	8%	12%	100%
3	69%	6%	10%	16%	100%
4	65%	8%	11%	17%	100%
5	61%	9%	13%	17%	100%
6	60%	7%	15%	19%	100%
7	56%	8%	16%	20%	100%
8	49%	9%	19%	22%	100%
9	44%	14%	19%	23%	100%
10	41%	24%	13%	22%	100%

Table Appendix4: Total deciduous volume in Kronobergs län by species in species dependent volume classes [m³], excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	sum	all deciduous
1	2,847,438	348,819	729,761	186,732	4,112,750	2,551,703
2	2,683,438	199,426	455,553	347,363	3,685,780	2,864,352
3	1,613,567	152,508	255,099	328,783	2,349,956	2,096,068
4	1,183,728	125,145	154,730	266,643	1,730,246	1,572,877
5	974,923	87,426	77,747	237,923	1,378,019	1,384,358
6	492,773	66,219	35,241	212,921	807,154	1,138,495
7	198,489	71,458	15,466	214,283	499,697	1,076,052
8	98,267	58,325	2,393	179,812	338,798	820,616
9	62,856	27,050	1,031	210,395	301,332	904,963
10	25,199	5,184	2,153	239,837	272,373	1,066,648
total	10,180,677	1,141,559	1,729,174	2,424,693	15,476,104	15,476,132
species %	66%	7%	11%	16%		

Table Appendix5: Total deciduous volume share in Kronobergs län within species dependent volume classes, excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	sum	all deciduous
1	28%	31%	42%	8%	27%	16%
2	26%	17%	26%	14%	24%	19%
3	16%	13%	15%	14%	15%	14%
4	12%	11%	9%	11%	11%	10%
5	10%	8%	4%	10%	9%	9%
6	5%	6%	2%	9%	5%	7%
7	2%	6%	1%	9%	3%	7%
8	1%	5%	0%	7%	2%	5%
9	1%	2%	0%	9%	2%	6%
10	0%	0%	0%	10%	2%	7%
total	100%	100%	100%	100%	100%	100%

Table Appendix6: Total deciduous volume share in Kronobergs län within species dependent classes, excluding pixel information from pixel with < 5m³ total volume

volume class	Birch	Beech	Oak	other deciduous	all deciduous
1	69%	8%	18%	5%	100%
2	73%	5%	12%	9%	100%
3	69%	6%	11%	14%	100%
4	68%	7%	9%	15%	100%
5	71%	6%	6%	17%	100%
6	61%	8%	4%	26%	100%
7	40%	14%	3%	43%	100%
8	29%	17%	1%	53%	100%
9	21%	9%	0%	70%	100%
10	9%	2%	1%	88%	100%

7.1.2 Total deciduous volume and deciduous stand volume

Table Appendix7: Total deciduous volume [m³] by species and strata*

Species	Kronobergs län	West	South	North-east	North-center
Beech	1,142,397	239,310	732,537	25,361	145,189
Birch	10,203,168	2,464,338	3,146,963	2,261,045	2,330,822
Oak	1,733,814	179,883	806,356	235,609	511,966
other deciduous	2,422,597	451,747	865,606	515,782	589,462
all deciduous	15,501,976	3,335,277	5,551,462	3,037,798	3,577,439

Table Appendix8: Deciduous volume in deciduous stands [m³] by species and strata*

Species	Kronobergs län	West	South	North-east	Center north
Beech	287,691	50,875	197,860	978	37,907
Birch	1,039,743	210,470	514,313	77,246	237,542
Oak	345,175	33,938	209,691	13,614	87,872
other deciduous	398,446	58,115	223,483	20,306	96,474
all deciduous	2,071,055	353,398	1,145,348	112,145	459,794

Table Appendix9: Relative share of deciduous volume in deciduous stands volume of total deciduous volume in Kronobergs län and strata

Species	Kronobergs län	West	South	North-east	Center north
Beech	25%	21%	27%	4%	26%
Birch	10%	9%	16%	3%	10%
Oak	20%	19%	26%	6%	17%
other deciduous	16%	13%	26%	4%	16%
all deciduous	13%	11%	21%	4%	13%

* deviations when summing up strata values from Kronobergs län values are due to the stratification

Table Appendix10: Area of deciduous stands containing at least 1 m³ of the species' volume

Kronobergs län and strata		Beech	Birch	Oak	other deciduous	all deciduous
Kronobergs län	No. of pixel	257,223	528,033	377,776	387,415	531,254
	Area [ha]	16,076	33,002	23,611	24,213	33,203
	% of area of all deciduous	48%	99%	71%	73%	100%
West	No. of pixel	46,899	119,130	56,191	72,006	120,594
	Area [ha]	2,931	7,446	3,512	4,500	7,537
	% of area of all deciduous	39%	99%	47%	60%	100%
South	No. of pixel	160,321	261,415	223,834	202,179	262,729
	Area [ha]	10,020	16,338	13,990	12,636	16,421
	% of area of all deciduous	61%	99%	85%	77%	100%
North-east	No. of pixel	1,718	43,484	15,560	27,824	43,640
	Area [ha]	107	2,718	973	1,739	2,728
	% of area of all deciduous	4%	100%	36%	64%	100%
North-center	No. of pixel	48,250	103,885	82,118	85,348	104,126
	Area [ha]	3,016	6,493	5,132	5,334	6,508
	% of area of all deciduous	46%	100%	79%	82%	100%

