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Abstract

During the last century Swedish forestry has developed to become one of the most advanced and intensive in the world. During this development many forest living species have suffered from habitat loss, for example the white-backed woodpecker *Dendrocopos leucotos L*. One of the forest companies in central Sweden, Bergvik Skog, is currently restoring habitats for this umbrella species by favoring deciduous trees and by creating dead wood. The aim of this study was to simulate the development of stands restored for the woodpecker. I simulated four scenarios for 100 years into the future: 1) free development of restored stands, 2) free development of control stands (i.e. unrestored), 3) thinning of spruce when it reaches 5% of the growing stock in restored stands and 4) management for timber production in control stands. The results show that the goals set by Bergvik Skog (maximum and minimum proportion of Norway spruce *Picea abies L.* trees and deciduous trees, respectively, and minimum volume of dead deciduous wood) can be achieved during most of the 100-year period under the spruce thinning scenario for restored stands. A threshold of 8 m^3/ha deciduous snag (used to indicate good white-backed woodpecker habitat) was only reached in two out of five stands during the last 20-45 years of the study period. When studying the biodiversity indicators dead wood volume, proportion of deciduous trees and density of large trees, different scenarios had different effects on the indicators. The main conclusions of the study are 1) the goals set by Bergvik Skog can be reached if the right management is chosen, 2) to reach the deciduous snag threshold one must probably use other methods than the ones simulated in this study and 3) the different scenarios had different effects on the biodiversity indicators and they must thus be chosen with consideration of the specific conservation goals of interest.

Introduction

Swedish forestry is one of the most technically advanced and intensive in the world (Berg et al., 1995). During the last century the forestry have developed from manual selective cutting with natural regeneration, to clear-felling with forest machines and planting of genetically improved seedlings, mainly Norway spruce, *Picea abies L.* (hereafter spruce) and Scots pine *Pinus sylvestris L.* (hereafter pine) (e.g. Esseen et al., 1997). Together with improved fire suppression and the removal of deciduous trees the boreal forests in Sweden have become more homogenous (Esseen et al., 1997). The managed forests also contain lower volumes of deciduous trees, large trees and dead wood than the unmanaged (Fridman and Walheim, 2000, Siitonen et al., 2000), structures recognized as important for a large number of species (Lindenmayer et al., 2012, Dahlberg, 2004). Due to this change a lot of species associated with forests have become threatened (Gärdenfors, 2010). To protect these species and to prevent others from being threatened key forest areas are currently being protected with the use of nature reserves, nature conservation agreements and voluntary set asides. In Sweden a total of 8.4% of the productive forests is currently protected (Christiansen, 2014). In addition large forest areas are being managed to restore disturbance regimes (i.e. fire and flooding) and to increase the amount of deciduous trees, large trees and dead wood (Forest Stewardship Council, 2010, Mild and Stighäll, 2005). An approach that is increasingly being used when restoring degraded ecosystems is the of use umbrella species such as the white-backed woodpecker *Dendrocopos leucotos L.* to guide restoration actions (Bell, 2015, Roberge et al., 2008b, Mild and Stighäll, 2005).

The white-backed woodpecker in Sweden

The white-backed woodpecker is a highly specialized woodpecker that requires large areas of deciduous forests with high concentrations of dead and dying trees where it can feed and breed (Mild and Stighäll, 2005, Aulén, 1988, Ahlen et al., 1978). It is currently listed as least concern (LC) in the IUCN red list (BirdLifeInternational, 2014) but it is one of the most endangered bird species in Sweden, listed as critically endangered (CR) in the Swedish red list 2010 (Gärdenfors, 2010), and a lot of efforts are made to save it from extinction. Before the 20^{th} century the white-backed woodpecker was locally a common bird in Swedish forests and it was found in almost the whole country (Mild and Stighäll, 2005, Aulén, 1986). Since then it has decreased and in 2014 only two confirmed successful breeding's took place: one at the lower part of the river Dalälven (the first in 19 years) and one in the county of Värmland. The current populations in Sweden are found at these two places and along the coast of the county of Norrbotten (K. Stighäll personal communication). The reason for its decline is the decreasing amount of deciduous forests with high concentrations of dead and dying trees upon which it depends (Carlson, 2000, Aulén, 1988).

In a study by Carlson (2000), a threshold was identified for the proportion of deciduous forest on the landscape level below which a white-backed woodpecker population cannot persist. Carlson (2000) found this threshold to be 13 ± 5%. In the counties of central Sweden, out of which Dalarna, Örebro and Värmland is considered in this study, the mean proportion of deciduous trees (considering all age classes in productive forests) is around 17% (Figure 1) (Christiansen, 2014, Olsson and Stighäll, 2013). This also includes young forests from which most deciduous trees are removed in pre-commercial thinnings and the proportion of deciduous dominated forests (≥75 % deciduous trees) is probably much smaller. According to Olsson and Stighäll (2013) the proportion of deciduous dominated forest is around 4.5 %. How large the proportion of deciduous trees and forest would be in a naturally dynamic forest landscape is debated (Axelsson et al., 2002) but the fact that many threatened species depend on deciduous substrates (Dahlberg, 2004) justifies actions to increase the proportion of deciduous forests.

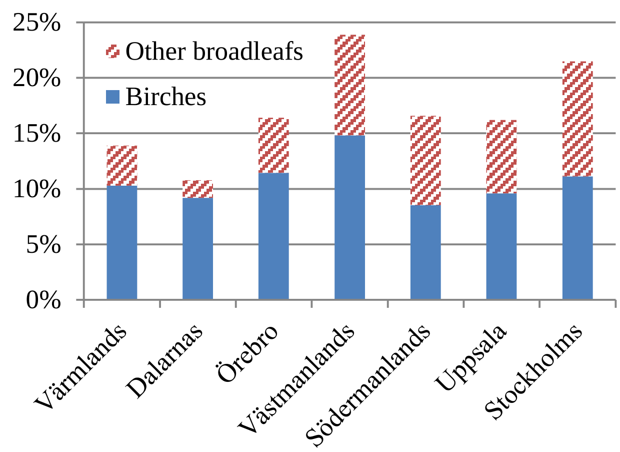

Figure 1: The proportion of birches and other broadleaved trees in productive forests in the counties of central Sweden (Christiansen, 2014).

According to Aulén (1988) the white-backed woodpecker prefers boreal deciduous forests before southern broadleaved and coniferous forests. The tree species used for foraging are mainly aspen *Populus tremula L.*, birches *Betula spp.*, goat willow *Salix caprea L.*, common alder *Alnus glutinosa L.* and grey alder *Alnus* *incana L.* which were overused in relation to their relative abundance in the study by Aulén (1988). Out of these species birches are the most common in the study area (Figure 1) and according to the study by Aulén (1988) this tree species is preferred as dead. In a study by Roberge et al. (2008a) the probability of white-backed woodpecker occurrence was related to the amount of deciduous snags (dead standing trees). The woodpecker had a high probability (0.9) of occurrence when the volume of deciduous snags was more than 8-17 m^3/ha depending on e.g. assumed tree shape index. From here on the lower threshold (8 m^3/ha) have been used to indicate good white-backed woodpecker habitat.

Natural habitats for the woodpecker are for example deciduous forests growing after fire, deciduous rich riparian forests, former grazed areas, steep slopes and late successional forests with high amounts of dead wood (Aulén, 1988). The past habitat contraction in Sweden is due to the alteration of these habitats. During the 20th century fire suppression has been very successful with the result that the deciduous rich forests that often follow fire are rare. Where disturbances take place the forests are most often planted with coniferous trees since these generate the highest income for the landowner, which is also why a large proportion of the deciduous trees are selectively removed at pre-commercial thinning when the forest is still young. Another alteration of habitat is the regulation of water regimes. Forest areas that naturally are flooded regularly have now been stabilized (smaller water level fluctuations) resulting in a shift towards higher coniferous proportions and lower mortality (Mild and Stighäll, 2005). A third important factor that may limit the growth of deciduous trees, especially aspen, goat willow and rowan, *Sorbus aucuparia L.*, is the moose *Alces alces L.* browsing that has increased along with the development of the clearcutting regime in Sweden. The use of clearcutting and the low abundance of predators have benefited the moose population and the browsing pressure from moose may severely damage the regeneration of deciduous trees (Mild and Stighäll, 2005, Angelstam et al., 2000).

Actions favoring the white-backed woodpecker

Today a lot of money is spent on the remaining white-backed woodpecker population in Sweden and large forest areas are currently being managed for the woodpecker. The ongoing restoration project is in fact the biggest ecological forest restoration project ever conducted in Sweden's history (J. M. Roberge personal communication). In the action plan for the white-backed woodpecker, stretching from 2005 to 2008, the main actions proposed aimed at protecting deciduous rich forests and at creating and improving new areas suitable for the white-backed woodpecker (Mild and Stighäll, 2005). Since the habitat loss in Sweden is a result of many different factors, different approaches must be used when trying to restore degraded habitats. Since 2005 the main action has been removal of spruce to favor deciduous trees. A lot of voluntary efforts have been devoted to creating dead wood with girdling of deciduous trees and the creation of high stumps. A few stands have also been burnt and a few have been fenced to limit the moose browsing pressure (K. Stighäll personal communication). In addition to these active restoration actions, currently good areas are being protected with nature conservation agreements, nature reserves and set-asides.

One of the biggest conservation actions was initiated by the forest company Bergvik Skog in corporation with the County Administrative Boards and the Swedish Forest Agency. It included 10,000 ha spread among 100 areas located in central Sweden. The distribution of Bergvik Skog’s areas assigned for the white-backed woodpecker in 2014 stretched from Värmland to the lower part of the river Dalälven (Figure 2). In these areas the aim is to increase the amount of deciduous trees and the amount of dead and dying deciduous trees and to decrease the amount of coniferous trees, mainly spruce to restore habitat for the white-backed woodpecker (Table 1). These actions are carried out with forest machines used in ordinary forestry or manually (e.g. burning and cleaning of forests) and some of the timber (mostly spruce) is extracted to cover some of the costs of the operations (B. Pettersson personal communication).

