Conservation Management in Riparian Zones

– A follow up of the Nissan water management agreement.

Joakim Isaksson

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Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
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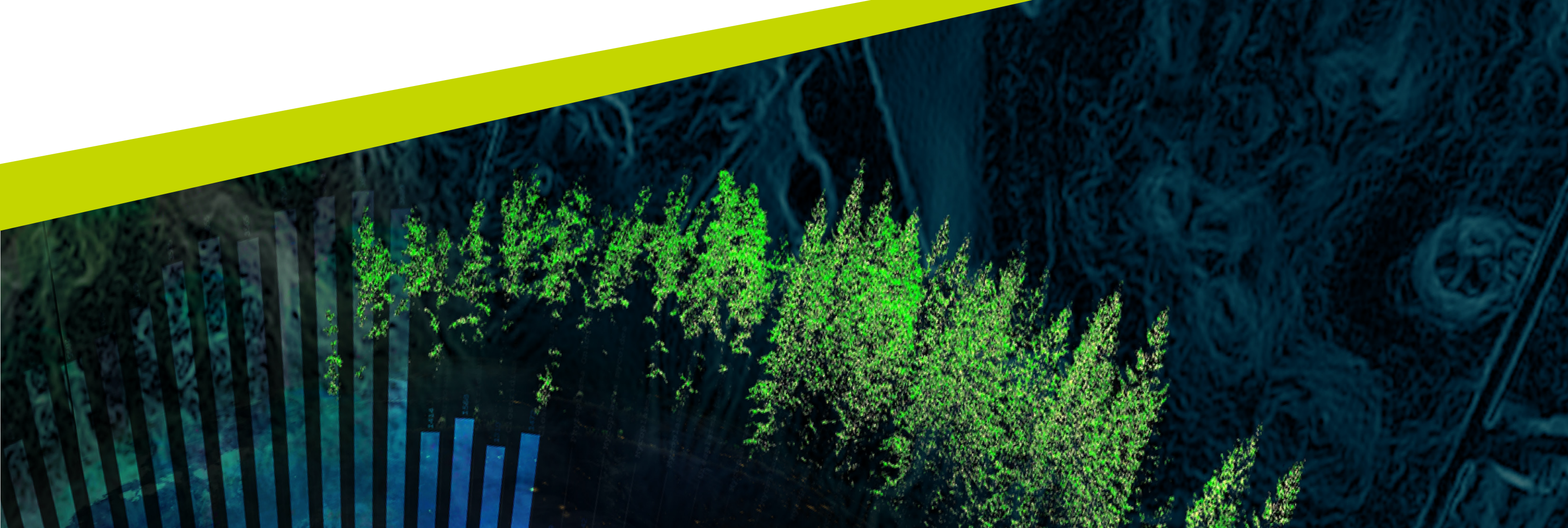

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Abstract

Forest management in riparian zones has consequences for the aquatic ecosystem. In 2015, Sveaskog signed a water management agreement for the river Nissan with the purpose of promoting broadleaves and improving the riparian ecosystems inside the agreement area. This study followed up the conservation cuttings made in older stands in the agreement area through a field inventory. To evaluate the need of future management, an Heureka StandWise analysis based on different field trials of mixed forests was made.

The inventory showed that broadleaves had been favoured in the conservation cuttings by removing conifers where there was established broadleaves, mainly along the water edge, where the highest density of broadleaved stems where found. Where there were less broadleaves, inside the buffer zone, larger gaps had been cut to provide opportunity for natural regeneration through reduced stem densities and larger canopy openness. There were, however, field vegetation that might compete with potential seedlings.

The StandWise analysis showed that active management is required to favour the broadleaves in the future. If monocultures were established after the conservation cuttings, future management had little effect on species composition. Future management should be adapted to each stands species distribution and site conditions vary due to the size and distribution of the agreement area.

Keywords: Riparian Zone, Broadleaves, Forest Management, Nissan

Sammanfattning

Skogsbruk i kantzoner mot vatten påverkar vattnets ekosystem. 2015 skrev Sveaskog ett vattenvårdsavtal för Nissans avrinningsområde. Målet var att förbättra och skydda vattendragens ekologiska status genom att gynna lövträd och återställa de naturliga miljöerna inom avtalets gränser. Denna studie följer upp de naturvårdshuggningar som hittills skett men en inventering i kantzonen samt undersöker behovet av skötsel i framtiden genom en Heureka BeståndsVis analys baserat på ett blandskogs fältförsök.

Inventeringen visade att lövträd hade gynnats genom att avveckla de konkurrerande barrträden, främst längs med vattenkanten, där lövstammarna var mest koncentrerade. Längre in i kantzonen, där det fanns färre lövstammar, hade luckor huggits upp för att gynna naturligföryngring. Det fanns dock ett dominerande fältlager av gräs och mossa som kan hämma den naturliga föryngringen.

BeståndsVis analysen visade att aktiv skötsel är nödvändig för att fortsatt gynna lövträden efter en inledande naturvårdshuggning. Om monokulturer etableras efter naturvårdshuggningarna har den framtida skötseln liten effekt på trädslagsblandningen. Framtida skötsel bör anpassas efter artsammansättning och ståndort.

Nyckelord: Kantzon, Lövträd, Skogsskötsel, Nissan

Preface

This thesis was done with the financial aid from Partnerskap Alnarp in collaboration with Sveaskog both of whom I would like to thank. I am very grateful for my supervisor, Emma Holmström and her research group, for all the support throughout the project and the Friday meetings. I also thank my friends who studied with me and supported me in and outside of the library.

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Abbreviations

FSC	Forest stewardship council
GLA	Gap Light Analyzer
NMD	Nationella marktäckedata (EN: Cadaster ENV Sweden)
PCT	Pre-commercial thinning
PEFC	Programme for the Endorsement of Forest Certification schemes

1. Introduction

1.1. Swedish forestry

Forest is the most common land use in Sweden with 69 % of the land area covered by forest (SCB 2015). This forested land has a dense network of approximately 100 000 kilometres of watercourses (Lindegren 2006). This means that a large share of the forest land is connected to and interacting with the water infrastructure of the landscape. Sweden's forests are managed for the production of timber and fibre (Roberge et al. 2020). One common production-oriented treatment is thinning. Thinning has many benefits in forestry. Main motivations include an increase of net revenue, reduction of self-thinning and increased diameter growth of remaining trees (Wallentin 2007). Many parameters are relevant when deciding when to thin. As such, thinning guidelines have been developed that recommend when the stand should be thinned or not (Agestam 2015). To ensure that the thinning is not negative for the stand development, two paragraphs exist in the Swedish forestry act. These are 10§, which ensures that the growth of the stand is still utilised after thinning, and 5§, which is a bottom baseline for when the forest has been cut to harsh and measures for regeneration must be made (Agestam 2015). This management can have negative effects for the forest ecosystems and is neighbouring ecosystems with which it interacts. To counteract these negative effects on the environment, forest certifications work towards more sustainable management providing further environmental protection than the legal requirements of Swedish law (FSC Sweden 1997; PEFC 2000; Johansson & Keskitalo 2014). Today approximately half of Sweden's productive forest land is certified. Changes in management are usually the result of implementation or changes to hard policy instruments such as laws and certifications (Hasselquist et al. 2020). There are currently only two relevant forest certification standards in Sweden, the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification schemes (PEFC). Both standards require protection of watercourses intersecting the managed forest stands. This is done by setting aside a riparian buffer zone. This means that the practice of retaining a buffer zone towards water is common practice for a large percentage of the forest area (Gustafsson et al. 2020). It could be enough with a thin line of alder along the water can reduce some of the negative impact of harvest, but not all (Piccolo & Wipfli 2002).

1.2. Riparian Zones

Riparian zones are the borders where aquatic and terrestrial ecosystems meet and interact. A change in a terrestrial ecosystem will affect nearby aquatic ecosystem as well (Bergquist 1999; Nyberg & Eriksson 2001; Broadmeadow & Nisbet 2004; Lindegren 2006). Current forestry practices work to negate its negative influence on aquatic ecosystems by leaving a buffer zone towards the open water (Skogstyrelsen 2014). In a study by Kuglerová comparing buffer zones in Sweden, Finland, and Canada, they found that the average buffer zone width for the surveyed watercourses lower in Sweden than in Canada and Finland. They conclude that most of the surveyed streams were insufficiently protected (Kuglerová et al. 2020). Width and management of the riparian buffer zones should be adapted to the local site conditions. There might not be significant relationships between water width and buffer width (Larsson & Nygårdh 2020). Based on a comparison between a 15-meter buffer zone and buffers widths based on different distances to ground water in the Krycklan catchment area, broadleaved volume ranged from 29 to 35 % of the standing volume (Risby 2014). In another study made focusing on northern Sweden, there was a higher proportion of broadleaves closer to the water (Larsson & Nygårdh 2020). Broadleaves can be beneficial to the aquatic ecosystem since the shed leaves add easily accessible nutrient while coniferous needles require decomposition prior to consumption (Soma & Saitô 1983). Fallen leaves have high value as food for water-based organisms (Lidman et al. 2017). In Alaska, higher proportion of alder in the canopy showed higher levels of invertebrates and detritus in the water downstream (Wipfli & Musslewhite 2004). Species richness tend to be higher closer to water (Larsson & Nygårdh 2020; Åström 2020). On a landscape level, adaptive widths create more heterogenous forest and more effective riparian buffer zones (Kuglerová et al. 2014). If stream restoration becomes relevant, it should be combined with riparian buffer zone management to enhance the effect (Hasselquist et al. 2015). The riparian zones are usually left unmanaged if it already contains high ecological values but can also be managed if it favours important or endangered aquatic species such as Freshwater pearl mussel (*Margaritifera margaritifera*, L) and Brown trout (*Salmo trutta,* L) (Ring et al. 2008; Sonesson et al. 2020). Unmanaged buffers have higher proportion of deciduous trees than coniferous while partially harvested buffers had no significant differences in proportion of broadleaf versus conifer (Jonsson 2018). Generally, broadleaves are preferred species in the riparian buffer zones. This is in part due to the underrepresentation of broadleaves in the Swedish forest landscape (Riksskogstaxeringen 2020). While broadleaves in the riparian zone have no direct positive effect on Brown trout in the water, they show no negative impact either (Thomas et al. 2015). This makes riparian buffer zones opportune areas for increasing the number of broadleaves in the forest landscape without negatively affect the aquatic ecosystem. The stem density decreases with increased distance from the water edge (Åström 2020).

