How hot are retention patches as structural hotspots?

- Comparing key elements for biodiversity in retention patches and reference forest stands

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Comparing key elements for biodiversity in retention patches and reference forest stands

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Abstract

Sweden's historical and current forestry regime has created structurally simplified forest stands with little resemblance of boreal old-growth forests, leading to a decline in many forest dwelling species. Retention forestry was introduced to counteract the negative development by retaining biologically important forest elements. Retention patches are intact forest areas left to represent conditions in the pre-harvest stand for harbouring of threatened species and structurally enriching managed forests. However, many biodiversity preservation goals connected to forests remain unfulfilled, which indicate a need for evaluation of what is retained during harvest and possible influences on why. I used the Swedish Forest Agency method for inventorying woodland key habitats to evaluate differences in substrate supply, conservational quality and physical prerequisites in retention patches compared to structurally similar reference forest stands located in spruce-dominated boreal forests in Hälsingland, Sweden. My results showed how retention patches scored lower in the natural value assessment, contained less deciduous live conservation trees and less coarse deadwood. In general, substrate amounts are either lower or indifferent in retention patches compared to in reference forests, indicating that retention patches are not structural hotspots. If retention patches do not hold equal conservation values as the pre-harvest stand, the forest landscape would continuously be impoverished, and the threatened species disfavoured. The structure of retention patches, underlying causes of retention decisions, and following implications for biodiversity need further studying to ensure that areas with the highest conservational importance are preserved.

Keywords: Retention forestry, retention patches, deadwood, live conservation trees, biodiversity preservation, substrate diversity

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Abbreviations

RF	Retention forestry
RP	Retention patch
RFS	Reference forest stands
LCT	Live conservation trees
LDW	Lying deadwood
SDW	Standing deadwood
CDW	Coarse deadwood
NVA	Natural value assessment
WKH	Woodland key habitat (Sw: Nyckelbiotop)
ONV	Woodland habitat of semi-high conservational value (Sw: Objekt med naturvärde)
LNV	Lower conservational value (Sw: Lägre naturvärden)

1. Introduction

1.1 Background

1.1.1 Forest landscape transformation in Sweden

Throughout history, human activities in northern Sweden's forests have up until a few centuries ago been small-scale practices like gathering of firewood, cattle grazing, or construction wood extraction, with local effects around settlements (Östlund, 1993). Fire and other natural disturbances has been the prevailing force altering the forest structure (Zackrisson & Östlund 1991; Östlund et al. 1997), leading to high levels of structural diversity with heterogenous stands containing large diameter trees, trees of very high age, high amounts- and a variety of deadwood in multistorey- and multidimensional stands (Linder & Östlund 1992). However, this started to shift with the pre-industrial cutting of deciduous trees and pine stumps and snags for potash burning and tar production followed by an industrialization of forestry from the second half of the 19th century with selective logging of large pine trees. Consequently, the forests of northern Sweden were to a large extent completely cleaned of almost all trees of a very high age (Linder & Östlund 1992). Following the pre-industrial selective logging and deadwood extraction was large scale intensive forest management with clearcutting, planting of trees and thinning that started to take place in the beginning of the 20th century (Östlund et al. 1997), and is up until today the prevailing forest management strategy. Deadwood elements characteristic for natural forests like lying- and standing deadwood, and dry snags have successfully been removed throughout the forest landscape as a consequence of both forest management and fire suppression (Linder & Östlund 1992).

Not only deadwood was influenced by the progression of forestry during the 20th century, but also the species composition. Axelsson et al. (2002) showed how the period when selective logging was dominant in Sweden favoured deciduous trees, whereas the following period with thinning operations, girdling and herbicide spraying in turn disfavoured deciduous trees. This development led to an extensive deficit of dead and old deciduous trees in Sweden's boreal forests. Over the course of one century, Sweden's forests had to a large extent been transformed, driven by human activities to extract timber and increase production. The successive development of intensified forestry led to a structural change from a complex forest composition prior to large-scale logging to a uniform structure with little resemblance of the old-growth forest it replaces (Östlund et al. 1997).

