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The Future of Retention Forestry – the historical legacy in stands and its impact on retention in the next generation

Framtidens naturhänsyn i skogsbruket – Det historiska arvet i bestånd och dess inverkan på naturhänsynen i nästa generation

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Abstract

Today, around 55% of the world's forests are already managed for timber production and other values. The need for actions concerning the fast decline in biodiversity was in the late 20th century met by the uprising of retention forestry. Retention forestry integrates conservation in commercially managed stands, enabling variation, connectivity, and continuity across the landscape, which makes it an important supplementary strategy to protected areas. However, there are uncertainties around retention practices effectiveness to protect all functional groups of species because some of them depend on certain ecological structures (e.g. old trees, deciduous tree, and dead wood). Here, I use the term Ecologically Valuable Retention Trees (EVRTs) to describe trees that either have potential to develop or already have high ecological value. The Swedish Cellulose Company (SCA) is a major forestry actor in Sweden. Most stands that SCA final-fell today originate from forests shaped by selective cutting, while in the future most stands will originate from already cultivated forests. The overall aim of my study is to forecast what SCA's possibilities/restrains for retaining EVRTs and deciduous trees throughout final-felling will be in the future. By comparing stands that have been cultivated/clear-cut (CC) with stands that have never been clear-cut (NC), I focus on potential differences between the two stand types. I also discuss how this difference should influence the retention strategy within SCA and Swedish forestry. My study was performed in the county of Västerbotten in northern Sweden. I measured the number of EVRTs and the proportion of deciduous tree species in 14 NC and 14 CC spruce dominated stands (systematically sampled with a PPS method). 10 sample plots with a 10-meter radius were systematically fitted within each stand. My results show that there will be less EVRTs in the future and that the deciduous proportions will remain similar. There are potential ways to mitigate the lack of ecologically important components in managed forests in the future, e.g. release thinning to promote the development of EVRTs, prescribed burning, and larger retention patches. My study shows that it will be increasingly critical to meticulously mark and protect EVRTs through the whole rotation period as well as to create/promote new ones for the future. Lastly, this study also stresses the continuous need of formal protection of forests with high ecological value and larger voluntary set asides because they function as irreplaceable supplements to retention forestry.

Keywords: Green tree retention clearcutting biodiversity ecological structures management landscape continuity secondary forests conservation threatened species

Sammanfattning

Idag är runt 55% av världens skogar redan aktivt brukade för timmerproduktion och andra nyttor. Den hastiga minskningen av biologisk mångfald i brukade skogar drev i slutet av 1900-talet på utvecklingen av naturhänsynen i skogsbruket (*Retention forestry).* Genom att lämna kvar träd efter avverkning kan variation, konnektivitet och kontinuitet skapas på landskapsnivå – en strategi som utgör ett viktigt komplement till formellt skyddade områden. Det finns samtidigt en viss osäkerhet kring hur väl naturhänsynen kan skydda alla funktionella grupper av arter eftersom vissa är beroende av specifika ekologiska strukturer (e.g. gamla träd, lövträdsarter och död ved). Träd som har stor potential att uppnå eller redan uppvisar höga naturvärden kallas allmänt för naturvärdesträd. I min studie använder jag termen *Ecologically Valuable Retention Trees* (*EVRTs),* vilken även syftar till att de lämnas kvar vid slutavverkning. Skogsföretaget SCA är en stor aktör inom svenskt skogsbruk. De flesta bestånd som SCA slutavverkar idag är präglade av olika typer av selektiv huggning, medan bestånd som ska slutavverkas i framtiden redan kommer ha kalavverkats och kultiverats. Det övergripande syftet med min studie är att förutspå hur många *EVRTs* och hur stor andel lövträd som finns att lämna kvar vid slutavverkning i framtiden. Genom att jämföra kultiverade/kalavverkade bestånd med bestånd som inte blivit kalavverkade, undersöker jag eventuella skillnader mellan dessa beståndsstyper. Jag diskuterar också hur dessa skillnader kan påverka framtida strategier för naturhänsyn inom SCA och svenskt skogsbruk. Min studie är utförd i Västerbottens län i norra Sverige. Jag inventerade antalet *EVRTs* och andelen lövträd i 14 kultiverade/kalavverkade och 14 icke-kalavverkade grandominerade bestånd (samplade genom systematiskt PPS-urval). 10 cirkelprovytor med radien 10 meter fördelades systematiskt ut inom varje bestånd. Mina resultat tyder på att det kommer att finnas färre *EVRTs* i framtiden och att lövandelen förblir densamma. Det finns flera möjligheter att lindra minskningen av ekologiskt värdefulla strukturer i brukade skogar i framtiden, e.g. genom frihuggning som främjar framtida *EVRTs,* hyggesbränning och att lämna kvar större trädgrupper. Min studie visar att det blir ännu viktigare att i framtiden märka och skydda, liksom aktivt gynna nya, *EVRTs* genom hela rotationsperioden. Min studie betonar även vikten av formellt skyddade skogar med höga naturvärden samt större frivilliga avsättningar eftersom dessa kommer att vara ovärderliga komplement till den generella naturhänsynen även i framtiden.

Nyckelord: Naturhänsyn trakthyggesbruk biodiversitet ekologiska strukturer skogsskötsel landskap kontinuitet sekundärskog bevarande hotade arter

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Abbreviations

CC stands	Cultivated/Clear-cut Forest Stands
EVRT	Ecologically Valuable Retention Trees
FSC	Forest Stewardship Council
GIS	Geographic Information System
GPS	Global Positioning System
GTR	Green Tree Retention
SCA	Swedish Cellulose Company (Forestry Company)
NC stands	Non-Clear-cut Forest Stands
NGO	Non-Governmental Organisation
PEFC	Programme for the Endorsement of Forest Certification
PPS	Probability Proportional to Size (sampling method)
SLU	Sveriges Lantbruksuniversitet (Swedish University of Agricultural Sciences)

