ALTERFOR

Deliverable 1.1 – FMM descriptions (in report form)

Project Title	Alternatives models and robust decision-making for future forest management
Project Acronym	ALTERFOR
Project Coordinator	Ljusk Ola Eriksson, Swedish University of Agricultural Sciences (SLU)
Scientific Coordinator	Vilis Brukas, Swedish University of Agricultural Sciences (SLU)
Project Administrator	Giulia Attocchi, Swedish University of Agricultural Sciences (SLU)
Project Duration	1 April 2016 – 30 September 2020
Project Duration in months	54
Authors, organizations (short name)	Main authors: Eric Agestam and Urban Nilsson, SLU Co-authors: local case coordinators
WP No., WPL(s)	WP1, Urban Nilsson and Eric Agestam
Date of delivery by Coordinator	07 June 2017
Date of delivery according to DoA	31 May 2017
Reviewed by	
Project coordinator, scientific coordinator, administrative coordinator	
Type of Deliverable	
Report	X
Demonstration	
Websites, patents, fillings, etc.	
Dissemination level	
Public	X
Confidential, only members of the consortium (including the Commission Services)	
Other	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

I. Forest Management Models (FMMs) description

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

9. Sweden

9.1. Background and forest history

Due to an increase in foreign demand associated with the industrial revolution, the export of wood became an economically lucrative business in Sweden during the 19th century. This resulted in repeated unregulated exploitative cuttings throughout the country. Diminishing timber dimension requirements combined with little care for regeneration meant that the forest state was poor in many parts of the country in the beginning of the 20th century. Emerging concerns over the forest state as well as a future wood-shortage stimulated the establishment of forest regulations and the principle of sustained yield were gradually institutionalized. Improved forest management methods, afforestation of former agricultural-land and transformation of broadleaved forests into productive conifer monocultures in southern Sweden all contributed to a steady increase in the standing stock as well as annual harvest during the 20th century. Forestry in Sweden is today highly mechanized and cost-effective, placing the country among the world leaders on the global wood-market despite its relatively small forest area, low forest productivity and high labour costs. In line with overall production-orientation, the very dominant FMM since the 1950s is the clear-cutting sys-tem, primarily of conifer monocultures. Scots pine are more common in northern Sweden while Norway spruce dominates in the south. Due to the long-lasting stability of current dominant practices, the level of scientific knowledge and practical "know-how" are much more advanced for clearcutting compared with alternative forest management approaches.

The production-oriented paradigm aiming for increased supply of timber for industrial use remained intact into the 1990s. However in 1993, stimulated by the conference in Rio and domestic tension with environmental interests the prevailing forest policy was put into place, stipulating that production goals and environmental goals are equally important. In addition to a steadily in-creasing share of protected areas, this policy shift has resulted in the integration of conservation measures into the management of production stands over the last decades, but in practice the production-orientation remains strong. Today much of the nature conservation activities in forestry are governed by the voluntary market based certification standards (PEFC, FSC), and more than half of the productive forestland is controlled by certified owners. Beyond integrative conservation measures, certified owners need to engage in forestland zoning at estate level to meet set-aside requirements.

9.2. Ownership

For all Sweden 50% of the forest land is owned by private, 25% by a few large limited companies as SCA, Stora Enso and BergvikAB, and 25% by public owners including church, communities and the state own limited company Sveaskog, Table 50. The ownership structure in Sweden shows distinct regional differences, a high proportion of the forest in the north are owned by big companies in-cluding state owned Sveaskog, whereas small-scale private forest ownership dominates in the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

south. Private forest owners in Sweden constitute a strong stakeholder group since a high proportion of them (around 50%) are organized in forest owner associations with their own wood-processing industries. This is especially valid in southern Sweden, where the members of the forest owner association Södra in addition to organizing more than half of the forest area have substantial industrial resources, including large pulp-mills.

9.3. The case study area

9.3.1. General description CSA Kronoberg

The Swedish Case study area is one region, Kronoberg. This is one of the 24(?) regions. The total land area is 840 000ha and 84% is forestland. Kronoberg County has a higher cover of productive forest relative to Sweden. The higher share of productive forest in the CSA express regional differences between southern and northern Sweden. With harsher climate and lower evapotranspiration, the share of unproductive forests increase with increasing latitude e.g. sparsely forested mires, and mountain forest. The forest yield capacity of $9m^3ha^{-1}y^{-1}$ is low compared to European conditions but higher than average for Sweden. For more information about the forest situation see Table 50.

Table 50. Data about Sweden and CSA. Götaland is one of the three "large" regions in Sweden, covering the very southern part. Sources: SLU. 2016. Skogsdata 2016 (Forest data 2016).

	CSA Kronoberg	Götaland	Sweden
Total area (ha)	840 000	8 639 000	40 827 000
Forest land (ha)	704 000	5 447 000	28 184 000
Forestland cover (%)	84	63	69
Productive forestland (ha)1	676 000	5 071 000	23 441 000
Productive forestland cover (%)	80	58.7	57.4
Average volume (m3ha-1)2	142	178	138
Site productivity (m3ha-1year-1)2	9.0	8.7	5.4
MAI 2011-2015 (m3ha-1year-1)2	5.9	7.2	5.3(?)
Ownership forestland (%)			
Companies	3.1	6.7	22.9
Private	75.1	76	49.1
Other (largely public)4	21.7	17.3	28
Protected areas (%)2,3	5-6	6.1	8.4

[1] $>1m^3ha^{-1}year^{-1}$

[2] On productive forestland

[3] Formal and voluntary protection

[4] The major public owner is the state forest company Sveaskog

[5] >10 % crown cover and minimum height of 5 meter

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

The area and cover of forestland is based on the international definition of forest, while productive forestland have a production potential of >1m^{3}ha^{-1}year^{-1}. This distinction is of high practical importance because forest management is not allowed in unproductive forests (<>1m^{3}ha^{-1}year^{-1}). The coverage of the different FMMs described in this questionnaire are therefore expressed as their coverage on productive forestland.

Table 51. Proportion (%) of forest land byu productivity and moisture classes on CSA Kronoberg. Productivity expressed as Site Index (SI) for the most producing trees specie, normally Scots Pine or Norway spruce.

Productivity/ moisture	**Site index (SI) m, and Productivity, (m^{3}ha-^{1}y-^{1})**	**Dry %**	**Mesic %**	**Moist %**	**Wet %**
High	SI 30 m - >10 (m^{3}ha-^{1}y-^{1}))	0.7	1.4	5.9	4.5
Medium	SI 24-30 m 5-10 (m^{3}ha-^{1}y-^{1})	1.9	23.3	19.2	7.9
Low	Si<24 m <5 (m^{3}ha-^{1}y-^{1})	0.8	21.8	8.7	3.9

Tree species in Sweden and in the CSA

Scots Pine and Norway spruce dominates forests in Sweden, together around 80% of standing volume. Broadleaves are nearly 20% with Birch as the important specie, Table 52. The CSA Kronoberg have more spruce, about 50% of standing volume, less pine than whole Sweden. Even if the growing conditions for oak and beech is more favourable in Kronoberg than in Sweden the amount of those species is together less than 4 % and among the broadleaves birch dominates heavily Table 52.

Table 52. Tree species, % of standing volume in CSA Kronoberg, in Götaland (southern "Large-region" of Sweden) and in Sweden. Skogsdata 2016.

Sweden Species (Latin name)	Kronoberg (CSA) (% total volume)	Götaland (southern Sweden) (% total volume)	Sweden (% total volume)
Picea abies	49.2	46	41.3
Pinus sylvestris	30.9	30.8	39.3
Betula spp.	12.1	10.8	12.3
Other broadleaves[1]	3.4	5.5	3.8
Quercus spp.	2.6	3.6	1.2
Fagus sylvatica	1.3	2.2	0.6
Exotic conifers[2]	0.2	2.2	1.2
Other noble broadleaves[3]	0.2	1.3	0.3

9.3.2. General about FMMs used in Sweden and in the CSA Kronoberg

In Sweden clear-felling systems are dominating heavily. In practical forestry more or less all forest are managed with clear-felling. The regeneration methods used are planting or natural regeneration, seeding is rather uncommon. In this report the clearfelling system have been divided in three groups, with short, intermediate and long rotation period. The division is dependent on tree species, actually it is more relevant to talk about variations or adaption of a methods to be used with different tree species than clearly separated forest management methods. Intermediate

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

rotation period is used for the most important species, Scots pine and Norway spruce, long rotation period only with oak and short rotation period for a number of broadleaves, mainly birch but also alder, aspen and introduced species as hybrid larch.

Except for Beech in the southernmost parts of Götaland, the seed-tree/shelter wood method is almost exclusively associated with Scots pine. Storm damages to seed trees make method very risky to use with many other species including spruce. Seed trees are also used for regeneration of pine stands but as they normally are harvested as soon as regeneration is established, normally within 10 years, the method is regarded as a variation of the clear-felling system. The clear-felling system is adapted also to different tree species and site fertility.

Factors that favour clearcutting and subsequent planting (almost exclusively with Norway spruce) over the seed-tree/shelterwood method: the prevailing high browsing pressure on Scots pine, different advantages associated with Norway spruce (experience, management simplicity, volume production), higher level of competition from vegetation, the higher productivity makes forest owners more prone to invest in active measures.

The clearfelling system is normally not used for areas with high nature values. Management is based to favour nature values. Sometimes this end with no management at all. But for other areas active management are done and include more or less all silviculture operations (tools) and the use of them is dependent on the stand, the site and the nature values. Below all this is presented as one FMM.

Table 53. The FMM used in CSA Kronoberg. There is no statistics about use of FMM in the CSA or in Sweden, the figures in the table is based on statistics on tree species occurrence as it is closely related to FMM and for seed-tree method, information about regeneration methods used.

Silviculture system	**FMM**	**Common & typical tree species**	**Coverage CSA (% forestland)**	**Coverage country (% forestland)**
Clearcutting systems	Intermediate rotation period	Spruce, Pine	83-88 %	72%
	Long rotation period	Oak		
	Short rotation period	Birch, alder		
Seed-tree method/ (Shelterwood method)		Pine	10%	18%
Nature Conservation	With management	“all” species	5-10%	8,4%
	Without management	“all” species		

Protection of forest is achieved through two pathways, formal protection and voluntary protection through forestland zoning at estate level. The lower proportion of protected forest in the CS-area express the fact that formally protected forests are more widespread in northern Sweden. Since formal protection involves economic compensation, the higher productivity in southern Sweden makes it more costly, whereas it is quite effective (in terms of area) to protect low productive and remote areas in the north. Forest protection in northern Sweden has also been facilitated by a higher share of state ownership and the existence of larger areas of old-growth forest.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

9.4. Other FMMs used in Sweden

The forest management models in Table 53 covers the absolute majority of forest land in Sweden and in CSA Kronoberg. There is an active ongoing discussion about different forms of management that can be characterized as continuous forest cover, CCF. It should be considered as an overall frame gathering a wide set forest management methods, that all have in common that they maintain a continuous cover of trees on the management unit (above the retention level required to meet stipulations in the forest act and the certification standards). Overall the use of CCF in Sweden is very marginal, but there is a growing interest especially among municipalities managing forest close to urban areas. The most widely accepted and developed CCF method in Sweden is called *Blädning* and closely resembles the selection system. Ideally it should be applied in multi-layered stands of Norway spruce and aims to maintain a simplified version of the inverted j-diameter distribution. Relying on natural regeneration the only measure involves harvest of mature spruce trees with a cutting cycle of 10-30 years. There also exist other marginal forest management approaches that involve continuous cover, such system has different fancy names such as "*Naturkultur*". The coverage of CCF in the CS area is unknown, but most likely very marginal. It is important to stress that CCF in practice is applied by both owners that manage according to special management schemes for timber production as well as owners where measures are conducted to obtain/maintain other forest functions. For example, a forest owner may have a stand where aesthetical values are prioritized, the management being characterized by thinning operations to yield some firewood and/or to promote an aesthetically attractive stand structure and species composition.

9.5. FMMs in CSA, Kronoberg

The clear-cutting system could be regarded as one management model used for different species. In Kronoberg mainly spruce and pine, but also other species. It could also be described for different species, but here it is divided into three sub-groups based on the rotation length. Short rotations are used for broadleaves, mainly birch but also some aspen and poplars. Clear cutting with intermediate rotation is more or less synonymous with spruce and pine forestry. Long rotation is used for oak in Kronoberg.