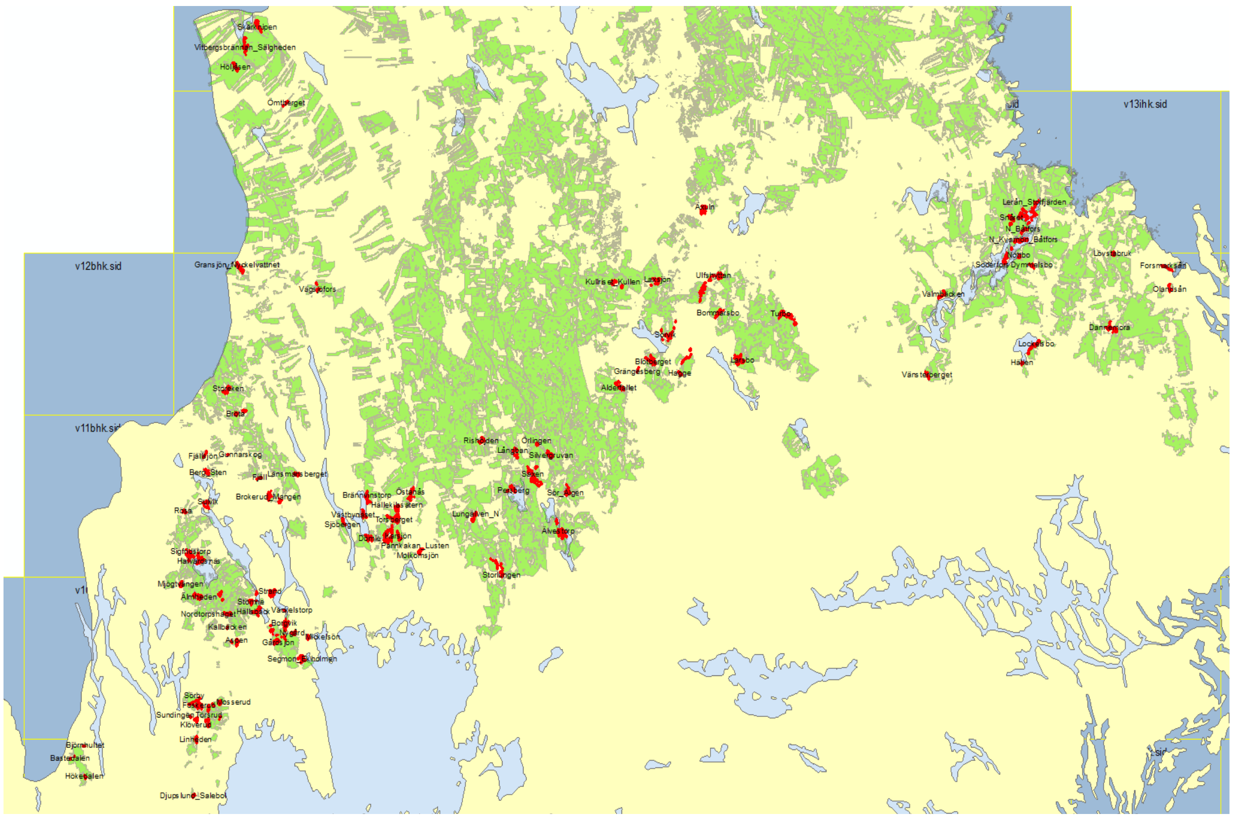

Figure 2: The distribution of Bergvik Skog´s forests (green areas) and their areas assigned for the white-backed woodpecker in 2014 (red areas) in central Sweden.
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Active killing and harming of trees have been shown to increase the supply of wood living insects, especially those depending on deciduous trees (Aulen, 1991). Since the natural processes provide the white-backed woodpecker with substrates relatively slowly, girdling and creation of high stumps is often suggested for fast habitat improvement (Mild and Stighäll, 2005). The active killing of birch is also easier, faster and cheaper than protecting aspen and goat willow from browsing.

Table 1: Bergvik Skog´s goals for restored stands in the white-backed woodpecker areas (B. Pettersson personal communication).

Parameter	Goal
Minimum total deciduous dead wood volume	20 m^3/ha or 20% of total (living + dead) deciduous volume
Minimum proportion of deciduous trees	75% of growing stock
Maximum proportion of spruce trees	5% of growing stock

Biodiversity in white-backed woodpecker habitats

The white-backed woodpecker is often considered an umbrella species (Roberge et al., 2008b, Törnblom et al., 2007) and in the action plans it is stated that 200 species are expected to benefit from the actions suggested (Mild and Stighäll, 2005). Since the inventory of species is often time consuming and complicated it is easier to inventory indicators that indicate different levels of biodiversity. In the present study I focus on three biodiversity indicators: 1) dead wood, 2) tree species composition and 3) large tree density.

Dead wood is often pointed out as a good biodiversity indicator since many species depend on or are associated with dead wood (Dahlberg, 2004, Stokland et al., 2004). Forestry has decreased the amount of dead wood in the landscape (Fridman and Walheim, 2000) with up to 90 % (Siitonen et al., 2000) and because Sweden conducts one of the world's most intensive forestry the Swedish red list contains a lot of species that depend on dead wood (Dahlberg, 2004). One of the things that make dead wood so important is that many species are adapted to dead wood of a specific decay stage, thus the species composition change over the course of decay (Dahlberg, 2004). This makes the decay stage distribution important to study.

The tree species composition is an important biodiversity indicator since it affects the microclimatic conditions and the availability of specific resources (Gamfeldt et al., 2013, Chavez and Macdonald, 2010, Barbier et al., 2008). Barbier et al. (2008) highlighted five different factors that are affected by tree species composition; 1) light, 2) water, 3) nutrients, 4) physical effects of litter and 5) phytotoxic compounds. Over the course of succession the tree species composition will change (e.g. from deciduous to coniferous) and since different species benefit from different stages of succession one stage cannot be considered as more important than another. When looking at the landscape scale, though, we see that the stages of succession with high proportions of deciduous trees are heavily underrepresented in boreal Sweden (Axelsson et al., 2002). When it comes to studying the effect of tree species composition on biodiversity it is hard to say whether a condition is the result of tree species composition or if the tree species composition is a result of the condition. As mentioned by Felton et al. (2010), some species react on certain structures rather than specific tree species. In any case, a large diversity of tree species indicates a diversity of site conditions which opens up for a great diversity of other species. Many red-listed species depend on deciduous tree species and together with the currently low deciduous forest proportion in the study area this makes the tree species composition important to study.

As mentioned, dead and dying trees are of great importance for biodiversity but it is also important to consider live growing trees since they will eventually die and become dead wood. Trees with high age and large diameter is an attribute that is rare in many managed forests in

Sweden as well as the rest of the world (Lindenmayer et al., 2012). What makes these trees interesting from a biodiversity perspective when still alive is the rough and thick bark they develop, hollows that form in the stem, sap-flows that start, branches and tops that die off (Nilsson et al., 2002), and the thick branches that are able to carry up big bird nests (Mild and Stighäll, 2005). These are features that are important to a large amount of species (Nilsson et al., 2002), of which many are threatened (Berg et al., 1994), and that makes it important to study from a biodiversity perspective.

Aim

The aim of this study is to model the future development of stands restored by Bergvik Skog to promote the development of deciduous forests. I will model the achievement of the goals set by Bergvik Skog (Table 1), the substrates needed for the white-backed woodpecker (≥ 8 m^3 deciduous snags/ha) and three biodiversity indicators: share of deciduous trees, dead wood volume and large tree density. The modeled forest management will be in accordance with the general guidelines used by Bergvik Skog. I ask the following questions:

1) is it possible to reach Bergvik Skog's goals and the deciduous snag volumes needed by the white-backed woodpecker,
2) with what management regime can the goals and snag volume be reached and how long will it take and
3) how will the conditions for biodiversity develop?

With this knowledge the selection of stands for restoration can be improved and the restoration can be adjusted to be as effective as possible.

Material and methods

Study site

The study site was located in Bergvik Skog's forests in the south boreal zone (Ahti et al., 1968) of central Sweden. Bergvik Skog is one of the largest forest owners in the region. A total of five stands managed to restore white-backed woodpecker habitats were selected from the company's stand register and inventoried in the field. These were former timber production stands which have been subjected to a restoration cutting where spruce has been removed and dead wood has been created. For a stand to be selected it had to be classified as white-backed woodpecker habitat in Bergvik Skog's stand register. Only recently restored stands (after 2010) were included in the study. The

Figure 3: Positions of the inventoried stands and the counties of central Sweden. © Lantmäteriet I2014/00764

stands were then ranked according to their tree species composition, basal area, age and stand size (Table 2) in order to select stands that still can be considered “forests” and large enough to enable future studies of breeding birds making use of the present study’s results. The selection of stands was also done with respect to driving distances for logistical reasons. Based on these criteria, a final set of 5 study stands were retained (Figure 3).

Table 2: Variables and criteria used to select stands for the study.

Variable	**Criterion**
Basal area	≥10 m^2
Year of restoration	2010 or later
Dominant tree species before restoration	Spruce
Dominant tree species after restoration	Deciduous
Stand age	≥30 years
Area	≥5 ha

Field inventory

The substrates presented in Table 3 were inventoried in sample plots with the radius 5.64 m (i.e. 100 m^2) in the autumn of 2014. In each stand, sample plots were placed in a quadratic grid with random starting point and with mirroring of plots partly outside the study area. The distance between the sample plots was adjusted (70, 80, 90 or 100 m) to get at least 10 sample plots in each stand but with a maximum inter-plot distance of 100 m, resulting in 10-13 sample plots per stand. The diameter at breast height (Dbh) of all standing trees ≥5 cm and snags ≥10 cm and downed dead wood ≥10 cm in diameter was calipered. Diameters of snags and dead wood were rounded to the closest whole centimeter. The lengths of downed dead wood were measured for the part falling inside the sample plot. Age determination of deciduous trees is relatively time consuming and therefore not measured in the field. The height of standing trees was measured. For snags this was measured on every tree and for living trees a number of randomly selected trees were measured. Breakage (1/0) and height to breakage of snags was measured to be used in the volume calculations. Decay classes (ranging from 1-5) were estimated with a method used by the Norwegian Forest Inventory (Anon, 1997) (described by Naesset (1999) and similar to the one used in the Swedish National Forest Inventory (Anon, 2014a)) but was translated to fit the decay classification in Heureka (ranging from 0-4). Dying trees (assumed to die within the coming years, e.g. broken spruce trees) were included in the first decay class. The classification is subjectively determined in the field and largely dependent of the surveyor. Therefore, these results should only be used in the dead wood continuity aspect and not as a measurement of the real decay class quantification. The cause of death (tree cutting or natural) was estimated by looking for traces after the cutting head of the harvester. The smallest diameter of low stumps were measured with the caliper at the cut according to the Swedish National Forest Inventory standard (Anon, 2014a) and rounded to the closest whole centimeter. Only the stumps originating from the restoration cutting (personal judgment) were included (Table 3).