1 Introduction

1.1 Background

The conflict between high fibre production and other ecosystem services, such as water quality, climate change mitigation, recreational use, soil protection, and biodiversity, has been intensified in forestry worldwide (Rist & Moen, 2013). The demand for renewable forest products has led to many societal conflicts over the use of forests, which in many parts of the world has resulted in allocating more areas to both protected areas and highly productive plantations (Gustafsson et al., 2012). Although net forest cover in the world's temperate regions increased with 2.2 M ha year^{-1} during the years 2010-2015, the growing pressure from forest goods and services makes sustainable forest management more challenging than ever (Keenan et al., 2015; Bennet & Balvanera, 2007). Many irreplaceable ecosystem services on which we depend and are challenged to maintain are connected to biodiversity. Rockström et al. (2009) addresses the global loss of biodiversity as an urgent problem which could severely affect ecosystem services and resilience. Main drivers to terrestrial species loss are deforestation of primary forests and land degradation pressured by human population growth (Pahari & Murai, 1999). Although the removal of primary forests and land degradation are major global problems (Geist & Lambin 2002), 55% of the world's forests are secondary and already managed for fibre extraction and other values (FAO, 2010). The management in production forests usually have sustainable timber harvest and economic profit as the main drivers while ecosystem functions are not necessarily secured (Bengtsson et al., 2000). The need for actions concerning the fast decline in biodiversity was in the late 20th century met by the uprising of retention forestry (Lindenmayer et al., 2012). Retention forestry (commonly referred to as "green tree retention") integrates conservation in commercially managed stands, enabling variation, connectivity, and continuity across the landscape, which makes it an important supplementary strategy to various forms of protected areas (Gustafsson et al., 2012). Where strictly protected areas are too few and too small, conservation efforts in secondary forests is crucial (Wilcove, 1989). Retention forestry can help secure global sustainability of environmental, economic, and cultural aspects of forest ecosystems (Lindenmayer et al., 2012).

The relatively small proportion and uneven geographical distribution of protected forest area in Sweden and other Nordic countries make retention forestry essential to protect biodiversity on a large scale (Mönkkönen, 1999). It has been shown that green tree retention (GTR) is an effective conservation practice in boreal ecosystems, but there is also a great deal of uncertainties around its effectiveness to protect all functional groups of species (Matveinen-Huju et al., 2006). Some species depend on certain structures like large diameter trees, why long-term retention actions are needed to achieve continuity of old forest characteristics (Lämås et al., 2015). Linder & Östlund (1998) show that many ecologically important structures have critically decreased in Swedish forests since the late 1800's and suggests that all remaining old-growth characteristics should be preserved. Fire-dependent tree species like *Salix caprea, Betula pendula*, and *Populus tremula,* which supports a high number of forest species, have drastically declined in boreal ecosystems (Östlund et al., 1997). Especially the deciduous element of pine-dominated forests has been eradicated. It is evident that structural stand characteristics and tree species composition have been altered to a very large extent since the 17th century when logging in Sweden did not yet affect the forest landscape other than on a local scale (Östlund & Linderson, 1995). By removing natural forest structures and dynamics, forestry has contributed to the decline of potential habitat for many threatened forest living species (Sandström et al., 2015). Swedish forestry companies have a large responsibility in limiting the impacts of forestry on flora and fauna as well as on soils and watersheds.

Sweden uses a multi-scaled approach to conservation that can be divided into three levels (Simonsson et al., 2015). The highest level of protection is represented by formally protected areas and larger set asides over 20 hectares (mostly state owned), the medium-scale by voluntary set asides of about 0.5-20 hectares, and the small-scale by retention of trees, tree groups, and areas of 0.5-1 hectare. By using a multi-scaled conservation strategy, consideration is taken to different scales of ecological processes and the risk of conservation measures being ineffective is spread out (Lindenmayer et al., 2006). Although retention forestry represents the lowest form of conservation it becomes important on a landscape level (Gustafsson et al., 2010). Trees that show high ecological value (in Swedish "*naturvärdesträd")* are especially important to protect and retain. The Swedish Forestry Agency ("*Skogsstyrelsen")* describe them as important trees for biodiversity with high potential for habitat of rare invertebrates, fungi, mosses, lichens, and birds, to mention some (Skogsstyrelsen, 2014). Alive "*naturvärdesträd*", and dead wood of them, function as crucial substrate for many forest species.

The Swedish Cellulose Company (SCA) is northern Europe's largest private forest owner with 2.6 million hectares of forest land and is a major actor in Swedish forestry (SCA, 2019a). As for most forest owners in Sweden, the main part of their conservation efforts is expressed during final-felling. Individual trees and tree groups are left with priority to buffer zones around streams and lakes, on ravines, in rocky areas, in swamps, and in sensitive biotopes (SCA, 2019b). Within harvested stands, 5% of the timber volume is left on average. Trees that show high ecological value (e.g. old-growth trees, certain deciduous trees, and fire scared trees) are planned to always be retained after final-felling (although some of them are likely to be windthrown after harvest) (Lavoie et al., 2012). Here, I use the term Ecologically Valuable Retention Trees (EVRTs) to describe trees that either have the potential to develop or already have high ecological value, which are also subjects for retention during final-felling.

The forest utilization history in stands that SCA harvest varies because they originate from a time when large changes in Swedish forestry occurred and harvest practices were different from today. During the 1800s, the most common form of harvest in northern Sweden was high-grading (i.e. cutting larger trees first) and other forms of selective cutting methods (Lundmark et al., 2013). Clearcutting was first discussed and introduced in the late 1800s and in the 1940's both selective cutting and clearcutting were viewed as rational forest management. It was not until after the 1940's that clearcutting took over as the main forestry practice. It is therefore reasonable to believe that most stands that SCA final-fell today originate from forests shaped by selective cutting. These forests have remnants of natural forest characteristics and should have some continuity of old trees (Lämås et al., 2015). However, it is not certain that all stands that are final-felled today have not been clear-cut before since the history of clearcutting is more complex than commonly believed. Some stands have possibly already been clear-cut and are now in the second rotation of clearcutting and planting (Lundmark et al., 2013). In the future SCA will more extensively final-fell already cultivated forests, i.e. stands that have already been clear-cut and planted. This will mean a shift in what type of stands that are being final-felled. The future stands will most likely be more homogenous in terms of stand structure, tree age, and potentially tree species composition. My study focuses on how this future shift will affect the degree and quality of conservation values that are left after final-harvest, into the new stand.

1.2 Aims of the Study

The overall aim of my study is to forecast what SCA's possibilities/restrains for retaining Ecologically Valuable Retention Trees and deciduous trees throughout final-felling will be in the future (when the major part of the final-felling will be of cultivated stands). By comparing stands that have been cultivated/clear-cut (CC) with stands that have never been clear-cut (NC), I focus on potential differences between the two stand types. To better understand the origin of the NC stands, I also investigate the tree age structure within them.

The specific questions I want to answer are the following:

(1a) How will the presence of Ecologically Valuable Retention Trees change when SCA start to final-fell stands on the second rotation of clearcutting?

(1b) How should this difference influence the strategy of retention trees in SCA's forestry?

(2) What is the potential for retention of deciduous trees in the future based on their occurrence in CC vs NC stands?

(3) What is the tree age structure within the NC stands and how can it be used to determine whether they have been subjected to clearcutting or not?

Based on these results, I also discuss how retention practices might need to change in the future, and thus widen the future perspectives on retention forestry in northern Sweden.