Today 81 % of the regenerations areas in Götaland (no statistics for Kronoberg) are planted and 6 % left with no measure according to the most recent statistics (SFA, 2016a). This does not indicate that 6% of the area actively managed in other management models. Many owners hope for natural regeneration with or without success, and then managed the grown up stand with clearcutting methods form pre-commercial stage.

In the context of southern Sweden this is a good proxy (87 %) for the coverage of clear-cutting on forestland managed for wood-production. This gives a clear-cutting coverage on all forestland (including 6 % protected areas) of 82 % in Götaland. However, based on forest management plans (2013-2016) from Södra the clear-cutting system seems to be more wide-spread in Kronoberg compared with the average for Götaland (see question 3 in uniform-shelterwood system) (Magnus Petersson, Södra). We therefore increase the estimated coverage of the clearcutting system on all forestland in Kronoberg to 83-88 %. After excluding clear-cutting short and long (based on

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

assumptions of their coverage) we reach an estimated coverage of clearcutting with intermediate rotation of 80-85 %.

There is a discussion about reducing the areas with spruce, (clearcutting and intermediate rotation period). On fertile sites (G32+) with good water availability regeneration with Norway spruce can be replaced with short rotation broadleaved species (*Populus*, Hybrid aspen, *Betula pendula*) or noble broadleaves (e.g. oak). This would also be a suitable risk-spreading strategy considering the likely event of a future with a warmer climate (Felton et al. 2010). On normal forestland Hybrid larch is a suitable short rotation alternative. Considering that Scots pine often are of quite low quality when managed through clearcutting in this relatively fertile part of Sweden, an increased used of shelter-wood systems with Scots pine is recommended if the goal is to produce high quality timber. More-over, an increased utilization of shelterwood systems or CCF (continuous cover forestry) is recommended to facilitate establishment under adverse conditions (frost, high water table, pine-weevils, competing vegetation) and promote other forest functions than timber production.

The level of both theoretical knowledge and practical know-how is much more advanced for the management of the species, pine and spruce, managed with intermediate rotation period compared for other tree species. This implies that it tends to be used as a blue-print alternative, especially clearcutting followed by establishment of Norway spruce. In addition, external factors such as market demand and a high browsing pressure favours this FMM (but Norway spruce rather than Scots pine), because forest owners consider alternatives to be associated with a higher level of risk and uncertainty.

9.5.1. Ecosystem services

Wood production are by far the most important ESs delivered by forests in Kronoberg. Other ESs exist and are the most important for FMM for nature consideration, Table 57.

Table 54. Ecosystem services for FMM in Kronoberg.

FMM	Typical tree species	Ecosystem services
Clearcutting Intermediate rotation period	Spruce, Pine,	Wood for commodity production, biodiversity (the Swedish complementary conservation model, see question 55)
Clearcutting Long rotation period	Oak	Wood production, recreation, biodiversity (equally important)
Clearcutting Short rotation period	Birch, alder	Wood-for commodity production, recreation and aesthetics biodiversity, Cultural services.
Nature consideration With management	"All"	Biodiversity Recreation *Recreation is relatively more important for this FMM compared with nature conservation with no management.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Nature consideration Without management		

9.5.2. Rotation period

In forest act (SFA 2016) is stipulated lowest age for final felling. The age depends on specie and site index, Table 56. For other species than spruce and pine the lowest age for final felling for stands where more than 50% of the volume are birch, aspen, alder :35 years; ash: 50 years; beech: 80 years and oak 90 years.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 55. Lowest age for final felling pine and spruce dominated stands according to forest Act (SFA 2016a). Site index; dominant height at 100 years; e.g. Site index spruce (Gran) G12= Hdom=12m, at 100 years total age.

Pine, site index	**T12**	**T16**	**T20**	**T24**	**T28**		
Spruce, site index	G12	G16	G20	G24	G28	G32	G36
Lowest age for final felling, years (total)	90	80	70	65	60	50	45

The ages given in table above is lower than age for maximal production, or culmination of mean annual increment (MAI). The market for Norway spruce is based on bulk-production and there are very low price premiums for quality timber. This, combined with the risk for storm felling with increasing stand height, as well as root-rot means that relatively short rotations are feasible, and this trend have been more clear after the storm Gudrun 2005.

Scots pine: most often forest owner's clearfell stand at an age 10-30 years higher than according to Table 56. Since there still exists a substantial price differentiation for different qualities longer rotations are feasible. With Scots pine there is also a lower risk of stand degradation (wind, root-rot) with increasing stand age.

Influences on rotation period

The Gudrun storm in 2005 felled 18.3 % of the standing stock in Kronoberg County. Norway spruce was more severely affected, constituting 80 % of the felled volume (Valinger et al. 2006). Gudrun was followed by the storm Per in 2007, which even not as destructive caused additional severe damages. These storms showed that harvest decisions not only are controlled by forest owners and the MARA e.g. 25-30 % of the areas felled in the Gudrun storm in Kronoberg were younger than 60 years (Valinger et al. 2006). Storms is factor that have and will influence the practical rotation age also in the future.

There is no obligation to conduct final-felling in the forest act. The forest owners can therefore decide if, and when to harvest based on their individual objectives. Kronoberg County is dominated by small-scale private forest ownership, owners that overall not are dependent on the incomes from forestry to support their livelihoods. Overall this implies that the rotations tend to be longer than what is optimal from an economical perspective. This can most likely be attributed to a number of factors such as: lack of time, knowledge and interest in forest management, different objectives than maximizing the economic output from forest management.

Deviations in general can also be attributed to factors that are not captured in guidelines for optimal rotation ages. For example guidelines assumes fixed prices, whereas harvest decisions in practice are influenced by market fluctuations

Size of stand and clearfelled areas

In general there is no upper size of clearfelled areas. There exist a stipulation in the forest act stating that properties above 50 hectares are not allowed to have more than 50 % of the productive forestland (>1m^{3}ha-1year^{-1}) below 20 years of age. However this restriction has recently been softened, and all properties are now allowed to have at least 50 hectares below 20 years (SFA, 2016b)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

These restrictions can indirectly restrict the area allowed for clear-cutting. Forest owners do not need to notify (normal forest stands) or seek permission (noble broadleaves) when final-felling smaller areas than 0.5 ha (SFA, 2016b) i.e. in practice the legal border between a gap and a final-felling. The largest clearfelled areas in CSA Götaland is approximately 15 ha (expert judgment Magnus Petersson Södra). The average area was 2.18 ha, of stands notified for final-fellings in Kronoberg 2015. (SFA, 2015a).

Origin of tree species and tree breeding

Tree species described in the FMMs are all European origin. There are some stands in the CSA with introduced tree species, such as Sitka spruce (*Picea sitchensis*), Grand fir, (*Abies grandis*), and larch species, European (*Larix decidua)*, Japanese (*Larix kaempferi*) and most common the hybrid between them. (*Larix x eurolepis*). For pine mostly Swedish provenances are used and for spruce provenances from eastern or north-eastern Europe, like Poland and Belarus. Often seeds are collected in seed orchards established in Sweden. This way of improving trees, tree breeding, is very common in Sweden for pine and spruce, this most often include transport of seeds more than 100 km.

Genetically modified seeds or trees are not used.

Hybrids are used for larch (Larix) and aspen, the hybrid between European aspen and American aspen (Populus tremula x tremuloides). There is no statistics on the use but in total it is very small areas and proportions.

Pesticides, herbicides and fertilization

Pesticides are used to protect conifers seedlings from Pine weevil damage. However, the use of chemical protection has been gradually decreasing due to requirements in the certification standards, where it after a long period with temporarily extended permits recently was banned. This has stimulated a development of different systems of mechanical protection that gradually replace the use of pesticides.

The use of herbicides is formally allowed on forestland, but associated with so many precautions that it is not used in practice.

No fertilization is currently conducted in Kronoberg (SFA, 2015c). Kronoberg County belongs to a region where the Swedish Forest Agency recommend forest owners to not fertilize (SFA, 2016b) and certified owners are obliged to follow these recommendations. In general southern Sweden annually receives a substantial amount of anthropogenic nitrogen deposition and the production gains that can be achieved with conventional forest fertilization (150 kg/N/ha, one or a few times during the rotation) in Norway spruce are much lower compared with northern Sweden. There is however a positive growth response on Scots pine but fertilization is uncommon or not practiced at all in Kronoberg.

Logging and extraction of wood

100 % of the wood harvest in final fellings and almost 100% in thinnings is fully mechanized (Magnus Petersson, Södra). The small reduction is explained by the some very few forest owners perform thinning (or firewood extraction) by themselves using chain-saw.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

A very small number of forest owners might extract some harvested timber by horses and it can now and then be used in stands close to urban areas, "recreation forest" but close to 100% of the wood is transported from forest to roadside by forwarders or forest equipped tractors.

On 46 % of the area reported for final felling in Kronoberg (in 2013) forest owners also reported that they intended to extract logging residues as biofuels (SFA, 2014). Since this only shows forest owners intentions the actual proportion is lower. The extraction of logging residues has decreased since then and we therefore estimate that 30 % are extracted within this FMM. The extraction of logging residues has decreased from its peak in 2010 due to reduced prices. This can mainly be attributed to a lower market demand when heating plants have shifted from burning domestically produced biofuels to imported garbage. In addition, the increasing supply of electricity from wind power has also resulted in an increased production of electricity at the national level, further contributing to the drop in prices.

Nature conservation

The Swedish conservation model relies on a complementary approach, combining protected areas set-aside from timber production with integrative conservation measures in the forest matrix (Gustafson and Perhans, 2010). These measures are mostly conducted at final felling and required according to stipulations in the forest act and in the voluntary certification standards (PEFC, FSC). This involves green tree retention of single trees and groups, leaving as well as creating deadwood (high-stumps) and the retention of buffer zones along water, mires, and sensitive habitats. The requirements are more quantified in the certification standards, where widely known stipulations requires retention of a minimum of 10 trees/ha and the creation of at least three high stumps per hectare (PEFC 2012, FSC 2010). On average 8.4 living trees/ha are retained and 1,5 high stumps/ha are created after final-felling in Götaland (SFA, 2014). When forest owners notify the Swedish Forest Agency that they will conduct final-felling of a particular stand they are required to specify which conservation measures they will take to fulfil the stipulations in the forest act (SFA, 2016b).

9.6. Clearcutting systems intermediate rotation period

An adequate name is also management models for coniferous stands. This is the totally dominating FMM in both the CSA and Sweden.

Characterization of the model

The main objective is production of conifer timber and pulpwood. It involves clear-cutting followed by scarification and planting of Scots pine or Norway spruce. Pre-commercial thinning(s) are often conducted, the main purpose being to reduce the amount of naturally regenerated birch and remove low quality trees. This is followed by commercial thinning. For Norway spruce it is crucial to consider the risk of storm damages, focusing on intensive early removals or reducing the need for thinning through wider initial spacing.

The minimum age for final felling is stipulated in the forest act and depend on the dominant species and site fertility. The high browsing pressure is currently a major problem in the CSA, favouring the establishment of Norway spruce at the expense of Scots pine.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Considering that the CSA is dominated by forest owners that overall not are economically dependent on the incomes from forestry it is not surprising that deviations from the ideal exists for all different management activities. Neglected pre-commercial thinning is probably the major concern, having a strong negative effect on the economic outcome in subsequent commercial thinnings.

Tree species and stand composition

Tree species are mainly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) but admixture of broadleaves becomes more common as certified forest owners need to retain a small proportion (> 10 % FSC, > 5 % PEFC) of broadleaves throughout the rotation (PEFC 2012, FSC 2010).

In general this FMM involves planting of monocultures of Scots pine or Norway spruce directly or a few years after final felling. However the characteristics of the nemo-boreal ecosystem means that additional naturally regenerated seedling, especially birch, establishes after clearance. The forest management ideal, stipulated in the widely adopted certification standards requires that a certain proportion of broadleaves. In general this implies that a typical production stand that meet certification standards should have approximately 10 % volume proportion broadleaves and 90 % conifers, mostly consisting of the conifer species originally planted. To facilitate management simplicity, the forest owner association Södra recommend forest owners to gather the broadleaves in groups and/or along stand borders. This is also applied by the state forest company Sveaskog (Personal communication with Johan Rowell, Planner of pre-commercial thinning at Sveaskog), who owns substantial areas of forests in Kronoberg (58,900 hectares productive forestland).