7.2 Forest area, k-NN and SMD

Table Appendix11: Total forest area in Kronobergs län, comparing k-NN and SMD data

raster based	*k*-NN	SMD	Overlapping (forest according to k-NN and SMD)	total (forest according to k-NN or SMD)
Pixel counts	9,807,033	11,096,666	9,580,704	11,322,995
Area [ha]	**612,940**	**693,542**	**598,794**	**707,687**
Pure area [ha]	398,448	479,050		877,498
Share of total area	87%	98%	85%	-

Table Appendix12: Forest area in Kronobergs län, exclude volume <5m3/ha for k-NN and clear felled areas and young forest from SMD

raster based	*k*-NN	SMD	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or SMD)
Pixel counts	9,144,103	8,871,690	7,113,614	10,902,179
Area [ha]	**571,506**	**554,481**	**444,601**	**681,386**
Pure area [ha]	126,906	109,880		236,785
Share of total area	84%	81%	65%	-

Table Appendix13: Forest area in Kronobergs län, *k*-NN deciduous volume share>70% and total volume >5m³, SMD class 40

raster based	*k*-NN	SMD	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or SMD)
Pixel counts	677,383	720,695	157,494	1,240,584
Area [ha]	**42,336**	**45,043**	**9,843**	77,537
Pure area [ha]	32,493	35,200		67,693
Share of total area	55%	58%	13%	-

Table Appendix14: Forest area in Kronobergs län, as Table Appendix13 but also excluding SMD on *k*-NN < 5m³

raster based	*k*-NN	SMD incl. *k*-NN areas < 5 m³	SMD on *k*-NN < 5 m³	SMD excl. *k*-NN areas < 5 m³	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or *SMD* excl.)
Pixel counts	677,383	720,695	41,383	679,312	157,494	1,199,201
Area [ha]	**42,336**	**45,043**	**2,586**	42,457	**9,843**	74,950
Pure area [ha]	32,493	35,200				67,693
Share of total area	56%	60%		57%	13%	-

Table Appendix15: Forest area in Kronobergs län, as Table Appendix14 but including *k*-NN volume classes 7-10, >60% deciduous volume

raster based	*k*-NN	SMD incl. *k*-NN areas < 5 m³	SMD on *k*-NN < 5 m³	SMD excl. *k*-NN areas < 5 m³	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or *SMD* excl.)
Pixel counts	942,474	720,695	41,383	679,312	225,229	1,396,557
Area [ha]	**58,905**	**45,043**	**2,586**	42,457	14,077	87,285
Pure area [ha]	44,828	30,967				75,794
Share of total area	67%	52%		49%	16%	-

Table Appendix16: Forest area in Kronobergs län, as Table Appendix15 but including *k*-NN volume classes 6-10, >60% deciduous volume

raster based	*k*-NN	SMD incl. *k*-NN areas < 5 m³	SMD on *k*-NN < 5 m³	SMD excl. *k*-NN areas < 5 m³	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or *SMD* excl.)
Pixel counts	1,251,565	720,695	41,383	679,312	294,664	1,636,213
Area [ha]	**78,223**	**45,043**	**2,586**	42,457	18,417	102,263
Pure area [ha]	59,806	26,627				86,433
Share of total area	76%	44%		42%	18%	-

Table Appendix17: Forest area in Kronobergs län, as Table Appendix16 but including *k*-NN volume classes 4-10, >30% deciduous volume

raster based	*k*-NN	SMD incl. *k*-NN areas < 5 m³	SMD on *k*-NN < 5 m³	SMD excl. *k*-NN areas < 5 m³	Overlapping (forest according to *k*-NN and SMD)	total (forest according to *k*-NN or *SMD* excl.)
Pixel counts	2,423,534	720,695	41,383	679,312	446,028	2,656,818
Area [ha]	**151,471**	**45,043**	**2,586**	42,457	27,877	166,051
Pure area [ha]	123,594	17,167				140,761
Share of total area	91%	27%		26%	17%	-

Table Appendix18: Locations of deviating deciduous forest areas in the k-NN and SMD data sets

	k-NN deciduous	SMD deciduous (code 40)
Pixel counts	677,383	720,695
total area [ha]	42,336	45,043
Overlapping pixel	157,494	157,494
Area [ha]	9,843	9,843
% of total area	23%	22%

	k-NN deciduous	SMD deciduous (code 40)
Location	on SMD forest (codes 40-50, 54-56))	on *k*-NN forest
Pixel counts	632,253	637,142
Area [ha]	39,516	39,821
% of total area	93%	88%

Location	on SMD 54 - clear felled	on kNN 30% - 70% dec, volume
Pixel counts	266,740	288,534
Area [ha]	16,671	18,033
% of total area	39%	40%

Location	on SMD 55 - young forest	on kNN <30% dec, volume and > 5 m^3 total volume
Pixel counts	75,393	191,114
Area [ha]	4,712	11,945
% of total area	11%	27%

Location	on SMD 44 - conifer forest 5-15m
Pixel counts	26,055
Area [ha]	1,628
% of total area	4%

Location	on SMD 48 - mixed forest not on mires or bare rock
Pixel counts	44,838
Area [ha]	2,802
% of total area	7%

totally found	84%	88%

7.3 Deciduous stands: size and distribution

Table Appendix19: Size class distribution of deciduous stands and their areas in Kronobergs län and the strata