1.1.2 Swedish forest governance

As large-scale forestry progressed during the second half of the 20th century, the debate intensified on the consequences and clear-cut forestry started to face increasing criticism and resistance (Simonsson et al. 2015). Consequently, implications of large-scale forestry were investigated, and actions were taken to consider and incorporate biodiversity preservation in production forestry, resulting in a revision of the Swedish Forestry Act from 1979 (SFS 1979:429), creating the Forestry Ordinance of 1993 (SFS 1993:553) to be the main legislative document. The Forestry Ordinance states that the overarching goal for Swedish forests management is to provide long-term revenue while also maintaining biodiversity; a paradigm shift where environmental values were given equal importance as production values. The forest management and governance that emerged thenceforth is commonly referred to as the "Swedish forestry model" (KSLA 2012). Here, the model for protecting biodiversity is based on formally protected areas supplemented by voluntary set-asides and general consideration in forestry operations, encapsulated by the phrase "freedom with responsibility" (Appelstrand 2012; KSLA 2012). Furthermore, the Swedish Environmental Protection Agency (SEPA) have defined 16 Environmental Quality Objectives (Naturvårdsverket 2022a), of which one focuses on sustainable forests, (Naturvårdsverket 2022b). These goals were formed as guidance for policies and environmental work in all levels of society, including the forestry sector.

In parallel to a more voluntary-based forest legislation and setting environmental objectives, forest certifications emerged; a cornerstone proven effective in management towards biodiversity preservation (Lehtonen et al. 2021). Forest certification is an economic incentive with labelling of forest management and products, showing how companies comply with several defined sustainability criteria. In 2021, a vast majority of Sweden's forests were either certified with FSC (Forest Stewardship Council), PEFC (Programme for the Endorsement of Forest Certification) or both (Lehtonen et al. 2021; FSC 2022; PEFC 2022). Lethonen (2021) show how many of the FSC requirements were absent in the legislation and requirements were larger in scope, more quantitative and more specifically expressed than in the legislation, underlining forest certification's role in reaching environmental protection goals.

The environmental goals described in the Forestry Act were ambitious and high above legislated demands, putting high expectations on forest owners to voluntarily consider biodiversity in forest management. However, the voluntary-based approach in Sweden raises concerns as no legal sanctions also lead to uncertainty in accountability, compliance and legitimacy (Appelstrand 2012). It has been clearly shown how the use of the "Swedish forestry model" is incompatible with meeting the Environmental Objectives for sustainable forests (Naturvårdsverket 2015), as well as national and international biodiversity targets (Angelstam et al. 2020). Instead, the model has been criticised as economy-prioritizing and that it is based on the unrealistic assumption that the forest can provide "more of everything" (Lindahl et al. 2017). Therefore, it is of interest to evaluate and review the practical management actions aimed at considering natural values in the Swedish forestry model.

1.2 Retention forestry

Retention forestry (RF) is the conventional method for nature consideration in Swedish clear-cut forestry today, regulated by law and elaborated in forest certifications (Gustafsson et al. 2010). The overarching goal is to during harvest retain biological legacies to maintain biodiversity, structural continuity and ecosystem functions in a long-term perspective, over subsequent forest generations. This is done through retention of structural elements that take time to develop, thus rarely found in short rotational managed forests, like trees of a high age and old deadwood. The acceptable level of RF and how it should be practiced is concretized by the SFA (Claesson et al. 2013) and in detail regulated by certification schemes (Lehtonen et al. 2021). In the study area of the southern parts of northern Sweden, on average 10.1% of the harvested area was left as retention during final felling (Skogsstyrelsen 2018).

As defined by Franklin et al. (1997), there are three prominent functions of RF. Firstly, the function called "lifeboating" of species where patches of retained habitat should harbour threatened species during the clear-cut phase until conditions are re-established in the cut forest for species to recolonize. Secondly, RF should improve the structural diversity in the subsequent forest stand by retaining biological legacies over forest generations. Finally, RF should promote connectivity and green infrastructure to facilitate species movement throughout the forest landscape. Further functions identified are to promote saproxylic (deadwood dependent) species and species connected to live trees during the regeneration phase and to maintain ecosystem functions like productivity and retention of nitrogen (Franklin et al. 1997; Gustafsson et al. 2010). Research on RF and practical application over a long time span has strengthened the soundness of this management practice as a proven way to promote biodiversity in managed forests (Gustafsson et al. 2012).

Many red-listed species depend on the retained habitats with old-growth characteristics in the managed forest matrix and an important tool in maintaining biodiversity is to, by mimicking natural processes in forest management, incorporate natural forest structures into production forests (Fries et al. 1997). Further, allowing fire processes, increasing the amounts of deadwood and deciduous trees, and elevating the extent and quality of unmanaged forests are highly important measures to promote biodiversity in Sweden's boreal forests. Here, RF plays an important role in achieving a structural enrichment in all forest operations.