Table 3: The inventoried parameters and the measurements taken.

Parameter	Measurements
Standing living trees ≥ 5 cm at breast height	Tree species Diameter at breast height (Dbh) Height (on sample trees)
Snags ≥ 5 cm at breast height	Tree species Diameter at breast height (Dbh) Height Decay class Breakage (1/0) Cause of death
Downed dead wood ≥ 10 cm	Tree species Diameter (thick and thin end) Length Decay class Cause of death
Low stumps from restoration cutting	Smallest diameter at cut Species

Dead wood volume calculations

The initial dead wood volume had to be calculated manually in Microsoft Excel (Microsoft, 2015). To calculate the volume of unbroken snags the equations in Table 4 were used. For the tree species goat willow, rowan, grey alder and common alder the equations for birch were used as in Fridman and Walheim (2000). Since all broken snags were lower than 3.2 m the volumes of broken snags were calculated as if they were cylinders with the Dbh representing the cylinder diameter. Also cut high stumps (approximately 4 m tall) were assumed to be cylinders. The volume of downed dead wood was calculated with the equation for truncated cones.

Table 4: The functions used to calculate volumes of snags. Pine, spruce and birch equations from Brandel (1990) and aspen equation from Eriksson (1973). D: diameter at breast height (cm). H: height (m).

Tree species	Volume equation	Latitude
Birch	$V = 10^{-0,89363} \times D^{2,23818} \times (D+20,0)^{-1,06930} \times H^{6,02015} \times (H - 1,3)^{-4,51472}$	Latitude: - 56.9°, H>=6 m, d>=4,5 cm
Birch	$V = 10^{-0,84627} \times D^{2,23818} \times (D+20,0)^{-1,06930} \times H^{6,02015} \times (H - 1,3)^{-4,51472}$	Latitude: 59.0° - , H>=6m, D>=4,5cm
Spruce	$V = 10^{-1,02039} \times D^{2,00128} \times (D+20,0)^{-0,47473} \times H^{2,87138} \times (H-1,3)^{-1,61803}$	Latitude: - 60°, H>=4 m, D>=4.5cm
Spruce	$V = 10^{-0,79783} \times D^{2,07157} \times (D+20,0)^{-0,73882} \times H^{3,16332} \times (H-1,3)^{-1,82622}$	Latitude: 60-°, H>=4 m, D>=4.5cm
Pine	$V = 10^{-1,38903} \times D^{1,84493} \times (D+20,0)^{0,06563} \times H^{2,02122} \times (H-1,3)^{-1,01095}$	Latitude: -60°, H>=4 m, D>=4,5cm
Pine	$V = 10^{-1,20914} \times D^{1,94740} \times (D+20,0)^{-0,05947} \times H^{1,40958} \times (H-1,3)^{-0,45810}$	Latitude: 60-°H>=4 m, D>=4,5cm
Aspen	$V = - 0,01548xD^2 + 0,03255xD^2xH - 0,000047xD2xH2- 0,01333xDxH + 0,004859xDxH^2$	D>=5 cm

Reconstruction of restored stands

To reconstruct the stands to their state before restoration, the diameters of the stumps were used to estimate the Dbh for each harvested tree. This was done with the equation used by the Swedish National Forest Inventory (B. Westerlund personal communication):

$$Dbh = \left(\left(\frac{Dls}{10}\right) + 0.28 * \left(\frac{Dls}{10}\right) * \ln\left(\frac{\left(\frac{h}{100}\right) + 1}{2.3}\right) \right) * 10$$

Dbh = Diameter at breast height (mm)
Dls = Diameter of low stump (mm)
h = Height of stump (cm)

The stump height was set to 10 cm for all low stumps and the equation was used for all tree species. Stumps that were not identified to species were attributed a species that corresponded to the general tree species composition of the stand. Two initial states were then obtained for each stand: restored (i.e. state measured in the field) and unrestored (i.e. pre-restoration reconstructed state). No consideration was taken to diameter growth of the cut trees that would have occurred between the time of cut and the inventory.

Modeling of stand development

To model the development of the stands, the decision support tool Heureka StandWise (hereafter ‘Heureka’) (Anon, 2014b, Bonta Bergman, 2014, Wikström et al., 2011) was used. The Heureka system is a software developed at the Swedish University of Agricultural Sciences (SLU) that may be used to simulate short and long term projections of for example timber, economic return and environmental conservation (Bonta Bergman, 2014). The software is currently being used by different research projects such as Future Forests but also by many forest companies, the County Administrative Boards and the Swedish Forest Agency (Bonta Bergman, 2014). Data about the standing living trees were imported directly into Heureka. To be able to import dead wood volumes in Heureka, volumes were calculated for each decay class in Microsoft Excel and then imported into Heureka. This resulted in a volume for each decay class without taking into account if the substrates was standing or lying. This allocation was done by Heureka according to the proportions in Table 5. Also the substrate species was modeled by Heureka since this was not possible to import. This caused problems when modeling the development of deciduous snags since the initial deciduous snag volume could not be taken into consideration. To circumvent this problem the initial deciduous snag volumes were set to 0 when modeling snag development, which is very close to what was measured in the field. Deciduous snags were only encountered in two out of five stands and in these stands the volumes were 0.6 and 1.7 m^3/ha (Appendix A). When looking at the dead wood as a biodiversity indicator or as one of Bergvik Skogs goals the position and species were excluded. Since the total dead wood volume (for each decay class) was not affected by the skewed tree species and position distribution I used the inventoried values as the initial state when modeling this. Another data that was not used in Heureka was the heights of the sample trees because the sample size was too small to provide reliable data. The input data used in Heureka and its sources is summarized in Table 6.

Table 5: Assumed proportions of lying and standing dead wood in each position for the different decay classes (Anon, 2014b).

Position/Decay class	0 and 1	2	3	4
Lying	0.39	0.70	0.91	0.98
Standing	0.61	0.30	0.09	0.02

Table 6: The data used in Heureka and sources.

Input data	Source
Stand data	
Stand age	Stand register
Site index (SI)	Stand register
Altitude	Elevation map (Google, 2015)
Size	Stand register
County	Stand register
Latitude	60.0 (true value: 59.5-60.2)
Living tree parameters:	
Species	Field inventory
Diameter at breast height (Dbh)	Field inventory
Height	Modeled in Heureka
Dead wood parameters:	
Diameters (thick and thin end)	Field inventory
Length	Field inventory
Decay class	Field inventory
Location (standing/lying)	Modeled in Heureka
Low stumps:	
Diameter	Field inventory
Harvested trees:	
Diameter at breast height (Dbh)	Modeled in Heureka
Height	Modeled in Heureka

Scenarios

The four scenarios I chose to model in this study included two management scenarios for restored stands and two for control (i.e. unrestored) stands. The two scenarios for restored stands were **free development (R-FreeDev)** and **spruce thinning (R-SpruceThin)**. The management scenarios for control stands were **free development (C-FreeDev)** and **timber production (C-TimberProd)**.

In the R-FreeDev and C-FreeDev scenarios the stands grow without any forest management according to the standard settings in Heureka. For the C-TimberProd scenario the standard settings for forest management in Heureka were used with a discounting rate of 3%, i.e. clear-cutting with extraction of branches and tops, soil scarification, planting of spruce and thinning. Here, the stands were allowed to be thinned 2-3 times and they were not fertilized. For the R-SpruceThin scenario the thinning grade was set to the same values as the spruce proportion (e.g. 24% spruce proportion yields 24% thinning grade). No deciduous and all coniferous trees were set to be removed in the thinning. Despite this the spruce proportion after thinning was sometimes high and then a new thinning was carried out in the following 5-year period. The time horizon for the simulations was set to 100 years from present for all scenarios to cover at least one complete rotation period in the C-TimberProd scenario. Girdling of trees and creation of high stumps that are then left to form dead wood is often suggested for areas like the ones I have studied, but since this is not possible to model in Heureka it was not included.

Modeled features

The selection of features to model was made with respect to: 1) Bergvik Skog's goals (Table 1), 2) volume of deciduous snags needed by the white-backed woodpecker and 3) the biodiversity indicators dead wood, tree species composition and large tree density. For Bergvik Skog's goals the total volume of deciduous dead wood, the proportion of deciduous trees (birch, aspen and other broadleaved) and the proportion of spruce trees of the growing stock were modeled. The volume of deciduous snags was modeled to assess habitat suitability for the white-backed woodpecker. I used the lower threshold (8m^3/ha) found by Roberge et al. (2008a) to indicate good woodpecker habitat. For dead wood, the total volume in each decay class was modeled. To assess the tree species composition, the proportion of deciduous trees was modeled since separate volumes for all tree species is not available in Heureka.

Results

The time of restoration cutting differed by a few years among the five study stands (Table 7). The stands differed in stand characteristics before restoration and these differences were also clear after the restoration treatments. All of the initial criteria for study stand selection were fulfilled in all but two cases: In Silvergruvan the basal area after restoration was too low and in Davidshyttan the dominant tree species before restoration was birch instead of spruce (Table 7).

Table 7: The year of restoration (within parenthesis), basal area, dominant tree species, stem density, volume, stand area, site index (SI) and altitude for the studied stands before and after the restoration.