Kronobergs län and strata		< 1 ha	1-5 ha	5-10 ha	10-20 ha	20-50 ha	50-100 ha	> 100 ha
Kronobergs län	decid. stand area [ha]	4,609	14,932	6,052	4,299	4,014	1,860	283
	No. of decid. stands	6,775	7,430	883	315	140	28	2
West	decid. stand area [ha]	1,209	3,742	1,503	1,130	592	126	-

	No. of decid. Stands	1,775	1,867	219	83	20	2	-
	decid. stand area [ha]	1,767	6,395	3,143	2,330	2,563	1,402	283
South	No. of decid. stands	2,592	3,108	455	167	88	21	2
	decid. stand area [ha]	652	1.594	379	192	55	-	-
North-east	No. of decid. stands	967	865	56	15	2	-	-
	decid. stand area [ha]	997	3,278	1,073	747	836	387	-
Center-North	No. of decid. stands	1,465	1,622	159	56	31	6	-

7.4 Distances

Table Appendix20: Deciduous stands in Kronobergs län in distance from other SMD classes

Distance [m]	Kronobergs län: Urban, agricultural areas and water surfaces				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	12,038	31,326	77%	87%	2.6
40	12,895	32,545	83%	90%	2.5
60	13,274	33,012	85%	92%	2.5
80	13,593	33,428	87%	93%	2.5
120	13,934	33,889	89%	94%	2.4
140	14,195	34,241	91%	95%	2.4
160	14,371	34,499	92%	96%	2.4
180	14,518	34,680	93%	96%	2.4
220	14,752	34,975	95%	97%	2.4
240	14,852	35,113	95%	97%	2.4
260	14,944	35,221	96%	98%	2.4
280	15,028	35,328	97%	98%	2.4
320	15,138	35,463	97%	98%	2.3
500	15,432	35,819	99%	99%	2.3
remaining	141	230			1.6
total	15,573	36,049			2.3

Table Appendix21: Deciduous stands in Kronobergs län in distance from urban areas

Distance [m]	Kronobergs län: urban areas (codes: 1-9; 13-20)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	3,943	16,175	25%	45%	4.1
40	5,824	20,193	37%	56%	3.5
60	6,972	22,478	45%	62%	3.2

80	7,882	23,908	51%	66%	3.0
120	8,899	25,599	57%	71%	2.9
140	9,524	26,690	61%	74%	2.8
160	10,060	27,506	65%	76%	2.7
180	10,514	28,153	68%	78%	2.7
220	11,207	29,237	72%	81%	2.6
240	11,593	29,800	74%	83%	2.6
260	11,903	30,289	76%	84%	2.5
280	12,223	30,745	78%	85%	2.5
320	12,653	31,354	81%	87%	2.5
500	14,158	33,709	91%	94%	2.4
remaining	1,415	2,341			1.7
total	15,573	36,049			

Table Appendix22: Deciduous stands in Kronobergs län in distance to agricultural areas

Distance [m]	Kronobergs län: agricultural areas (codes 30-32)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	11,375	29,822	73%	83%	2.6
40	12,028	30,736	77%	85%	2.6
60	12,405	31,263	80%	87%	2.5
80	12,757	31,781	82%	88%	2.5
120	13,132	32,359	84%	90%	2.5
140	13,433	32,757	86%	91%	2.4
160	13,643	33,082	88%	92%	2.4
180	13,838	33,365	89%	93%	2.4
220	14,154	33,769	91%	94%	2.4
240	14,288	33,984	92%	94%	2.4
260	14,407	34,175	93%	95%	2.4
280	14,522	34,341	93%	95%	2.4
320	14,683	34,572	94%	96%	2.4
500	15,195	35,300	98%	98%	2.3
remaining	378	750			2.0
total	15,573	36,049			

Table Appendix23: Deciduous stands in Kronobergs län in distance to water surfaces

Distance [m]	Kronobergs län: water surfaces (codes: 80;81)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	1,490	8,853	10%	25%	5.9
40	2,441	11,436	16%	32%	4.7
60	2,778	12,181	18%	34%	4.4
80	3,008	12,594	19%	35%	4.2
120	3,301	13,276	21%	37%	4.0

140	3,555	13,927	23%	39%	3.9
160	3,773	14,377	24%	40%	3.8
180	3,997	14,831	26%	41%	3.7
220	4,332	15,562	28%	43%	3.6
240	4,562	16,025	29%	44%	3.5
260	4,770	16,435	31%	46%	3.4
280	5,012	16,980	32%	47%	3.4
320	5,325	17,639	34%	49%	3.3
500	6,987	21,025	45%	58%	3.0
remaining	8,586	15,024			1.7
total	15,573	36,049			

Table Appendix24: Deciduous stands in the West in distance from other SMD classes

Distance [m]	West: Urban, agricultural areas and water surfaces				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	3,272	7,312	83%	88%	2.2
40	3,440	7,552	87%	91%	2.2
60	3,512	7,648	89%	92%	2.2
80	3,579	7,733	90%	93%	2.2
120	3,649	7,811	92%	94%	2.1
140	3,694	7,882	93%	95%	2.1
160	3,722	7,923	94%	95%	2.1
180	3,750	7,956	95%	96%	2.1
220	3,807	8,022	96%	97%	2.1
240	3,820	8,037	96%	97%	2.1
260	3,838	8,058	97%	97%	2.1
280	3,848	8,072	97%	97%	2.1
320	3,867	8,099	98%	98%	2.1
500	3,922	8,169	99%	98%	2.1
remaining	44	133			3.0
total	3,966	8,302			2.1