1.3. Naturally regenerated forest

Many of Sweden's most common broadleaved tree species such as Silver birch (*Betula pendula*, Roth), Downy birch (*Betula pubescens*, Ehrh), European aspen (*Populus tremula*, L) and Black alder (*Alnus glutinosa*, Gaertn) are pioneer species and light demanding (Andersson 2005). A disturbance such as creating a gap in the canopy and exposing mineral soil is usually needed to for a successful germination and survival of the seeds (Andersson 2005; Karlsson et al. 2017). Broadleaved tree species are not favoured in production forestry and are underrepresented when compared to their natural extent (Lindbladh et al. 2014). As such, broadleaves are crucial for diversity. Conservation stands are therefore a natural place for broadleaves (Löf et al. 2012). A large part of our endangered species is tied to broadleaves (Rytter 2019). Keeping broadleaves close to water creates an environment where stems are continuously exposed to sun with less influence of neighboring stands. Many rare species are tied to sun exposed wood of both living and dead broadleaved species. Broadleaved forests with reoccurring floods are a rare habitat in Sweden due to ditching of forest land and altercations to watercourses for log driving (Nilsson 2007). Broadleaves provide specific ecosystem services that cannot be produced by conifers. One such example is the importance of broadleaves for pollinators (Rytter 2019). There is a significantly higher proportion of naturally regenerated broadleaved saplings than coniferous saplings in riparian zones (Jonsson 2018).

Norway spruce (*Picea abies*, (L) H.Karst.) is with Scots pine (*Pinus sylvestris,* L.) the most common tree species in Sweden (Riksskogstaxeringen 2020). Norway spruce can regenerate in the shade and grow up and outcompete already established broadleaves. In addition, Norway spruce is preferred over other species in planted regenerations in southern Sweden (Felton et al. 2020). As such, management towards conservation of broadleaves entails the removal of Norway spruce and releasing the crown of the future broadleaves that should remain (Andersson & Holmberg 2007; Nitare 2011). Whether the goal is to promote established broadleaves or to promote regeneration, ample light is necessary. One way of measuring light transmittance in a forest is through hemispherical photography of the canopy. Hemispherical photographs can be used to calculate canopy openness and transmittance of light to the forest floor. Studies show that there is a correlation between light transmittance and number of saplings in mature stands (Canham et al. 1994; Petersson et al. 2019). In riparian buffer zones, the canopy cover was estimated to be higher in older stands (Åström 2020). Through partial cutting, the regeneration of early successional broadleaved species increases (Palik et al. 2012). Regeneration of shrubs and trees were denser and more species diverse in gaps created in riparian buffer zones (Mallik et al. 2014).

1.4. Nissan Agreement

The Environmental Protection Agency is responsible for surveying and identifying ecologically valuable watercourses in Sweden. Protection priority is given to those that are deemed nationally or regionally important (Naturvårdsverket 2003). Parts of the Nissan catchment area is classified as nationally important (Carlsson & Liliegren 2005). The catchment area is dominated by forest with 82 % of the land area covered by forest land followed by agricultural land (8 %) and water (5%) (Vattenmyndigheterna & Länsstyrelserna u.å.). Within the catchment area there are high natural values related to water, mainly bound to the species rich bottom fauna, valuable fish species, water flora and rich bird life. The values bound to forest include swamped and seasonally flooded broadleaved forests. On top of this there are recreational values in sport fishing, hiking, and foraging as well as cultural heritage from remains of previous water uses such as grain mills (Vattenmyndigheterna & Länsstyrelserna u.å.). In 2015 the Swedish state forest company Sveaskog signed a nature conservation agreement with the county board in Jönköping which encompass parts of the catchment area of the river Nissan (Figure 1). More specifically, the agreement covers stretches of the following watercourse: Nissan, Helgaboån, Sågån-Grissleån, Bullerbäcken, Åsabäcken, Svanån, Västerån and Valån. The motivation for the agreement was the natural population of Brown trout, European crayfish (*Astacus astacus*, L) and Freshwater pearl mussel within the catchment area. The purpose of the agreement was to:

- Preserve and strengthen biodiversity linked to streams with migration routes and suitable habitats for fish and other aquatic organisms.
- Contribute to achieving a favourable conservation status for watercourses.
- Develop and preserve an ecologically functional riparian zone towards the watercourse with its biological diversity.
- Develop and preserve adjacent forests with high natural values.
- Promote the presence of broadleaves.
- Promote the presence of dead wood.

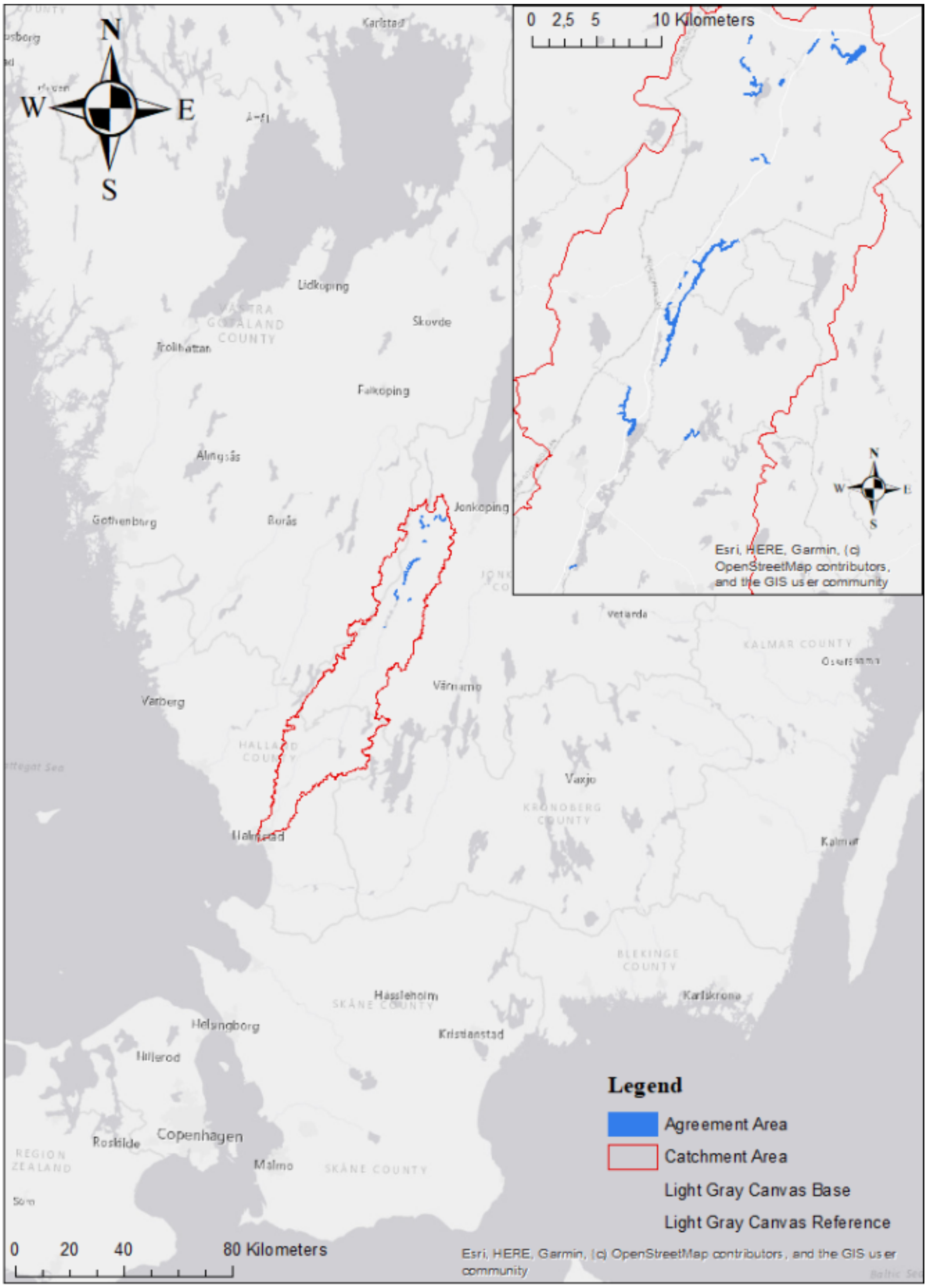


Figure 1. The Nissan catchment area (SMHI 2017) and the agreement area (Länstyrelsen & Sveaskog 2015) locations in Götaland, Sweden.

The management that will be applied according to the agreement was conservation cuttings in forests of all ages. The timetable for the cuttings was sectioned into 4 groups with five years between each group deadline (2015, 2020, 2025, 2030). In 2030 the entire agreed area should be worked through. Stands should then be reviewed and managed with 30-year intervals. The basic goals of the forest management were stated as following:

- Strengthen and develop existing broadleaves.
- Create opportunities for regeneration.
- Create gaps to favour bats, butterflies, and birds.
- Increase the temperature in the stands and change the climate to favour the insect fauna.
- Imitate natural disturbances such as flooding and fire.