On sites that are typical for Kronoberg, i.e. average fertility and good water availability Norway spruce is normally the first alternative due to high production. However, substantial proportions of the forestland are also suitable for Scots pine (average/low fertility and a bit drier soils).

The tendency to plant Norway spruce on areas better suited for Scots pine is a consequence of the high browsing pressure, especially by moose. This makes regeneration with Scots pine problematic or impossible in large parts of Kronoberg County.

Regeneration

The clearcutting systems with conifers rely on artificially regenerated seedlings. These seedlings, most often spruce, have superior growth and (often) survival compared to local seed sources. Nursery seedlings have a better nutritional status (nursery effect), their performance have often been improved through breeding programs (selecting for desired traits like growth) and they have sometimes been selected from special regions and Norway spruce originating from Belarus or north-east Poland are often used.

A small amount of seedlings originate from natural regeneration, but the occurrence is uneven and difficult to predict. A lot of naturally regenerated birch generally establish after felling. The regeneration inventories performed by the Swedish Forest Agency do not discriminate between naturally regenerated and planted seedlings. The forest act states a minimum number of seedlings at a certain time after harvest, for Kronoberg typically 2000-2800/ha, the number differ depending on specie and site quality. The proportion of broadleaves in the regenerations in Götaland is 27 % (SFA, 2016a), which is a good proxy for naturally regenerated birch considering the marginal role of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

planted broadleaves. However, a high proportion of the naturally regenerated birches is most often removed in pre-commercial thinning (approx. down to 10 %). This estimation is based on retention of naturally regenerated birches and use of additional naturally regenerated conifer seedlings.

Scarification

Today scarification is used on approximately 70 % of the clear-felled areas. Based on statistics of regeneration methods and scarification in final-fellings in Götaland (SFA, 2016a). This figure includes both clear-cuts that been planted and clear-cuts where no regeneration measures have been conducted. The scarification share for plantations is 74 %. 100 %.

There are many arguments to increase scarification to 100% of the regeneration areas. Scarification is an important measure that increases the likelihood of establishment success. It results in an increased initial growth of the seedlings through better nutritional status (nutrient release when the soil is disturbed, reduced competition from vegetation) and reduced mortality (e.g. frost, pine-weevils, water-logging). Pine-weevils are the major agents causing mortality in conifer plantation, and with proper protection (mechanical or chemical) seedlings can often be planted without scarification. However, scarification is still needed to achieve optimal stand development.

Browsing and fencing

Except during a short period (2006-2010) after the Gudrun storm, when forest owners could receive subsidies for fencing stands designated for naturally regeneration of Scots pine (Wallstedt, 2013), there have never been subsidies available to support fencing of conifers. Fencing is therefore excluded as a potential measure due to the high costs. 0 %

With the current level of browsing the establishment success of Scots pine plantations in Kronoberg would benefit from fencing, and in some areas it is most likely decisive. However, fencing is a very costly measure, involving costs for establishment, maintenance and removal. This cannot be economically justified considering the long rotations and relatively low volume production of Scots pine. In addition, a widespread use of fencing would not solve the problem with browsing damages but rather redistribute the browsing damages to other areas.

Stand management

Pre-commercial thinning

Pre-commercial thinning is decisive measure for the economic performance. It is especially important for the economic outcome of the first commercial thinning i.e. whether or not it yields a net income. Pre-commercial thinning in planted coniferous stand is normally not reducing the density of planted seedling but much more reducing the competition from natural regenerated birch, and controlling the tree species distribution. In some cases, birch are preferred.

There is no data available for Kronoberg. An estimate is that75% of the area is pre-commercially thinned at least once. This figure is based on statistics from Götaland, calculated from the amount of pre-commercial thinning performed on the permanent sample plots of the national forest inventory. This figure was used in the most recent nationwide simulation of the future forest state and associated ecosystem services (Claesson et al., 2015).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Commercial thinning

Nearly all spruce and pine stands are thinned at least once, most common two or three times. Recommendations for thinning have changed over the last 100 years. Commercial thinning has been an integral part of the Swedish clearcutting-system for a long period of time, there is therefore a tendency to see commercial thinning as self-explanatory measure, disregarding evident risk factors in individual stands.

After the storm 2005 changes in management regimes are discussed; wider initial spacing, less frequent thinnings esp. in the later part of the rotation, reduced rotation period.

In Kronoberg, wood-purchasers and forest management planners, especially from Södra play a big role in promoting thinning among private forest owners. With large-pulp mills Södra represents an organization with a continuous demand for pulpwood. A demand that will increase in the near future due to recent investments. To maximize the profits of the cooperative it is therefore in their self-interest to obtain their pulpwood from relatively cheap small-dimension wood harvested in thinning. Since other organizations sell pulp-wood to Södra and other industrial actors this also affects the advice they provide to forest owners.

Pruning

Pine very rarely are pruned. It is a time consuming and/or expensive measure. The relatively small price differentiation (compared with oak) for different qualities of Scots pine combined with uncertainties regarding future market demand means that it is uncertain that an investment in pruning will pay-off. Moreover, shelterwood systems with natural regeneration are less demanding alternatives for owners that want to produce high quality timber of Scots pine.

For Norway spruce pruning is not even a measure to consider, the risk for fungi and the not existing difference in prize for timber with different properties.

9.7. Clear cutting system with long rotation period

The only specie in Kronoberg with a long rotation is oak. Oak currently constitutes 2.6 % of the standing stock on forestland in Kronoberg County (SFA, 2014). A lot of oak dominated stands are set-aside from timber production due to their high biodiversity and aesthetical values, especially among private forest owners to fulfil the certification requirements (5 % of the productive forestland set-aside from timber production) (FSC 2010; PEFC 2012). This is supported by a study performed by the Swedish Forest Agency, showing that areas classified as noble broadleaved forest constitutes 20 % of the area voluntary set-aside in Götaland (i.e. far higher than the overall proportion of noble broadleaves forest) (Stål et al. 2012). In addition, oak is an admixture species within conifer forest. We therefore estimate the 0.5-1 % coverage of oak dominated stands managed for timber production in Kronoberg County.

On the very best sites (G32++) with good water availability the proportion of oak could increase at the expense of Norway spruce. In addition, this is a suitable alternative for forest owners that want to afforest abandoned agricultural land. Overall, compared with Norway spruce, Oak yields much lower economical incomes, but an increased use is still desirable due to a wide range of other benefits. An increased use of Oak would increase the perceived beauty of the forested landscape. It

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

also serves as a suitable risk-spreading strategy considering the risks of storm damages and in the likely event of a future with a warmer climate (Felton et al. 2010). An increase in actively managed oak forests will yield a positive impact on biodiversity, moving the species towards its natural occurrence in southern Sweden (Lindbladh et al 2014). Finally, Oak constitutes the most dominant species among the noble broadleaves and there is a market demand for timber for flooring industry and also for high quality timber.

The level of both theoretical knowledge and practical know-how is much more advanced for the clearcutting system with the native conifers. Oak forestry aiming for high quality timber is management intensive with long-rotation periods i.e. forest owners might therefore regard this FMM as to complicate. The long rotations also make it ill-suited for forestry investments based on economic calculations such as the Faustman-formula, which is a common method when comparing different alternatives within Swedish forestry. In addition, in a region (and country) with a conifer dominated market there are also uncertainties regarding the short- and long term market demand. Finally, according to the current legislation forest owners need to maintain the dominance of noble broadleaves (see intro) in noble broadleaved stands (SFA, 2016a) i.e. regeneration with noble broadleaves is mandatory. A fear of reducing the management freedom for future generations might therefore be a factor that makes forest owners reluctant to establish oak on new sites.

With a historical perspective it is evident that the current proportion of Oak (and broadleaves) is much lower than the “natural level”. This is due to a large number of factors (see Lindbladh et al 2014). Large areas of broadleaved forest in southern Sweden have been lost due to clearcutting followed by establishment of conifer monocultures. Agricultural land also expanded at the expense of broadleaves, and when abandoned, mostly during the last 100 years, they were largely replanted with Norway spruce. The current legislation aiming to safe-guard the existence of noble broadleaves also in the future was established in 1974 and 1980, initiated by a fear that forest of noble broadleaves would be largely lost from southern Sweden (Enander, 2007).

Characterization of the model

Here it is classified as a clearfelling system. There is a lack of data regarding how oak forestry is conducted in practice. In general our overall impression is that ideal Swedish model for management of oak seldom is conducted in Kronoberg County. At this overall level it is most likely so that a lot of oak stands in practice are managed somewhere in between clear-cutting and shelterwood systems. Involving extended rotations and gradual removal of the old-stand in many thinning operations. This can be due to aesthetical values or other forms of individual attachments to particular stands, but can also have an economical rationality. If oak timber is of high quality it is currently the best paid assortments on the market. Given that a stand has an uneven diameter distribution, it can be a good idea to embrace a single tree perspective rather than making decisions based on stand averages (e.g. mean diameter), which is the common practice in Swedish forestry. Gradual removal of single trees when they reach high grading quality can therefore make the rotation period less distinctive.

Tree species and stand composition

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

In Sweden there are two species of oak, Quercus robur and Quercus petreae. Both grows in Kronoberg but most common is Quercus robur. Seedling found on the market are most often Quercus petreae.

Stand are normally established by planting or seeding without any admix species. Due to its high value for biodiversity in southern Sweden there are no requirements to have any additional tree species in Oak plantations, neither in the forest act nor in the certification standards. However to achieve high quality timber it is recommended to retain understory trees as quality enhancers (reduce the emergence of epicormics branches), this can involve trees that naturally act as understory e.g. Hazel, Beech, but not are so competitive i.e. Norway spruce. Light demanding trees (e.g. Alder, Birch) can also be used if they are high cut to prevent competition with the crowns of the Oaks.

First of all, according to the legislation the only requirement is that the volume proportion of broadleaves are kept > 70 %, whereof > 50 % noble broadleaves for the stand to remain as noble broadleaved (SFA, 2016a) i.e. there is no obligation to adhere to a management ideal for Oak according to the legislation. On the relatively fertile sites where Oak is growing there is a potential for natural regeneration and good performance of a wide range of species including other noble broadleaves (see intro), trivial broadleaves (alder, birch, aspen) and Norway spruce.

Overall, admixtures with other species is therefore a result of: forest owners using naturally regenerated trees to compensate mortality on planted seedlings, poorly implemented pre-commercial thinning and/or thinning, forest owners that strive for species mixtures due to a wide range of factors (e.g. aesthetical preference, the value attached to having many tree species, quality enhancing understory).

Rotation period for oak

The lowest age for final felling according to the forest act is 90 years but most often the rotation is longer or much longer. The ideal management of Oak should aim at producing high quality timber of large dimensions within the shortest rotation period possible. Planted at fertile sites and with an intensive thinning program, 50-100 crop/trees should reach the target diameter (+60 cm) within 100-140 years of age. Reducing the rotation period is critical for the economic outcome but it is the not possible to get large dimensions and high prizes.

The ideal management program of oak is seldom applied in practice. Too low site fertility and the lack of intensive thinning programs imply that the timber seldom reaches the high grading dimensions within the optimal rotation period (in addition the timber often being of quite poor quality). As described previously, if not set-aside from timber production, Oak stands are also often retained due to aesthetical preferences, the management been characterized by thinnings. Overall this means that Oak forestry is characterized by longer rotation periods than economically optimal and the rotation is often less distinctive compared with other FMMs.

Regeneration

Natural regeneration of oak is not used in Sweden or CSA Kronoberg. (not including naturally regenerated understory tress retained to enhance the timber quality).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

Oak is planted or seeded, but a naturally regenerated trees also establish after final-felling, especially naturally regenerated birches. However, a substantial proportion are removed in pre-commercial thinning. We estimate a lower use of naturally regenerated seedlings for this FMM compared with conventional methods (clear-cutting intermediate). The higher risk of mortality (different forms of browsing i.e. ungulates and rodents, competition from vegetation) being compensated by a wide range of factors such as:

Since new plantations of Oak are relatively rare forest owners are probably very orientated towards favouring the Oaks over other species (and they are also required to do so according to the legislation).

The current legislation implies that forest owners are obliged to maintain the dominance of noble broadleaves (SFA, 2016a). Since this force forest owners to regenerate with species with high establishment costs the legislation is supported with subsidies (SFA, 2016b). The subsidies covers 80 % of the regeneration cost (scarification, planting, fencing). The ideal is therefore to utilize the subsidies and plant seedlings from selected proveniences available in nurseries. These proveniences have been selected based on desired characteristics (e.g. quality) and should consequently be favoured throughout the rotation.