1.2.1 Retention patches

Retention patches are smaller forested areas left during final harvest to mitigate the negative impact on biodiversity, varying in size but mainly small areas around 0.01-0.5 ha (Djupström et al. 2008), also referred to as aggregated retention (Martínez Pastur et al. 2020). These smaller areas retained aims at maintaining habitat patches throughout a production forest matrix that holds a higher structural diversity and a higher amount of quality substrates, to enable the retention patch to act as a lifeboat for sensitive species. Successful retention forestry planning should therefore set aside areas with the highest nature conservational values in a stand and protect biotopes that contribute to maintaining the structural complexity on a landscape level (Gustafsson et al. 2012).

Additionally, RPs play an important role in maintaining the function of landscape connectivity, as RPs can work as "stepping stones" for species across the managed forest matrix, so that they can colonize new areas and maintain a viable population (Saura et al. 2014). The consequences of broken forest connectivity and habitat loss as a result of clearcut forestry vary depending on species characteristics. Some species with lower dispersal abilities require larger areas of intact habitat whilst survival of species that have better dispersal abilities may be promoted by facilitating habitat connectivity and improving the matrix composition and quality (Villard & Metzger (2014).

In accordance with the forest certifications, patches within a management unit with high natural values should be detained from any forestry measures that may negatively influence the values (FSC Sweden 2020). FSC encourages using the SFAs nature consideration targets (Claesson et al. 2013) when implementing forest management, as a basis for deciding on what is important to retain in a stand and what precautions management need to take. Examples of areas that require consideration could be older forests on bare rock, wet forests with virgin forest characteristics and moist areas along watercourses rich in vascular plants. These areas are often retained as retention patches when surrounding forests are clearcut. However, it is of importance that patches retained are representative of the forest removed when clearcutting for it to provide suitable habitat for species that are or are likely to be present in the stand (Perhans et al. 2009; Gustafsson et al. 2016).

The intention with RPs is to leave them unmanaged at least until the new forest stand has reached maturity for final harvest again. However, RPs are not under any formal protection and forest owners can cut or manage RPs much earlier if they want too. Nevertheless, the Forestry Ordinance states that nature consideration during harvest like retention of single trees, tree groups or deadwood should be protected in further management procedures (SFS 1979:429). Though, this lack of legislative protection leads to a level of uncertainty on the long-term benefits for biodiversity, as RPs can be removed or disturbed before the surrounding stand regain a suitable habitat status for harboured species. Furthermore, removing or degrading RPs counteracts the stepping stone function, central in species population viability, by connecting isolated suitable habitats (Saura et al. 2014). By investigating possible management actions in RPs, the long-term function can be evaluated.

Often mentioned when discussing species preservation in forest management is habitat and fragmentation threshold values, namely the amount of undisturbed intact habitat that if exceeded drastically lower the possibility for species long-term survival (Ovaskainen & Hanski 2003). This threshold is not based on the actual aerial proportion, but the remaining proportion of the original, or pre-industrial amount of the biotope or habitat needed for species survival. Simulations have shown that the threshold values of minimum habitat demands are positively affected by the quality of the matrix (Fahrig 2001). Therefore, retention forestry setting aside a diversity of biotopes and increasing the managed forest matrix quality can have a positive impact on the threshold values (Roberge 2018). In the Swedish model for preserving biodiversity, general nature consideration in management using RF and RPs should be seen as a complement to formally protected reserves, partially as it helps to fulfil the RF functions (Franklin et al. 1997), and with buffering the habitat thresholds. Additionally, RPs provide a divergent habitat that has shown to have a deviant species composition than reserves (Djupström et al. 2008), with species connected to sun-exposed habitats. However, as RF has been practiced for a relatively short period of time, it comes with a great level of uncertainty in the long-term effectiveness for biodiversity preservation. Therefore, it is of high importance to evaluate the outcome of current forest management practices and closely follow the development of Sweden's forest.

1.2.2 Current state of Sweden's forests

The historical development towards modern silviculture with rotation forestry and clearcuts has shifted the composition of boreal forests to something far away from what is expected to find in a virgin forest. The continuous exploitation of old growth forests and clearcut forestry with short rotation periods imply that there is not only an active loss of biological legacies but forests also fail to regenerate important substrates to maintain biodiversity under the short rotation forestry regime (Larsson 2011).