2 Materials and Method

2.1 Background to Retention Forestry

2.1.1 The Emergence of Retention Forestry

The retention forestry approach originates from the pacific north-west in North America. Developed in the 1980's it was marketed as "new forestry" but also referred to as "green tree retention" (GTR) or "variable retention". It has since then become a well-known concept around the world and an applied forestry practice in many boreal and temperate regions of the world (Gustafsson et al., 2012). The idea behind retention forestry is to maintain or create a complex stand structure and species composition that is favourable for biodiversity, aesthetic values, and other values. Implementation varies depending on ecosystem and specific goals, but always involves some level of retention of individual trees (live, snags, and downed-logs) or tree groups during regeneration harvest (Franklin et al., 1997). Franklin et al. (1997) lists three main purposes of GTR practices: (1) Lifeboating of species over the regeneration phase and into the new forest stand, (2) Increasing the structural variation of the new stand, and (3) Enhancing connectivity in the forest landscape. Two additional benefits are to sustain ecosystem functions and to preserve species that depend on dead wood and live trees in an early successional state (Gustafsson et al., 2010). Retention of trees is today to a various extent incorporated into forest management in Sweden, Finland, Norway, the Baltic states, Germany, Canada, the United States, Argentina, and Australia (Gustafsson et al., 2012). The introduction of forest certification (e.g. FSC and PEFC) has, by including elements of retention, helped propel the global spread of retention forestry. These concepts have also been included in legal policy in North American and European countries, including Sweden.

Although GTR has many positive effects on biodiversity, they are likely to vary depending on the structural legacy, presence of old-growth trees, species composition, level of natural disturbances and number of large snags and downed-logs (Hansen et al., 1991). Rosenvald & Lõhmus (2008) found that only certain taxa respond well to GTR in comparison to traditional clearcutting. In a long term-perspective, GTR does not seem to effectively preserve species that depend on forest-interior conditions and some early-successional species (Fedrowitz et al., 2014). There is little known about how retention of trees affects landscape connectivity (i.e. dispersal and extinction-immigration dynamics) and how the forest utilization history affects the efficiency of retention forestry (Rosenvald & Lõhmus, 2008; Kouki et al., 2011).

2.1.2 History of Retention Forestry in Sweden

Ideas about retention forestry appeared for the first time in Sweden in the beginning of the 1970's when the criticism towards large clear-cuts was prominent (Simonsson et al., 2015). Already in the 1940' and 1950's, the increased use of clear-cut forestry started a major shift towards monocultural single-storied stands (Östlund et al., 1997). Simonson et al. (2015) show that the primary concept behind retention of trees and groups of trees was in the beginning mainly to improve the aesthetic values of the clear-cuts, as an attempt to gain more public acceptance of them. The focus towards the negative ecological effects of clearcutting gained momentum in the late 1970's when ecologists expressed concern about the biodiversity losses in forest ecosystems. At that time, foresters disregarded the knowledge of others and viewed the conflict solely as an information problem, which upset environmentalists from NGOs such as the Swedish Society for Nature Conservation ("*Naturskyddsföreningen*"). In the late 1980's a more constructive conversation between the two groups had emerged and the need of more reserves, forest continuity, and retention forestry was recognized in the Forestry Act, which soon required retention of trees in all clear-cuts (Simonsson et al., 2015). With the birth of FSC in the mid 1990's the creation of a Swedish FSC standard was soon developed including retention requirements of at least 10 living large and old trees ha^{-1} (on average) and all dead wood (Gustafsson et al., 2010). From being one of the first countries to implement retention forestry, its practices are today widely used by both forest companies and individual forest owners in Sweden (Gustafsson et al., 2012). With both legislation and certification as a backbone, retention practices define Swedish forestry today. The Swedish forestry model has historically been and is in present times characterized by the mantra "freedom under responsibility" (Ekelund & Hamilton, 2001).

2.2 Field Data Collection and Analysis

2.2.1 Study Area Description

The study area is located within a coastal forestry district owned by SCA located in the county of Västerbotten (64°N, 20°E) in northern Sweden (Figure 1). It represents a total area of 116 612 hectares, of which 112 719 hectares productive forests land and actively managed. The studied forest stands are mostly situated north-west of the coastal town Nordmaling.

The superficial geology consists mainly of moraines, mostly with local bedrock as parent material but sometimes with a mix of more nutrient rich minerals transported from far away (Lindström et al. 2000). Pelagic, washed up, sediment soils are commonly found in the areas that are situated under the historically highest coast line and glaciofluvial deposits (appearing as large ridges) are interspersed in the landscape. Forests are dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Birch (*Betula pubescence* and sometimes *Betula Pendula*) is the most common deciduous tree species followed by Aspen (*Populus tremula*), Sallow (*Salix caprea*), Rowan (*Sorbus aucuparia*), and Grey alder (*Alnus incana*). The field layer consists mainly of dwarf shrubs such as Blueberry (*Vaccinium myrtillus*), Lingonberry (*Vaccinium vitis-idaea*), and Heather (*Calluna vulgaris*) mixed with grasses and herbs. The bottom layer consists predominantly of mosses, often *Hylocomium splendens* and *Pleurozium shreberi*, and various lichens. Moose are widely present in these forests and their selective browsing on young trees is sometimes retarding regeneration (Hytteborn et al., 1987).

2.2.2 Stand and Plot Sampling

I sampled stands by using the following basic inclusion criteria: all stands had to be spruce dominated (>60% spruce) and the stand age between 55-70 years for Cultivated/Clear-cut (CC) stands and 100+ years for Non-Clear-cut (NC) stands. The CC stands in the study area had 15-20 years left prior to final-felling. By setting the NC stand age limit to 100+ years, the likelihood of them being historically clear-cut is low. However, there is no guarantee that they have not been clear-cut because this practice was widely applied in Sweden already during the early 1900s (Lundmark et al., 2013). tands of both forest types respectively were randomized using PPS sampling (Probability Proportional to Size) from a total of 162 NC stands and 59 CC stands. This gave larger stands, which represents a greater proportion of the total area, a higher probability to be included. The size of the studied stands ranged between 2.3 hectares and 22.8 hectares.

I laid out circular plots by spatially distributing 10 plot centres evenly within each stand. The positions of the sample plots were created by running a “fishnet tool” in ArcGIS (ESRI, 2017). The tool provided a “net” of points within each stand, where each point represented the centre of a sample plot and the starting point was random. The radius of the plots was 10 meters. I used the mobile phone application *Avenza Maps* together with the GPS and orthophoto maps to navigate to the sample plots (Avenza Systems, 2019). A compass direction was set to objectively walk the last 10 meters to each plot centre. From the sampled 20 CC+ 20 NC stands, I collected data from 14 CC stands and 14 NC stands (Figure 1). Six of the NC stands and one of the CC stands I planned to visit turned out to be recently clear-cut or in other ways inaccessible and could not be used.