When establishing oak on former agricultural land direct seeding can be a suitable alternative regeneration method (not possible on forestland due to seed predation of rodents).

Site preparation/scarification

Site preparation or scarification is very common when establishing oak stands, most probably close to 100%. The proportion of actively regenerated Oak stands that are scarified are most likely much higher compared with regeneration of conifers. Scarification is relatively cheap compared with the costs of oak seedlings and fencing. Subsidies are also available for all establishment measures for oak (SFA, 2016b). In addition, forest owners need to apply for permission for final-felling and financial support to the Swedish Forest Agency (SFA, 2016a). This means that regeneration of noble broadleaves involves a much higher level of exposure to forest consulting compared with conventional methods, and consultants are well-aware of how critical scarification is for regeneration success.

To achieve high quality timber within economically justified rotations Oak should only be planted on fertile sites. On such sites competition from vegetation can be very heavy. Radical scarification is therefore decisive to reduce competition from vegetation and associated problems with rodents. When planting oak on former agricultural land a radical scarification should ideally be complemented with the application of herbicides to further increase the likelihood of regeneration success.

Browsing and fencing

The prevailing high browsing pressure constitutes a big problem for forestry in Kronoberg, especially for Oak that are among the most preferred species by browsers. Utilizing the subsidies that are available for fencing (SFA, 2016b) is therefore critical for regeneration success. The subsidies for fencing therefore constitutes a critical policy instruments, currently maintaining forest management with Oak somewhat economically justified for private forest owners. Fencing is more or less necessary for establishing oak, and it is most often done.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Stand Management

Pre-commercial thinning

The management scheme for Oak aims at producing high quality timber within the shortest possible rotation. Pre-commercial thinning is an important measure for a number of purposes:

- Removal of competing naturally regenerated trees

- Removal of low quality Oaks i.e. quality selection.

-Early stand density manipulation. Oak is often planted at high densities (e.g. 5000 seedlings/ha), and even though a high spacing is required to achieve good quality (trunk with no branches) pre-commercial thinning is still recommended to give a decent level of diameter growth.

Subsidies are also available that covers 60 % of the costs for pre-commercial thinning (SFA, 2016b).

Estimated that precommercial thinning one or more times are done on the absolute majority of stands.

We estimate a higher level of pre-commercial for this FMM compared with clear-cutting intermediate. Firstly, this is related to the higher initial spacing. Secondly, this FMM is much more demanding compared with management of conifers. We therefore assume that forest owners that chose to harvest and regenerate oak, rather than using them as set-asides in their forest management plans, have a higher interest in forest management than the average owner. Finally, the subsidies that are available make it more attractive to perform pre-commercial thinning for this FMM.

The divergence that we still think exists can be explained by the factors mentioned in clear-cutting intermediate (see question 45 in clearcutting-intermediate).

Pruning

Due to the high prices for high quality timber oak is the only tree species in Sweden were pruning can be economically justified. The use of artificial pruning also implies that heavy thinning programs can be initiated at an earlier stage of stand development, thereby reducing the rotation period and increasing the economic performance of this FMM. The ideal management scheme involves selecting approximately 100-200 oaks/ha (two times the numbers of crop trees) that are pruned to 5-6 m clear bole. The crowns of the crop trees are subsequently favoured by a heavy thinning program, complemented with continuous removal of epicormical branches.

However this is a very intensive and time consuming management program, and forest owners might also plant oak due to other forest functions than timber (biodiversity, aesthetics, recreation). We therefore suggest a 50 % pruning proportion for this FMM.

Management for high quality timber of Oak is a project that spans generations. Combined with uncertainties regarding future market demand it is not surprising that forest owners that not are dependent on the economic revenue from forestry to support their livelihood do not perform this time-consuming measure. In addition, pruning is only meaningful if initiated early or performed on

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

trees that already are of high quality (removal of epicormics branches) i.e. on substantial areas of oak forest pruning is not even a measure to consider.

Commercial Thinning

We believe that all Oak dominated stands are thinned at least once during the rotation. However, very few stands are managed according to ideal management schemes, thinnings being conducting less frequent and more random (not promoting a pre-selected number of crop trees).

This FMM should ideally be characterized by frequent thinning's to favour the crown development and diameter growth of 50-100 crop trees. Due to the risk for epicormics branches thinning can't be strong/heavy but instead thinnings are done frequently, approximately every 5-10 years. This is critical to achieve the high grading dimension within a rotation period that can be economically justified.

Harvest and extraction of wood

The forest owner association Södra recommend that Oak > 35-40 cm dbh should be harvested by chain-saw. Trees above this dbh are too heavy for the harvester, and there is a high risk that the harvested timber is destroyed due to cracks. When harvesting Oak stands chain-saw and harvester are often used complementary. Södra estimates that approximately 50 % of the wood harvest of Oak is fully mechanized (from commercial thinning and onwards). Transport of timber is most often done by forwarders. A very small number of forest owners might extract some harvested timber by tractor or horses.

There is no data about use of logging residues of oak.

9.8. Clear cutting system with short rotation period

Another name for this management model could be management of broadleaves. Absolutely most common management of broadleaves are with clearcutting. For beech a method with shelterwoods are used, but the amount of beech is very low in Kronoberg due to the climate.

Characterization of the model

An increased use of pioneer broadleaves (Silver birch, Hybrid aspen, Populus) is suitable on fertile sites (G32+) with good water availability. Populus species and Hybrid aspen (*Populus tremula x tremuloides)* should be planted only on the very best sites. In addition, this is a suitable alternative for forest owners that want to afforest abandoned agricultural land. An increased use of broadleaves would increase the perceived beauty of the forested landscape. It also serves as a suitable risk-spreading strategy considering the risks of storm damages and the likely event of a future with a warmer climate (Felton et al. 2010).

Hybrid larch can be used as a complement to Scots pine and Norway spruce on many sites. Being a fast-growing pioneer species it can yield similar or higher mean annual volume production compared with Norway spruce, but within a substantially shorter rotation, but it can also produce large dimensions with a longer rotation period. Hybrid larch can be used on sites where the high browsing pressure makes establishment of Scots pine problematic and/or impossible (which is currently practiced to some extent in Kronoberg).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Overall, the use of exotic species (such as Hybrid aspen, Populus and Hybrid larch) is limited in Kronoberg County. However, the interest increased in the aftermath to the storm Gudrun in 2005 (Wallstedt, 2013). In the entire area affected by Gudrun (which is much larger than Kronoberg), 1400 ha of Hybrid aspen and 225 ha of Populus were planted. This is largely explained by the reforestation grants that were available after the storm that compensated for the higher establishment cost of broadleaves. Approximately 4000 ha of Hybrid larch were also planted after Gudrun (in the entire Gudrun area). In addition to being limited in extent, the stands of these species are of young age. To exemplify, exotic conifers in Kronoberg, where Hybrid is by far the most common, only constitutes 0.2 % of the standing stock (SFA, 2014).

Birch is the third most dominant species in Kronoberg County (SFA, 2014). However there is no tradition of forest management of pure Birch stands in Sweden. The vast majority of the birch grows as a mistreated admixture in conifer plantations.

Forestry in Kronoberg is focused on the native conifers, especially Norway spruce. The use of these alternative species is therefore currently restrained by the lack of experience and uncertainties regarding the future market demand.

The use of exotic tree species (i.e. Hybrid larch, Hybrid aspen and Populus) is also restricted in the widely adopted voluntary certification standards (FSC ≤ 5 %, PEFC ≤ 25 % coverage on productive forestland per certified forest holding) (FSC 2010; PEFC 2012). However, the stricter FSC requirement only pertains to stands established after 2009. Birch, Populus and Hybrid aspen are also expensive to establish (artificially), especially since the current level of browsing often implies that fencing is required.

Due to the re-sprouting potential of Hybrid aspen and Populus these species might be managed as coppice in the future. However reported problems with crooked sprouts and the fact that the re-sprouting capacity on Swedish forestland is largely unknown, means that it is hard to tell which silvicultural system these stands will be managed with in the future. In this FMM we will not describe different management alternatives for second generation sprouts of Hybrid aspen/populus.

In the description of this FMM we focus on stand establishment through artificial regeneration i.e. planting. However, the characteristics of the nemoboreal ecosystem implies that naturally regenerated birch generally establish after clearance. Beyond being used as an admixture in plantations, stands can also be established solely relying on naturally regenerated birch. This does not require retention of seeds trees, given that substantial amount of birch is present in the surroundings. The pros with this alternative is self-evident i.e. no regeneration cost. The drawbacks are connected with substantial reduction in growth and quality compared with the genetically improved material. In addition, there is a higher risk of failure.

Tree species and mixture

Most important species in this management models are *Betula* spp (Mainly *Betula pendula*), Hybrid larch, Hybrid aspen, Populus species. Plantations with these species are currently very marginal in Kronoberg County. Most of the birch stands are natural regenerated. Hybrid larch is the most common species to plant within this FMM, followed by birch. However, as already described, birch is a dominant admixture species in the forest landscape of Kronoberg.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Rotation period

Typical rotation periods are; Hybrid larch 30-45 years, birch 45-55 years and Populus/Hybrid aspen 20-35 years (on forestland, these species are also managed on agricultural land where the rotation need to be kept below 20 years). Very often stands are not managed properly and to get larger dimensions the rotation periods above are prolonged.

The benefits with these species from an economical perspective is connected with the short rotation period (high internal rate of return, short pay-back time).

Due to uncertainties regarding future market demand for timber, Hybrid larch and Populus/Hybrid aspen can also be managed without thinning in short rotations, aiming for bulk assortments such as pulpwood (Hybrid larch can sometimes be sold as pulpwood) and/or bioenergy. The rotations should then be at the lower end of the optimal rotation interval (or even a bit lower).

This FMM involves planting of monocultures directly or a few years after final felling. However the characteristics of the nemoboreal ecosystem means that additional naturally regenerated seedling, especially birch, establishes after clearance.

Regeneration

Scarification is an important measure that increases the likelihood of establishment success. It results in an increased initial growth of the seedlings through better nutritional status and reduced mortality. Since Birch, Hybrid aspen and *Populus* ideally should be planted on fertile forest sites, where herbicides not are used (compared with afforestation on agricultural land), intensive scarification is decisive to reduce competition from vegetation and associated problems with voles.

If used in afforestation of agricultural land, it is recommended to complement the scarification with herbicide treatment to increase the likelihood of regeneration success.

Pine-weevils are the major agents causing mortality in conifer plantation, and with proper protection (mechanical or chemical) seedlings of Hybrid larch can often be planted without scarification. However, scarification is still needed to achieve optimal stand development.

Fencing and browsing

The main argument here is similar to the answer in clearcutting-intermediate. With the current level of browsing most species would benefit from fencing, and it can often be critical for success. The very high cost for fencing and the high browsing pressure most probably reduce the planting of birch and hybrid aspen.

In general a lot of the plantations with Birch, Hybrid aspen and Populus were established in 2006-2010 as a consequence of the subsidies after Gudrun (Wallstedt, 2013). Fencing was both a requirement to obtain financial support and was covered by the amount granted. Since then the interest in planting these species has decreased, mainly due to the lack of financial support for fencing.

Stand management

Pre-commercial thinning

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

All the species used with short rotation clear-felling models are fast growing pioneers. If established on suitable sites they should be able to outcompete naturally regenerated tress, such as Birch, and approach merchantable diameters rapidly. In addition, Hybrid aspen and Populus are also generally planted at wider initial spacing than commonly practiced (1000-1500 seedlings/ha).

An alternative is to use natural regenerated birch. Then pre-commercial thinning is a must to create a stand with an even distribution and good number of seedlings. Also to increase the accessibility in future thinning operations and for the purpose of quality selection it can still be a good idea to perform pre-commercial thinning also in planted stands.

Commercial thinning

Commercial thinning is a decisive for achieving the desired dimension within optimal rotation periods (the short rotations being the major advantage with this FMM). With the very short rotations one hard thinning can be adequate for Hybrid aspen and Populus. Hybrid larch and Birch should be thinned more frequent. If the aim is high quality timber production of birch it recommended to embrace a single-tree perspective, favouring a pre-selected number of crop trees with frequent crown enhancing thinnings.

Pruning

Pruning is in general an expensive and/or time consuming activity. For these species there is also a high level of uncertainty regarding the future market demand for quality assortments.