A substrate known to be of great importance for many species is coarse woody debris (CWD, including all deadwood >10cm in diameter) (Dahlberg & Stokland 2004) and one of the functional goals of RF identified by Gustafsson et al. (2010) is to increase the amount of deadwood to promote deadwood dependent species. However, the amount of CDW has shown to be 1-2 times greater in old-growth forests compared to managed forests in Sweden, and *Picea abies* deadwood reaches 15 times greater amounts (Jonsson 2000). Furthermore, managed forest stands in northern Sweden contain up to 30% of the amount of deadwood found in unmanaged stands, while in middle- and southern Sweden, there is an even greater difference where managed stands contain 2-3% of the deadwood amount found in unmanaged stands (Dahlberg & Stokland 2004). This is in line with Fridman & Walheim (2000) summary of temperate and boreal forest studies, showing how the amount of deadwood in managed forests ranges between 2-30% of the amount found in unmanaged stands. Amounts of deadwood distributed in the managed forest landscape of Fennoscandia, in which wood dependent species have developed, has been reduced with over 90% (Siitonen 2001).

Data from the Swedish National Forest Inventory (NFI) show that in 2021, the production forests outside of formally protected areas in the southern parts of northern Sweden had a measured volume of 11.4 m3/ha deadwood in total (SLU Riksskogstaxeringen 2021), where spruce were the dominating species followed by pine and lastly deciduous species. The NFI further concludes that the volume of deadwood in 2018 was approximately three times lower in managed forests outside of formally protected areas. In contrast to deadwood amounts in managed forests, the average volume of deadwood in virgin boreal reserves in northern Sweden has been measured to 89 m^3 ha^{-1}, with an average number of 247 ha^{-1} deadwood elements in spruce-dominated stands (Linder et al. 1997). This correlates well with the results on European old-growth forests from (Nilsson et al. 2003), showing a total density of 100-200 logs ha^{-1} and 95-300 standing dead trees ha^{-1}. These numbers on amount and volume of deadwood in unmanaged old-growth forests can be seen as a baseline on how much deadwood that should be present without human intervention in the boreal forest ecosystems, in which many species have developed. Successful RF planning should therefore aim at preserving areas with equal levels of deadwood found in unmanaged forests to provide adequate substrate amounts for saproxylic species. Furthermore, the deadwood should preferably be retained in RPs, to avoid being damaged during final felling or by regeneration operations (Vanha-Majamaa & Jalonen 2001; Rudolphi et al. 2014). Consequently, it would be reasonable to expect that RPs represent deadwood hotspots in managed forests.

Another significant structural change that has been highly altered as a consequence of large-scale forestry is the age distribution. The intense forest exploitation practiced for over half a century (Östlund et al. 1997) has resulted in that the majority of productive forest land in Sweden consists of less than 5% of old forests (SLU Riksskogstaxeringen 2021). This amount is dramatically different compared to the age distribution naturally found in Sweden's boreal forests (Östlund et al. 1997; Andersson & Östlund 2004), stressing the need to increase the proportion of older forests. Here, retention forestry can play an essential role in integrating patches of old forest and old tree elements into production forests to try to recreate a more natural forest structure. This enrichment of old tree elements would likely be found either dispersed over harvested areas or left aggregated in retention patches, as these elements should be prioritized in retention planning (Lie et al. 2009; Claesson et al. 2013).

Moreover, the NFI show a change in species composition in Sweden's boreal forests, where older (>80 years) deciduous-rich forests (at least 3/10 of the basal area is deciduous), have decreased since 1985 from approximately 800 000 hectares to approximately 500 000 hectares in 2018. This development is linked to modern forestry's focus on coniferous production where broadleaved trees are systematically removed from stands through forestry measures like thinning, on the expense of numerous broadleaf-dependent species (Bell et al. 2015). Broadleaf trees are a natural part of the boreal forest, linked to how these forests were historically highly affected by fire disturbances (Axelsson et al. 2002), and retention of groups or single deciduous trees can help provide an admixture of deciduous species in an otherwise coniferous dominated landscape.

1.2.3 Implications of Swedish forestry for biodiversity

Although Sweden has taken action and formulated concrete conservation goals, the 2020 red list shows a negative trend for biodiversity (SLU Artdatabanken 2020).