Table Appendix25: Deciduous stands in the West in distance from urban areas

Distance [m]	West: urban areas (codes: 1-9; 13-20)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	1,054	3,286	27%	40%	3.1
40	1,583	4,335	40%	52%	2.7
60	1,924	4,916	49%	59%	2.6
80	2,174	5,324	55%	64%	2.4
120	2,454	5,767	62%	69%	2.4
140	2,634	6,070	66%	73%	2.3

160	2,763	6,280	70%	76%	2.3
180	2,870	6,418	72%	77%	2.2
220	3,034	6,660	77%	80%	2.2
240	3,132	6,784	79%	82%	2.2
260	3,207	6,911	81%	83%	2.2
280	3,279	7,019	83%	85%	2.1
320	3,372	7,133	85%	86%	2.1
500	3,691	7,713	93%	93%	2.1
remaining	275	589			2.1
total	3,966	8,302			

Table Appendix26: Deciduous stands in the West in distance from agricultural areas

Distance [m]	West: agricultural areas (codes 30-32)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	3,116	6,980	79%	84%	2.2
40	3,269	7,162	82%	86%	2.2
60	3,342	7,259	84%	87%	2.2
120	3,507	7,499	88%	90%	2.1
160	3,604	7,651	91%	92%	2.1
220	3,713	7,781	94%	94%	2.1
320	3,795	7,914	96%	95%	2.1
500	3,883	8,055	98%	97%	2.1
remaining	83	247			3.0
total	28,312	60,548			2.1

Table Appendix27: Deciduous stands in the West in distance from water surfaces

Distance [m]	West: water surfaces (codes: 80;81)				
	No. of decid. stands	Decid. stand area [ha]	% of No. of decid. stands	% of decid. stand area [ha]	mean stand size [ha]
20	374	1,649	9%	20%	4.4
40	576	2,209	15%	27%	3.8
60	657	2,375	17%	29%	3.6
120	798	2,702	20%	33%	3.4
160	908	2,898	23%	35%	3.2
220	1,034	3,171	26%	38%	3.1
320	1,281	3,602	32%	43%	2.8
500	1,709	4,428	43%	53%	2.6
remaining	2,257	3,874			1.7
total					

Table Appendix28: Deciduous stands in the South in distance from other SMD classes and urban areas

Distance [m]	South urban, agri.areas and water surf.				urban areas (codes: 1-9; 13-20)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	4,889	15,741	76%	88%	1,788	9,391	28%	53%
40	5,287	16,335	82%	91%	2,541	11,200	39%	63%
60	5,447	16,535	85%	92%	2,975	12,126	46%	68%
120	5,736	16,946	89%	95%	3,694	13,364	57%	75%
160	5,928	17,216	92%	96%	4,108	14,093	64%	79%
220	6,098	17,447	95%	98%	4,591	14,844	71%	83%
320	6,276	17,690	98%	99%	5,184	15,778	81%	88%
500	6,400	17,848	99%	100%	5,878	16,883	91%	94%
remain.	33	36			555	1,001		
total	6,433	17,884			6,433	17,884		

Table Appendix29: Deciduous stands in the South in distance to agricultural areas and water surfaces

Distance [m]	South: agricultural areas (codes 30-32)				water surfaces (codes: 80;81)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	4,588	14,946	71%	84%	631	5,340	10%	30%
40	4,856	15,376	75%	86%	1,042	6,606	16%	37%
60	5,026	15,640	78%	87%	1,180	6,950	18%	39%
120	5,332	16,132	83%	90%	1,375	7,403	21%	41%
160	5,563	16,457	86%	92%	1,579	8,037	25%	45%
220	5,794	16,797	90%	94%	1,811	8,591	28%	48%
320	6,053	17,220	94%	96%	2,181	9,630	34%	54%
500	6,279	17,554	98%	98%	2,872	11,139	45%	62%
remain.	154	330			3,561	6,745		
total								

Table Appendix30: Deciduous stands in the North-east in distance from other SMD classes and urban areas

Distance [m]	North-east: urban, agri.areas, water surf.				urban areas (codes: 1-9; 13-20)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	1,384	2,295	73%	80%	367	795	19%	28%
40	1,508	2,453	79%	85%	583	1,128	31%	39%
60	1,559	2,510	82%	87%	732	1,378	38%	48%
120	1,652	2,596	87%	90%	994	1,708	52%	59%
160	1,709	2,668	90%	93%	1,155	1,925	61%	67%
220	1,751	2,711	92%	94%	1,288	2,096	68%	73%
320	1,811	2,784	95%	97%	1,448	2,294	76%	80%
500	1,870	2,841	98%	99%	1,625	2,548	85%	89%
remaining	35	31			280	325		
total	1,905	2,872						

Table Appendix31: Deciduous stands in the North-east in distance to agricultural areas and water surfaces