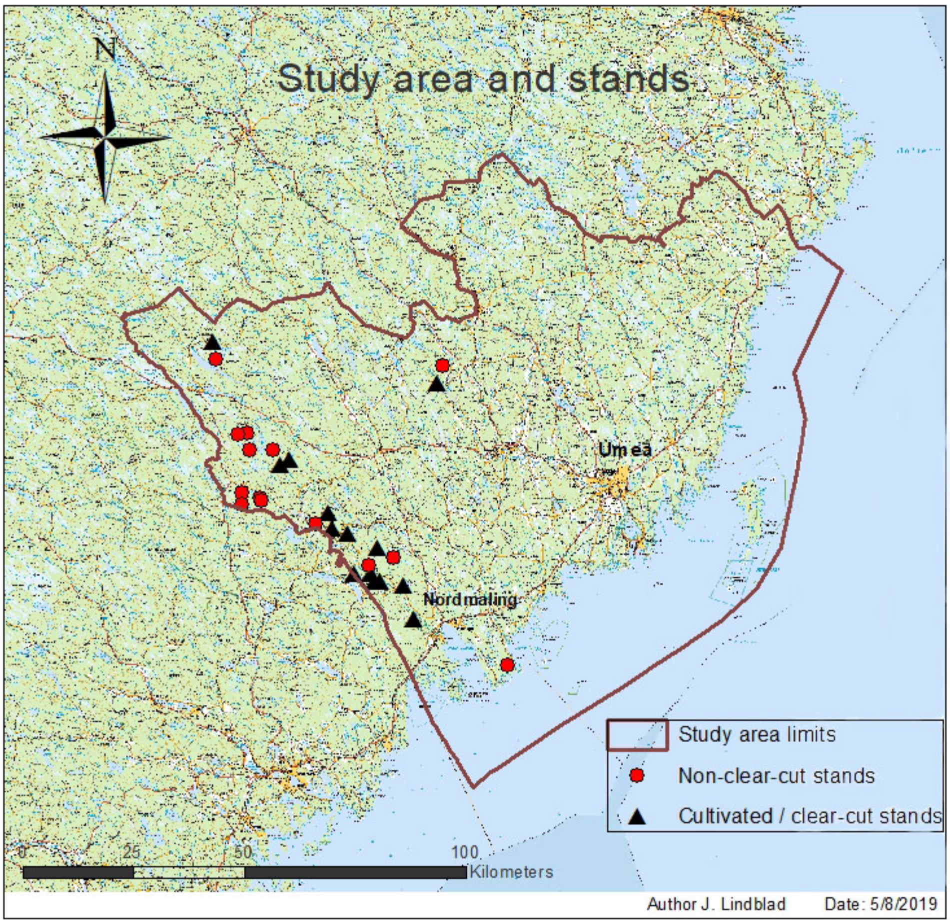

Figure 1. Map of the study area and locations of all 28 studied stands

2.2.3 Ecologically Valuable Retention Trees

The criteria for Ecologically Valuable Retention Trees (EVRTs) used are the same as the criteria that the Swedish Forestry Agency and SCA uses to define "*naturvärdesträd*" ("ecologically valuable trees"). My evaluation method was calibrated in the field with the assistance of a conservation specialist from SCA. EVRTs are generally thick, old, or divergent from the rest of the forest stand (detailed descriptions of criteria in *appendix 1*).

General characteristics are visible old cultural markings, open fire scars, thick branches, well-developed/mature canopy, and animal nests (Skogsstyrelsen, 2014). For spruce, thick plated bark and wrenched steeper hanging branches are strong indicators. For pine the bark is even thicker and clearly plated, the canopy is flattened, branches thick, or the tree has an open fire scar. Criteria for old-growth aspen are knots caused by stem rot and a more wrinkled thicker bark. EVRTs of birch also show thick bark and a mature canopy. Sallows and rowans that are tree shaped and vital (over 5 cm dbh) are also included. The tree dimeter at breast height is naturally a strong indicator of maturity/age why spruces > 60 cm dbh, pines > 50 cm dbh, and aspen/birches > 40 cm dbh are automatically classified as EVRTs. However, if a tree fulfils other criteria it could nevertheless be regarded as an ERVT.

Figure 2. Example of an Ecologically Valuable Retention Tree - an old-growth *Pinus sylvestris* with fire scar. (Photo: Jan Lindblad, SLU.)

2.2.4 Field Data Collection – EVRTs and Tree Species Composition

I inventoried EVRTs and measured their diameter with a caliper. If a part of the plot was laid out outside of the stand, this area was mirrored, and I counted EVRTs within the mirrored area twice. Tree species specific basal area was measured with a relascope and top height for spruce with a Haglöfs digital height meter. The two top height trees were the thickest spruces in the plot that had no obvious damages or deviations. I calculated mean basal area for every species and mean top height for spruce within each stand and the means for all CC and NC stands respectively. Templates for thinning from the Swedish Forestry Agency were used to estimate the total stand volume per hectare (Skogsstyrelsen, 1985).

2.2.5 Increment Core Sampling

I extracted an increment core from the first spruce that fell within the relascope, starting towards north and going clock-wise, in each plot. I drilled as far down the stem and close to the ground as possible by using a 400 mm long increment borer. If the pith was missed, or the stem had rot, I also measured the diameter at the height of the drilling hole. I rolled every increment core in a sheet of paper and sealed it with duct tape. The samples were stored dry in paper bags until analysis to prevent moulding.

2.2.6 Increment Core Analysis

I analysed the increment cores in the forest history lab at the University of Agricultural Sciences in Umeå. I prepared each increment core sample by gluing it to a wooden batten and sand it twice (with a rougher and a finer coarseness) using a belt sander. Zink paste was applied to increase contrast between rings. The year rings were then counted by putting each sample on a high precision movable board while using a stereo microscope. Extra years were added to samples that missed the pith by using a correction template with concentric rings or by using the diameter to visually estimate how many rings that were missing. I also visually examined growth patterns and year ring width differences among the 10 samples within each stand.

2.2.7 Statistical Calculations and Analysis

I estimated the number of EVRTs of each tree species in each of the 28 stands by using the Horvitz-Thomson method for PPS sampling (Probability Proportional to Size) (equation 1).