Over 50% of all red-listed species in 2020 were forest dwelling, and forestry was determined to be one of the processes that affect most red-listed species, with approximately 1400 species negatively affected. The negative effects forestry had on species was said to be linked to their demand for forest continuity and thus their inability to survive the environmental conditions of the clear-cut phase, together with short rotation periods where there is not enough time for needed substrates or conditions to regenerate (Gustafsson et al. 2012; SLU Artdatabanken 2020). Consequently, the red list shows a strong connection between loss of continuity forests through intensive forest management and an increased number of red-listed and threatened butterflies, beetles, fungi, and lichen. In addition to providing an intact and undisturbed forest climate, old-growth forests also provide old trees, which constitutes an important substrate for many species (Berg et al. 1994; Lie et al. 2009). Not only are old trees important when alive (Berg et al. 1994), but also as they die they often create old hard wood that many lichen species are confined to (Santaniello et al. 2017).

The systematic removal of deciduous trees in managed forests has had negative consequences for deciduous dependent species (Dahlberg & Stokland 2004; Bell et al. 2015; Rytter 2019). One example is *Populus tremula* (L.) that is an important substrate for many species and its reduction in frequency in the boral landscape has had severe consequences, where a larger proportion of species are critically endangered (CR) with aspen as host tree compared to other tree species. Therefore, groups of aspen trees in boreal forests are viewed as biodiversity hotspots (Tikkanen et al. 2006), and should thereby be prioritized for retention in coniferous dominated stands.

Deadwood is a critical element to consider when discussing the development of threatened species. In Sweden, at least 6000-7000 species are saproxylic (deadwood interactive), and 25% of the red-listed species are saproxylic, stressing the need for management strategies to promote deadwood development, specifically deadwood of varying species and qualities (Jonsson et al. 2016). 50% of saproxylic species are specifically connected to deciduous deadwood, and 75% of the red-listed species are connected to deciduous deadwood (Dahlberg & Stokland 2004), that further underlines the importance to increase the amount of deadwood found in the managed forest matrix, but also providing sufficient amounts of deciduous deadwood to counteract the development of the red-list.

In light of the structural difference in managed forests and unmanaged forests and the associated implications for biodiversity, this study will focus on the structural composition of RPs to evaluate if they succeed at encasing the highest natural values of a stand and thereby are able to fulfil functional objectives. To evaluate the structural composition and quality, it is of interest to collect data on how much deadwood, coarse deadwood and how many live conservation trees (LCT) are found in retention patches to evaluate their quality and thus their importance for maintaining a substrate supply in managed boreal forests. To harbour threatened species successfully and supply enough substrates, the amount of deadwood and LCT should preferably reach levels found in old-growth boreal forests. If high amounts are found in RPs, this would indicate a high importance of this management practice for many threatened species. To maximize the benefit of RPs, they should preferably be placed in areas where large amounts of deadwood and LCT are present, as many species are connected to these substrates (Dahlberg & Stokland 2004; Lie et al. 2009).

1.2.4 The physical prerequisite's influence on retention planning

One important aspect of nature consideration with RPs is that they should be representative of the harvested area and include naturally occurring biotope types to provide habitat continuity for the species present (Gustafsson et al. 2016). Though, there are many other factors to consider in forest management planning besides nature conservation. Requirements by law states that retention should not significantly reduce the value of the stand, and an acceptable retention level would be 5% of the stand volume. This leaves room for management adaptations that reflect the goals of stakeholders involved. Thus, stakeholder interests are expected to highly influence decisions regarding nature consideration and the level and quality of retention (Wikberg et al. 2009). For stakeholders with a high interest in nature consideration, management practices with the highest biodiversity promotion will presumably be chosen, and more effort is probably put into gathering of information on natural values and occurring species, whereas for stakeholders as forest owners and forest companies, other values like economy and personal interests are likely to be given weight and prioritized (Wikberg et al. 2009).

Forest owners are by law required to identify natural values prior to harvest and this evaluation is done by a forest planner. How the method for placement of retention patches relates to threatened species is unclear and instead, it is mainly based on structures (Wikberg et al. 2009). Information available on species present is normally sparse and areas left as retention are often unsuitable for harvest, like areas where logging is operationally difficult e.g. steep slopes and boulder-rich areas, or areas with low economic interest like deciduous tree groups, low-productivity wet sites or nutrient-poor bedrock (Djupström et al. 2008).