Stand	Before/after restoration	Basal area (m^2/ha)	Dominant tree species	Stems/ ha	Volume (m^3/ha)	Area (ha)	SI (H100, m)	Altitude (m.a.s.l)
Davidshyttan	Before	26.9	Birch	1783	180	11.2	28	150
(2013)	After	16.9	Birch	992	109			
Kastenshult	Before	35.6	Spruce	846	317	16.3	26	200
(2011)	After	13.1	Birch	254	104			
Silvberg	Before	27.6	Spruce	2250	180	11.9	26	190
(2013)	After	16.2	Birch	1160	104			
Silvergruvan	Before	24.0	Spruce	577	217	5.9	26	250
(2014)	After	3.8	Birch	215	23			
Stenåsen	Before	28.9	Spruce	1073	229	13.1	26	150
(2013)	After	12.2	Birch	436	89			

In the C-TimberProd scenario the length of the first complete rotation simulated by Heureka (i.e. time from the first final felling to the second final felling) was 60 years for all stands, an effect of their similar site index, SI. In that scenario, all stands were thinned once during the rotation period. In the R-SpruceThin scenario the stands were thinned 1-4 times (Table 8).

Table 8: The treatments in the C-TimberProd and R-SpruceThin scenarios (years from present) and the resulting rotation length (final felling to final felling).

Stand	**First final felling (C-TimberProd)**	**Second final felling (C-TimberProd)**	**Nr of thinnings (C-TimberProd)**	**Nr of thinnings (R-SpruceThin)**	**Rotation length (yrs) (C-TimberProd)**
Davidshyttan	20	80	1	3	60
Kastenshult	0	60	1	3	60
Silvberg	25	85	1	1	60
Silvergruvan	10	70	1	3	60
Stenåsen	15	75	1	4	60

Bergvik Skog's goals for restored forests

With the R-SpruceThin scenario all stands could reach all three goals set by Bergvik Skog (Table 1) after 25 years and for the whole period afterwards (Figure 4 and Appendix B). On stand level all three goals were achieved during the entire time horizon for Kastenshult and Silvergruvan, for Silvberg and Stenåsen from 20 years and for Davidshyttan from 25 years from present and onwards (Appendix B). With the R-FreeDev scenario a maximum of three stands simultaneously achieved all goals and this only occurred for a very short period (Figure 4). In this scenario the spruce proportion grew to a proportion too large (>5%) in 0-40 years in

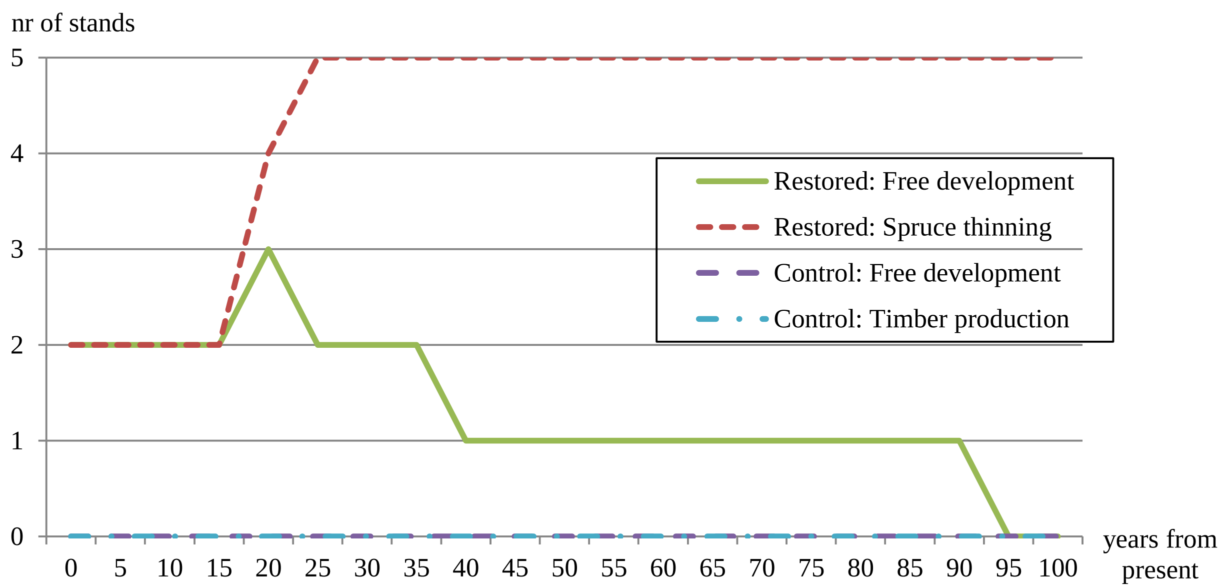

Figure 4: The number of stands out of five achieving all goals set by Bergvik Skog during the studied time horizon (years from present) with the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). The two control scenarios never resulted in the simultaneous achievement of all goals.

all stands except Silvberg (Figure 4 and Appendix B). In this stand the spruce proportion stayed at a maximum of 5% for 90 years from present. The C-FreeDev scenario never resulted in the simultaneous achievement of all three goals. With the C-TimberProd scenario none of the goals were achieved during the studied time horizon.

Dead wood threshold for the white-backed woodpecker

The modeled volumes of dead wood in Heureka differed both in position and distribution between deciduous and coniferous tree species compared to field inventoried values (Appendix C). In the modeling of deciduous snag development the initial snag volumes were set to zero, which was true in all but three cases: in the stand Kastenshult the deciduous snag volume was 0.6 m^3/ha both before and after restoration and in the stand Stenåsen the deciduous snag volume was 1.7 m^3/ha after restoration (Appendix A).

The volume of deciduous snags over which the white-backed woodpecker may be present (8 m^3/ha) is reached to a lesser extent than the goals set by Bergvik Skog (Figure 5). A deciduous snag volume of ≥8 m^3/ha was possible to reach in the stands Davidshyttan and Silvberg (Figure 5 and Appendix A). The higher volume of the threshold interval found by Roberge et al. (2008a) (17 m^3/ha) was never reached in any of the study stands. In total, during the studied time horizon, the studied stands could provide the white-backed woodpecker with enough substrates for 20-45 years depending on which stand and scenario that was assessed. The deciduous snag volume stayed below 8 m^3/ha during the first 55 years irrespectively of scenario and stand. The C-TimberProd scenario never produced high enough deciduous snag volumes for the white-backed woodpecker. In the stand Silvberg the C-FreeDev, R-FreeDev and R-SpruceThin scenarios resulted in the same time period with deciduous snag volumes of ≥8 m^3/ha. In the stand Davidshyttan the C-FreeDev resulted in 5 and 10 years longer time period with high enough deciduous snag volumes than the R-SpruceThin and R-FreeDev scenarios respectively (Figure 5).

Biodiversity indicators – Dead wood

The dead wood volumes were merged to a mean value for the whole study area and the highest volume of both total (all decay classes) and hard dead wood (decay class 0-2) was achieved with the C-FreeDev scenario (Figure 6). In the restoration cuttings, 21.3 and 23.2 m^3/ha of hard and total dead wood were created, respectively. In the C-FreeDev scenario the dead wood volumes increased throughout the studied time horizon and 100 years from present the hard and total dead wood volume was 52 and 204 m^3/ha respectively. The C-TimberProd scenario yielded the lowest volumes of both total and hard dead wood. The variation between the R-FreeDev and R-SpruceThin scenarios were largest 100 years from present. At this point the R-FreeDev scenario resulted in 27 and 16 % more hard dead wood and total dead wood, respectively, than the R-SpruceThin scenario (Figure 6).

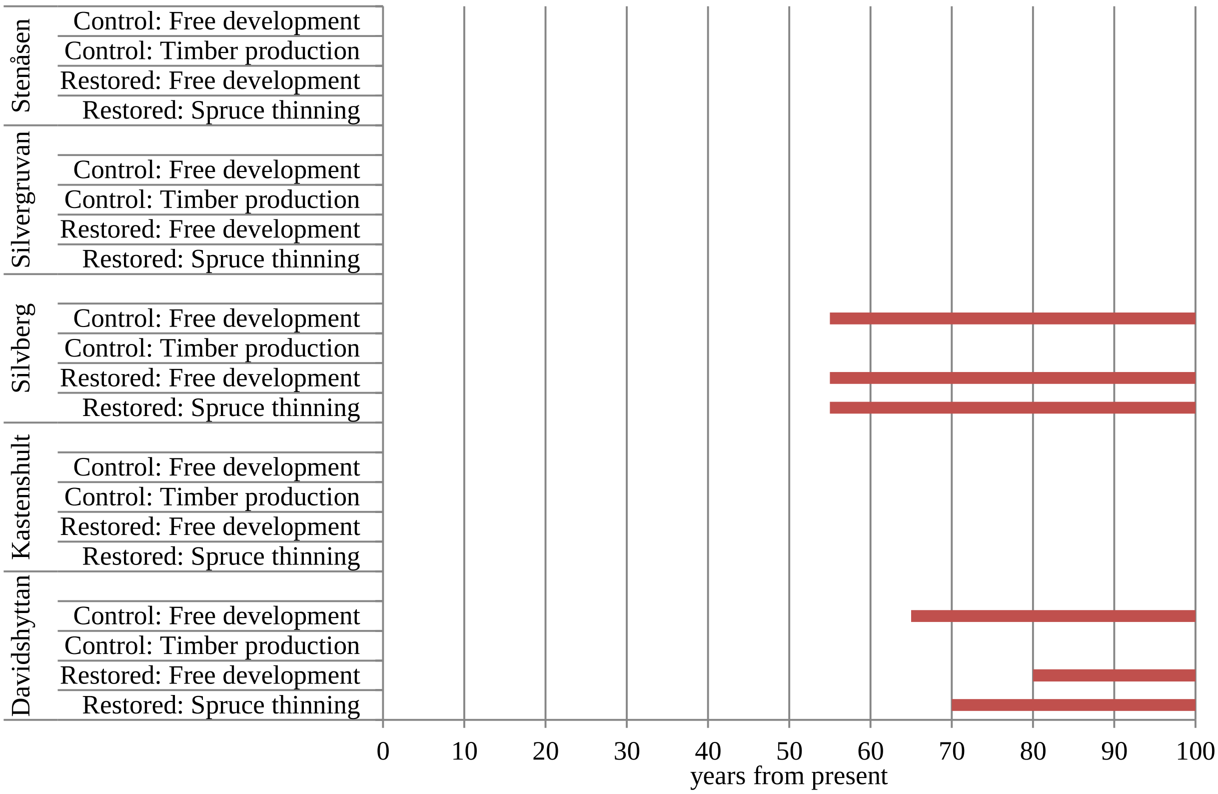

Figure 5: The years during which the volume of deciduous snags is high enough (≥8m^3/ha) for the white-backed woodpecker to survive in the stands (red bar) with the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd).