Equation 1.

$$y_i = \frac{F_1F_2}{A}\sum_{j=1}^{10} y_jI_j$$

where

$\boldsymbol{y_i}$ *is the estimated number of EVRTs in stand* ***i****;*

$\boldsymbol{y_j}$ *is the observed number of EVRTs in plot* ***j****;*

$\boldsymbol{F_1}$ *and* $\boldsymbol{F_2}$ *are grid lengths in meter for north/south and west/east directions respectively; and*

$\boldsymbol{I}$ *is an indicator for tree species.*

According to the systematic PPS method, I calculated the inclusion probability for each of the sampled 20 CC and 20 NC stands. The 40 stands were randomized from a total of 59 CC and 162 NC stands respectively (equation 2).

Equation 2.

$$\pi_i = \lambda * x_i \qquad (2.1)$$

$$\lambda = \frac{n}{X} \qquad (2.2)$$

where

$\boldsymbol{\pi_i}$ *is the inclusion probability for stand* ***i****;*

$\boldsymbol{\lambda}$ *is a probability constant;*

$\boldsymbol{x_i}$ *is the stand size for stand* ***i*** *in square meters; and*

$\boldsymbol{X}$ *is the total area in square meters of all stands within the total CC and NC area respectively*

By using the Horvitz-Thomson formula for PPS sampling, I estimated the total number of EVRTs in all 14 NC and 14 CC stands respectively (equation 3).

Equation 3.

$$\hat{Y} = \sum_{i=1}^{14} \frac{y_i}{\pi_i}$$

where

$\boldsymbol{\hat{Y}}$ *is the estimation of the total number of EVRTs;*

$\boldsymbol{y_i}$ *is the estimation of the number of EVRTs in stand* ***i****; and*

$\boldsymbol{\pi_i}$ *is the inclusion probability for stand* ***i.***

Lastly, I did variance calculations for the estimations of the total as well as the tree specific numbers of EVRTs for CC and NC stands respectively (equation 4). By comparing these values ± two standard deviations, it could be determined whether there were any statistical differences in the number of EVRTs between the CC and NC forests.

Equation 4.

$$VAR(\hat{Y}) = \sum (\hat{y} - \hat{\bar{y}})^2$$

where
$\hat{\boldsymbol{Y}}$ *is the estimated total number of EVRTs;*
$\hat{\boldsymbol{y}}$ *is the estimated number of EVRTs in each stand; and*
$\hat{\bar{\boldsymbol{y}}}$ *is the estimated mean for all studied stands within CC and NC stands respectively*

3 Results

3.1 Stand Structures and EVRTs

The studied forest area displayed a variety of managed spruce dominated stands. Stand characteristics varied to some degree between all stands although NC and CC stands differed in a few aspects. The CC stands were often more homogenous than the NC stands in spatial distribution of trees and had less tree diameter variation. The forest structure in NC stands were often more complex and multi-storied. There were in general more stands that displayed a mature open stand structure within the NC forest while CC stands were denser. Some stands of both forest types contained wetter areas, e.g. mires and streams, and/or gaps with rocky impediment, where productivity is lower. The majority of the observed EVRTs were found in NC stands. In most CC stands only one single or a couple of EVRTs were observed in total. In contrast, it was common to count a total of around 8-12 EVRTs in NC stands. The estimated mean of the total number of EVRTs per hectare is 20.5 / ha (±1.26) for NC stands and 1.4 / ha (± 0.06) for CC stands (± two standard deviations give the intervals 19.99-23.03 EVRTs / ha and 1.23-1.47 EVRTs / ha for NC and CC stands respectively).

I found EVRTs of spruce, pine, birch, aspen, and sallow. Some stands were dominated by EVRTs of spruce, others of pine, and some had a higher proportion of deciduous species. There were more EVRTs per hectare of all species in the NC forest than in the CC forest and the greatest difference is seen for spruce (Figure 3). There were 8.91 spruces / ha (±0.93) and 0.05 spruces / ha (±0.00) in NC and CC forests respectively. Another distinct feature of CC stands was the absence of birch-EVRTs. The least dramatic difference between the two forest types was the number of EVRTs of sallow; CC stands had 0.67 individuals / ha (±0.02) and NC stands had 1.76 individuals / ha (±0.20).

The defining characteristic of observed EVRTs include thick bark, wrenched branches, a flattened mature canopy, open fire scars, fungi inflicted knots (aspen), and large diameter trees. Diameter was only sometimes the determining factor, instead trees were often included by other characteristics indicating old age. The diameter at breast height ranged between 26.0 - 56.0 cm for spruce, 23.6 - 55.0 cm for pine, 21.6 - 47.3 cm for birch, 12.6 - 49.9 cm for aspen, and 5.3 - 45.2 cm for sallow. Open fire scars were uncommon, only a few pines displayed this. No cultural traces or markings were observed among the inventoried EVRTs.

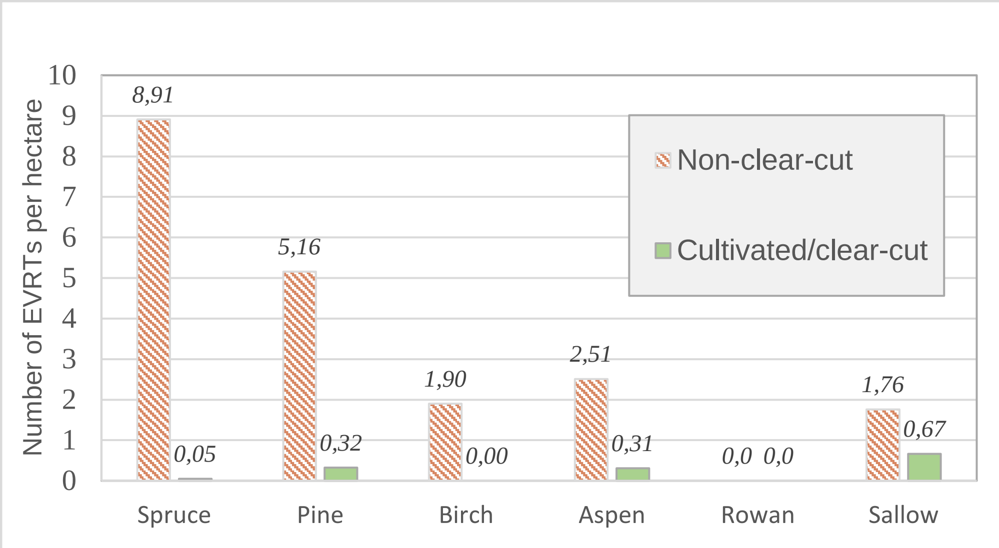

Figure 3. Estimated mean number of ecologically valuable retention trees of each tree species per hectare for non-clear-cut and cultivated/clear-cut stands respectively. The variances for NC/CC forest areas respectively are for spruce ±0.93/±0.00, pine ±0.49/±0.01, birch ±0.39/±0, aspen ±0.42/±0.01, and sallow ±0.20/±0.02.