My concern with this standard approach to retention patch placement is that the aim is to minimize costs instead of maximizing biodiversity benefits. If areas chosen as retention patches are consistently chosen because of their physical prerequisites and thus operational difficulty, will they fulfil the criterion on representativeness of the harvested stands, or will retention patches have deviant characteristics? Although species richness often coincides with operationally difficult wet and paludified areas (Vanha-Majamaa & Jalonen 2001), species require a wide array of habitats and low-profitable habitats routinely set aside may fail at "lifeboating" species linked to the harvested forests characteristics. This could lead to negative consequences for biodiversity if retention patches representativeness is unsuccessful. An investigation of the physical prerequisites of patches left is therefore of interest to evaluate whether nature conservation is the primary objective in operational planning or if profit is given higher priority.

1.3 Knowledge gaps

Several studies in Fennoscandia have previously been published about the importance and consequences of retention forestry and retention patches for biodiversity preservation (Vanha-Majamaa & Jalonen 2001; Hyvärinen et al. 2006; Matveinen-Huju et al. 2006; Gustafsson et al. 2010, 2012; Gustafsson & Perhans 2010; Johnson et al. 2014; Rudolphi et al. 2014; Sverdrup-Thygeson et al. 2014). However, these studies often narrow it down to specific management options, species, or substrates, whereas this study tries to provide a more holistic overview of the natural values and structures preserved in retention patches in northern central Sweden. To evaluate conservational quality both holistically and on a substrate-level can help illuminate general retention patch qualities and shortcomings. Furthermore, the possible influence that physical prerequisites and thus operational difficulty have on retention patch placement and the implications for biodiversity preservation is barely studied (Wikberg et al. 2009; Perhans et al. 2011). Investigating the influence of physical factors could lead to improved retention planning with increased efforts to preserve the existing natural values and species.

1.4 Aim and research questions

This study aims at increasing the knowledge about what nature consideration values are retained in a managed forest landscape by studying the structural composition of retention patches. My goal is to evaluate structural variations and differences in conservational values found in retention patches compared to in reference forest stands to evaluate if executed retention has succeeded in identifying biodiversity hotspots and if other values possibly have interfered with retaining the areas of the highest conservational quality. This will be evaluated by performing a natural value assessment using the SFAs method for inventorying woodland key habitats where data is collected on quantity of LCT, deadwood, and occurrence of other conservational quality elements. Further, the physical prerequisites of soil moisture, slope and occurrence of boulders will be examined to investigate if these factors influence placement of retention patches and possible effects this may have on biodiversity preservation. Investigating this can provide an insight into the basis of retention patch placement, how well retention patches match or exceed conservational values found in unmanaged forest stands and in addition, possibly clarify what key elements that retention patches lack.

The main research questions are:

1. Do the retention patches differ in structural composition compared to the reference forest stands? If so, how do they differ?
2. Is the placing of the retention patches affected by any physical factors that complicate logging operations? If so, what factors?

The main questions will be answered by investigating the following:

1. How do retention patches differ from reference forest stands in terms of a natural value assessment score?
2. How does the number of live conservation trees, lying- and standing deadwood, and coarse deadwood differ in the retention patches compared to the reference forest stands?
3. How do retention patches differ in occurrence of boulders, soil moisture and slope compared to reference forest stands?

2. Method

2.1 Study area

This survey was conducted at sites distributed in the central parts of Sweden in the province of Hälsingland, Gävleborgs county, an area in the transition zone between middle and southern boreal vegetation. The original study sites consist of 80 mature forest stands owned by Holmen Skog that was selected in 2002 for field studies of red-listed bryophytes and lichens (Gustafsson et al. 2004), based on fulfilling the criteria 1) mature to be logged, 2) age ≥ 110 years, 3) size >3 ha and < 16 ha, 4) altitude <400 m.a.s.l., 5) relative basal area of *Picea Abies* (L.) Karst >70%, 6) relative basal area of deciduous trees >10%, 7) site quality ≥ G20 (a site quality of G20 indicates that a *P.abies* tree will reach at least 20 m of height in a 100 years), 8) vegetation of dwarf shrub or low herb type and 9) soil-moisture-type mesic or moist. These criteria were chosen to identify a relatively homogenous representation of soon to be harvested spruce-dominated stands. Out of the 80 stands that fit the criteria, 30 were randomly selected for surveying. These are the 30 forest stands initially included in my field survey.