Biodiversity indicators – Proportion of deciduous trees

After the restoration cuttings the proportion of deciduous trees was 92% of the growing stock compared to 43% before (restored and control stands respectively) (Figure 7). With the C-FreeDev and R-FreeDev scenarios this proportion decreased during the studied time horizon. With the C-TimberProd scenario the proportion was highest in the beginning of the rotation periods and then decreased towards the final fellings. The scenario that kept the highest proportion of deciduous tree was the R-SpruceThin scenario. In this scenario the stands had a high enough proportion of deciduous trees to be regarded as deciduous forest (≥75 % deciduous trees) during the entire studied time horizon. For the R-FreeDev scenario this was true for the first 70 years (Figure 7).

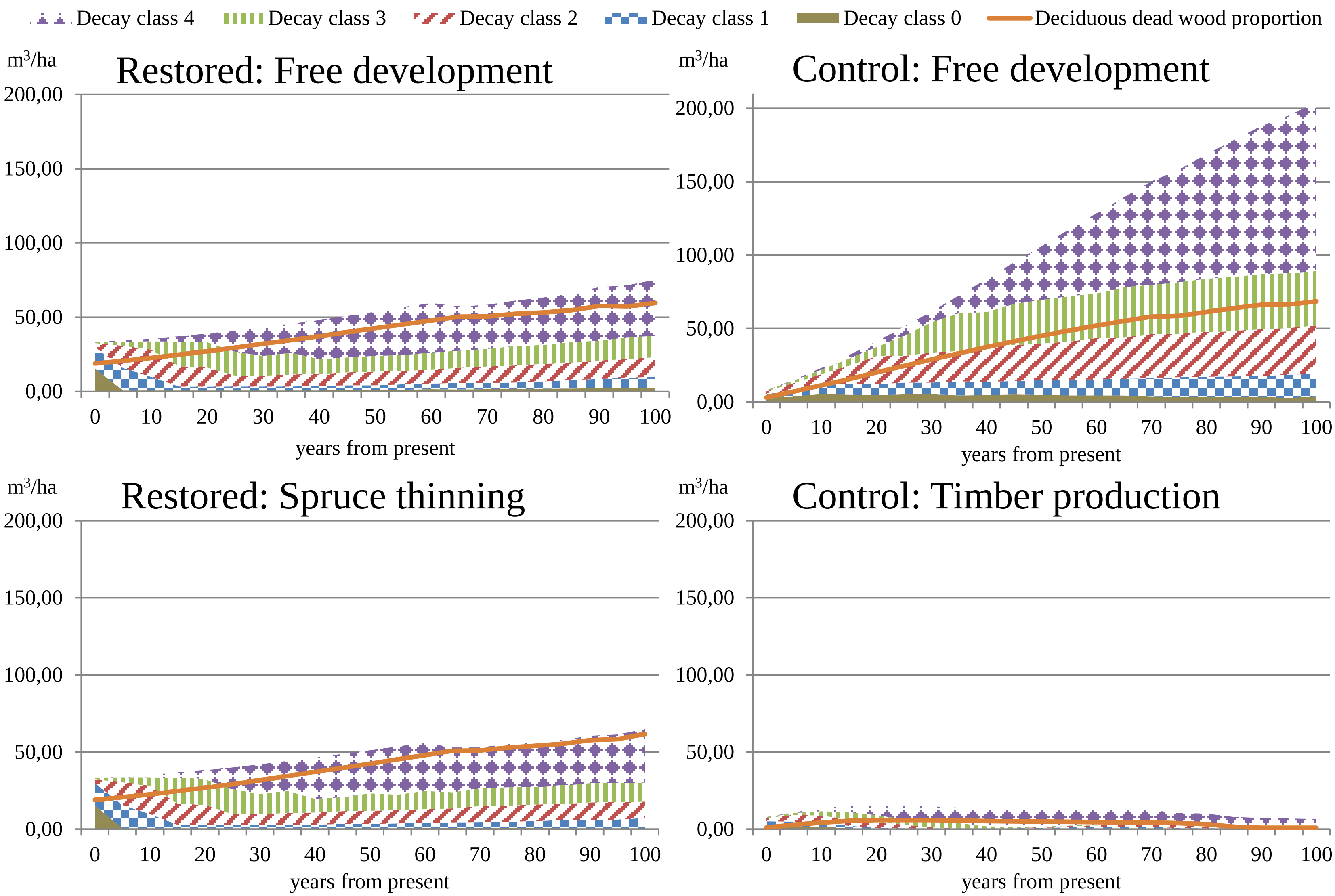

Figure 6: Dead wood in the decay classes 0-4 and the deciduous volume during the studied time horizon for the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). Average for the study area calculated as the mean volume per ha per stand.

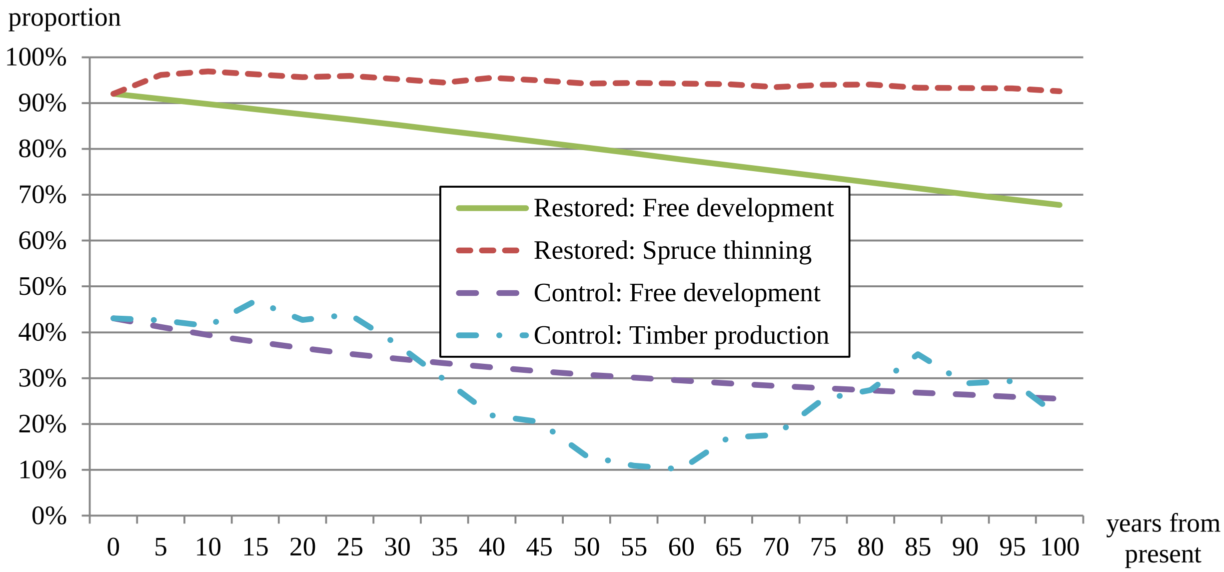

Figure 7: Development of the proportion of deciduous trees of the growing stock during the studied time horizon with the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). Average for the study area calculated as the mean proportion of deciduous trees per stand.

Biodiversity indicators – Large trees

Almost no large deciduous trees were cut in the restoration cuttings which resulted in similar numbers of large deciduous trees for all scenarios at the initial state of the study (Figure 8). For the C-TimberProd scenario the number of large deciduous trees was lowered to 0 after 25 years and the number of large coniferous trees after 35 years from present. The R-FreeDev scenario resulted in a higher total number of large trees after 100 years than the R-SpruceThin scenario (78.3 and 71.0 respectively) but had a lower number of large deciduous trees than the R-SpruceThin scenario (53.5 and 67.2 respectively). In the restoration cuttings all large coniferous trees were removed and the first large coniferous trees appeared after 50 and 35 years with the R-FreeDev and R-SpruceThin scenario respectively. With the R-SpruceThin scenario the number of large coniferous trees was kept below 4 per ha throughout the studied time horizon (Figure 8).