Combined with an intensive management program (frequent crown enhancing thinnings) it can be an interesting alternative for *Betula pendula*. This can be combined with wider initial spacing to reduce the regeneration cost. Since the future market is uncertain it should not be regarded as a safe-investment, rather as an interesting activity for forest owners with a lot of time and interest in forest management. In “practical” forestry, pruning is very limited, if done at al.

Nature protection

The Swedish conservation model rely on a complementary approach, combining protected areas set-aside from timber production with integrative conservation measures in the forest matrix (Gustafson and Perhans, 2010). These measures are mostly conducted at final felling and required according to stipulations in the forest act and in the voluntary certification standards (PEFC, FSC). This involves green tree retention of single trees and groups, leaving as well as creating deadwood (high-stumps) and the retention of buffer zones along water, mires, and sensitive habitats. The requirements are more quantified in the certification standards, where widely known stipulations requires retention of a minimum of 10 trees/ha and the creation of at least three high stumps per hectare (FSC 2010, PEFC 2012). When forest owners notify the Swedish Forest Agency that they will conduct final-felling of a particular stand they are required to specify which conservation measures they will take to fulfil the stipulations in the forest act (SFA, 2016a).

9.9. Management of stands with high nature values

How much forest that needs to be set-aside from timber production to safe-guard biodiversity in Sweden and in Kronoberg is widely debated and an issue of great uncertainty. In addition to the requirements of different species a lot of factors influence what can be considered as a suitable level of protection, such as:

The level of ambition, the intensity of forest management and amount of integrative conservation measures (i.e. retention in harvest operations) in the forest matrix, the value of voluntary set-asides (are they long term commitments?), the value of unmanaged unproductive forestland for biodiversity (e.g. mires with sparse tree-cover).

However, considering that the Swedish forest policy currently should be guided by an overall orientation that puts equal emphasis on production and conservation goals (see intro), it is evident that the area designated for nature conservation needs to increase from the current level. This is also reflected in the steadily increasing share of forest designated for this purpose and a recent increase in government funding.

A tool in the work with conservation goals especially the voluntary set aside, is the use of classification of stands depending on goals; management goals. Four classes are used;

Production with general considerations, PG.

Production with stronger considerations, PF.

Nature conservation with management, NS.

Nature conservation, free development/without management, NO.

How much forest that needs to be set-aside from timber production to safe-guard biodiversity is widely debated and an issue of great uncertainty. In addition to the requirements of different species a lot of factors influence what can be considered as a suitable level of protection. The classification above is not mandatory, but very often used.

Approximately 5-6% of the area is classified as nature conservation and it is assumed that 2-3% of this is managed and another 2-3 is without management. These figures are based on the coverage of the different types of formal protection in (nature reserves, habitat protection and nature conservation agreements) in Kronoberg County (about 1.8 %) (SFA, 2016c; SFA, 2014) combined with the most recent estimate of voluntary protection in Götaland (3.9 %) (Stål et al., 2012).

This estimation of voluntary protection includes both certified and uncertified forest owners (Stål et al., 2012). It is common practice that forest owners with forest management plans specify areas set-aside for nature conservation purposes. However, certified forest owners need to set-aside ≥ 5 % of the productive forestland (> $1m^3$ ha^{-1} yr^{-1}) from wood production to fulfil certification requirements (FSC, 2010; PEFC, 2012).

The voluntary set-asides are the most common form of protection in southern Sweden. With a high share of private forest owners forest management plans from Södra provides a good source for estimation the ratio between NO/NS. Forest management plans produced by Södra in Kronoberg County (2007-2013) show a 4.05 % and 3.82 % coverage on productive forestland of NO and NS respectively (Magnus Petersson, Södra). In addition, even though probably not to the same extent, formally protected areas are also sometimes managed to enhance their value for biodiversity (or recreation).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

It is critical that strict protection is complemented with active conservation measures to fulfil conservation goals at both a national and regional level. For example, broadleaved stands dominated by Oak, who host a wide range of threatened species, face the risk of being transformed to conifer dominated stands through secondary succession if left unmanaged. Reintroducing fire as a natural disturbance agent is another important measure in forest dominated by conifers (mainly of Scots pine), thereby securing the conservation status of many fire dependent species.

9.10. Nature conservation with management

This FMM is applied in stands where the active management interventions are needed to enhance and/or maintain the conservation value.

It is estimated that it covers 2 - 3% of the forest area in Kronoberg but it is recommended to increase at least twice.

The management activities in stands with nature values depends on both the existing, and future potential, valuable structures in the specific stand. This means that this FMM can be highly variable and involve any measures that are conducted to promote the conservation value (and sometimes also recreation) i.e. specifying an ideal management scheme is therefore contradictory to the objective of this FMM. Clearfelling might not be very common, but all sort of silviculture systems and cuttings can in principle be used, such as selective and shelterwood systems, commercial and pre-commercial thinnings and more.

In voluntary protected areas measures to promote the conservation value are specified in the forest management plan, together with all other suggested measures for the individual estate. The restrictions in utilization, as well as management activities to promote the conservation value in formally protected areas are often specified in specific management plans.

Tree Species and specie mixture

Management in stands with high nature values is applied independent of tree species, but high nature values are often connected to broadleaved dominated stands. (especially uncommon species as oak). Active measures are often needed to maintain the future dominance of broadleaves.

Examples of different measures

The most common measure in Kronoberg is nature conservation thinning, favouring broadleaves at the expense of Norway spruce. Due to the good performance and shade tolerance of Norway spruce this is often needed to maintain the dominance of broadleaves and associated conservation values also in the future. The first thinning in such stands often involves large removals of Norway spruce and can therefore yield substantial incomes (Magnus Petersson, Södra). After the first thinning the primary target is to keep the stands free of Norway spruce. Subsidies supporting nature conservation thinning in broadleaved dominated stands are available through the Swedish Forest Agency (9000 SEK/ha) (SFA, 2016d).

Other common measures among private forest owners involves releasing large Oaks from competition, and measures conducted in buffer zones along water to enhance their conservation value (Magnus Petersson, Södra).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Large forest owners (>5000 ha), such as Sveaskog, certified according to FSC are obliged to burn an area corresponding to 5 % of the annual area final-felled on dry/mesic soils (FSC, 2010). This is often conducted on clear-cuts prior to planting but also involves burning standing forest designated for conservation. This is a very effective way to reach the area required since the burned area in such stands should be multiplied by an upward adjustment factor of three. This should ideally be conducted in stands dominated by Scots pine, a species who grow on sites that historically experienced frequent forest fires.

Finally, some protected areas are also important for recreation, and close to cities nature reserves created by municipalities often have this as a primary objective. In such areas management activities to promote the perceived beauty (e.g. favour broadleaves) and/or increase the accessibility are common.

9.11. Nature conservation without management

It can be discussed it this is a forest management model or not. But the concept with Management Objective “nature conservation without management” described above is widely accepted and used in Kronoberg. It is estimated that it cover 2 - 3% of the forest area in Kronoberg but it is recommended to increase at least twice.

This FMM is used in stands where the nature conservation goal is best achieved through no intervention. For example stands of conservation value that are left unmanaged to further increase the quantity and quality of structures of high importance for biodiversity (dead wood, old trees etc.).

9.12. References

Persons involved:

PhD student and LCC Isak Lodin

WP1 leader Professor Urban Nilsson

Anders Ekstrand, specialist in the management of deciduous species at Södra.

SkogDr Magnus Petersson, Head of the department of silviculture and forest technique at Södra.

Johan Rowell, Sveaskog, Planner of pre-commercial thinnings in Kronoberg.

Written and other sources

Appelstrand, M., 2012. Developments in Swedish forest policy and administration – from a “policy of restriction” toward a “policy of cooperation”. Scandinavian Journal of Forest Research 27, 186-199.

Brukas, V., Sallnäs, O., 2012. Forest management plan as a policy instrument: Carrot, stick or sermon? Land Use Policy 29, 605-613.

Claesson, S., Duvemo, K., Lundström A., Wikberg P-E. 2015. Skogliga konsekvensanalyser 2015 – SKA 15. (Impact assessments within forestry 2015 – SKA 15. Report 10-2015. Swedish Forest Agency, Jönköping.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

Enander, K-L. 2007. Skogsbruk på samhällets villkor (Forestry in line with the conditions of society). SLU, Department of Forest Ecology and Management, Umeå. Report 1-2007. (In Swedish).

Felton, A., Ellingson, L., Andersson, E., Drössler, L., Blennow, K., 2010. Adapting production forests in southern Sweden to climate change: Constraints and opportunities for risk-spreading. International Journal of Climate Change Strategies and Management 2, 84-97.

FSC (Forest Stewardship Council), 2010. Swedish FSC standard for Forest certification including SLIMF indicators. FSC-STD-SWE-02-02-2010. FSC Sweden, Uppsala

Gustafsson, L., Perhans, K. 2010. Biodiversity conservation in Swedish forests: Ways forward for a 30-year-old multi-scaled approach. Ambio 39, 546-554

Ingemarson, F., Jansson, V., Malmhall, J., Merkell, B., Nasic, S., Svensson, S. Å. 2007. Hur drabbades enskilda skogsägare av stormen Gudrun? Resultat av en enkätundersökning (How were private forest owners affected by the Gudrun storm? Results of a representative survey). Skogsstyrelsen förlag, Jönköping, 69 pp.

Lindbladh, M., Axelsson, A-L., Hultberg, T., Brunet, J., Felton, A. 2014. From broadleaves to spruce-the borealization of southern Sweden. Scandinavian Journal of Forest Research 29, 686-696.

Lindahl, K.B, Stens, A., Sandström., Johansson, J., Lidskog, R., Ranius, T., Roberge, J-M.(2015) The Swedish forestry model: More of everything? Forest Policy and Economics.

PEFC (Programme for the Endorsement of Forest Certification Schemes), 2012. Svensk PEFC skogsstandard (Swedish PEFC forest standard). PEFC SWE 002:3. PEFC Sweden.

SFA (Swedish Forest Agency). 2014. Statistical Yearbook of Forestry 2014. Jönköping

SFA (Swedish Forest Agency). 2015a. Avverkningsanmälningar (Areas notified for final felling). The official statistics of Sweden. Product code: JO0314

SFA (Swedish Forest Agency). 2015b. Älgbetesinventering (ÄBIN) 2015 (Inventory of moose browsing 2015). Swedish Forest Agency, Jönköping.

SFA (Swedish Forest Agency). 2015c. Statistik över åtgärder i skogsbruket (Statistics of measures within forestry). The official statistics of Sweden. Product code: JO301

SFA (Swedish forest agency). 2016a. Återväxtens kvalite (The quality of the regeneration). The official statistics of Sweden. Product code: JO0311.

SFA (Swedish Forest Agency). 2016b. Skogsvårdslagstiftningen. Gällande regler 1 Januari 2016 (Swedish Forest Act. Valid rules January 1 2016). Swedish Forest Agency, Jönköping.

SFA (Swedish forest agency). 2016c. Biotopskydd och naturvårdsavtal 2015 (Habitat protection and nature conservation agreements 2015). The official statistics of Sweden. Product code: JO1402.

SFA (Swedish forest agency), 2016d. Stöd för skogens miljövärden (Support for the nature values of forests). http://www.skogsstyrelsen.se/Aga-och-bruka/Skogsbruk/Stod-och-bidrag/Skogens-miljovarden/ (Visited 2016-07-04)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Skogforsk, 2011. Provenienser-förflyttning av gran och tall (Proveniences- movement of Norway spruce and Scots pine). http://www.kunskapdirekt.se/ sv/KunskapDirekt/Alla-Verktyg/Plantval/Genvag-till-battre-skog/Val-av-proveniens-froplantage1/

Stål, P-O., Christiansen, L., Wadstein, M., Grönwall, A., Olsson, P. 2012. Skogsbrukets frivilliga avsättningar (The voluntary protection within forestry). Report 5-2012. Swedish Forest Agency, Jönköping.

Valinger et al. 2006. Analysis of risk factors after the storm Gudrun. Report 2006:8 Swedish forest Agency, Jönköping.