3.2 Tree Species Composition

The mean proportions of deciduous trees were similar between the total NC and CC forest land (Table 1 and Table 2). The ratio was 14.3 % deciduous / 85.7 % conifer for NC stands and 14.5 % deciduous / 85.5 % conifer for CC stands. The mean total standing volume was estimated to 135 m^3sk/ha (±26) and 162 m^3sk/ha (±34) for CC and NC stands respectively. The 28 stands varied in tree species composition although spruce was always dominant, pine often the second, and birch often the third most common. The most birch (27.4 %) was found in stand CC 1 and the least (0 %) in CC 14, which consisted only of spruce and pine. Stand CC 6, CC 8, and NC 1 were the only stands with a substantial amount of aspen. There was no rowan, the occurrence of sallow were sparse, and for alder it was almost non-existent. The deciduous proportion ranged from 0 % to 28 % within each of the 28 stands. Only five stands (CC 3, CC 14, NC 2. NC 9, and NC 10) had a deciduous proportion below 5 %.

Table 1. *Mean basal area in square meters per hectare and each tree species proportion of the total basal area for cultivated/clear-cut stands.*

CC	Spruce	Pine	Birch	Aspen	Rowan	Sallow	Alder
Basal area	*12.5 (±3.64)*	*4.2 (±2.65)*	*2.3 (±1.61)*	*0.4 (±0.80)*	-	*0.1 (±0.07)*	*0.1 (±0.14)*
Proportion	63%	22%	12%	2%	0%	0%	0%

Table 2. *Mean basal area in square meters per hectare and each tree species proportion of the total basal area for non-clear-cut stands.*

NC	Spruce	Pine	Birch	Aspen	Rowan	Sallow	Alder
Basal area	*13.7 (±3.64)*	*5.3 (±2.93)*	*2.8 (±1.83)*	*0.3 (±0.66)*	-	*0.1 (±0.14)*	*0.0 (±0.06)*
Proportion	62%	24%	13%	1%	0%	0%	0%

3.3 Age Variation in NC Stands

The NC stands showed all different levels of age variation among the sampled 10 spruces (Figure 3). The mean stand age ranged from 81 to 135 years. All stands except NC 8 and NC 13 had an age span of at least 50 years among the sampled spruces while several stands (NC 5, NC 6, NC 7, NC 10, NC 14) had an age spans of over 100 years. The oldest spruce was 254 years old and found in stand NC 5. The youngest one was 32 years old and found in NC 6.

The increment core analysis showed within stand differences in growth patterns and year ring width. In each stand, there were spruces that had very narrow juvenile year rings, i.e. slow juvenile growth, as well as individuals that showed rapid juvenile growth. Within several stands, it was evident that the relationship between age and diameter at the drill hole height varied between the sampled spruces.

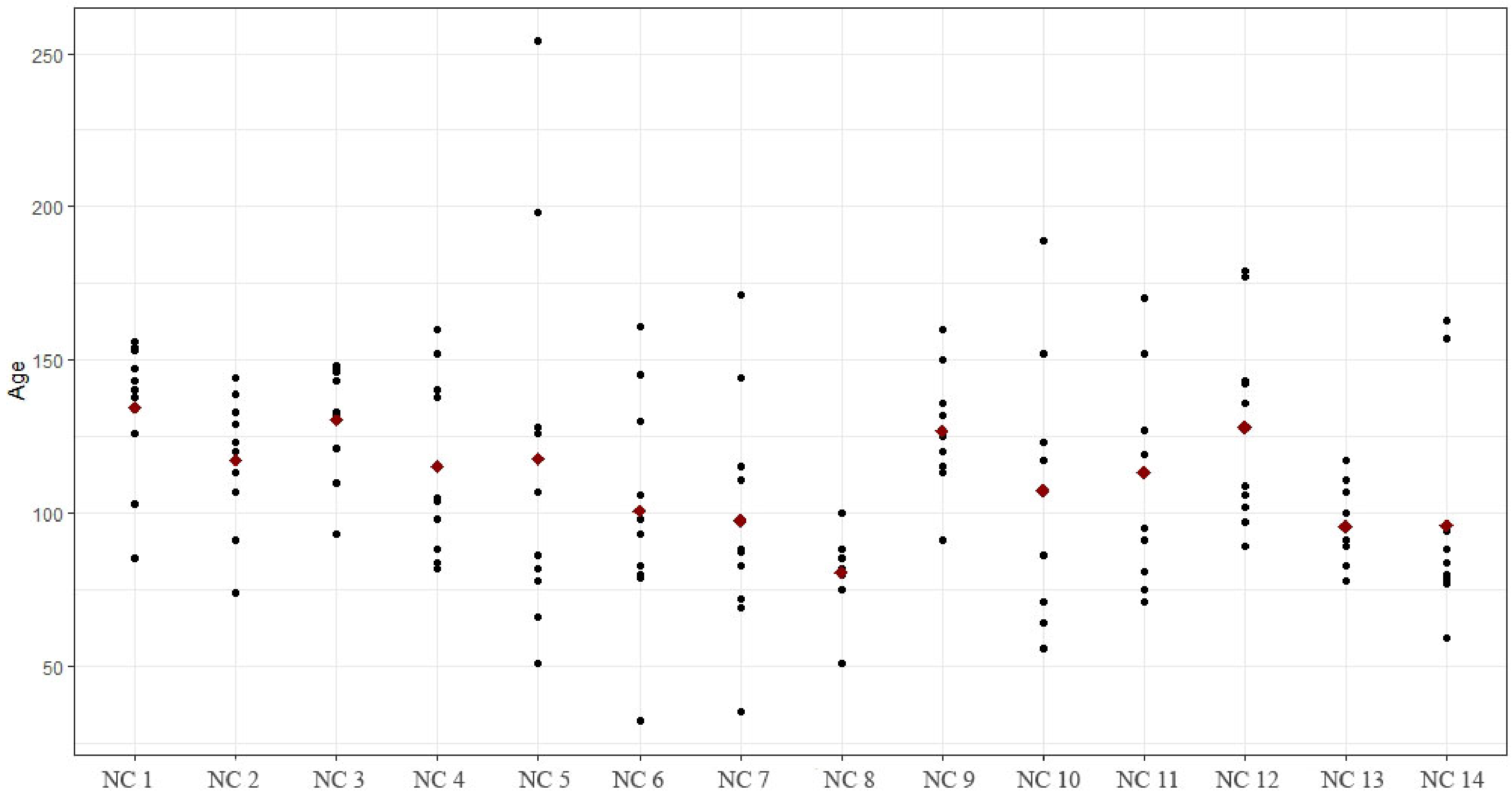

Figure 3. Tree age in years for each of the 10 sample spruces in each of the 14 non-clear-cut stands. The red squares mark the mean age for the 10 sample spruces within the same stand

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4 Discussion

In this study I have compared how the coming shift towards final-felling of cultivated/clear-cut stands (as opposed to stands with no history of clearcutting) will change the potential for retention of ecologically valuable trees and deciduous trees into the next generation. I will discuss the main results and focus on how the structural differences found between Cultivated/clear-cut (CC) and Non-clear-cut (NC) stands might influence future retention strategies.