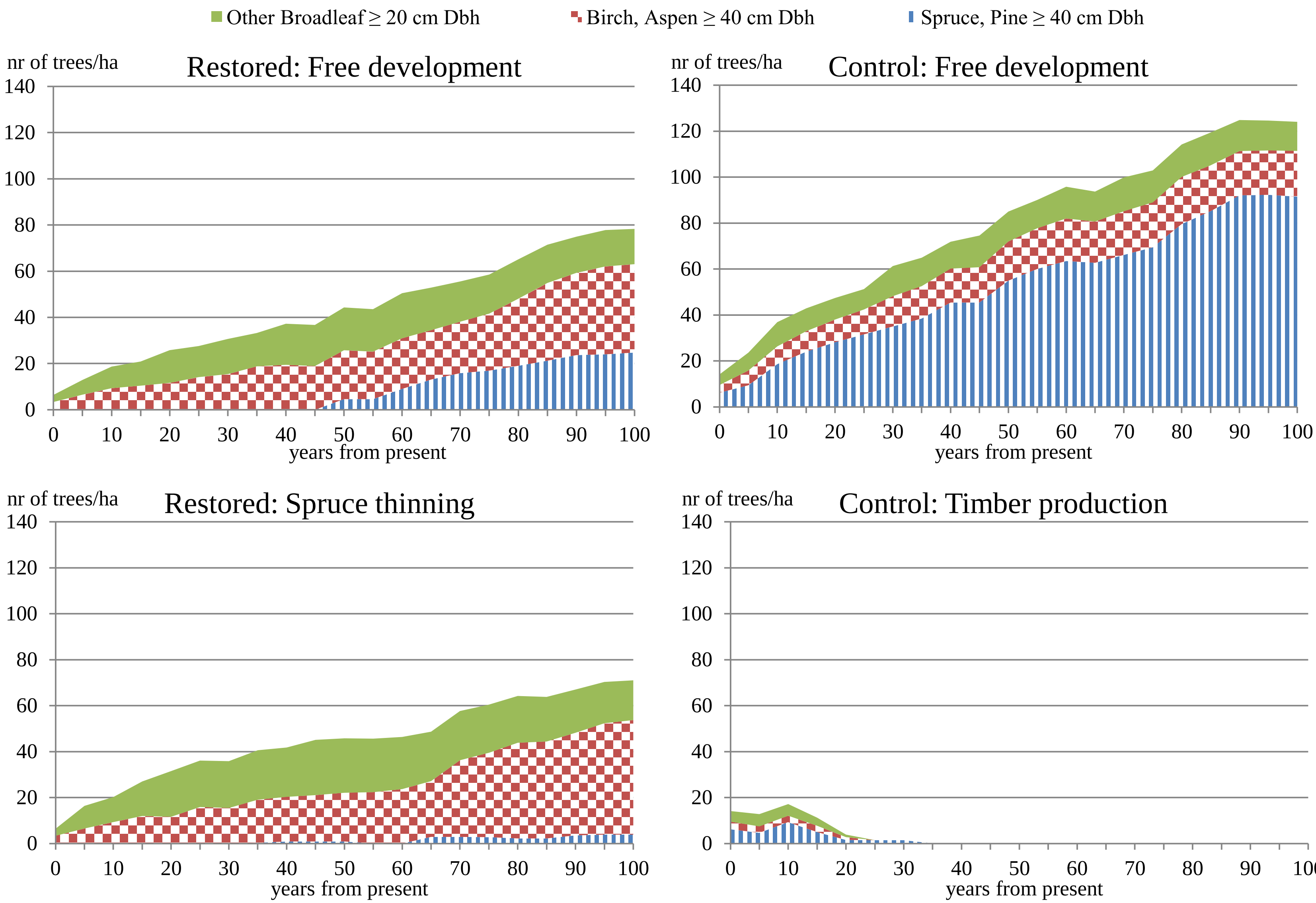

Figure 8: Number of large trees during the studied time horizon for the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). Average for the study area calculated as the mean number of stems per ha per stand.

Discussion

The aim of this study was to answer three questions: one regarding Bergvik Skog's goals, one about the deciduous snag volume needed by the white-backed woodpecker, and one about the development of biodiversity indicators. On the first question ("Is it possible to reach Bergvik Skog's goals and the deciduous snag volumes needed by the white-backed woodpecker?"), the answer is yes. All three goals set by Bergvik Skog could be achieved in all stands if thinning operations were performed to keep the proportion of spruce trees low (Appendix B). Time to achieve Bergvik Skog's goals was depending on the scenario assessed but the R-SpruceThin scenario was generally the scenario that resulted in the longest time period of goal achievement (Appendix B). The deciduous snag volume needed by the white-backed woodpecker (≥8 m^3/ha) was only possible to achieve in two out of five stands (Figure 5). The time period with high enough deciduous snag volume for the white-backed woodpecker was 20-45 years depending on stand and scenario (Figure 5). For the development of the conditions for biodiversity the answer is more complex. The C-FreeDev scenario yielded the highest volume of dead wood in all decay classes. The proportion of deciduous trees was highest in the R-SpruceThin scenario. The highest *total* number of large trees was achieved with the C-FreeDev scenario, although the highest number of large *deciduous* trees was achieved with the R-SpruceThin scenario.

Bergvik Skog's goals

The R-SpruceThin scenario had the highest goal achievement as a consequence of the maximum proportion of spruce trees which was one of the goals. Without this goal a less management intensive scenario would probably be enough to achieve the other goals. The proportion of deciduous trees in the R-FreeDev scenario was for example shown to be ≥75 % for 80-100 years in all stands but Davidshyttan where the proportion was ≥75 % only in the first five years (Appendix B). The achievement of the goal 'minimum deciduous dead wood volume' differed with at most five years between the R-FreeDev and R-SpruceThin scenarios. This is probably because all harvested trees in the thinning operations were extracted from the stand. Not surprisingly, the C-TimberProd scenario never reached any of the goals. This was expected since the approach when producing timber is to benefit spruce and pine before deciduous trees and to harvest the trees before they die.

Deciduous snag volume

The initial distribution of dead wood as standing (snags) and downed dead wood is modeled by Heureka and not possible to control. The solution of setting the initial dead wood volume to zero only works if the true initial volume will not affect the result. In this study the initial volumes were small and their addition to the modeled result would probably not have helped in reaching the threshold for the white-backed woodpecker (Appendix A). When birch and aspen were girdled and notched to increase the food supply for the white-backed woodpecker, 50% of the notched trees and the girdled birches were broken off within eight years (Aulen, 1991). Before this point in time the total volume is too low to reach the threshold even with their addition (Appendix A). The deciduous snag volume never reached the higher threshold level (17 m^3/ha).

In some stands large volumes of dead deciduous wood had been created in the restoration cutting but the majority was lying. If this had been created as standing dead wood it would have served the white-backed woodpecker better (Aulén, 1988), although it has an important role for biodiversity also as downed dead wood (Dahlberg, 2004, Berg et al., 1994). The active killing of trees was not modeled in this study but would have prolonged the period with volumes ≥8 m^3/ha of deciduous snags. It would also increase the chance of reaching the 17 m^3/ha-level, something that should be aimed for. If girdling or notching of trees is carried out it is important to consider the possibility to create snags in the long-term, which is decided by the supply of deciduous trees suitable for girdling or notching. With the current state, where birch is dominating among the deciduous trees, I suggest that the active killing of trees is focused to birch since birch is also preferred as dead by the white-backed woodpecker (Aulén, 1988). The creation of high stumps for the white-backed woodpecker has for example been shown to provide habitat for many saproxylic beetles, out of which many are potential food for the white-backed woodpecker (Bell, 2015, Jonsell et al., 2004, Aulen, 1991). The deciduous snag threshold was reached in the two stands with the largest basal area and the highest stem density after restoration (Table 7). Therefore I suggest that no deciduous trees are harvested in the restoration cutting (except when using girdling or notching) and that stands with larger deciduous volume and stem density are chosen before stands with smaller deciduous volume and stem density.

Biodiversity indicators

Because of the problem of deciding when very decayed dead wood is to be considered as soil, the last decay class may be overestimated in Heureka. In this study the dead wood left the system at a density of 0.05 g/cm^3 (dry weight/raw volume). The dead wood volume in the last decay class may be overestimated in all scenarios, especially with the C-FreeDev scenario where the total dead wood volume increases throughout the studied time horizon. Siitonen et al. (2000) found the total volume of dead wood in near natural forests to be just over 100 m^3/ha, compared to volumes of over 200 m^3/ha with the C-FreeDev scenario in this study. The dead wood volume is however depending on the decay rate which may be affected by micro climatic conditions. Since it is possible to change the density at which dead wood leaves the system in Heureka, it is possible to adjust the reported dead wood volumes. This density will always be a source of error though, which is why I also looked separately at hard dead wood, which is not prone to the "last decay class problem". The distribution between snags and downed dead wood, which was not possible to import into Heureka, also makes the decay rate hard to predict since the position of the dead wood probably affects the rate of decay. Another reason for looking at both total and hard dead wood volume is that the species composition in dead wood changes over the course of decay (Dahlberg, 2004), and therefore it is desirable to have dead wood in all decay classes. The highest volumes were not surprisingly retained with the free development of unrestored stands. If large volumes of dead wood irrespectively of tree species is the goal, the stand should be left without treatment (C-FreeDev). Interestingly this scenario also produced the largest volume of deciduous dead wood (Figure 6). Since the proportion of deciduous trees in this scenario were decreasing throughout the studied time horizon (Figure 7), the supply of deciduous dead wood were also decreasing which can be seen in the decreasing accumulation of deciduous dead wood (Figure 6). In the restored stands, which were all dominated by deciduous trees, the free development retained the highest volumes of both total and hard dead wood volume. It should be taken into consideration, however, that the R-SpruceThin scenario probably produces dead wood of larger diameters than the R-FreeDev and C-FreeDev scenarios since the thinning will promote diameter growth (Figure 9). This dead wood will add to the system later since the thinning will promote the survival of these trees.

When using the tree species composition as a biodiversity indicator, it is desirable to look at the complete tree species composition since many tree species have different effects on biodiversity (Barbier et al., 2008). Because this was not possible in Heureka, I chose to look at the proportion of deciduous trees. This is also relevant since deciduous trees are underrepresented in the study area (Christiansen, 2014, Olsson and Stighäll, 2013) and because they are of high importance to many threatened forest species (Dahlberg, 2004, Stokland, 2001). In the C-FreeDev and C-TimberProd scenarios the spruce is dominant during the whole period, but with the R-FreeDev and R-SpruceThin scenarios the forest can be kept as deciduous forest (Olsson and Stighäll, 2013) for at least 75 years (Figure 8). It is important to remember, however, that these figures include all deciduous tree species and the proportion of birch is probably dominating.