Wallstedt, A. 2013. Återväxtstödet efter stormen Gudrun (The reforestation grants after the Gudrun storm). Report 1-2013. Swedish Forest Agency, Jönköping.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

II. Ranking of Ecosystem Services (ES)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

2.8. Sweden

2.8.1. Contrasting the relative biological diversity of Sweden's stand level FMMs

We used previously identified biodiversity goals for Sweden (Felton et al., 2016a) to identify positive vs. negative outcomes for three key determinants of habitat availability in production forests: Tree species composition, forest structures, and spatial-temporal disturbance patterns. We then ranked each FMM and in most cases their relevant subcategories, on a 7 point scale with respect to each of the three key determinants of forest habitat availability, with an average of the three scores providing a summary rank (Table 39). The allocated ranking was determined by two researchers with expertise evaluating the biodiversity contribution of different production forest alternatives in Sweden. As there is an unavoidable element of subjectivity in this assessment, the net result should be as an approximate indicator of relative biodiversity value. Inevitably the net biodiversity value of any FMM will vary with biogeographical context, the availability of source populations, and the availability of habitat alternatives in a landscape. See the associated text for motivation, and the summary FMM document for full descriptions of the FMMs assessed.

Clearcutting with intermediate rotation – Norway spruce.

Rotationally clear-cut even-aged stands of Norway spruce dominated stands, though native, are intensively managed, structurally-simplified, single-species dominated, and thus relatively homogenous production forest alternatives (Felton et al., 2010). This FMM is the most dominant form of production forest in this region by volume (SFA, 2014). Whereas this FMM does use a native conifer tree species, the FMM overall provides only limited allowance for broadleaf and other tree species which are largely removed during pre-commercial and commercial thinning (with the exception of those provided by green tree retention). Note that the loss of broadleaves and the widespread structural simplification of forest cover, are two key drivers of biodiversity concerns in this region (Lindbladh et al., 2014a). Due to its homogenous even-aged structure, these stands likewise are generally lacking in adequate deadwood accumulation and structural heterogeneity for support many forest-associated species. Likewise, the use of clearcutting is inconsistent with attempts to better align production forest disturbance regimes with the natural disturbance regimes of this region, which would involve smaller scale disturbances and better allow for natural processes of growth and decay (Kuuluvainen, 2009). The net result is an intensively managed, widely applied, conifer dominated, and greatly simplified forest ecosystem, with therefore relatively limited biodiversity values. Note also that current rotation times are likely to get shorter in the future (Roberge et al., 2016; Felton et al., 2017).

Clearcutting with intermediate rotation – Scots pine.

Whereas Scots pine production forests likewise involve the rotational clearcutting of even-aged stands, this stand type supports distinct floral and fauna communities, and is declining in the landscape primarily as a result of its vulnerability to increased browsing pressure by forest ungulates (Månsson et al., 2007). With respect to biodiversity, pine stands provide different bark and dead wood characteristics, and their more open crowns and branches alters the understorey microclimatic and soil conditions that arise (Kuusinen, 1996; Jonsell et al., 1998; Barbier et al., 2008). As a result Scots pine forests are often found to support distinctive communities of epiphytic lichens (Marmor et al., 2013); macrofungi (Ferris et al., 2000); bryophytes (Augusto et al., 2003);

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

and birds (Gjerde and Saetersdal, 1997). In addition, Bilberry (*Vaccinium myrtillus*) is often associated with Pine stands (Miina et al., 2010), which is also important food resource for many species. Pine itself also provides a substantial part of the winter diet for Moose and roe deer. For these reasons we rank Scots pine higher than Norway spruce in terms of habitat provision and associated biodiversity value in this region.

Clearcutting with intermediate rotation – Spruce-birch mixture.

Spruce-birch mixtures are ranked higher than spruce monocultures, due to the benefits of diversifying tree species composition via the addition of a broadleaf tree species, with the additional implications for understorey conditions. The addition of a broadleaf tree species will likely increase levels of soil insolation and rates of nutrient cycling, raise soil quality in terms of mineral content and carbon:nitrogen ratio, and therefore benefit the diversity of vascular plants and associated taxa (Barbier et al., 2008; Felton et al., 2016c). Stand-scale increases in species richness and abundance may be expected for birds, understory vegetation, saproxylic beetles, and lichens (Felton et al., 2010). Recent reviews and empirical studies thus provide substantial justification for expecting increased biodiversity benefits with the use of this FMM relative to Norway spruce monocultures (Felton et al., 2010; Felton et al., 2011; Felton et al., 2014; Felton et al., 2016c).

Clearcutting with intermediate rotation – Spruce-pine mixture.

Spruce-pine mixtures are ranked higher than spruce monocultures, due to the addition structural complexity of adding pine to the stand and the associated biodiversity benefits linked to this tree species specific characteristics, as outlined above (Felton et al., 2016c).

Clearcutting with short rotation - birch

The advantages of using broadleaf tree species within stands, is that by so doing production forests help to rectify long terms trends in regional land-use change which have generally acted to reduce the percentage cover of broadleaf trees, in favor of conifer trees (Lindbladh et al., 2014a). For this reason, even-aged birch dominated stands are considered more positive for biodiversity than conifer dominated stands. These benefits are however tempered by the relatively short rotations (Felton et al., 2016a). It is important to note however that birch is a pioneer tree species and often has a shorter natural lifespan than other tree species in the region (e.g. pine, oak).

Clearcutting with short rotation – hybrid aspen

Whereas the use of hybrid aspen is consistent with the goal to increase the proportion of broadleaf trees, it requires caveats with respect to the goal to favor native tree species and the associated limitations of short-rotation forestry (Felton et al., 2016a). There are also are concerns regarding the extent of introgression occurring between hybrid aspen and wild populations of European aspen. These are risks that may increase with climate change (Felton et al., 2013). We also note that there are substantial uncertainties regarding whether hybrid aspen has the same epiphytic benefits of European aspen with respect to the bark conditions provided. Furthermore, hybrid aspen's intensive rate of growth enables stands to reach heights in 25 years that are comparable to Norway spruce during normal rotation periods of 60–70 years on similar sites. The associated benefits in terms of tree size must however be balanced by the short time window for establishment, and the need for stable substrates. . Further complexity is added by the need to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

fence these stands and the associated diverse structurally complex understories that result from the absence of ungulate browsing (Lindbladh et al., 2014b). For these reasons hybrid aspen stands have aspects that are both potentially consistent and inconsistent with biodiversity goals addressing forest structures.

Clearcutting with short rotation – hybrid larch

Hybrid larch is a cross between European larch (*Larix decidua*) and Japanese larch (*Larix kaempferi*), and neither are native to Sweden. As such this FMM involves a combination of clearcutting, short rotation, and hybrid exotic conifer, and is thus considered very low in terms of general biodiversity value. However, in relation to understorey biodiversity (Felton et al., 2013), there are some indications that the relatively sparse and deciduous nature of larch canopies, can favor a relatively rich understorey of flora compared to dense canopied conifers (Barbier et al., 2008; Wang et al., 2009).

Clearcutting with long rotation - Oak

Whereas oak production stands are managed using the same intensive prescriptions as other even-aged monocultures, this FMM is managed over relatively extended rotation periods and involves one of the most important broadleaf tree species for biodiversity in Sweden. Oak is associated with a substantial number of species from a wide range of taxa (Jonsell et al., 1998; Thor, 1998; Berg et al., 2002; Götmark and Thorell, 2003; Koch Widerberg et al., 2012; Felton et al., 2016b), many of which are threatened (Gärdenfors, 2015). For this reason oak production stands achieve the highest biodiversity value of the production forest alternatives assessed.

Uniform shelterwood – Scots pine

Unifrom shelterwood involving Scots pine ranks slightly higher than clearcutting with intermediate rotation Scots pine, due to the allowance for some percentage of mature trees to temporarily remain after clearcutting to act as seed trees. As these trees provide larger categories of dead wood when they blow down, they are slightly more consistent with goals for forest structures.

NS – nature conservation with management

Although nature conservation with management can be expected to provide higher biodiversity values than many of the production forest alternatives, these values are like to range widely and thus are provided with a range of scores for the aspects assessed.

N – Voluntary and official set asides

Although voluntary and official set asides can be expected to provide higher biodiversity values than many of the production forest alternatives, these values are like to range widely and thus are provided with a range of scores for the aspects assessed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 39 Six Swedish FMMs and associated subcategories ranked in terms of their relative capacity to close the gap between the habitat provided in production forests and the habitat requirements of forest dependent flora and fauna. See Felton et al. (2016a)

FMM	FMM subcategory	Tree species composition (Native trees, broadleaf trees, tree species diversity)	Forest structures (older / larger trees coarse woody debris)	Disturbance regime (emulate natural disturbance regimes spatially and temporally	Rank out of 7
Clear cutting with intermediate rotation	Norway spruce (>70% basal area)	2	2	2	2,0
	Scots pine (>70% basal area)	3	3	3	3,0
	Spruce-birch mixture (30%-70% birch)	5,5	3	3	3,8
	Spruce-pine mixture (30%-70% pine)	4,5	3	3	3,5
Clearcutting with short rotation	Birch	5	3	3	3,7
	Hybrid aspen / populous	3	3	1	2,3
	Hybrid larch	1	1	1	1,0
Clearcutting long rotation	Oak	6	5	4	5
Uniform shelterwood Pine	Scots pine shelterwood	3	3,5	3	3,2
NS - Nature conservation with management	Mix of tree species possibilities but, mostly beech, oak, broadleaves	2 to 7	5 to 7	7	4 to 7
NO- Voluntary and official set asides	Mix of species possibilities	2 to 7	5 to 7	7	4 to 7

2.8.2. Contrasting the relative and absolute carbon mitigation value of Sweden's stand level FMMs

We used the Heureka system to compute the figures for stock of C in forest and HWP and the resulting figures on harvest to assess the substitution effect of HWP. The system estimates the C

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

content on all fractions of biomass related to trees and has in addition a soil carbon model, thus enabling a rather comprehensive assessment of C stock.

The assessment is based on the same stand input in order to make a comparison possible. It may well be that the different FMM normally find use under different site conditions, but differentiating them would make comparisons rather difficult. Another feature of the assessment is that we made a steady-state analysis, i.e. the assessment answers to the question “What is the stock and flow for a normal forest given the FMM?” One reason for that is that the initial state would have such an impact that comparing different FMM based on them would be rather meaningless. This would not be a problem if all FMM were even aged FMM; however, the continuous cover FMM and the no management FMM cannot reasonably be initiated with the same state as rotation FMM. You may then run the model for a very long time to make the initial state less important; yet this does not work with Heureka where age tends to slow growth for continuous cover FMM and no management forest.

The assessment should be interpreted with great care. The relative ranking of FMM is dependent on the fact that they are based on the same conditions. It may well be that another ranking could result if conditions were different (e.g. less fertile soils) and FMM application adapted to those conditions. The common site conditions assumed correspond to the average conditions in the Kronoberg CSA (Table 40). All FMM were simulated for 400 years. The data for the rotation FMM were taken from the last rotation over the 400 years to have soil carbon to stabilize. The continuous cover FMM were assessed as average over years 100-200 (production tends to decrease for longer periods) and the no management FMM over the years 200-400.

Table 40 Site conditions assumed correspond to average conditions in Kronoberg CSA

Altitude (m)	Latitude (°)	SIS (m at age 100)
178	56.8	27

The assessment follows the minute instructions in “Guidelines for C sequestration DSS” to the extent possible. After the evaluation a few comments on the instructions are given in case an updated C guideline will be made available.

The FMM descriptions below are shortened descriptions of what is found in the document Biodiversity Sweden.

Clearcutting with intermediate rotation – Norway spruce.

Rotationally clear-cut even-aged stands of Norway spruce dominated stands, though native, are intensively managed, structurally-simplified, single-species dominated, and thus relatively homogenous production forest alternatives (Felton et al., 2010). This FMM is the most dominant form of production forest in this region by volume (SFA, 2014). Whereas this FMM does use a native conifer tree species, the FMM overall provides only limited allowance for broadleaf and other tree species which are largely removed during pre-commercial and commercial thinning (with the exception of those provided by greentree retention).

Clearcutting with intermediate rotation – other species.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

/The intermediate rotation is only reported for the spruce monoculture FMM motivated by the rather similar implications for C stock and flow that would result from other combinations. /

Clearcutting with short rotation – larch

It is interesting to evaluate the potential for a fast growing species with short rotation with respect to C stock and flow. Unfortunately, Heureka is not equipped with hybrid species like hybrid aspen or hybrid larch. The best we could do was ordinary larch. Thus, the figures for this FMM represent most certainly an underestimate of what is actually possible for a short rotation FMM.