Distance [m]	North-east: agricultural areas (codes 30-32)				water surfaces (codes: 80;81)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	1,302	2,155	68%	75%	115	329	6%	11%
40	1,407	2,292	74%	80%	239	525	13%	18%
60	1,454	2,344	76%	82%	292	608	15%	21%
120	1,552	2,448	81%	85%	370	735	19%	26%
160	1,608	2,520	84%	88%	420	809	22%	28%
220	1,667	2,583	88%	90%	501	925	26%	32%
320	1,741	2,688	91%	94%	652	1,160	34%	40%
500	1,830	2,799	96%	97%	869	1,474	46%	51%
remaining	75	73			1,036	1,398		
total								

Table Appendix32: Deciduous stands in the North center in distance from other SMD classes and urban areas

Distance [m]	North-center: urban, agricultural areas and water surfaces				urban areas (codes: 1-9; 13-20)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	2,531	6,192	76%	85%	739	2,726	22%	37%
40	2,706	6,441	81%	88%	1,128	3,598	34%	49%
60	2,804	6,572	84%	90%	1,354	4,129	41%	56%
120	2,952	6,829	88%	93%	1,780	4,867	53%	67%
160	3,071	6,990	92%	96%	2,063	5,330	62%	73%
220	3,155	7,094	94%	97%	2,334	5,804	70%	79%
320	3,248	7,209	97%	99%	2,700	6,356	81%	87%
500	3,308	7,286	99%	100%	3,027	6,878	91%	94%
remaining	31	32			312	440		
total	3,339	7,318						

Table Appendix33: Deciduous stands in the North-center in distance to agricultural areas and water surfaces

Distance [m]	North-center: agricultural areas (codes 30-32)				water surfaces (codes: 80;81)			
	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	2,404	5,949	72%	81%	375	1,550	11%	21%
40	2,539	6,136	76%	84%	595	2,127	18%	29%
60	2,628	6,252	79%	85%	661	2,309	20%	32%
120	2,792	6,564	84%	90%	773	2,500	23%	34%
160	2,922	6,740	88%	92%	885	2,708	27%	37%
220	3,036	6,897	91%	94%	1,006	2,950	30%	40%
320	3,156	7,062	95%	97%	1,238	3,412	37%	47%
500	3,270	7,211	98%	99%	1,574	4,199	47%	57%
remaining	69	106			1,765	3,118		
total								

Table Appendix34: Deciduous stands in Kronobergs län and the strata in distance to road sites

Kronobergs län					The West			
Distance [m]	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	7,940	25,422	51%	71%	2,073	5,634	52%	68%
40	9,054	27,019	58%	75%	2,358	6,034	59%	73%
60	9,951	28,346	64%	79%	2,589	6,380	65%	77%
120	12,131	31,437	78%	87%	3,142	7,166	79%	86%
160	13,170	32,879	85%	91%	3,416	7,561	86%	91%

220	14,235	34,280	91%	95%	3,657	7,884	92%	95%
320	15,105	35,352	97%	98%	3,850	8,122	97%	98%
500	15,475	35,806	99%	99%	3,949	8,254	100%	99%
remaining	98	243			17	49		
total	15,573	36,049			3,966	8,302		

South					North-east			
Distance [m]	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	3,349	13,331	52%	75%	891	1,669	47%	58%
40	3,805	14,082	59%	79%	1,041	1,842	55%	64%
60	4,175	14,663	65%	82%	1,163	1,986	61%	69%
120	5,079	16,007	79%	90%	1,422	2,321	75%	81%
160	5,469	16,552	85%	93%	1,539	2,454	81%	85%
220	5,893	17,103	92%	96%	1,695	2,638	89%	92%
320	6,228	17,523	97%	98%	1,838	2,796	96%	97%
500	6,374	17,719	99%	99%	1,897	2,857	100%	99%
remaining	59	165			8	16	0%	1%
total	6,433	17,884			1,905	2,872		

North-center				
Distance [m]	No of decid. stands	Decid. stand area [ha]	% of total stand number	% of total stand area
20	1,648	4,989	49%	68%
40	1,877	5,291	56%	72%
60	2,060	5,554	62%	76%
120	2,538	6,209	76%	85%
160	2,802	6,593	84%	90%
220	3,052	6,945	91%	95%
320	3,254	7,211	97%	99%
500	3,323	7,299	100%	100%
remaining	16	19	0%	0%
total	3,339	7,318		

7.5 Species dominances

Table Appendix35: Species volume dominances within the deciduous stand pixel and associated areas in Kronobergs län and the strata

Stratum	Species	No. of decid. stand pixel with a species volume share of >= 70%	% of total decid. stand pixel	Decid. stand area [ha]
Kronobergs län	Birch	217,096	41%	13,568.5
	Beech	17,878	3%	1,117.4
	Oak	2,886	1%	180.4
	Other deciduous	2,873	1%	179.6
	Mixed deiduous	290,400	55%	18,150.0
	total decid. stand pixel	5,131,133	100%	320,695.8
West	Birch	65,618	54%	4,101.1
	Beech	4,555	4%	284.7
	Oak	680	1%	42.5
	Other deciduous	1,041	1%	65.1
	Mixed deiduous	48,700	40%	3,043.8
	total decid. stand pixel	120,594	100%	7,537.1
South	Birch	88,777	34%	5.548.6
	Beech	13,039	5%	814.9
	Oak	790	0%	49.4
	Other deciduous	881	0%	12.4
	Mixed deiduous	159,286	61%	9,955.4
	total decid. stand pixel	262,773	100%	16,423.3
North-east	Birch	29,192	67%	1,824.5
	Beech	5	0%	0.3
	Oak	341	1%	21.3
	Other deciduous	199	0%	12.4
	Mixed deiduous	13,903	32%	868.9
North-east	total decid. stand pixel	43,640	100%	2,727.5
Center north	Birch	33,509	32%	2,094.3
	Beech	279	0%	17.4
	Oak	1,075	1%	67.2
	Other deciduous	752	1%	47.0
	Mixed deiduous	68,511	66%	4,281.9
	total decid. stand pixel	104,126	100%	6,507.9