In general, the plan was to remove Norway spruce in the buffer zones and favour broadleaved species. However, where the natural values are connected to old grown Norway spruce, they will be kept (Länstyrelsen & Sveaskog 2015). While some of the motivation for the management was to improve water conditions inside the catchment area, all management is limited to the forest stands. This will be done by improving conditions for broadleaves through conservation cutting and by recreated swamped forests by plugging ditches that have previously drained the riparian stands within the agreement (Länstyrelsen & Sveaskog 2015).

1.5. Aims of the study

This study was divided into two parts. Firstly, the tree and vegetation composition and structure were described in the recent conservation cuttings. For this purpose, an inventory was made in the riparian buffer zone with the goal to measure the results of conservation management practices by describing buffer zone attributes immediately after the treatment. Secondly, the possible long-term effect of the conservation cuttings was evaluated using Heureka StandWise. Different management alternatives were applied to monocultures and mixtures of birch and Norway spruce for 50-year simulations. The results were then applied to the stands in the Nissan agreement area. As mentioned in (Hasselquist et al. 2015), short time monitoring is not enough to see the results of treatments. Nature conservation management requires time to show results and simulating future stands allows for some sort of evaluation of management alternatives. Even though it might not be able to predict how nature values will develop in the stands, it can provide implications for stand structure which can be linked to structures of current valuable stands.

2. Material and Methods

2.1. Nissan Agreement Area

Nissan's catchment area is located in three counties, Jönköping County, Halland County and Västra Götaland County in southern Sweden. It roughly stretches from Jönköping down to Halmstad. The catchment area covers 2 682 km^2 and is 140 km long from North to South. The main river Nissan flows in a south-western direction from Jönköping to Halmstad where it ends in Kattegat. The area is dominated by coniferous forest. Since the area stretches in a north-south direction for 140 km, the climate varies quite a bit. The growing season in the catchment area ranges between 180 and 210 days with a decrease in northern direction. The temperature sum is between 1200 to 1500+ daily degrees ºC. The annual precipitation inside the catchment area ranges between 600 mm in the northern tip to 1200 mm near the coast. The number of snow-covered days varies between 0 and 100 days (SMHI 2021).

The agreement signed between Jönköping County and Sveaskog covers 340 hectares of riparian forest. The agreement area is in the northern half of the Nissan catchment area and covers stretches along Nissan, Helgaboån, Sågån-Grissleån, Bullerbäcken, Åsabäcken, Svanån, Västerån and Valån (Figure 1). A landscape analysis of the agreement area was performed, compiling the proportion and area of forest types and tree species using Cadaster ENV Sweden (Swe: Nationella Marktäckedata, NMD) (NMD 2020). The NMD is a raster with 10 m x 10 m resolution with classified forest type and land use. In this study, only the vegetative categories were relevant, so classes regarding exploited land and water was excluded. Using the shapefile of the agreement area as a template, the relevant cells were extracted. The categories were then generalized into three forest types; conifer dominated forest, broadleaf dominated forest, or mixed forest, and in two categories of open land; temporary deforested, which is mainly clear-cuts but still forested land, and other (Table 1). The area was then calculated by adding up all the cell areas for each category and dividing by 100 to convert the area into hectares (Table 1).

Table 1. Reclassification of NMD classifications to more generalized classes and area attributed to each class.

Classification	Reclassification	Area (ha)
Pine	Conifer dominated forest	80.84
Spruce	Conifer dominated forest	62.41
Mixed conifer	Conifer dominated forest	18.30
Pine on wetlands	Conifer dominated forest	40.11
Spruce on wetlands	Conifer dominated forest	14.19
Mixed conifer on wetlands	Conifer dominated forest	3.85
Trivial broadleaves	Broadleaf dominated forest	15.04
Nobel broadleaves	Broadleaf dominated forest	0.32
Trivial broadleaves with Nobel broadleaves	Broadleaf dominated forest	0.07
Trivial broadleaves on wetlands	Broadleaf dominated forest	12.77
Mixed forest	Mixed forest	18.88
Mixed forest on wetlands	Mixed forest	13.28
Temporarily deforested	Temporarily deforested	21.85
Temporarily deforested on wetland	Temporarily deforested	0.97
Open Wetland	Other	56.61
Other open land with vegetation	Other	6.98

2.2. Treatment Area

The inventory focused on stands that had been managed through conservation cuttings for the purpose of promoting broadleaves along the watercourses. The original stands were divided as new management units because of the agreement, dividing a larger stand into the riparian buffer zone and the original stand outside the agreement area. There were 24 stands with conservation cuttings in the original data from Sveaskog. However, since some of them were adjacent to each other and the general management strategy and goal was the same for all stands, they were aggregated into fourteen stands. All the stands were adjacent to water and were included in the plot distribution process, see 2.4.1. These stands were distributed along six watercourses. The number of plots per watercourse varied between 16 and 69 (Table 2).

Table 2. Number of aggregated stands and sample plots per watercourse.

Watercourse	Stands	Plots
Bullerbäcken	2	28
Grissleån	1	22
Helgaboån	1	20
Nissan	6	69
Svanån	3	28
Västerån	1	16
Sum	14	183

2.3. Inventory

2.3.1. Sampling design

The inventory was made at the water edge and in the buffer zone in all the stands. Sample plots was distributed with 100 meters distance following the water body in paired plots. The water edge plot was first distributed at a distance 1 meter from the water. A parallel plot in the buffer zone was then distributed with 10 meters distance from the water edge plot, with 90-degree angle to the water edge. This resulted in paired plots 1 meter and 11 meters from the water (Figure 2). The distribution of the water edge plots was made prior to the visit in field using ArcMap. A feature with stands from Sveaskog and features of the water bodies from the official map *Lantmäteriet terrängkarta* (Lantmäteriet 2015) was used as initial source of information. A parallel line to the water features was made along the water's edge at 1 meter distance. The inventory plots were then distributed along the created line with an interval of 100 meters. Buffer zone plots were located 10 meters from the water edge plots perpendicular in relation to the waterline and was distributed in field during the inventory. In cases where the watercourse meanders the plots were moved so that it was possible to have the plots one meter and 11 meters from the waterline.

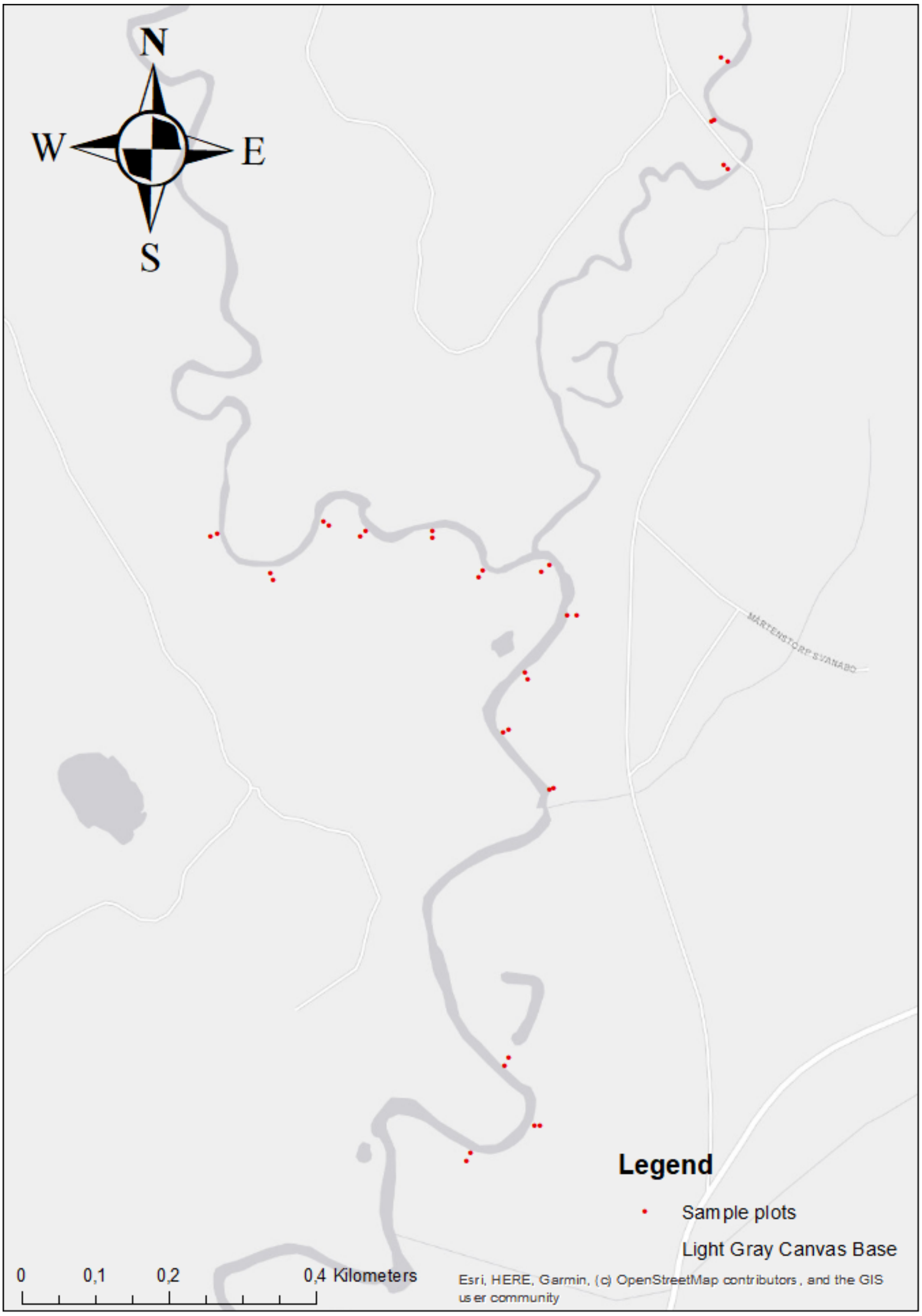


Figure 2. Distribution of paired sample plots in three aggregated stands along the river Nissan.