Spruce, pine, aspen and birch was considered large when ≥40 cm Dbh, a threshold commonly used in the Swedish forestry and by conservation biologists (Nilsson et al., 2002, Aulén, 1988). The category “other broadleaved” (e.g. goat willow, rowan and alders) were considered large when ≥20 cm Dbh. The Swedish Forest Agency uses 7 cm Dbh as a threshold for when goat willow and rowan are considered “tree shaped”, thus being of high biological value (Swedish Forest Agency, 2014). The extra high value of *large* goat willow, rowan and alders are though highlighted by the Agency without stating any diameter threshold. To my knowledge there are no studies investigating this threshold and therefore this threshold value (20 cm) had to be set without the support of earlier studies. The highest number of large deciduous trees was 67 trees/ha (R-SpruceThin scenario). Nilsson et al. (2002) found a total of 50-100 large trees in boreal, boreonemoral and nemoral old-growth forests. Comparisons like this must, though, be handled with care since the density of large trees depends on for example the productivity (Nilsson et al., 2002). As soon as the regenerated trees have grown too high for the moose to reach them, the management can be directed to benefit rare tree species by removing competing trees around them. In this way the manager also has the possibility to promote the diameter growth of specific tree individuals.

Limitations of the study

The selection of potential stands was based on Bergvik Skog’s stand register which was not consistent in all cases. The basal area referred to the area before restoration in some stands and after restoration in others. By using this method some suitable stands may have been left out because of values not updated in the stand register. In order to make this selection easier in future studies, and to make it possible to evaluate the actions, I suggest that all stands subjected to restoration cuttings are described both before and after treatment. With a complete register of restored stands it would also be easier to decide whether the stands studied are representative or not. The method of removing spruce in order to benefit deciduous regeneration is though thought to be representative since fencing and burning is only carried out at a limited scale (B. Pettersson personal communication).

The decision to model the development for 100 years was done to include at least one full rotation period in the C-TimberProd scenario. The results must be handled with care, since Heureka simulations will be more insecure when looking far into the future especially with forest management that differs a lot from common forest management (T. Lind personal communication). In addition to this potential derailing problem there is the problem of deciding when to consider dead wood as soil. This problem may be of particular importance to consider if comparing modeled results with results from inventories. This is because the decay class determination may differ between people carrying out the inventory and because of the problem of detecting dead wood that is almost entirely decayed in the field.

The other drawback of the modeling was that observed initial distribution between standing and downed dead wood could not be imported into Heureka (Table 9). An import routine is currently under development (T. Lämås personal communication) and I must stress the importance of the functionality this would add to the system. This will be crucial if similar studies are to be conducted in stands where the distribution is of greater importance than in the present study.

Conclusion and future studies

Despite the fact that the white-backed woodpecker action plan is the most expensive and includes the biggest ecological restoration project in Sweden, this is, according to my knowledge, the first modeling of the development of restored stands ever conducted. The main message of my study is that the goals stated could be reached and the conditions for biodiversity could be improved. It is important to highlight the need of adapted forest management both between and within stands to get the most out of every stand. The forest management should also if necessary be changed over time to fit the current state of the forest.

Aulén (1988) found that the white-backed woodpecker prefers standing dead wood but he also found downed dead wood to be used to some extent but the snow conditions during winter time in central Sweden make this substrate unavailable for part of the year. The standing volume is therefore practical to assess since this is available throughout the year and I suggest that the absolute deciduous snag volume (e.g. 8 m^3/ha) is introduced as a goal for restoration. Considering the results from the present study I further suggest that stands are ranked according to their possibility of producing deciduous snags in the long term when choosing stands for future restoration.

For the future it would be of great interest to revisit the stands in this study to see how the development follows the results generated with Heureka. It would also be interesting to model the potential of killing trees by girdling or high cutting, something that was not included in this study. This is an action frequently suggested for fast habitat improvement for the white-backed woodpecker but it is not possible to model in Heureka today.

As mentioned in the introduction, the browsing of moose may severely hamper the regeneration of aspen, rowan and goat willow. Therefore I suggest that the browsing pressure in the restored stands is to be inventoried so that fencing can be carried out where motivated. If it is possible to calibrate Heureka to the results from fencing studies it would be of interest to model the effect of fencing operations on both stand and landscape scales.

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Appendix A

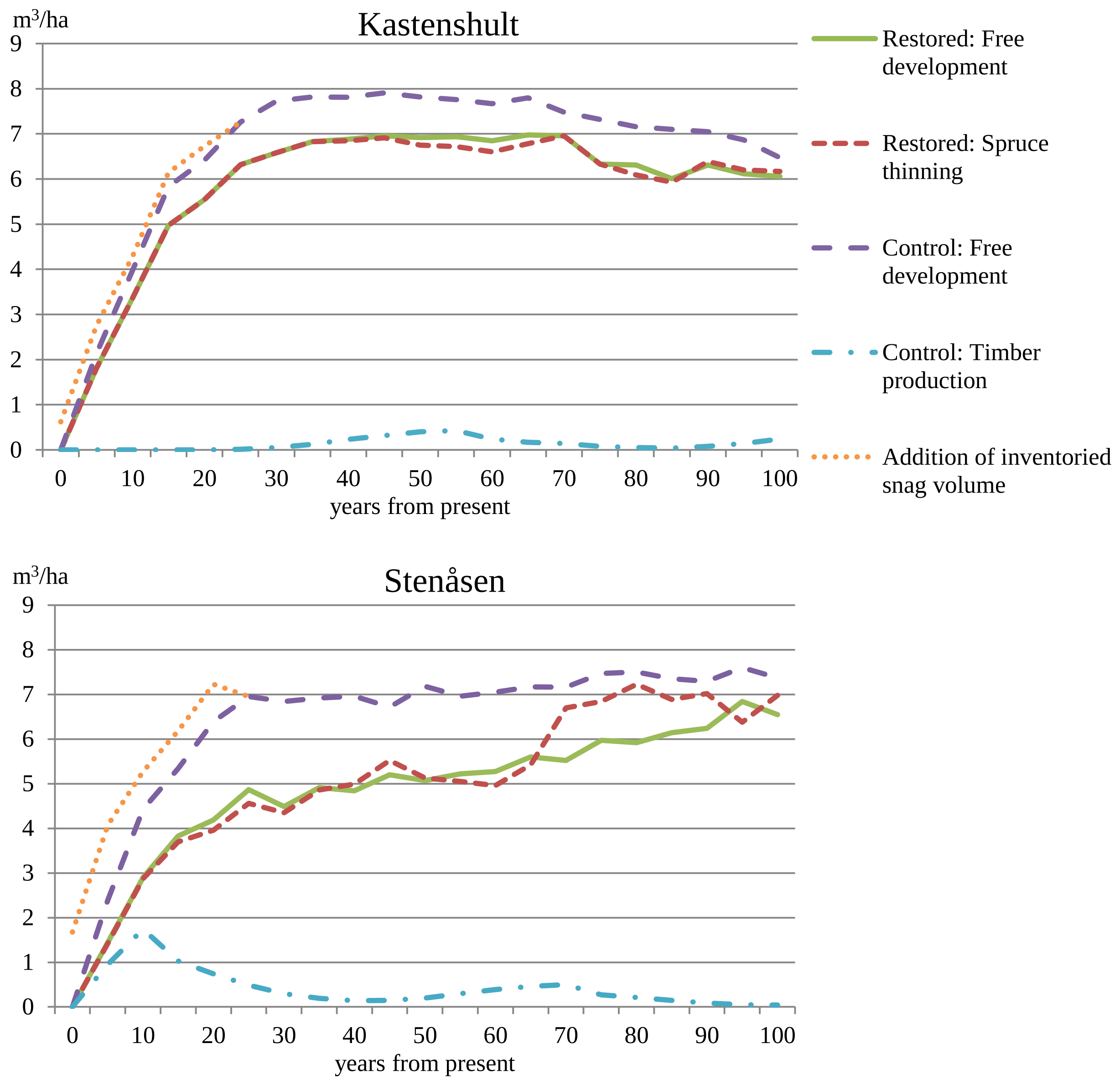
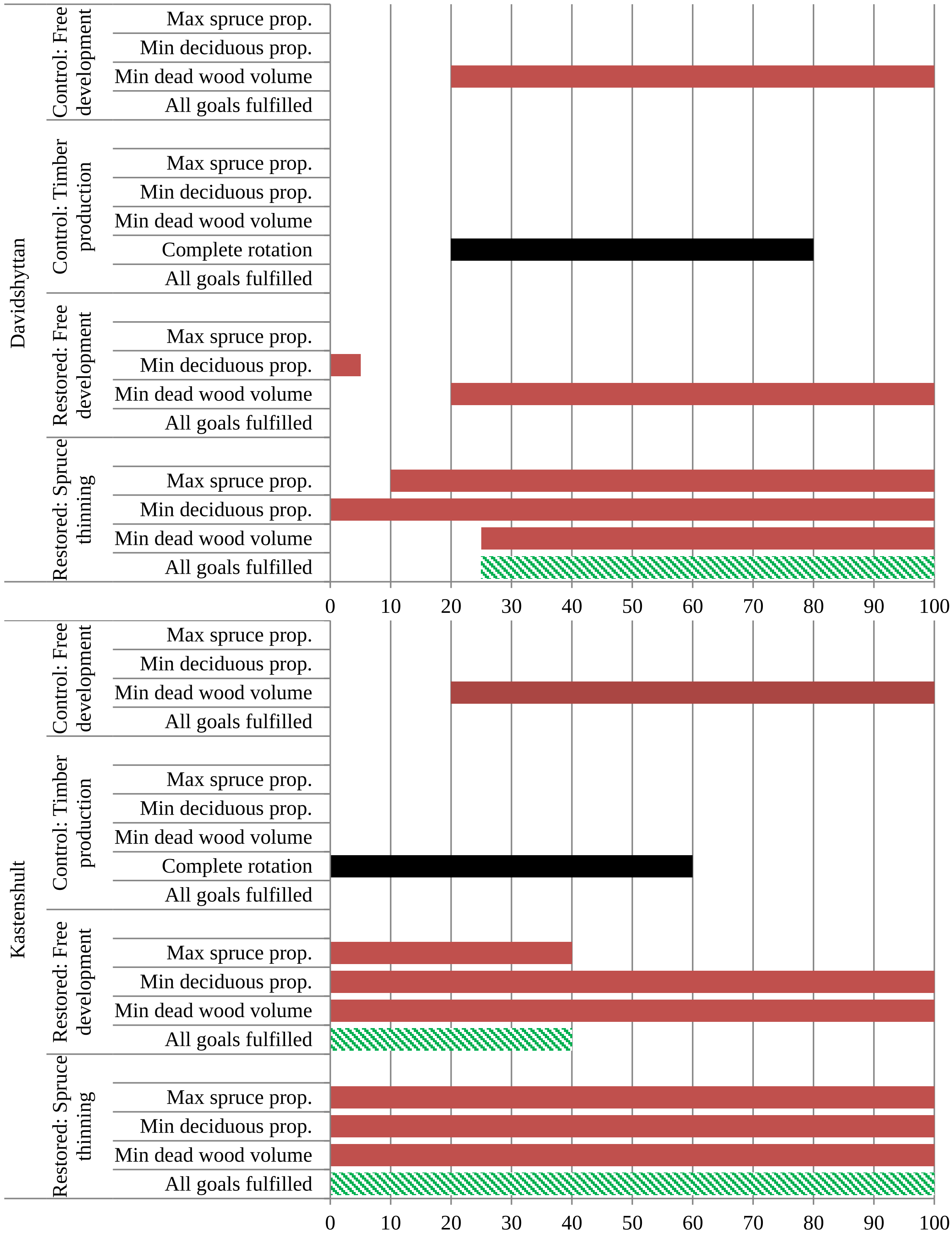