7.6 Deciduous stands density and shape

Table Appendix36: Deciduous stand densities and mean distances in Kronobergs län and the strata

Stratum	Total area [ha]	No. of decid. stands	Decid. stand density per 1,000 ha	Mean dist. betw. decid. plot centers [m]	*Mean dist. to nearest neighbour [m] (Fragstats)*
West	272,855	3,966	14.5352	829.4488	
South	272,634	6,433	23.5957	651.0034	*151.331*
North-east	219,379	1,905	8.6836	1,073.1243	*287.45*
Center north	177,756	3,339	18.7842	729.6321	
Kronobergs län	942,624	15,573	16.5209	778.0063	

Table Appendix37: Polygon mean angle of the deciduous stand polygons

	in North-South bearing (angle -90°;90°)	% in N-S bearing	in East-West bearing or square (angle 0)	% in E-W bearing
No. of decid. stands	9,861	63%	5,712	37%
Dedid. stand area [ha]	26,168	73%	9,882	27%

Table Appendix38: Minimum perimeter area ratio compared for the five stand size classes containing most deciduous stands

Size class number	Decid. stand size [m²]	No. of decid. stands	% of total decid. stand number	mean minimum-ratio	median minimum-ratio
1	5,000	1,241	8%	0.682	0.625
2	5,625	1,095	7%	0.684	0.587
3	6,250	968	6%	0.641	0.625
4	6,875	850	5%	0.645	0.589
5	7,500	817	5%	0.603	0.562
	total	4,971	32%	-	-

Table Appendix39: Minimum perimeter ratios

size class	Minimum-ratio	Number of decid. stands	% of total size class decid. stand no.
No. 1 size: 5000 m²	0.556	313	25%
	0.625	482	39%
	0.714	394	32%
	0.833	52	4%
	lower than mean	795	64%
No. 2 size: 5625 m²	0.528	199	18%
	0.587	358	33%
	0.662	374	34%
	0.758	160	15%

	0,887	4	0%
	lower than mean	931	85%
No. 3 size: 6250 m²	0.511	148	15%
	0.563	239	25%
	0.625	311	32%
	0.703	224	23%
	0.804	46	5%
	lower than mean	698	72%
No. 4 size: 6875 m²	0.494	91	11%
	0.538	178	21%
	0.589	253	30%
	0.662	213	25%
	0.741	104	12%
	0.843	11	1%
	lower than mean	522	61%
No. 5 size: 7500 m²	0.471	51	6%
	0.513	152	19%
	0.562	216	26%
	0.612	193	24%
	0.683	159	19%
	0.774	46	6%
	lower than mean	419	51%
total	lower than mean	3.365	68%

7.7 Age

Table Appendix40: Age class distribution of deciduous stand pixel and pixel with a deciduous volume share > 70%

Age class	Decid. stand pixel		Pixel with a decid. volume share > 70%	
	No. of pixel	Area [ha]	No. of pixel	Area [ha]
1-10	102,352	6,397.00	154,980	9,686.25
10-20	87,629	5,476.81	208,653	13,040.81
20-30	72,193	4,512.06	174,159	10,884.94
30-40	56,382	3,523.88	118,907	7,431.69
40-50	62,946	3,934.13	84,695	5,293.44
50-60	61,420	3,838.75	58,526	3,657.88
60-70	37,350	2,334.38	37,126	2,320.38
70-80	21,994	1,374.63	17,512	1,094.50
80-90	24,015	1,500.94	4,250	265.63
90-100	3,205	200.31	786	49.13
100-110	1,643	102.69	212	13.25
110-120	108	6.75	64	4.00
120-130	17	1.06	15	0.94
130-140			2	0.13

7.8 Fragstats

Table Appendix41: Results from Fragstats for different class metrics, "Min" and "Max" refer to minimum and maximum values including the other SMD land use classes

Class metrics abbrevation	Class metrics	West			South		
		Min	Max	Dec. stand value	Min	Max	Dec. stand value
TYPE	class type	2	84	2	2	84	2
CA	class area	1	72,832	8,385	1	83,312	17,892
PLAND	% of total land	0.0	18.0	2.1	0.0	20.1	4.3
NP	no. of patches	7	158,058	44,559	1	75,379	5,585
PD	patch density per 100 ha	0	39	11	0	18	1
LSI	Landscape shape index	3	532	243	2	344	178
NLSI	normalized landscape shape index	0.49	0.94	0.66	0.05	0.81	0.33
SHAPE_ MN	Shape MN: mean	1.00	2.23	1.10	1.09	2.82	2.21
SHAPE_ MD	Shape MD: median	1.00	2.06	1.00	1.00	2.82	2.00
SHAPE_ RA	Shape RA: range	0.25	9.96	1.92	0.00	43.20	43.20
Class metrics abbrevation	Class metrics	West			Soth		
		Min	Max	Dec. stand value	Min	Max	Dec. stand value
PARA_ MN	Perimeter area ratio MN: mean	895	1,554	1,232	208	1,498	709
PARA_ MD	Perimeter area ratio MD: median	847	1,600	1,200	208	1,600	700
PARA_ RA	Perimeter area ratio RA: range	640	1,252	1,082	-	1,576	1,418
PARA_ SD	Perimeter area ratio SD: standard deviation	87	312	269	-	701	192
CLUMPY	Clumpidness index			0.32			0.65
AI	Aggregation index			33.68			66.86
ENN_MN	Euclidean nearest neighbour MN: mean				66.92	59.658,60	151.33