The inventory was made in March 2021. In field, every plot at the water edge distributed prior to the inventory was located using GPS. A centre stick was put into the soil in the centre of the 5.64 m radius circular sample plots. After the water edge plot was measured, the corresponding buffer zone sample plot was located with measuring tape, and then followed by the same procedure for collection of data (Table 3).

Table 3. Variables and respective Estimates and Units for the data collected in conservation cutting inventory plots.

Variables collected	Estimates	Unit
Treatment	Direct/Indirect	Yes/No
Water width	0-10+	Meter
Distance to water	Water edge/Buffer zone	-
Field layer	0-25 26-50 51-75 76-100	%
Bush layer	0-25 26-50 51-75 76-100	%
Basal area	-	m^2/hectare
Tree species distribution	-	Stems per hectare
Hemispherical photography	-	-
Comment	General plot description	-

Treatment refers to signs of active management within the plot i.e., stumps, high stumps, tracks, or logging residue from the forestry machines within a 5,64-meter radius from the plot centre. Direct plots contain these signs while indirect plots do not.

Water width refers to the estimated width of the watercourse that forms the nearest waterline. The width estimates range from 0 meters to 10+ meters with 1-meter intervals.

Distance to water refers to the location of the plot centre in relation to the nearest waterline. *Water edge* is located one meter from the waterline and *buffer zone* are ten meters from the corresponding water edge plot, perpendicular to the waterline.

Field layer was estimated as proportion cover of the circular plot. The field layer was defined as herbs, grasses, half-grasses, low-growing shrubs, ferns, Equisetum and Lycophytes. Mosses, lichens, and exposed mineral soil was not included in any layer. This definition was taken from The Swedish National Forest Inventory field instruction (Bredberg et al. 2020).

Bush layer was defined as any shrub or tree that does not fall into the field layer or the tree species distribution i.e., trees lower than four meters in height or that have a breast height diameter lower than four centimetres. Because of these criteria all woody vegetation was accounted for in the inventory.

Basal area of the forest surrounding the plot was measured by relascope from the centre of the plot. All trees were included, even those from neighbouring stands or from across the water since they would contribute to competition for light.

Tree species distribution was measured within circular plot with 5,64-meter radius from the plot centre. All trees with a diameter at breast height (1.3 m above ground) above four centimetres or trees more than four meters tall were counted. The tree species composition was registered with stem densities of Scots pine, Norway spruce and broadleaves.

Hemispherical photographs were taken with a Nikon D5300 with a 4.5mm F2.8 EX DC circular fisheye HSM lens 1 meter above the ground from the plot centre. All the spirit levels on the camera were levelled to ensure that the camera lens was pointed at the zenith.

2.3.2. Image Processing

The hemispherical photographs were processed to calculate the canopy openness. For this purpose, the programs ImageJ and Gap Light Analyzer (GLA) were used. ImageJ was used to convert the photos from red, green, blue photos to black and white. While GLA can do the same, it requires manual input which could affect the results through bias. The ImageJ process is more objective since it processes the images automatically. More specifically, the macro "Hemispherical_2.0" for ImageJ was used (Beckschäfer 2015). Except for the image cropping, all processing is done automatically in ImageJ. To get an overview of the result, all photographs were compared side by side with their black and white copy (Appendix 1). Out of 183 photographs, 165 were deemed acceptable. The remaining 18 had obvious faults caused by nonoptimal conditions in the original photograph. The following reasons seemed to yield bad results: the sun was visible in photo, light was reflecting on stems and branches, bright birches were blending into the clouds, fogging on the lens, raindrops on the lens, clusters of small diameter branches of birch not registering. The ImageJ process was discarded for these 18 pictures and the photographs were wholly processed in GLA instead. The motivation for this was the potential loss of 10% of plots which seemed high while the results are still comparable to the automated process in ImageJ. GLA was then used to calculate canopy openness.

2.3.3. Statistical analysis

The statistical analysis was done in Microsoft Excel. A grouped t-test was used to see if there was a statistically significant difference in Basal area, Number Scots pine, Norway spruce or Broadleaved stems, Stem density and Canopy openness between water edge and buffer zone plots as well as direct plots compared to indirect plots. A p-value of below 0,05 signifies that there is a significant difference.

2.4. Heureka Scenarios

The simulation of future development of the treatment area was made using Heureka StandWise. Heureka StandWise is a decision support system (Wikström et al. 2011) which predict stand development based on management in terms of stand density, species composition, total growth, net income et cetera, presented in five-year periods. Treatments in StandWise happen in the middle of each five-year period. Heureka was chosen as it is currently the premier decision support system in Swedish forestry with functions based on a substantial amount Swedish data.

2.4.1. Tree lists, input Data

The future stand development in the managed parts of the agreement area in terms of species composition and growth was predicted using Heureka StandWise simulations. The simulations were based on measured sample plot data imported into StandWise as tree lists. The tree lists came from a precommercial thinning (PCT) experiment of mixed forests, established in 2013. The experiment is located in Tagel, Lat 14˚ Long 57˚, approximately 100 km from the Agreement area, on similar soils and climate conditions. At the time of the experiment establishment the stand was a mixture of naturally regenerated birch and planted Norway spruce (two-year old seedlings), 7 years after final felling, soil scarification and planting. The experiment consists of three blocks with four randomized treatments within each block. The following four forest stand types was created through the treatments with precommercial thinning in 2013:

1. 100% Spruce: 100% Norway spruce
2. 100% Birch: 100% Birch
3. 66% Birch: 66% Birch + 33% Norway spruce
4. 66% Spruce: 66% Spruce + 33% Birch

The data used in this study was the tree list measurements of diameter and heights four years after the PCT. Since the entire experiment was established at the same time, the mean age was noted as 11 years. Within every treatment plot four circular sample plots with a radius of 5.64 meters was used for measurements, which means that from every treatment/stand type, 12 sample plots with tree lists were used. Tree species, diameter at breast height (1.3 m above ground), and height was noted for each tree inside the plots. Saplings below 50 cm in height were not noted. The four forest types had similar mean heights (Norway spruce 4.27 m and birch 4.49 m), but diameter development ranged between 5.7 and 7.6 cm (Table 4)

Table 4. Summary of Tree list data for each forest type and species that was used as input data for Heureka StandWise.

Forest type	Norway spruce			Birch		
	stem density	height (dm)	dbh (cm)	stem density	height (dm)	dbh (cm)
100% Spruce	1733	47	5.7	0	0	0
100% Birch	0	0	0	1985	59.7	5.7
66% Birch	700	65.5	7.6	1241	60.7	6
66% Spruce	1283	58.3	7	675	59.1	6.5

2.4.2. Heureka StandWise settings

In StandWise, five management programs were created to simulate different future management alternatives in the agreement area. A time frame of 50 years was chosen for the simulations to evaluate stand development and economical return. The following management alternatives were used:

No Management: Do nothing after the conservation cuttings.

Anti-Spruce: Wait until the stand reaches an average stem diameter of 8 cm, then harvest all Norway spruce stems with a diameter of 8 cm or above. The stand is then left for free development.

Thinning Guideline: Follow the Swedish forest agency's thinning guidelines for the dominant species in the stand. For the 66% Spruce stand, the spruce guide was used until it suggests final felling, the birch guide was then used.

§10: For every 30^{th} year after the final PCT, thin down to the baseline volume in the appendix of the SVL's tenth paragraph (Figure 3).

§5: For every 30^{th} year after the final PCT, thin down to the baseline volume in the appendix of the SVL's fifth paragraph (Figure 3).

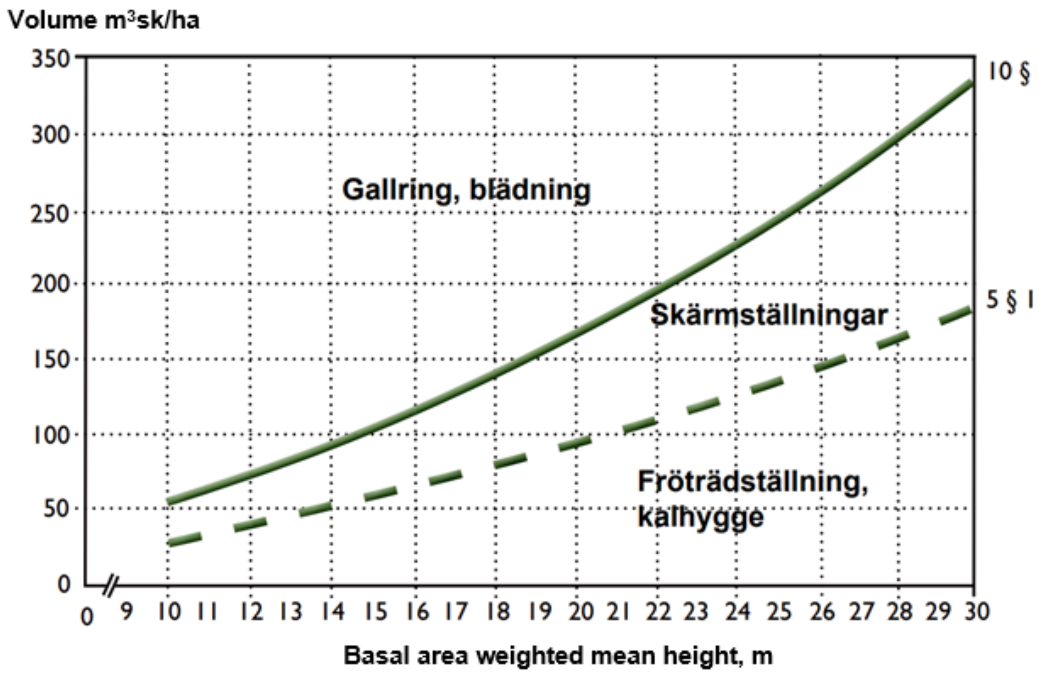


Figure 3. Appendix of the Swedish forestry act regarding standing volume for a mean height. Above 10§: Thinning and Continuous Cover Forestry. Below 5§: Seed trees and Clear Cuts. Inbetween: Shelter woods. (Albrektson et al. 2012)