In 2002, the dominating tree species in the selected stands was *Picea abies* that on average constituted 79% of the basal area, whereas deciduous trees constituted on average 12% of the basal area and *Pinus sylvestris* (L.) on average 9%. The main deciduous species found in the study area was *Betula spp*. (L.), *Populus tremula*, *Salix caprea* (L.) and *Sorbus aucuparia* (L.). Average wood productivity was 5,77 m^3sk/ha/yr. The average age was 120 years, the average number of trees/ha was 950, and the average volume was 315 m^3/ha. The mean size of the stands was 6 ha and the elevation ranges between 40 and 390 m.a.s.l. However, it is noteworthy that all the forest stand parameters were measured when initiating the first field studies by SLU in 2002 and may to some degrees have changed today.

Over the past 20 years, the forest stands have been managed by Holmen Skog where some stands have been harvested starting in 2003 up until today, and some have been left without active management. This has resulted in that today, the forest stands are separated into three treatment categories; harvested, partially harvested, and not harvested.

2.2 Natural value assessment

2.2.1 The Swedish Forest Agency's method for inventorying woodland key habitats in NW Sweden

The natural value assessment performed in this study was a version of the specially developed Swedish Forest Agency (SFA) method for inventorying woodland key habitats (WKH) in NW Sweden. This method classifies the inventoried object as a WKH (Sw: nyckelbiotop), ONV (Woodland habitat of semi-high conservational value (Sw: Objekt med naturvärde) or (LNV) lower conservational value (Sw: Lägre naturvärde). A WKH is defined as a forested area that from a collected assessment of the biotope structure, species, history, and physical environment today is of very high importance for the forest flora and fauna. Red-listed species are found or are expected to be found (Wester & Engström 2016). An ONV is a forested area that holds high conservational values today, linked to either structures or species that are connected to the forest history or physical environment, but an area that fails to meet the criteria for a WKH. Areas that hold high populations of a species or a high frequency of important structures without fulfilling the WKH criteria can be classified as a ONV. Examples of areas that may be classified as ONV are areas with very high amounts of deadwood or areas that are unusual on a landscape level (Rune & Claesson 2020).

The SFA method for NW Sweden uses checklists and circular sample plots to enhance the survey's objectivity (Wester et al. 2019). The checklists were developed to be used only for the biotope types 1) Coniferous forest, 2) Natural coniferous forest, 3) Broadleaf-rich coniferous forest, and 4) wetland-forest mosaic, because these biotope types are predominant in NW Sweden (Roberge 2018), and because there is more suitable assessment support for other biotope types (Wester et al. 2019). Further, the checklists are adapted to inventorying spruce-dominated forests, pine-dominated forests and broadleaf-rich coniferous forests (Sw: barrskogar med höga lövvärden) for the inventory to carry out a fair assessment of the biotope, where quality structures and characteristics vary depending on dominant tree species. Forest quality structures and characteristics are often referred to as *key elements*; structures that contribute to the conservational value of the biotope or structures particularly valuable for red-listed species, e.g deadwood and LCT. The presence and quality of key elements is what determines a biotopes ability to host red-listed species and an indicator of which species that are likely to be present (Claesson 2022).

Inventory workflow

When inventorying an object in NW Sweden, a point grid of 200x200 meters is laid out to determine sample plot placement, with the option to move the plots if deemed necessary to obtain representative sample plots. In smaller objects (<0,5hectare), the sample plot is placed in a representative area. Medium sized objects (0,5-10 hectares) require 2-5 sample plots placed using the point grid or by representative placement of sample plots. Larger objects (>10 hectare) require one sample plot every fourth hectare. If part of an object >0,5 hectares is clearly deviant from the dominant biotope type, the area should be delineated and separately surveyed and assessed (Claesson 2022).

The circular sample plot should be 25 or 18 meters in diameter and for each plot, data is collected using the checklists on the following key elements and properties:

1. Live conservation trees (species and quality)
2. Standing dead wood >10cm in diameter and >1,3 meters of height (species and quality)
3. Lying dead wood >10cm in diameter (species and quality)
4. Fire/silver stumps of pine >1,3 meters of height.
5. Characteristics (qualities of conservational value in the forest/environment adjacent to the sample plot)

The assessment of LCT is based on the definition in the conservation targets by the Swedish Forest Agency (Claesson et al. 2013). To calibrate the evaluation on the occurrence of LCT and trees of high age, an increment corer can be used in some of the sample plots to core trees and count annual rings when age is difficult to determine judged by the tree characteristics.