4.1 Ecologically valuable retention trees in the present forest and the potential for retention forestry in the future

My results show a significant difference in the total number of ecologically valuable retention trees (EVRTs) between the two forest types NC and CC. Estimations show that EVRTs of each of the tree species spruce, pine, birch, aspen, and sallow are clearly more common in NC stands than in the CC stands. The retention of trees during past clearcuttings was most likely very low in CC stands, the few trees that were left were probably randomly retained with no other than aesthetic goals in mind (Simonsson et al., 2015). This legacy of reduced structural diversity has here limited the number of present EVRTs of all species. My comparison reveals an especially dramatic difference in the number of spruce-EVRTs, which are much less common in CC stands than in NC stands.

This study shows that the potential to retain EVRTs is lower in CC stands, which should lead to a future decrease in the number of EVRTs that is left after final-felling. In these stands, it will become important to re-develop old-growth attributes and to promote future EVRTs as they harbour habitat for many threatened forest species (Rosenvald & Lõhmus, 2008; Sandström et al., 2015). The need to manage for old-growth characteristics in production forests is increasingly recognized and valued by society (Bauhus et al., 2009). Cultivated forest stands that originates from the era of traditional clearcutting could need stronger attention around their ecological state, as shown in my results. The intensive management for production, which was the direction in Swedish forestry from over a century ago up to the 1990's, resulted in structurally simplified forests and species decline (Gustafsson et al., 2010), and today this past phase causes time-lagged ecological problems in forestry. While the total number of retention trees has increased in Sweden since the 1980's (Kruys et al., 2013), my study illustrates that their individual ecological value might be lower in the future – at least initially. This means that, even with a similar degree of retention at final harvest, the decrease of EVRTs could result in less ecologically valuable post-cut habitat/substrate and old-growth structures left into the next rotation, compared to today. The decline and relative absence of really old and large trees is a recognized problem in northern Sweden where forest landscapes have been structurally transformed since the 19th century (Linder & Östlund 1998; Östlund et al., 1997). A shift in management that restores structural complexity is needed in homogenized secondary forests (Bauhus et al., 2009).

4.2 Comparison of the Deciduous Component in CC and NC Stands

Although NC and CC stands diverged structurally, I found no general difference in their tree species compositions. The component of birch was the same while the occurrence of aspen, sallow, rowan, and alder were low or non-existent within both NC and CC forest areas. The tree species composition varied between all 28 stands, especially the amount of birch and the presence of aspen varied. Some NC and CC stands had a very small deciduous proportion, which might result in a local absence of deciduous trees for future retention. However, my results for the total area of 14 CC stands compared with the total area of 14 NC stands indicate that the deciduous component of retention trees will remain similar when cultivated stands are final-felled. However, it is important to note that old-growth attributes such as thick bark and branches, hollowness, and open scars are crucial for many threatened species that live on live or dead deciduous trees (Sandström et al., 2015). Even though there is an abundance of birch in CC stands, I found no EVRTs of birch in any of them which raises the questions on how to promote this ecologically important component in the future. My results also show that EVRTs of aspen and sallow are less common in CC stands. The deciduous trees, and the EVRTs, carry a very large share of the biodiversity in the boreal forest (Sandström et al., 2015). There is a general lack of old and large deciduous trees in Swedish boreal forests (Fries et al., 1997). The suppression of fire and the widespread use of herbicides during the

1950's – 1980's clearly have had far-reaching consequences on the occurrence of deciduous tree species in the forest landscape (Östlund et al., 1997; Laestander, 2015). The increased number of clear-cuts contributed to a dramatic increase of Sweden's moose population since the 1960's (Lavsund et al., 2003). The browsing by moose also led to a much higher pressure on deciduous trees in many areas. Selectivity by moose can cause a dramatic reduction of less abundant tree species such as aspen, rowan, and sallow (Edenius et al., 2002).

4.3 Origin of "Non-clear-cut" Stands

The age analysis generally supports the assumption that the NC stands have not been clear-cut and artificially regenerated. Even though the age span between sampled spruces varies from stand to stand, the relatively high degree of variation makes it likely that all of them have not yet been clear-cut. A possibility which cannot be totally ruled out is that smaller clear-cuts could have been carried out within some of the stands, even if no obvious signs of this were observed in field. The large variation in year ring width among spruces in NC stands further supports that they have been naturally regenerated. It should be mentioned that cultivated stands are not expected to have a completely homogenous age structure either because planting is never 100% successful and natural dynamics will always shape a stand to some degree. However, the age variation shown within most studied NC stands is likely to be too large for a stand that have been clear-cut and artificially regenerated.

4.4 Limitations in the CC / NC Comparison

The CC stands in this study were the oldest (55-70 years) spruce dominated cultivated stands that could be found within the study area, while the NC stands were of 100+ years of age. This difference of 30-45+ years, makes the comparison of EVRTs between NC and CC stands somewhat imbalanced. The older NC stands are obviously more likely to have reached a mature state and thus contain more EVRTs. However, the CC stands are planned to be final-felled within 15-20 years, making this time more relevant to focus on from a forestry perspective. To compare EVRTs in NC and CC stands, I made the general assumption that EVRT-qualities will not develop in CC stands during the next 15-20 years. Another limitation of my study is the number of sampled stands; I sampled and inventoried 28 stands (14+14), of a total of 221 stands in the study area. Although a larger sample would have been better, it seems as if the results are statistically robust. The PPS-sampling method was useful because it put the focus on the whole CC and NC forest areas respectively rather than on individual stands.

4.5 Concluding Remarks – Implementations for Future Retention Forestry

Retention forestry has been a very important response to the decline of biodiversity caused by the loss of complexity and continuity of ecological structures in a managed forest landscape (Gustafsson et al., 2012; Franklin et al., 1997). Although green tree retention (GTR) is a prevalent practice in boreal ecosystems, little attention has, until quite recently, been given to ecologically valuable characteristics (e.g. age, diameter, shape of crown) of retained trees (Rosenvald & Lõhmus, 2008). These may determine the success of retention to lifeboat certain taxa/species groups (e.g. Sandström et al., 2015; Lõhmus 2006; Hazell et al., 2008). I conclude that the strategy for future retention within SCA's already cultivated/clear-cut stands might need to be extended to withhold the current ecological quality of retained trees. The amount of EVRTs in the studied CC stands are likely to mirror the future occurrence of EVRTs in similar stands that were clear-cut as late as the 1980's (i.e. before GTR were fully adopted).