For this analysis, the thinning function was the only one used. There was no limit to how intense the thinning might be since that would stop the heavier thinnings. The breast height diameter limit for thinned trees was set to 8 cm since it is the limit for commercially viable pulpwood (Bergström et al. 2010). This further motivated in the agreement where Sveaskog reserves the rights to extract roundwood from future management and it is unlikely that a harvester would be used unless it was economically viable. Especially if the Norway spruces are kept through a PCT. In the thinnings, Norway spruce is prioritized with birches being second to be thinned if no Norway spruce meets the criteria.

2.4.3. Selection of Result Variables.

Result outputs from the Heureka simulations was selected to demonstrate stand development, occurrence of deadwood and economic result after 50 years (Table 5). Stand development was described by dominant species, basal area, and stem density per species. Dead wood was assessed both as downed deadwood on the forest floor and by dead stand trees. The total harvested volume was relevant as estimate of roundwood removed for use in the industry. Because of this, there was also a net revenue connected to management of these stands (Table 5).

Table 5. Summary of used output variables from Heureka StandWise.

Result type	Variable	Unit
Financial Value	Total Harvest Volume Fub	m^3fub/ha
Forest Data	Dominant Species After	species
Forest Data	Basal area (incl overstorey) After	m^2/ha
Financial Value	Net Revenue	SEK/ha
Dead Wood	Downed Deadwood	m^3/ha
Dead Wood	Dead Standing Trees	m^3/ha
Data per Species	Stems After harvest	trees/ha

2.5. Landscape Scenarios

A basis for the landscape scenarios was that all the agreements forested area would been put through conservation cuttings. The management alternatives from 2.5 was applied to the landscape analysis from 2.2. To make the alternatives compatible with the NMD, each reclassification had to be assigned a mix from Tagel. Since these scenarios would take place after a conservation cut, it was assumed that none of the stands would remain as monocultures. As such, the 100% Spruce and 100% Birch mixes was not used here. Half of the mixed forest area and all of the conifer dominated area was assigned the 66% Spruce mix. The other half of the mixed forest area as well as the broadleaved dominated area and temporarily deforested area was assigned the 66% Birch mix. The definition for mixed forest was no more than 70% of a single tree species. The first management alternative was *No Management*, that is, no more treatments, which was applied to the whole treatment area. This was done to see how the management area would develop without anything else than the original conservation cut. Secondly, the *Anti-Spruce* management was applied. This alternative was chosen to see a low intensity approach could produce broadleaf dominated forest. Lastly, the *thinning guidelines* were followed to see if a commercial approach is viable in conversion even after the original conservation cut.

3. Results

3.1. Conservation Cutting

3.1.1. Agreement area Analysis

The agreement area was by 76 %, 303 hectares, covered by forest land, and the remaining area was open land area. The most common forest types were conifer dominated forest (60 %), of which, 33% was dominated by Scots pine and 21 % was dominated by Norway spruce. Mixed forest covered 9 % and only 8 % was broadleaf dominated forest. The remaining 6% was classified as temporarily deforested (Figure 4).

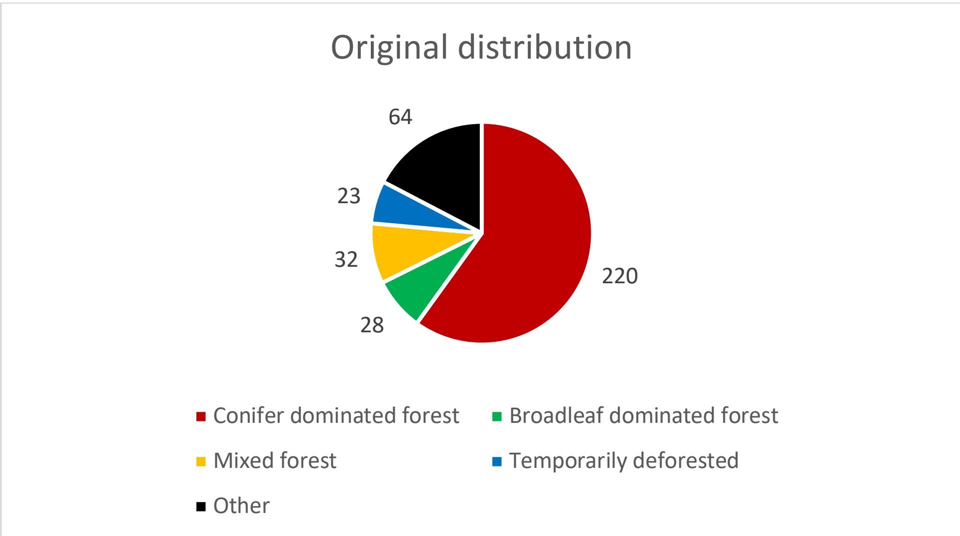


Figure 4. Original distribution of aggregated forest type classifications in the Nissan agreement area before conservation cuttings in hectares.

3.1.2. Conservation Cutting results

Conservation cutting was made in fourteen stands, where of eight coniferous stands, two broadleaved and four mixed stands. Five of the conifer stands was Scots pine dominated, and three stands were Norway spruce dominated. All fourteen stands were created as new management units, dividing a larger stand into the buffer zone and the original stand outside the agreement area. A general trend was that the nearby stands outside of the agreement area had been subjected to either a thinning or a final felling at the same time as the conservation cutting. Three stands had been thinned and two more were partially thinned. Five stands had been final felled and two more had been partially felled. The two partially thinned and partially harvested stands was from the same aggregated stands and was a result of combining adjacent stands, see 2.3. Four stands had only been selectively cut. Most of agreement area was dominated by low shrubs of the Vaccinium sp. but towards the water, there was a tendency for more grass and moss vegetation.

At the water edge black alder and birch was the two dominating tree species, followed by Norway spruce and Scots pine, in that order. The stem density varied between the direct plots (756 ± 508) and the indirect plots (902 ± 498). Similarly, the basal area was higher in the indirect plots (14 ± 6) than in the direct plots (13 ± 4). The mean Canopy openness differed between 57.6% for direct plots and 49.6% for indirect plots (Table 7). The buffer zone area was also dominated by broadleaved tree species, but black alder was less prevalent in the buffer zone in favour of birch. Scots pine was the second most common species in the direct plots while Norway spruce was second in the indirect plots. The basal area was higher in the indirect plots (15 ± 7) when compared to the direct plots (11 ± 4). The stem density was also higher in indirect plots (689 ± 426) than the direct plots (396 ± 270). Canopy openness followed the same trend with a mean of 50.2% and a standard deviation of 20.3% for indirect plots and 63.3% and 13.6% in the direct plots, respectively (Table 6).

Table 6. Inventory result means and standard deviations (SD) sorted by the Water Edge and Buffer zone as well as Direct and Indirect plots.

	Water Edge		Buffer Zone	
	Direct	Indirect	Direct	Indirect
	n = 45	n = 48	n = 54	n = 36
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Basal area (m^2/ha)	13 (4)	14 (6)	11 (4)	15 (7)
Scots Pine (stems/100 m^2)	0.71 (1.32)	1.10 (1.46)	1.44 (1.50)	1.00 (1.60)
Norway Spruce (stems/100 m^2)	1.31 (2.15)	2.33 (2.12)	1.07 (1.46)	2.61 (3.16)
Broadleaves (stems/100 m^2)	5.53 (4.54)	5.58 (4.22)	1.44 (1.95)	3.28 (3.12)
Stem density (stems/ha)	756 (508)	902 (498)	396 (270)	689 (426)
Canopy openness (%)	57.6 (11.5)	49.6 (16.9)	63.3 (13.6)	50.2 (20.3)

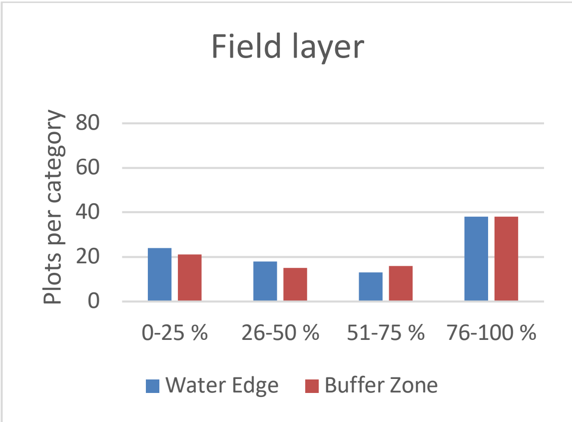
At the water edge, there was a significantly lower stem density of Norway spruce (p=0.023) and larger canopy openness (p=0.010) in direct plots compared to indirect plots. In the buffer zone, similar differences were found for Norway spruce stems (p=0.003) and canopy openness (p<0.001). However, there was also significantly lower basal area (p<0.001), density of broadleaved stems (p=0.001) and stem density (p<0.001) in the direct plots. There were no significant differences in Scots pine density between direct (p=0.179) and indirect (p=0.184) for the buffer zone (Table 7). When only comparing direct plots from the water edge and buffer zone, there was significantly larger Scots pine density (p=0.012) and larger canopy openness (p=0.028) in the buffer zone. There was also significantly lower basal area (p<0.001), broadleaved density (p<0.001) as well as stem density (p<0.001). There was, however, no statistical proof of any differences in Norway spruce stems. Comparing the indirect plots over the water edge and buffer zone yielded only significantly lower broadleaved stem density (p=0.007) and stem density (p=0.042) in the buffer zone. There was no significant difference in canopy openness between water edge indirect plots and buffer zone indirect plots (Table 7).