ENN_MD	Euclidean nearest neighbour MD: median				50.00	59,658.60	100.00
ENN_RA	Euclidean nearest neighbour RA: range				-	62,556.53	1,674.09
ENN_SD	Euclidean nearest neighbour SD: standard deviation				-	29,489.43	144.71

Class metrics abbrevation	Class metrics	North-east			Center-north		
		Min	Max	Dec. stand value	Min	Max	Dec. stand value
TYPE	class type	2	84	2			
CA	class area	3	77,813	2,982	1	53,614	7,353
PLAND	% of total land	0.0	14.8	0.6	0.0	20.2	2.8
NP	no. of patches	1	63,763	1,727	1	46,619	3,009
PD	patch density per 100 ha	0	12	0	0	18	1
LSI	Landscape shape index	2	330	97	2	281	129
NLSI	normalized landscape shape index	0.05	0.77	0.44	0.04	0.82	0.37
SHAPE_ MN	Shape MN: mean	1.15	3.41	2.03	1.09	3.97	2.14
SHAPE_ MD	Shape MD: median	1.00	3.41	1.86	1.00	3.97	2.00
SHAPE_ RA	Shape RA: range	0.00	47.15	47.15	0.00	42.73	42.73
SHAPE_ SD	Shape SD: standard deviation	0.00	1.29	1.29	0.00	2.18	1.13
PARA_ MN	Perimeter area ratio MN: mean	111	1.450	776	121	1.495	744
PARA_ MD	Perimeter area ratio MD: median	111	1,600	750	126	1,600	720
PARA_ RA	Perimeter area ratio RA: range	-	1,565	1,367	-	1,556	1,388
PARA_ SD	Perimeter area ratio SD: standard deviation	-	609	187	-	566	200
CLUMPY	Clumpidness index			0.55	0.18	0.96	0.62
AI	Aggregation index			55.70	18.43	95.87	62.62

ENN_MN	Euclidean nearest neighbour MN: mean	66.92	59,658.60	287.45			
ENN_MD	Euclidean nearest neighbour MD: median	50.00	59,658.60	152.07			
ENN_RA	Euclidean nearest neighbour RA: range	-	62,556.53	4,638.08			
ENN_SD	Euclidean nearest neighbour SD: standard deviation	-	29,489.43	361.19			

7.9 The Simulation

7.9.1 Square investigation:

7.9.1.1 Volume

Table Appendix42: Total deciduous volume in the simulation square in volume classes [m³]

volume class	Conifers	Birch	Beech	Oak	other deciduous	all deciduous
1	243,570	9,960	-	980	2,353	13,293
2	40,811	4,809	8	890	1,469	7,176
3	16,641	3,254	39	855	1,216	5,364
4	7,303	2,253	11	854	956	4,073
5	4,680	1,957	13	831	915	3,716
6	2,745	1,611	37	766	929	3,343
7	1,989	1,675	40	941	1,077	3,734
8	781	918	38	655	669	2,280
9	523	994	57	771	915	2,737
10	165	805	59	830	911	2,605
total	319,209	28,236	303	8,372	11,408	48,321
%	87%	8%	0%	2%	3%	
total volume	367,528					

Table Appendix43: Total deciduous volume share in the simulation square within species

volume class	Birch	Beech	Oak	other deciduous	all deciduous
1	35%	0%	12%	21%	28%
2	17%	3%	11%	13%	15%
3	12%	13%	10%	11%	11%
4	8%	4%	10%	8%	8%
5	7%	4%	10%	8%	8%

6	6%	12%	9%	8%	7%
7	6%	13%	11%	9%	8%
8	3%	13%	8%	6%	5%
9	4%	19%	9%	8%	6%
10	3%	19%	10%	8%	5%
total	100%	100%	100%	100%	100%

Table Appendix44: Total deciduous volume share in the simulation square within classes

volume class	Birch	Beech	Oak	other deciduous
1	75%	0%	7%	18%
2	67%	0%	12%	20%
3	61%	1%	16%	23%
4	55%	0%	21%	23%
5	53%	0%	22%	25%
6	48%	1%	23%	28%
7	45%	1%	25%	29%
8	40%	2%	29%	29%
9	36%	2%	28%	33%
10	31%	2%	32%	35%

Table Appendix45: Area and area share of volume classes in the simulation square

volume class	No of pixel	Area [ha]	% of total area
1	15,673	980	52%
2	4,479	280	15%
3	2,646	165	9%
4	1,667	104	6%
5	1,629	102	5%
6	1,026	64	3%
7	1,186	74	4%
8	577	36	2%
9	665	42	2%
10	476	30	2%

7.9.1.2 Forest area and SMD classes

Table Appendix46: Forest area in the simulation square, comparing k-NN and SMD

	No of pixel	Area [ha]	Forest cover %
Square size	40,000	2,500	
SMD forest	33,376	2,086	83%
k-NN forest	30,024	1,877	75%
overlapping	29,647	1,853	74%
joint forest	33,753	2,110	84%