There are potential ways to mitigate the lack of ecologically important components in managed forests in the future. One way is to increase old-growth continuity in future post-cut stands by promoting the development of EVRTs in earlier stages of the rotation period. Re-establishing deciduous species can be done by systematically release-thin around individuals of sallow, rowan, aspen, and birch already in the first (or second) thinning to strengthen their vitality. This kind of active conservation management could even be implemented already in the pre-commercial thinning stage. Another strategy is to use prescribed fires after final-felling to promote fire-dependent deciduous species. The regeneration of these tree species is likely to be extensive even though their representation were low in the stand before the fire (Granström, 2001). Other fire-favoured species like some plants, saproxylic fungi and insects, may require burning as a complement to GTR to be effectively protected (Granström and Schimmel, 1993; Wikars, 1997; Hyvärinen et al., 2005). However, I suggest that burning is carried out with such an intensity that present EVRTs are not killed. To successively create a continuity of EVRT-spruces in spruce dominated stands, I propose larger groups of them (also in combination with deciduous trees) should be left across the harvested area, not only in wetter areas. Spruces easily become windthrown if left unsheltered in paludified areas, or in too small groups after final-harvest (Vanha-Majamaa & Jalonen, 2001). Retention patch size is also crucial to maintain a moist microclimate on which some threatened mosses, fungi, and lichens (that live on old-growth spruce, aspen, and sallow) are dependent (Sandström et al., 2015).

Furthermore, I conclude that the future retention forestry needs to broaden the perspective of *what, where*, and especially *how* trees should be retained. To favour as many functional groups of species as possible in managed forests, the type of retention should be determined by the local natural disturbance regimes and ecological structures (Bauhus et al., 2009). On a stand level, retention might have to focus on protecting some prioritized structures whereas on a landscape level habitat connectivity and long-term continuity are more important. Furthermore, it is crucial to recognize the ecological value of the structures that are left post-harvest rather than randomly retain "ecologically trivial" trees and tree groups for aesthetic or practical reasons. Current retention practices do account for this, for example by leaving dead wood and snags or protecting stream and lakes but may fail in other aspects like preserving fire-dependent or management sensitive species. More applied research is therefore needed to better understand how retention forestry can fulfil multiple conservation targets (Rosenvald & Lõhmus, 2008). My study shows that it will be increasingly critical to meticulously mark and protect current EVRTs throughout the whole rotation period as well as to create/promote new ones for the future. Lastly, this study also stresses the continuous need of formal protection of forests with high ecological value and larger voluntary set asides because they function as irreplaceable supplements to retention forestry.

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Appendix

Detailed Criteria for EVRTs

These are the detailed criteria for EVRTs used in this study. They are mostly based (slightly modified) on the Swedish Forestry Agency's definition of *"naturvärdesträd"* (Skogsstyrelsen, 2014), and further specified in this chapter. Since sallow and rowan are very rare species, they are included as EVRTs not only when they already have high ecological values, but also for their potential to develop such values. If a criterion in *italic* is fulfilled, the tree is automatically classified as an EVRT. If not, all the other criteria (non-italic) need to be fulfilled to include it. All trees that have nests of predatory birds are also EVRTs.

Aspen

- *A diameter over 40 cm at breast height*
- Occurrence of fungi inflicted knots on the stem (indicates rot and old age)
- A crimped thicker bark

Pine

- *A diameter over 50 cm at breast height*
- Coarse and old branches (often very curved)
- Flat and well-developed crown
- Mature and plated bark (sometimes visually patterned like medallions)
- *Pre-dominant (trees with a crown that is above the general level of the canopy) pines from an older pine generation with divergently coarse branches.*
- *Open fire-scars that expose the wood*
- *Old cultural markings that reveals a historical way of living (examples are carvings, bark harvest, and different kinds of markings in the bark/wood)*

Sallow and Rowan

- *Tree-shaped, vital, and with a diameter over 5 cm at breast height*

Birch

- *A diameter over 40 cm at breast height*
- A wide and mature crown
- Thick plated bark

Spruce

- *A diameter over 60 cm at breast height*
- Plated bark
- Coarse branches
- "Hanging" branches that are more wrenched
- *Spruces that have been left from a time with a past land use of grazing. These have very wide branches that reach all the way down to the ground*.

SENASTE UTGIVNA NUMMER

2018:3	Författare: Hanna Glöd Forest drainage effects on tree growth in Northern Sweden. – Developing guidelines for ditch network maintenance
2018:4	Författare: Anna Jonsson How are riparian buffer zones around Swedish headwaters implemented? – A case study
2018:5	Författare: Martin Hederskog Är uteblivna bränder i skogslandskapet en bidragande orsak till igenväxning av myrmarker?
2018:6	Författare: Gustav Stål Carbon budgets in northern Swedish forests, 1800-2013
2018:7	Författare: Johan Gotthardsson Faktorer som påverkar antalet ungskogsröjningar i tallbestånd
2018:8	Författare: Rasmus Behrenfeldt Vindens inverkan på höjdtillväxten i ett tallbestånd (*Pinus sylvestris*) längs en sluttning
2018:9	Författare: Erik Sundström Brandhårdhetens påverkan på knäckesjukans omfattning på brandfältet i Sala
2018:10	Författare: Jenny Dahl How is soil carbon stock in old-growth boreal forests affected by management?
2018:11	Författare: Johannes Larson Know the flow – spatial and temporal variation of DOC exports and the importance of monitoring site specific discharge
2018:12	Författare: Sanna Nilsson Hur tidpunkten för och samordningen av föryngringsåtgärder påverkar föryngrings-resultatet och konkurrenstrycket i plantskogen
2019:1	Författare: Lina Arnesson Ceder Skogshistoria kommer upp till ytan – en akvatisk inventering efter samiskt påverkad död ved i tjärnar kring Mattaur-älven
2019:2	Författare: Linda Norén “Det var ett äventyr” – en studie om livet som flottare efter Piteälven
2019:3	Författare: Elin Edman Bladyta och virkesproduktion i fullskiktad granskog skött med blädningsbruk
2019:4	Författare: Sofie Dahlén Sjöbergh Skogskollo för tjejer – Vad hände sedan?
2019:5	Författare: Fredrik Ögren Hantering av forn- och kulturlämningar inom SCA Norrbottens skogsförvaltning – Informationshantering från planering till markberedning
2019:6	Författare: Elias Hannus Beslutsstöd för att finna diken och bedöma behov av dikesrensning