Clearcutting with short rotation – other species

/The short rotation FMM is only reported for larch because other species would probably show results that are even more an underestimate of the potential of the FMM/

Clearcutting with long rotation – Oak

Whereas oak production stands are managed using the same intensive prescriptions as other even-aged monocultures, this FMM is managed over relatively extended rotation periods and involves one of the most important broadleaf tree species for biodiversity in Sweden.

Uniform shelterwood – Scots pine

/This FMM is not evaluated because it would most likely perform as good as intermediate rotation spruce. Additionally, the FMM is preferred on sites less productive than the one chosen for the comparison. /

NS – nature conservation with management

Management of sites for nature conservation may take many different forms depending on what kind of structures and features should be enhanced. The assumption here is that management is relatively intensive and follows more or less a continuous cover forest kind of management. The simulation is based on oak which is the dominant species in this kind of FMM.

N – Voluntary and official set asides

This FMM assumes no intervention at all. As pointed out above, the growth in Heureka tends to slow down over time. The figures showed something like a stabilization in the last decades of the 400 year simulation. The stand is a pure spruce stand.

Table 41 Stock and flow of C for different FMM (all figures per ha; the same color = the same C impact).

FMM	FMM subcategory	Rotation length (y)	Stock (tC)	Substitution (tC/y)	Rank out of 7 (stock/subst)
Clear cutting with intermediate rotation	Norway spruce (>70% basal area)	75	171	0.235	5/6
	Scots pine (>70% basal area) ~ spruce				
	Spruce-birch mixture (30%-70% birch) ~ spruce				

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

FMM	FMM subcategory	Rotation length (y)	Stock (tC)	Substitution (tC/y)	Rank out of 7 (stock/subst)
	Spruce-pine mixture (30%-70% pine) ~ spruce				
Clearcutting with short rotation	Birch ~ larch				
	Hybrid aspen / populous ~ larch				
	Larch (not Hybrid larch)	40	80	0.105	2/5
Clearcutting long rotation	Oak	130	155	0.188	4/4
Uniform shelterwood Pine	Scots pine shelterwood ~ spruce intermediate				
NS - Nature conservation with management	Oak for continuous cover forestry	~	122	0.027	3/2
NO- Voluntary and official set asides	Spruce	~	367	0.000	7/1

It appears that set asides give the largest stocks at the expense of no substation. The standard spruce program comes out as a good alternative due to its growth and usability. The short rotation is most likely underestimated as regards stock and handicapped by no substitution effect attributed paper products. The NS FMM is the result of oak being less productive than e.g. spruce. The substitution effect is surprisingly small in this steady state analysis.

Table 42 Stock and flow of C for different FMM under different scenarios (all figures per ha).

FMM	Rotation oak	Rotation larch	Rotation spruce	Cont. cov. for.	No mgm
BAU					
Stock (tC)	155	80	171	122	367
Substitution (tC/y)	0.188	0.105	0.235	0.027	0.000
HFD					
Stock (tC)	155	80	171	122	367
Substitution (tC/y)	0.304	0.301	0.397	0.109	0.000
HSV					
Stock (tC)	168	81	186	122	367

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Substitution (tC/y)	0.236	0.042	0.278	0.000	0.000

The figures in Table 41 is based on what could be termed a BAU scenario. The other required scenarios are High fuelwood demand (HFD) and High substitution value (FHSV) (Table 42). As indicated the stock figures do not change much (as expected) whereas the flow do. The latter are improved by a turn to more energy use of wood.

2.8.3. Assessment of the provision of cultural services by the stand level FMMs in the Swedish case study

The ranking of the FMMs in the Swedish case study have departed from the guidelines provided for cultural services. The concepts, dimensions and attributes used in the ranking are presented in Table 43. Each attribute has been qualitatively ranked 0-1 (0=very bad, 1=very good) based on expert judgment i.e. no DSS or quantitative data has been used in the assessment.

Table 43 Concepts, dimensions, attributes used to rank the aesthetic/recreational

Concepts	Dimension	Attribute	Indicator	Effect
Stewardship	Sense of care	Amount of logging residue	Frequency of thinning/final felling. Very high (0) – No intervention (1).	-
Naturalness/ disturbances	Alternation/ impact	Frequency of final fellings	Frequency of final felling. Very high (0) – No intervention (1).	-
Complexity	Diversity	Tree species diversity within stands	Monculture (0)- Higly Mixed (1)	+
Complexity	Variety	Variation in tree size within stands	Even aged (0)- Uneven aged (1)	+
Visual scale	Openess	Visual penetration	Extremly dense (0)- Open (1)	+
Historicity/ imageability	Historical richness	Age of trees in stands	Relative age/size* at final-felling. Very low (0) - Similar to "natural" conditions (1)	+
Ephemera	Seasonal change	Presence of broadleaves	Totally absent (0)- 100 % broadleaves (1)	+

**Relative to the species lifespan and growth pattern, because a fast growing species will reach the size associated with higher aesthetical/recreational values faster.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 44 Qualitative assessment of the recreational/ aesthetical values associated with FMMs in the Swedish case study.

FMM/Concept*	S	N	C	V	H	E	Average
Clearcutting intermediate							
Norway spruce (>70% basal area)	0.5	0.5	0.1	0.25	0.25	0.1	0.28
Scots pine (>70% basal area)	0.6	0.7	0.1	0.5	0.4	0.1	0.4
Spruce-pine mixture (30%-70% pine)	0.5	0.6	0.3	0.375	0.3	0.1	0.36
Spruce-birch* mixture (30%-70% birch)	0.5	0.5	0.35	0.375	0.25	0.5	0.41
Clearcutting short							
Birch	0.4	0.4	0.1	0.5	0.25	1	0.44
Hybrid aspen/populous	0.25	0.25	0.1	0.35	0.25	1	0.37
Hybrid larch	0.4	0.4	0.1	0.3	0.25	0.1	0.26
Clearcutting long- oak	0.5	0.8	0.5	0.6	0.75	1	0.69
Uniform shelterwood system – Pine	0.6	0.75	0.15	0.5	0.45	0.1	0.43
NS - Mix of tree species possibilities but mostly beech, oak, broadleaves	0.75	1	0.25-0.875	0.75	0.75	0.75	0.71-0.81
NO - Mix of species possibilities	1	1	0.25-0.875	0.25-0.75	1	0.25-0.75	0.62-0.89

**s= Stewardship, N= Naturalness/disturbances, c= Complexity, v= Visual scale, h= Historicity/imageability, e= Ephemera*

Clearcutting intermediate

The range in this FMM is explained by the variability in dominating species. Scots pine scores higher than Norway spruce due to increased visual penetration and longer rotations. The birch admixture increases the recreational/aesthetical value.

Clearcutting short

This FMM involves establishing plantations of fast growing pioneers. For birch and Hybrid aspen/populus the economic performance (expressed as NPV) is highly dependent on a short rotation period, thereby partly compensating for the high establishment cost. The positive effect due to the broadleaved component is therefore partly neutralized by the intensive management regime (in addition the negative effect due to fencing, which often is required, has not been considered). As an intensively managed exotic conifer, clearcutting short with Hybrid larch has the lowest ranking of all FMMs.

Clearcutting long with Oak

This FMM is ranked highest among the FMMs oriented for wood production. Oak is a broadleaved species managed with long rotations to obtain a large target diameter. The open canopy implies good visibility and the possibility of admixture with other broadleaved species. All these are factors that gives this FMM a high aesthetical/recreational value.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Uniform Shelterwood system with pine

Similar to clearcutting with Scots pine. The higher score is due to a little bit longer rotation and aesthetical qualities associated with the seed trees.

NS- Nature conservation with management

The range is explained by the fact that this FMM is applied in different stand types. However, among private forest owners in Kronoberg it is almost exclusively used in broadleaved stands, situated close to houses/farmland/lakes. Aesthetical/recreational goals are generally overlapping with nature conservation goals. The high score is explained by the management regime, which is oriented towards favoring/maintaining large broadleaved trees.

NO- Nature conservation without management

This FMM is used in very different stand types and the big range is explained by variability in complexity, openness and the proportion of broadleaves. The lack of cutting gives it a high score.

2.8.4. Regulatory services- Assessment of the risk of storm felling for the FMMs in the Swedish case study

Storm damage has been the most significant disturbance factor to the forests of southern Sweden over the past decades. This is especially valid for Kronoberg County, which is situated in the core of the area affected by the devastating winter storms of 2005 and 2007, felling 75 and 15-20 million m^3 in southern Sweden respectively. Beyond such catastrophic events, minor winter storms are more or less annually occurring. Due to its magnitude in terms of damage, as well as its potential detrimental effects on the economic outcome of forest management, we focus our regulatory service assessment on the FMMs relative susceptibility to storm felling.

The ranking of the FMMs is based on expert judgement, supported by earlier research and information regarding the local forest management practices, the later obtained from qualitative interviews with forest consultants/wood buyers currently working in the County. This ranking is based on general characteristics of the different FMMs. The risk associated with an FMM at a particular site and time, will be influenced by factors such as local exposure (e.g. edges, neighboring stands, topography) and seasonal factors (e.g. leaves or not, frozen ground). Below are some comments for each indicator that have been influential for the ranking of the FMMs.

Indicators[3]:

Species – Norway spruce has a lower mechanical stability than both Scots pine and Birch (Peltola, 2000), the other common species in Kronoberg. The relative susceptibility of different species to storm damage is also influenced by season, since broadleaves (and Hybrid larch) are leafless during the winter. This ranking is based on storms in the winter, the peak season in southern Sweden for devastating storms. An analysis of the damages inflicted by the winter storm Gudrun revealed that

[3] It is quite difficult to provide an assessment of the different individual indicators because they are hard to asses in isolation e.g. stand height/species affect the risk associated with thinning. This implies that the total average score provides the most just assessment.

the damages were positively correlated with the proportion of spruce (Valinger & Fridman, 2011). Mixing spruce with Scots pine and birch reduced the risk of damage. This was especially evident for birch, where an admixture of 30 % reduced the risk with 50 %.

Height at final felling - The risk of storm felling increases with increasing stand height. When comparing height development curves of different species at sites where they typically are grown, it is evident that the height of Norway spruce overall tend to be higher at the age of final felling i.e. on average relatively more stands of spruce will grow to a higher height. In this regard it is also important to remember that the site index (defined as dominant height after 50/100 years) of spruce generally is higher than all other native species regardless of site productivity (Ekö et al., 2008). According to the forest consultants/wood buyers rotations have been reduced due to the lessons learned after the Gudrun storm, where large areas of over mature (from a silvicultural perspective) forests were damaged. The strongest actor in the county, the forest owners association Södra, has also reduced their recommended rotation periods. The reduced rotation periods invoked by the increased risk awareness implies that no FMM reach the highest score for this indicator.

Standing volume – In general, a forested landscape consisting of stands with a higher standing stock will suffer more storm damage in absolute numbers. The average standing stock during a rotation depends on the growth and the rotation i.e. a FMM used for a productive species (high MAI) with long rotation (often later MAI culmination) will have a higher average standing stock during a rotation compared with other FMMs. Also here spruce scores high.

Thinning program – The risk of storm felling is increased after thinning. Thinnings at a high height, and especially late and heavy interventions in previously unthinned stands are associated with a high risk. However, due to the lessons learned in the Gudrun storm the thinning practices in Kronoberg County have changed over the last decade. Thinning in mature stands of Norway spruce has largely been abandoned, and a widely acknowledge guideline is to not perform any thinnings in stands higher than 20-22 m. Due to the increased risk awareness the thinning programs of all FMMs are ranked medium in risk, with two exceptions. The uniform shelter wood system scores high due to the seed tree cutting, where approximately 50-150 seed trees of Scots pine are retained, thus left heavily exposed and suffering a high risk of storm felling. According to the consultants/wood buyers many private forest owners interest in this method has dropped due to the frequent fellings of the seed trees. Thinning in NS (nature conservation with management) stands scores below average since it is oriented towards favoring broadleaves at the expense of spruce.

2.8.5. Water - Assessment of the effect of different FMMs on the chemical and ecological status of streams and lakes in the Swedish case study

In the guidelines for ES water five different subcategories are listed in Table 46. Our assessment has focused mainly on the fifth category; chemical conditions of freshwater. In addition, some FMM characteristics that can be related to ecological processes in streams have also been included in our assessment.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 45 Assessment of the risk of storm felling (1-5) of the FMMs in Kronoberg County.