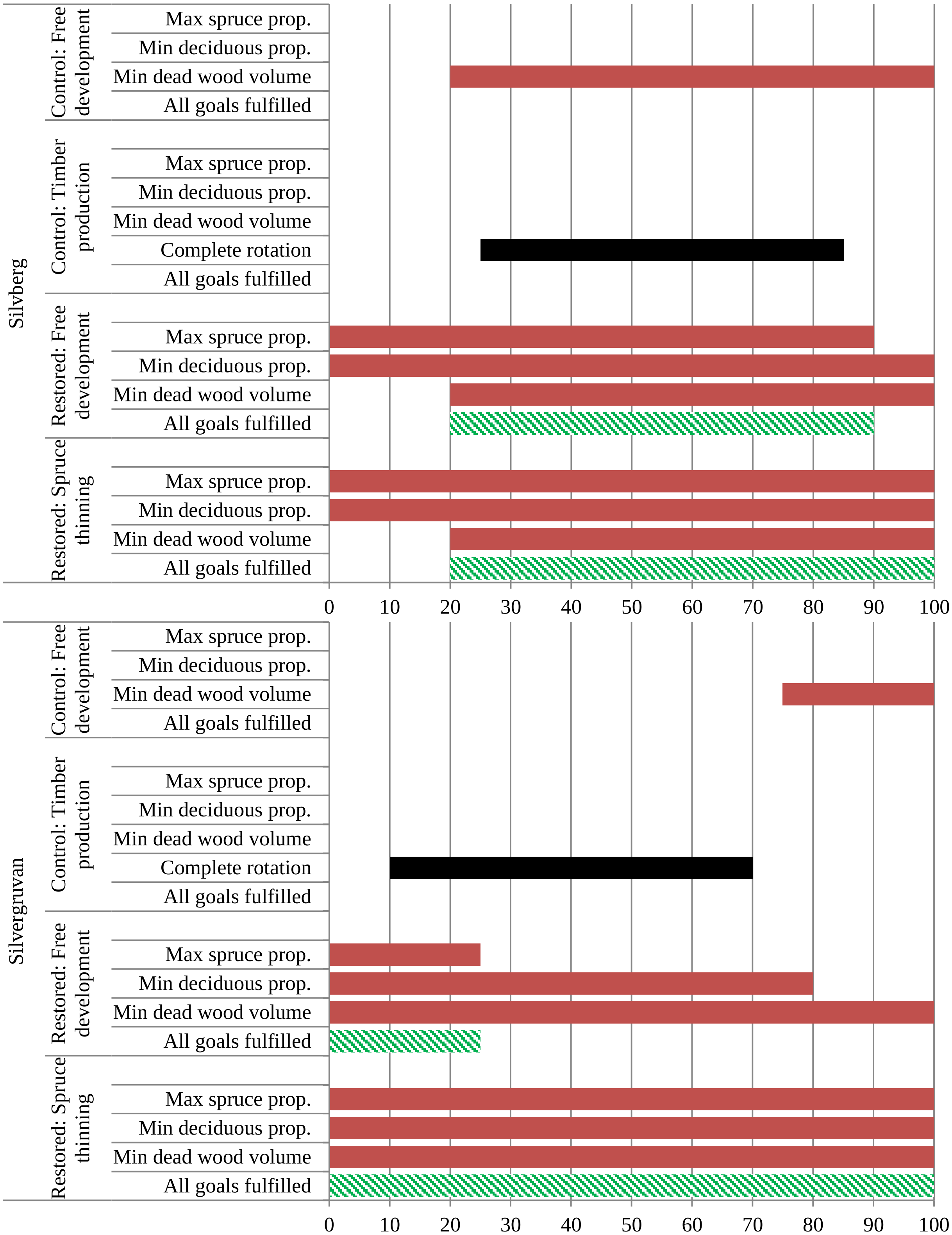
Figure A: Development of deciduous snag volume in the two stands with initial snag volume larger than 0 for the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). The addition of the initial deciduous snag volume was made to the C-FreeDev scenario because this was the scenario which was closest to reaching the 8 m^3/ha target for deciduous snags. The whole initial volumes were added for the first 10 years. Between 10 and 20 years the additional volume was decreased by 50% according to the results by Aulen (1991) and after 20 years from present the initial volume was decreased to zero, assuming that none of the deciduous snags were still standing at that time. Even with addition of the initial observed deciduous snags, the volumes never passed the 8 m^3/ha threshold.

Appendix B



Davidshyttan
Control: Free development
Control: Timber production
Restored: Free development
Restored: Spruce thinning
Max spruce prop.
Min deciduous prop.
Min dead wood volume
Complete rotation
All goals fulfilled
Kastenshult
0
10
20
30
40
50
60
70
80
90
100

Appendix B *(Continued)*



Appendix B *(Continued)*

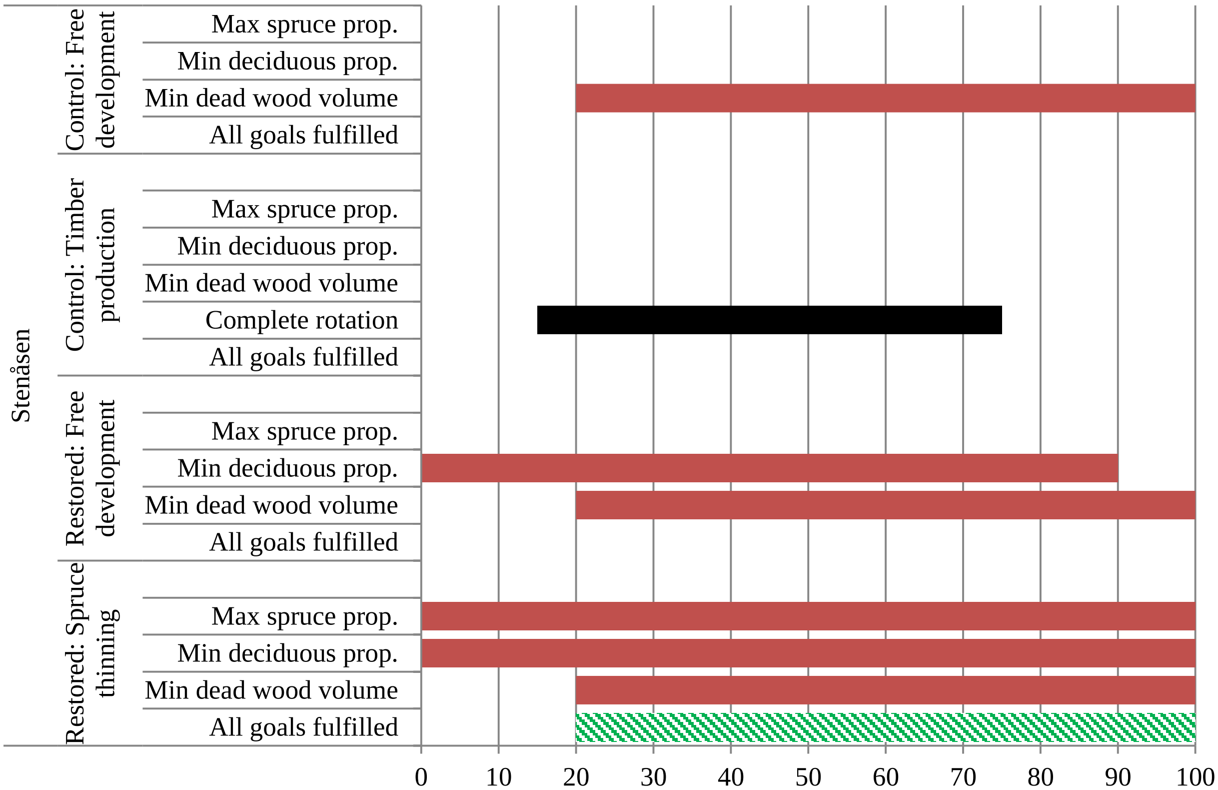


Figure B: The years from present during which the different goals set by Bergvik Skog was achieved with the four scenarios: Restored - Free development (R-FreeDev), Control - Free development (C-FreeDev), Restored - Free development (R-FreeDev) and Control - Timber production (C-TimberProd). Red solid bars show the different goals and green striped bars show when all goals are achieved. Black solid bars show the complete rotation periods from the first final felling to the second final felling in the C-TimberProd scenario.

Appendix C

Table C: The volume of dead wood (m^3/ha) in different categories from the field inventory compared to the volumes modeled by Heureka (from the proportions in Table 5) within parenthesis.

Stands	**Deciduous**	**Coniferous**	**Snags**	**Downed dead wood**
Restored	22. 7 (18.9)	10.7 (14.5)	1.1 (19.0)	32.3 (14.4)
Control	4.5 (3.1)	3.5 (4.9)	0.3 (3.8)	7.6 (4.1)

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