Table Appendix47: SMD land cover classes in the simulation square

SMD classes	Description	No of pixel	Area [ha]	% total area
30,32	agriculture	3,978	249	10%
40,41	deciduous forest	2,326	145	6%
44,45,46	coinferous forest	22,235	1,390	56%
48,49	mixed forest	3,343	209	8%
54	clear felled	4,344	272	11%
55	young forest	1,128	71	3%
71,72	peatland	906	57	2%
81	lakes	1,740	109	4%

7.9.1.3 Deciduous stands

Table Appendix48: Stand features of all stands in the simulation square

Stand feature	Value
Total stand area [ha]	1,877
Total number of stands	424
Mean stand size [ha]	4.4
Total decid. stand area [ha]	107
Total number of decid. stands	51
Mean decid. stand size [ha]	2.1
Mean decid. stand distance [m]	607

Table Appendix49:Size class distribution of all stands and the deciduous stands in the simulation square

stand size	No. of stands	Total stand area [ha]	No. of decid. stands	total decid. stand area [ha]
<1 ha	102	51.9	18	6.8
1-5ha	213	511.5	27	58.5
5-10 ha	64.0	432.4	5.0	31.8
10-20 ha	27	393.8	1	10.3
20-50 ha	18	487.1		

7.9.2 Simulation Results: Production

Table Appendix50: Species groups in the simulator and their initial deciduous share

	Simulator species group	Volume class	Initial decid. volume share
1	71-90% pine volume	2,3	18%
2	71-90% spruce volume	2,3	18%
3	71-90% spruce and pine	2,3	18%
4	>70% deciduous volume	8,9,10	84%
5	>90% spruce and pine	1	5%
6	> 70% deciduous volume	8,9,10	84%
7	> 70% deciduous volume	8,9,11	84%
8	mixed (remaining)	4,5,6,7	47%

Table Appendix51: Simulated outcomes for harvest volume, standing volume and deciduous volume for all simulated cases

Simulated outcomes		Reference	Case A	Case B con	Case B hom
Harvest volume all periods	in m³	773,207	749,668	744,977	747,024
	% of Ref.		97%	96%	97%
	m³/ha	412	399	397	398
Standing volume in period 15	total m³	372,485	408,241	402,763	400,657
	% of Ref.		110%	108%	108%
	m³/ha	198	217	215	213
Standing volume in production stands (period 15)	total m³	304,812	285,293	279,990	277,849
	% of Ref.		94%	92%	91%
	m³/ha	171	169	166	165
Standing decid. volume (period 15)	in m³	97,866	107,391	120,282	120,841
	% of tot. vol	26%	26%	30%	30%
	% of Ref.		100%	114%	115%
Standing decid. volume (mean period 13-15)	in m³	90,583	99,781	111,535	112,132

Simulated outcomes		Case B low	Case C	Case D	Case O
Harvest volume all periods	in m³	749,360	735,311	744,330	772,110
	% of Ref.	100%	98%	99%	103%
	m³/ha	399	392	397	411
Standing volume in period 15	total m³	400,094	429,363	403,232	372,142
	% of Ref.	100%	107%	101%	93%
	m³/ha	213	229	215	198
Standing volume in production stands (period 15)	total m³	276,419	287,890	280,009	284,710
	% of Ref.	100%	104%	101%	103%
	m³/ha	164	180	166	174

Standing decid. volume (period 15)	in m³	112,603	131,592	123,173	121,414
	% of tot. vol	28%	31%	31%	33%
	% of Ref.	100%	109%	109%	116%
Standing decid. volume (mean period 13-15)	in m³	104,612	123,811	114,093	112,816

7.9.3 Simulation results: Biodiversity

Table Appendix52: Properties of deciduous stands and deciduous patches for each simulated case. Deciduous patches summarize adjacent deciduous stands into one patch

	Reference	Case A	B con	B hom
Area <10% decid. volume	979.6	126.3	860.5	849.6
No. of deciduous patches	45	45	29	77
Deciduous patch area [ha]	107.4	107.4	381.6	381.7
Mean decid. patch size [ha]	2.4	2.4	13.2	5.0
NN dist. decid. patches [m]	136	136	103	118
Mean dist decid. patches [m]	646	646	805	494
No. of deciduous stands	51	51	98	109
Deciduous stand area [ha]	107,4	107,4	381,6	381.7
Mean decid. stand size [ha]	2.1	2.1	3.9	3.5
NN dist. dec. stands [m]	106	106	29	61
Mean dist. decid. stands [m]	607	607	438	415

	B low	Case C	Case D	Case O
Area <10% decid. volume	921.4	979.6	126.3	824.2
No. of deciduous patches	78	64	29	119
Deciduous patch area [ha]	382.3	190.7	381.6	215.4
Mean decid. patch size [ha]	4.9	3.0	13.2	1.8
NN dist. decid. patches [m]	118	116	103	73
Mean dist decid. patches [m]	491	542	805	397
No. of deciduous stands	142	84	98	159
Deciduous stand area [ha]	382.3	190.7	381.6	215.4
Mean decid. stand size [ha]	2.7	2.3	3.9	1.4
NN dist. dec. stands [m]	58	57	29	48
Mean dist. decid. stands [m]	364	473	438	344

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