Table 7. Grouped T-test results from the inventory data. Statistically significant differences are highlighted as bold.

	Water Edge p-value	Buffer Zone p-value	Direct p-value	Indirect p-value
Basal area (m^2/ha)	0.342	**<0.001**	**<0.001**	0.697
Scots Pine (stems/100 m^2)	0.179	0.184	**0.012**	0.757
Norway Spruce (stems/100 m^2)	**0.023**	**0.003**	0.518	0.631
Broadleaves (stems/100 m^2)	0.956	**0.001**	**<0.001**	**0.007**
Stem density (stems/ha)	0.164	**<0.001**	**<0.001**	**0.042**
Canopy openness (%)	**0.01**	**<0.001**	**0.028**	0.894

3.1.3. Field and Bush Layer

More than 41 % of the plots had a field layer cover above 75 % (Figure 5). Most stands had a field layer covering the soil, less than 43 % of plots had a field layer below 50 %. The field layer coverage was not different in the water edge compared to the buffer zone. The field layer coverage was slightly lower in the direct treatment plots (Figure 5).



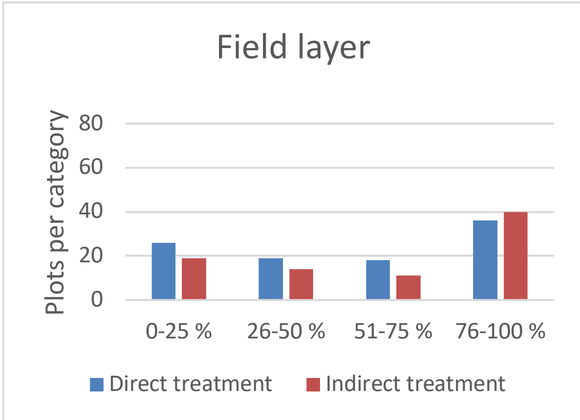
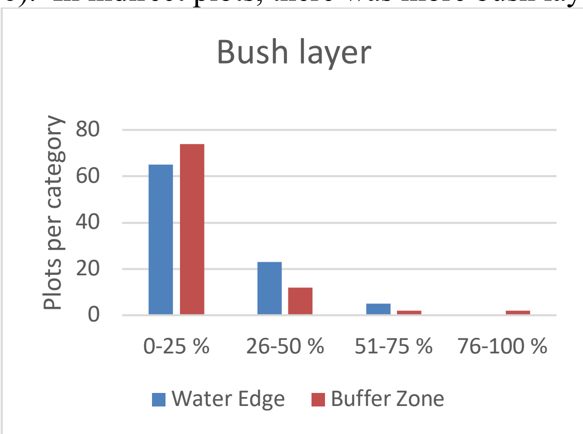


Figure 5. Amount of field layer estimated in 25% categories for Water Edge/Buffer Zone and Direct/Indirect plots.

There was hardly any bush layer in any of the plots as 76 % had less than 25% covered by a bush layer. Only 9 plots, 5 %, had more than 50 % coverage (Figure 6). In indirect plots, there was more bush layer coverage than in direct plots.



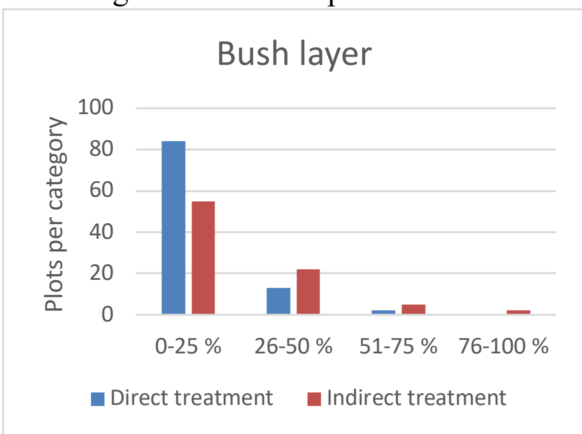


Figure 6. Amount of bush layer estimated in 25% categories for Water Edge/Buffer Zone and Direct/Indirect plots.

3.2. Heureka Scenario Analysis

3.2.1. Management intensity

The tree species composition in the initial four forest types did not affect the thinning intervals in most of the scenarios. 100 % Birch + *Anti-Spruce* and *§10* as well as 100% Spruce + *Thinning guideline* were the only combinations that differed in number of treatments inside each management alternative. *Thinning guideline* was the only management alternative in which the year of the treatments varied (Table 8).

Table 8. Time of thinnings in StandWise in years after simulation start.

Future management	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	-	-	-	-
Anti-Spruce	7.5	-	7.5	7.5
Thinning Guideline	22.5, 32.5	2.5, 7.5, 27.5	2.5, 22.5, 47.5	22.5, 32.5, 42.5
§10	17.5, 47.5	47.5	17.5, 47.5	17.5, 47.5
§5	17.5, 47.5	17.5, 47.5	17.5, 47.5	17.5, 47.5

3.2.2. Net revenue and harvested volume

The net revenue of the management alternatives varies between 0 SEK/ha in *No Management* and 144 322 SEK/ha for 66% Spruce when *Thinning guideline* was applied. This was 55 912 SEK/ha more than the second most profitable combination, which was *10§* applied to 66% Spruce. The smallest net revenue of the managed alternatives was 100% Birch with the *Thinning guideline* that resulted in 3 647 SEK/ha (Table 9).

Table 9. Net revenue for each of the future stands after 50 years in SEK/ha.

Treatment\Stand	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	0	0	0	0
Anti-Spruce	5810	0	5394	7294
Thinning guideline	26867	3647	34792	144322
§10	76889	13505	60165	88410
§5	69434	27457	47874	75315

The total harvest volume varied between 0 m³fub/ha and 509,8 m³fub/ha for the 100% Birch with *Thinning guideline* and 66% Spruce with *Thinning guideline*, respectively. The second highest harvested volume was from the 66% Spruce with *§10* management that resulted in 334.9 m³fub/ha. Lowest of the managed alternatives was 64.8 m³fub/ha from the 66% Birch with *Anti-Spruce* management (Table 10).

Table 10. Total harvested m³fub/ha after 50 years.

Treatment\Stand	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	0	0	0	0
Anti-Spruce	93	0	64,8	95.5
Thinning guideline	144.3	69.2	192.6	509.8
§10	311	78,8	220.3	334.9
§5	307.5	162.9	252.4	317.4

3.2.3. Stand structure

The tree species composition after 50 years was dependent on the starting values and initial forest type. In the two monocultures (100% Spruce & 100% Birch), there was almost no other species being introduced in any of the management options. The exceptions of this were in the *§5* management in the 100% Birch stand where some spruce had regenerated 20 years after the cutting. For the two mixed stands (66% Birch & 66% Spruce), the original species was retained but the proportion changed with time and management. (Figure 7).