FMM	FMM subcategory	Tree species	Height at final felling	Standing volume	Thinning program	Average
Clearcutting intermediate	Norway spruce (>70% basal area)	5	4	5	3	4.25
	Scots pine (>70% basal area)	3	3	4	3	3.25
	Spruce-pine mixture (30%-70% pine)	4	3	4	3	3.5
	Spruce-birch mixture (30%-70% birch)	3	3	3-4	3	3.13
Clearcutting short	Birch	1	2	2	3	2
	Hybrid aspen/populus	2	3	3	3	2.75
	Hybrid larch	2	4	4	3	3.25
Clearcutting long	Oak	1	2	2	3	2
Uniform shelterwood pine	Pine	3	3	4	5	3.75
NS- nature conservation with management	Mix of tree species possibilities but. mostly beech. oak. broadleaves	1-3	3-5	3-5	2	2.25-3.75
NO- nature conservation	Mix of species possibilities	1-5	3-5	3-5	0	1.75-3.75

The effects of forest management on freshwater goes beyond the differences associated with the FMMs. General considerations in harvesting such as retaining buffer zones along streams and lakes, measures to minimize the soil damage inflicted by machinery and the use of temporary bridges when crossing streams are all crucial. The following ranking assumes that such considerations, which are stipulated in the forestry act and certification standards, are taken for all FMMs. In addition, it is important to remember that this assessment has been conducted at a general level. For example, the tree species that are possible to utilize at a specific site depends on the site conditions e.g. in reality you cannot contrast oak with Scots pine on a very poor site.

Below are some comments regarding the two FMM characteristics, tree species and harvest intensity, which have guided our ranking of the FMMs. They were both among the suggested DSS outputs relevant for an assessment on the chemical conditions of freshwater in the guidelines. Among other relevant factors, fertilization and burning has been disregarded. No fertilization is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

conducted in Kronoberg due to the limited growth response and/or requirements in the certification standards and the forestry act. Prescribed burning is only conducted by certified forest companies, and with 80 % share of small private forest ownership in Kronoberg the activity in prescribed burning is negligible.

Tree species: Regarding water quality there is strong support to suggest that FMMs with broadleaves are superior to conifer FMMs (Felton et al. 2016). Conifer litter produce higher concentrations of dissolved organic carbon (DOC), and subsequently higher levels of leakage and brownification. In broadleaves stands favorable light conditions, as well as the leaf litter, has positive effects on the ecological processes in streams, this includes favoring the development of heterotrophic biofilms, which retain stream nutrients and thereby reduce leakage of inorganic carbon. In contrast, a spruce forest will support less broadleaves and understory vegetation producing high quality litter due to the low light availability. The relative ranking within the conifers and broadleaves are based on light availability e.g. Scots pine and Hybrid larch (open at least at the end of the rotation) scores higher than spruce.

Harvest intensity: Clear-felling increase the runoff of nitrogen, phosphorus, metyl mercury, DOC (dissolved organic carbon) (Eriksson et al. 2011). Hence, the annual area of final felling in a catchment is linked to the quality of ground and stream water. The annual area cut depends on the rotation, and the FMMS have therefore been ranked based on their relative rotation length.

In summary, an ideal FMM for the ecological and chemical status of freshwater at both smaller (the individual stream crossing a stand) and larger spatial scales (the catchment) would consists of a broadleaved species managed with CCF. In contrast, an intensively managed conifer monoculture with short rotation and dense canopy would get the lowest score.

Table 46 Assessment of relative suitability (1-5) of different FMMs for the chemical and ecological status of streams and lakes (1= very bad, 5=very good).

FMM	FMM subcategory	Tree species	Harvest intensity	Average
Clearcutting intermediate	Norway spruce (>70% basal area)	1	3	2
	Scots pine (>70% basal area)	2	3.5	2.8
	Spruce-pine mixture (30%-70% pine)	1.5	3.25	2.4
	Spruce-birch* mixture (30%-70% birch)	3	3	3
Clearcutting short	Birch	4	2	3
	Hybrid aspen/populus	4	1	2.5
	Hybrid larch	2	2	2
Clearcutting long	Oak	5	4	4.5
Uniform shelterwood pine	Pine	2	3.75	2.9
NS- nature conservation with management	Mix of tree species possibilities but, mostly beech, oak, broadleaves	3-5	5	4-5
NO- nature conservation	Mix of species possibilities	1-5	5	3-5

**For this FMM we assume that the birch component is clustered along streams, in line with the guidelines of the major forestry actors (e.g. Sveaskog, Södra) in Kronoberg.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

2.8.6. References

Augusto, L., Dupouey, J.L., Ranger, J., 2003. Effects of tree species on understory vegetation and environmental conditions in temperate forests. Annals of Forest Science 60, 823-831.

Barbier, S., Gosselin, F., Balandier, P., 2008. Influence of tree species on understory vegetation diversity and mechanisms involved—A critical review for temperate and boreal forests. Forest Ecology and Management 254, 1-15.

Berg, A., Gärdenfors, U., Hallingbäck, T., Noren, M., 2002. Habitat preferences of red-listed fungi and bryophytes in woodland key habitats in southern Sweden - analyses of data from a national survey. Biodiversity and Conservation 11, 1479-1503.

Ekö, P-M., Johansson, U., Petersson, N., Bergqvist, J., Elfving, B., Frisk, J., 2008. Current growth diffrences of Norway spruce (picea abies), scots pine (pinus sylvestris) and birch (betula pendula and betula pubescens) in diffrent regions in Sweden. Scandinavian Journal of Forest Research 23 (4), 307-318.

Eriksson, L-O., Löfgren, S., Öhman, K., 2011. Implications for forest management of the EU water frameworks directives water quality requirements – A modeling approach. Forest Policy and Economics 13, 284-291.

Felton, A., Andersson, E., Ventorp, D., Lindbladh, M., 2011. A Comparison of Avian Diversity in Spruce Monocultures and Spruce-Birch Polycultures in Southern Sweden. Silva Fennica 45, 1143-1150.

Felton, A., Boberg, J., Björkman, C., Widenfalk, O., 2013. Identifying and managing the ecological risks of using introduced tree species in Sweden's production forestry. Forest Ecology and Management 307, 165-177.

Felton, A., Gustafsson, L., Roberge, J.M., Ranius, T., Hjältén, J., Rudolphi, J., Lindbladh, M., Weslien, J., Rist, L., Brunet, J., Felton, A.M., 2016a. How climate change adaptation and mitigation strategies can threaten or enhance the biodiversity of production forests: Insights from Sweden. Biological Conservation 194, 11-20.

Felton, A., Hedwall, P.O., Lindbladh, M., Nyberg, T., Felton, A.M., Holmström, E., Wallin, I., Löf, M., Brunet, J., 2016b. The biodiversity contribution of wood plantations: Contrasting the bird communities of Sweden's protected and production oak forests. Forest Ecology and Management 365, 51-60.

Felton, A., Lindbladh, M., Brunet, J., Fritz, Ö., 2010. Replacing coniferous monocultures with mixed-species production stands: An assessment of the potential benefits for forest biodiversity in northern Europe. Forest Ecology and Management 260, 939-947.

Felton, A., Lindbladh, M., Elmberg, J., Felton, A.M., Andersson, E., Sekercioglu, C.H., Collingham, Y., Huntley, B., 2014. Projecting impacts of anthropogenic climatic change on the bird communities of southern Swedish spruce monocultures: will the species poor get poorer? Ornis fennica. 91, 1-13.

Felton, A., Nilsson, U., Sonesson, J., Felton, A.M., Roberge, J.-M., Ranius, T., Ahlström, M., Bergh, J., Björkman, C., Boberg, J., Drössler, L., Fahlvik, N., Gong, P., Holmström, E., Keskitalo, E.C.H., Klapwijk, M.J., Laudon, H., Lundmark, T., Niklasson, M., Nordin, A., Pettersson, M., Stenlid, J., Sténs, A.,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Wallertz, K., 2016c. Replacing monocultures with mixed-species stands: Ecosystem service implications of two production forest alternatives in Sweden. Ambio 45, 124-139.

Felton, A., Sonesson, J., Nilsson, U., Lämås, T., Lundmark, T., Nordin, A., Ranius, T., Roberge, J.-M., 2017. Varying rotation lengths in northern production forests: Implications for habitats provided by retention and production trees. Ambio In press.

Ferris, R., Peace, A.J., Newton, A.C., 2000. Macrofungal communities of lowland Scots pine (Pinus sylvestris L.) and Norway spruce (Picea abies (L.) Karsten.) plantations in England: relationships with site factors and stand structure. Forest Ecology and Management 131, 255-267.

Gjerde, I., Saetersdal, M., 1997. Effects on avian diversity of introducing spruce Picea spp. plantations in the native pine Pinus sylvestris forests of western Norway. Biological Conservation 79, 241-250.

Gärdenfors, U. (Ed.), 2015. The 2015 Red List of Swedish Species. ArtDatabanken, SLU Uppsala. (In Swedish with English summary).

Götmark, F., Thorell, M., 2003. Size of nature reserves: densities of large trees and dead wood indicate high value of small conservation forests in southern Sweden. Biodiversity and Conservation 12, 1271-1285.

Jonsell, M., Weslien, J., Ehnström, B., 1998. Substrate requirements of red-listed saproxylic invertebrates in Sweden. Biodiversity and Conservation 7, 749-764.

Koch Widerberg, M., Ranius, T., Drobyshev, I., Nilsson, U., Lindbladh, M., 2012. Increased openness around retained oaks increases species richness of saproxylic beetles. Biodiversity and Conservation 21, 3035-3059.

Kuuluvainen, T., 2009. Forest Management and Biodiversity Conservation Based on Natural Ecosystem Dynamics in Northern Europe: The Complexity Challenge. Ambio 38, 309-315.

Kuusinen, M., 1996. Epiphyte flora and diversity on basal trunks of six old-growth forest tree species in southern and middle boreal Finland. The Lichenologist 28, 443-463.

Lindbladh, M., Axelsson, A.-L., Hultberg, T., Brunet, J., Felton, A., 2014a. From broadleaves to spruce – the borealization of southern Sweden. Scandinavian Journal of Forest Research 29, 686-696.

Lindbladh, M., Hedwall, P.-O., Wallin, I., Felton, A.M., Böhlenius, H., Felton, A., 2014b. Short-rotation bioenergy stands as an alternative to spruce plantations: implications for bird biodiversity. Silva Fennica 48.

Marmor, L., Torra, T., Saag, L., Leppik, E., Randlane, T., 2013. Lichens on Picea abies and Pinus sylvestris - from tree bottom to the top. Lichenologist 45, 51-63.

Miina, J., Pukkala, T., Hotanen, J.-P., Salo, K., 2010. Optimizing the joint production of timber and bilberries. Forest Ecology and Management 259, 2065-2071.

Månsson, J., Kalen, C., Kjellander, P., Andren, H., Smith, H., 2007. Quantitative estimates of tree species selectivity by moose (Alces alces) in a forest landscape. Scandinavian Journal of Forest Research 22, 407-414.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Peltola, H., Kellomäki, S., Hassinen, A., Granander, M., 2000. Mechanical stability of Scots pine, Norway spruce and birch: an analysis of tree-pulling experiments in Finland. Forest Ecology and Management 35, 143-153.

Roberge, J.-M., Laudon, H., Björkman, C., Ranius, T., Sandström, C., Felton, A., Sténs, A., Nordin, A., Granström, A., Widemo, F., Bergh, J., Sonesson, J., Stenlid, J., Lundmark, T., 2016. Socio-ecological implications of modifying rotation lengths in forestry. Ambio 45, 109-123.

SFA, S.F.A., 2014. Statistical yearbook of forestry 2014, Official statistics of Sweden. In: Christiansen, L. (Ed.). Swedish Forest Agency, Jönköping, p. 370.

Thor, G., 1998. Red-listed lichens in Sweden: habitats, threats, protection, and indicator value in boreal coniferous forests. Biodiversity and Conservation 7, 59-72.

Valinger, E., Fridman, J., 2011. Factors affecting the probability of windthrow at stand level as a result of Gudrun winter storm in southern Sweden. Forest Ecology and Management 262, 398-403.

Wang, W.-J., Wang, H.-M., Zu, Y.-G., 2009. Plant biodiversity in a larch plantation from the view point of photosynthetic nitrogen use efficiency in northeast China. Landscape Ecol Eng 5, 147-156.

The model to simulate storm felling in Heureka: http://heurekaslu.org/help/en/index.html?stormfallning.htm

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.