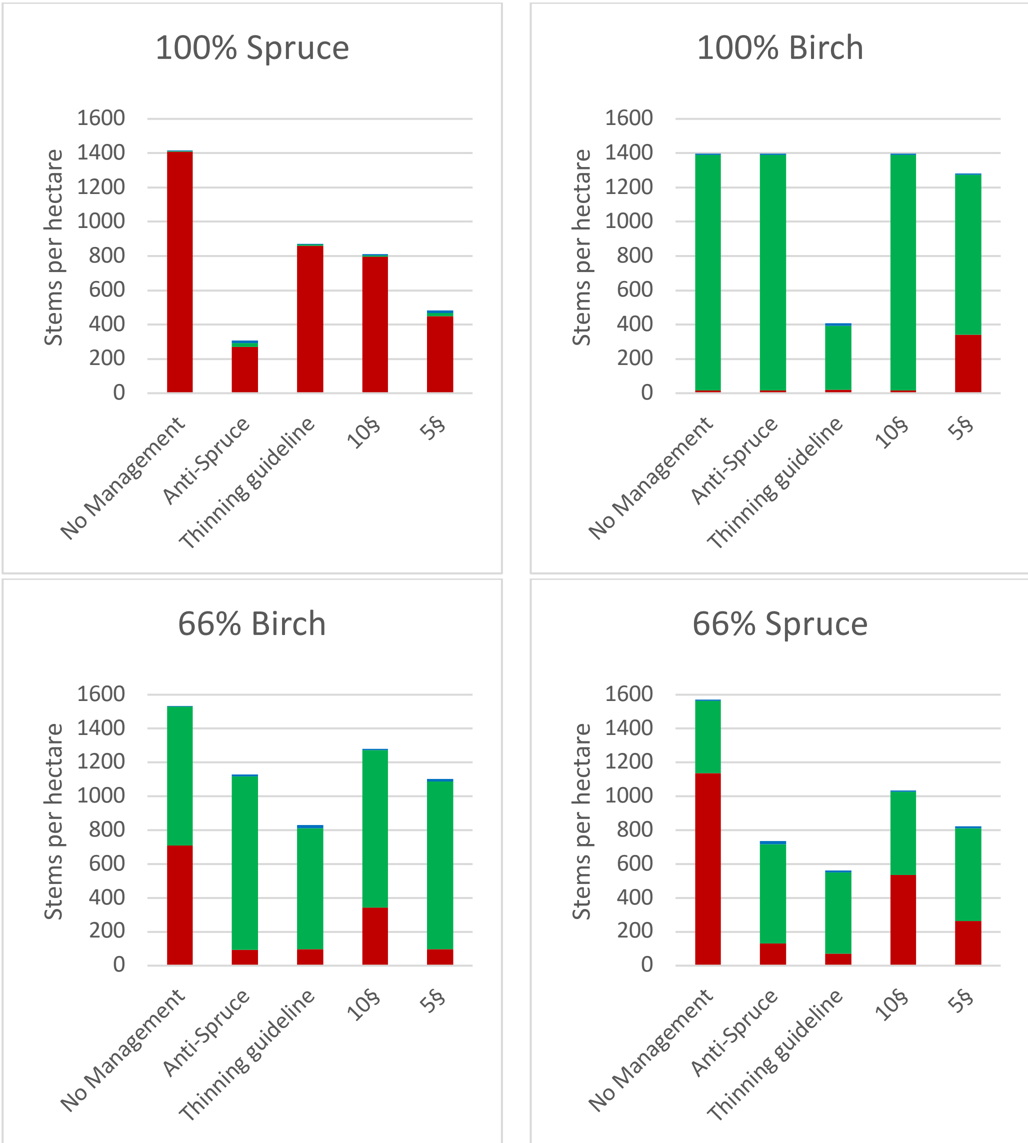


Figure 7. Tree species distribution and stem density for each combination of PCT treatment and future management program after 50 years. Green = Birch, Red = Spruce, Blue = Other tree species.

The management option did not matter for dominant species in the monocultures as the dominant species did not change after 50 years in 100% Spruce or 100% Birch. However, the management option did matter for the mixed stands. If *No Management* was applied, Norway spruce will dominate the 66% birch stand after 50 years. Similarly, the *No Management* and *10§* options are not intensive enough to remove the dominance of Norway spruce in the 66% Spruce stand (Table 11).

Table 11. Dominant species in each future stand after 50 years, changes in dominant species are highlighted with bold text.

Treatment\Stand	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	Spruce	Birch	**Spruce**	Spruce
Anti-Spruce	Spruce	Birch	Birch	**Birch**
Thinning guideline	Spruce	Birch	Birch	**Birch**
§10	Spruce	Birch	Birch	Spruce
§ 5	Spruce	Birch	Birch	**Birch**

The amount of deadwood varied between 3 (100% Spruce + *Anti-Spruce*) and 105 (100% Spruce + *No Management*) m^3/ha. *No management* always produced the highest amount of dead wood in each forest type. (Table 12).

Table 12. Sum of deadwood (m^3/ha), standing + downed, in after 50 years.

Treatment\Stand	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	105	25	30	50
Anti Spruce	3	25	13	9
Thinning guideline	20	6	8	20
§10	15	25	16	18
§5	10	12	10	11

The percentage of broadleaves varied between 0% (100% Spruce + *No Management*) and 99% (100% Birch + *No Management*/*Anti-Spruce*). The broadleaved percentage decreased for all 100% Birch options, all *No Management* options and for *§10* + 66% Spruce. If the definition of mixed forest is that no more than 70 % may be of a single species, only 66 % Birch + *No Management* and 66% Spruce + *§10* achieve this definition (Table 13).

Table 13. Percentage of broadleaves after 50 years.

Treatment\Stand	100% Spruce	100% Birch	66% Birch	66% Spruce
No Management	0%	99%	54%	27%
Anti-Spruce	7%	99%	91%	82%
Thinning guideline	1%	95%	95%	87%
§10	1%	98%	83%	65%
§5	2%	96%	87%	81%

3.3. Landscape scenario analysis.

With the landscape scenario *No Management*, the amount of conifer dominated forest increased from 220 to 236 hectares (Figure 8). The Broadleaved Forest turned into mixed forest and the conifer dominated part of the mixed forest turned into conifer dominated forest (Figure 8, No Management). With the *Anti-Spruce* management both the conifer dominated, and mixed forest types transformed into broadleaf dominated forest with 303 hectares (Figure 8, Anti-Spruce). This would also result in a net revenue of 2 081 000 SEK. The *Tinning guideline* scenario had the same outcome on forest classification as the Anti-Spruce alternative (Figure 8, Mixed management). However, following the *Thinning guideline* resulted in a net revenue of 36 362 000 SEK.

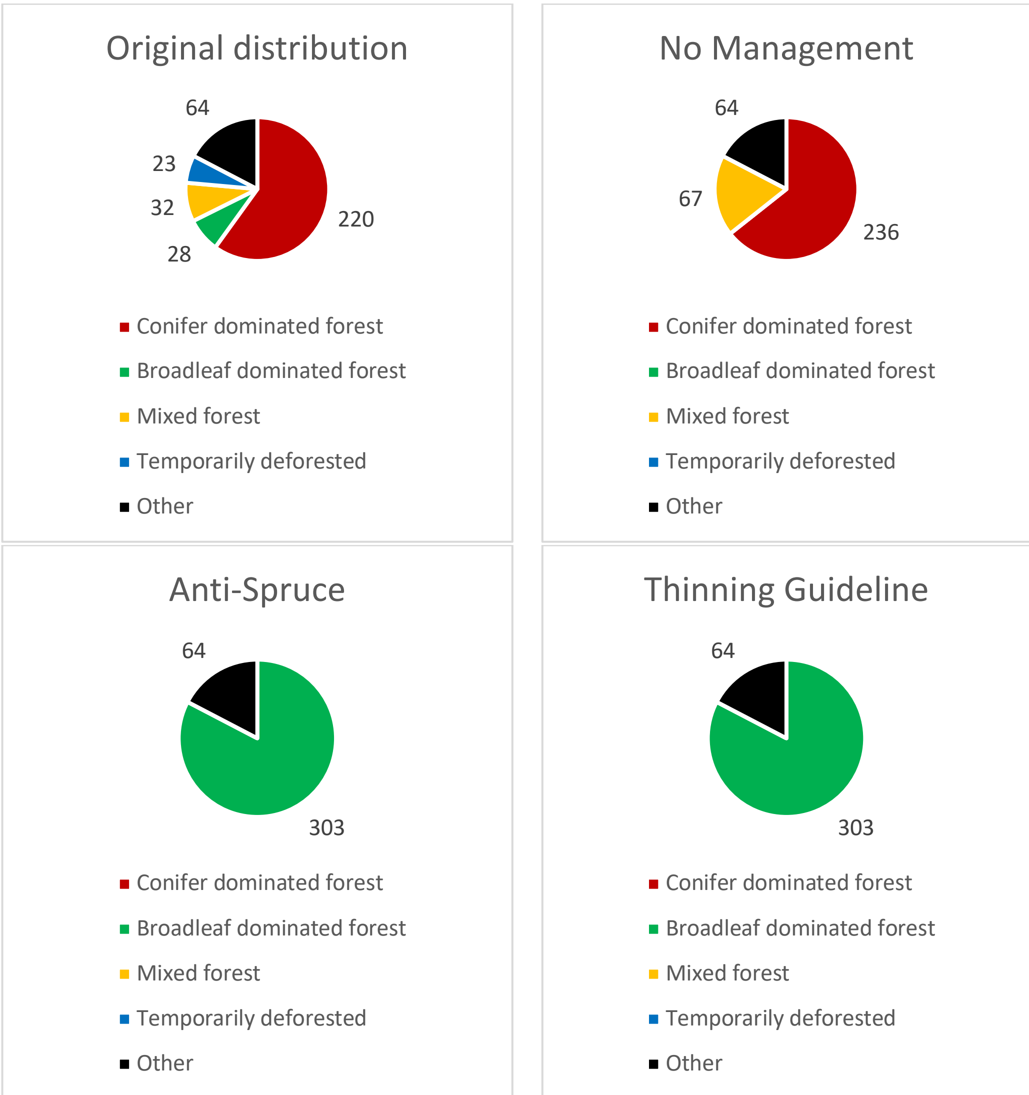


Figure 8. Heureka management alternatives applied to the forest types of the agreement area in hectares.

4. Discussion

4.1. Agreement area Analysis

The landscape analysis of the agreement area showed that much of the forest land was dominated by conifers when the agreement was made. There are parts of the agreement with ecological values tied to the older, large diameter Norway spruce. Because of this, the actual conifer dominated area in need of conservation cuttings is smaller than the 220 hectares currently conifer dominated. A part of the agreement area also consists of mixed forest of conifers and broadleaves. A large proportion is dominated by Scots pine, not Norway spruce. In general, mixed Scots pine stands should be of less importance to manage with conservation cuttings since Scots pine does not have the shade tolerance which allows Norway spruce to pose a threat to light demanding broadleaves. If there is a limit to the management resources, priority should be on performing conservation cuttings in the Norway spruce dominated stands.

4.2. Conservation cuttings

The water edge had a higher canopy openness and a reduced density of Norway spruce in plots with signs of cuttings (direct treatment), compared to plots without (indirect treatment). This indicated a targeted removal of Norway spruce in the conservation cutting which was in line with the instructions from the agreement. It also shows that the conservation cuttings increased canopy openness in the water edge. More effects of the conservation cuttings were measurable in the buffer zone in terms of lower basal area and stem density. Since there is a significant difference in basal area and stem density in the buffer zone but not at the water edge one can assume that the management in the buffer zone was more intense. The higher removal in the buffer zone was probably an effect of the lack of broadleaves and difficulty to find possible retention trees. There were also signs that the conservation cutting was focused on creating gaps in the buffer zone, since there were fewer broadleaved stems when there were signs of cutting. The inventory showed higher stem density at the water edge when compared to the rest of the buffer zone. This could be explained by the higher number of broadleaved stems at the water edge which had been kept when the stand was cut. The increase of broadleaved stems near the water is in line with the findings of Larsson & Nygårdh 2020 and Orlikowska et al. 2004. Since the buffer zone seem to lack broadleaves, the gap cutting and the resulting increase in canopy openness and light transmittance should provide the disturbance needed to promote regeneration of broadleaves (Canham et al. 1994; Jonsson 2018; Petersson et al. 2019). Keeping a strip of broadleaves along the water edge can help to offset negative effects of the heavier cuttings in the buffer zone (Piccolo & Wipfli 2002).

There was a field layer present in most plots. This might increase due to the increased light availability after the conservation cuttings. This is negative for tree regeneration due to competition for light, water, and nutrients. Since the trees lower than 4 meters are included in the bush layer, it shows that there was very little regeneration before the conservation cutting and there has been very little recent tree regeneration after the cutting as well. The bush layer that existed in some plots was due to raspberry thicket and groups of dense young spruces. However, the bush layer was mostly insignificant throughout the plots, both in terms of established tree regeneration and bushes suppressing future regeneration. Other studies have shown a response with increased regeneration of early successional broadleaves and more diverse species composition emerging in after gap cutting (Palik et al. 2012; Mallik et al. 2014). It is probably just a matter of time before natural regeneration starts here.

Before the agreement was signed, there was most likely a management of the stands where a narrow buffer zone close to the water was set aside from forest operations, in line with recommendations in the Swedish Forestry Act and the forest certifications (PEFC 2017; FSC Sweden 2020). This practice is one of the reasons that there are more broadleaves at the water edge. Given time, the now broader buffer zone might develop a similar structure, especially after the conservation cutting. However, the high coverage of grass might become a problem for establishing broadleaved regeneration. The inventory was made only 5 years after treatment, and there were little signs of saplings, probably due to competing ground vegetation. It is therefore too early to tell if the management will promote broadleaved regeneration.

4.3. Heureka Scenario analysis

The StandWise analysis was made under the assumption that the conservation cuttings would develop into mixtures of conifers and broadleaves over time. The management that was most intense in terms of number of cuttings was the *Thinning guideline.* This was mainly due the lack of restrictions when compared to the alternatives. The other management alternatives had set intervals for when the management should take place while *Thinning guideline* did not. In particular, the 66% Spruce alternative was very intensive and resulted in extreme values. This was due to the transition in dominant species from Norway spruce to, which resulted in a "final felling" of all Norway spruce. When the Norway spruce thinning guideline suggested final felling, the birch guideline suggested heavy thinning to reduce the stem density to achieve the recommended density based on the birch thinning guideline.

The *No Management* alternative showed negative outcomes in basically all variables except amount of deadwood. If a low intensity approach is desired, the *Anti-Spruce* approach might be a better alternative since it reduced stem density, increased the proportion of broadleaves, and provided an income. While the other three management alternatives represent "common" management, the *§10* and *§5* represent two baselines based on volume and height. Therefore, the management alternatives *§10* and *§5* are more comparisons between themselves. One can compare the outcome of these to see which volume the stand might hold after cutting to produce the desired stand structure. While *§10* was better in economic terms, both provided similar harvested volume. When the initial stand was a Norway spruce dominated mixture, the *§10* management was not enough to establish birch as the dominant species in fifty years.

The StandWise analysis showed that if the stand developed into a monoculture, none of the management programs would change the tree species composition within fifty years. This implies that the occurrence of broadleaves is decided at an earlier stage of the stand development. The idea of managing and deciding stand structure earlier in the rotation is in line with the conclusions of Maher Hasselquist et al. 2021. However, if there are already broadleaves mixed into the stand, management can guide the proportions. This is further proved by the dominant species, where the result from mixed stands varies with management. For a natural forest to support species dependent on deadwood, around 20 m^3/ha is needed on a landscape level (De Jong et al. 2005). If 20 m3/ha is a threshold value, many of the options become less relevant. No stands achieve this amount for *§5*, and 3 out of the 4 stands fail for *Anti-Spruce* and *§10*. This is not an issue due the fact that we can manually increase the amount of deadwood any time we are there to cut. The threshold value for mixed forest used in this study was maximum 70 % of a single species. As such only two alternatives resulted in mixed forest, 66% Birch + *No Management* and 66% Spruce + *§10*. The rest were either Norway spruce or birch dominated. Again, for the monocultures there was little difference in broadleaf percentage. For the mixes, the variation was larger. If the goal of the management is to promote broadleaves, then the best management options would be *Anti-Spruce*, *Thinning guideline* and *§5*. This indicates that there is a need for heavy removal of Norway spruce to reduce its dominance in the riparian zones over a 50-year period. This was mainly shown in the 66% Spruce stand. Since *§10* resulted in Norway spruce dominance in 66% Spruce, we can assume that the remain volume/height required is somewhere in between the *§5* and *§10* line to promote broadleaves in a Norway spruce dominated stand.

4.4. Landscape scenario analysis.

Applying the different management strategies to the agreement area makes it clear that the *No Management* alternative is a step backwards as it decreases the broadleaf dominant forest and increases the conifer dominant forest area. This is done with the assumption that the conifer and broadleaf dominated forest are not 100% monocultures, but rather has some other species mixed into the stands. In this case the 100% Spruce and Birch mixes from the Tagel trials did not yield any results other than that the dominant species stays the same over time. For this reason, the 66% mixes were applied to all stands with conservation cuttings. For the *Anti-Spruce* area there is a positive change when just removing Norway spruce at one time in the 50 years. For the landscape scenario with *Thinning guideline*, the result was the same as *Anti-Spruce*. The landscape scenarios imply that active management is necessary to change the forest type composition after the original conservation cuttings, however, it might be as simple as just cutting away Norway spruce when they become competitive.

4.5. Further studies

Inventories like this one that map the initial state directly after treatments, has a value in long term assessments of conservation cuttings. However, the limitation for this specific study is the time frame. The inventory could have been more extensive with a larger time frame. It could also be argued that given the same amount of time, the distance between the plots could have been longer or a third plot further away from the water edge could have been made.

The inventory was made during the winter when the broadleaves had shed their leaves. This obviously has a big impact on the canopy openness. Because of this, one can assume that the canopy openness is overestimated in plots with more broadleaved stems during summer, that is, water edge plots since they hold the greatest number of broadleaved stems. An additional summer inventory could possibly add information on seasonal changes of canopy openness over the water sources in the agreement area. An inventory of tree species regeneration should also be made to see if the conservation cuttings have the desired effect.

In order to make StandWise scenarios, the future regeneration in the gaps had to be estimated. Experimental data from mixed forest regenerations with Norway spruce and birch is used in this study. Inside the agreement area, both Scots pine and Norway spruce are common tree species in the mature forest. The future conifer natural regeneration in the gaps after the conservation cuttings could consist of both species. However, the analysis shows trends for management intensities, which is applicable for many species similar to Norway spruce and birch. The analysis also shows the robustness of the monocultures since they did not change much in the proportion of birch. The StandWise simulations is based on regenerations after PCT which might indicate that not only regeneration but also the strategy in the PCT will shape the future stand even earlier than our management options. Natural regeneration in the conservation cuttings could be the subject of a future study of the area. This could then be used for a simulation with more accuracy.

4.6. Suggestions for future management.

The forests within the agreement area were dominated by Norway spruce and Scots pine. To change the forest composition was one of the main reasons for including management into the agreement. The original conservation cuttings applied to the inventoried stands seems adequate to achieve the goals stated in the agreement, however this study does not include direct evidence of broadleaves regeneration. There could have been more broadleaves cut to create more high stumps and deadwood. For future management, since there is a difference in broadleaf proportions between the water edge and the buffer zone, I would suggest a passive management at the water edge and simply remove competing Norway spruce much like the Anti-Spruce option. For the buffer zone, more active management is needed to help the broadleaves establish on the site. Depending on the mix proportions, a goal between *§10* and *§5* might be suitable if the 30-year intervals from the agreement are to be used. Regardless of management option, creation of deadwood, both laying and standing, might be necessary to reach the recommended amount. Åström 2020 suggests selective logging of coniferous trees in wider buffer zones to compensate for economic loss which would also encourage deciduous tree species. This is a reasonable option if there are enough robust broadleaves to depend on. Otherwise, harder management might be necessary to aid the broadleaves to establish. While the agreement seems to indicate passive management with 30 years between treatments, one could disturb the ground vegetation through light soil scarification to favour regeneration even further. Such management is not recommended in riparian zones due to the potential negative effects on the water and should not be used. Another alternative that is mentioned in the agreement is prescribed fire, but this would only be relevant in pine stands with low amounts of broadleaves and older Norway spruce individuals as to not damage existing values.

4.7. Conclusions

The Nissan catchment area is an important structure in the southern Swedish landscape. The agreement between the forest owner Sveaskog and Jönköping County have the purpose to develop broadleaved forest, imitate natural disturbances, and favour wildlife. The inventory showed that there were differences in stand structure between the water edge and the rest of the buffer zone. The conservation cuttings seem to be adapted to differences and promote established broadleaves and disturb the remaining stand to allow regeneration. However, it is too soon to comment on the success of the actual regeneration. The simulations showed the need of further active management in these stands if a broadleaved dominance is to be established and kept for the future.

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Appendix 1 - Extract of hemispherical photographs before and after processing