Outside of the sample plots, a continuous assessment of characteristics and any quality that contributes to the conservational value is noted to be considered in the overall assessment of the object. This could be a meandering natural creek, a spring flow or a protected microclimate. In addition, *species of conservational value* should be registered regardless of being within or outside of sample plots.

Species of conservational value, e.g indicator species, red-listed or formally protected species (Rune & Claesson 2020) is a non-structural part of the NVA that can contribute to the overall assessment of the conservational value of the object. Indicator species (in this report marked with I) are not red-listed species that indicates conservational values. The strength of the indication can vary depending on what part of the country the species is found. Red-listed species are conservational species where the national risk of extinction is classified according to the IUCCN system with classes DD, NT, VU, EN, CR or RE (IUCN 2021). The classification of a species is re-evaluated every 5 years. Formally protected species (in this report marked with §) are species found in the Species Protection Ordinance (SFS 2007:845). Many of the formally protected species can also be found on the red list. However, the woodland key habitat inventory is mainly focused on the biotope itself and its associated structures, so the amount of time searching for species of conservational value should be limited to only when there is uncertainty in how to classify the biotope. Nevertheless, any species of interest found when inventorying should be registered (Rune & Claesson 2020).

Points in the NVA can be assigned if any of the following criteria is met: 1) High frequency of indicator- and/or red-listed species 2) At least six indicator- and/or red-listed species are found, 3) Species classified as VU, EN and/or CR are found.

Checklist structure

As shown in Appendix 1 (Swedish), the back of the checklist is for filling in sample plot data. After, this data is summarized and upscaled to number of structures per hectare. These numbers are then used as a basis to see if the object fulfils the WKH criteria, that have been divided into basic criteria and supporting criteria. Firstly, the basic criteria met are filled in and if a specific number of them are met, the supportive criteria is not necessary to support the overall assessment. If not, the supportive criteria can help evaluate the overall assessment.

The basic criteria are similar for all checklists, where threshold values are stated for LCT and deadwood types. In addition, the characteristics "tree continuity" and "deadwood continuity" are part of the basic criteria for spruce- and pine-dominated stands. Tree continuity means that the area has had a long history of continuous forest cover and continuously held some old tree individuals where some level of disturbance is accepted, for example selective cutting, as it still leaves the forest cover intact (Skogsstyrelsen 2022). Deadwood continuity means that there should be a striking amount of deadwood of a certain species in different stages of decomposition in the area without needing to search for it (Skogsstyrelsen 2022). For deciduous-rich coniferous stands, the tree continuity should be of deciduous trees and instead of having deadwood continuity as a basic criterion, the area should be characterized by fire disturbance.

The supporting criteria for all checklists are also partly based on threshold values of elements found in the sample plots, but the characteristics are more varying. For spruce, some examples are patch dynamics, tall herb dominated ground vegetation and older forest with a browsing history. For pine, many characteristics are connected to different traces of fire disturbance but also occurrence of trees on bare rock, vertical rock walls and a high occurrence of boulders. The criteria for deadwood in pine stands includes dry snags, and silver logs or stumps. For deciduous-rich coniferous forests, a number of the supporting criteria are similarly connected to fire disturbance, but for this forest type, more emphasis lies on values connected to deciduous trees like trees with cavities and polypore fungi (see Appendix 1).

All included criteria have been evaluated for their importance as conservational value indicators, where important criteria are weighted by the number of criteria needed to attain WKH status and number of "points" they can generate (see Appendix 1). For example, LCT and deadwood can generate points in both basic criteria and supportive criteria (Wester et al. 2019). There are calibrated threshold values for WKH and ONV to guide the object classification. In pine-dominated forests and broadleaf-rich coniferous forest, at least 4 basic criteria or 7 supporting criteria is needed for a WKH classification. In spruce-dominated forests, 4 basic criteria or 8 supportive criteria are needed (Wester et al. 2019).

2.2.2 Adapted method for natural value assessment in northern Sweden

The SFA no longer inventory WKH, but the method can be used to objectively and in a systematic matter identify areas of conservational value. Wester et. al (2019) conclude that the method for inventorying WKH in NW Sweden is applicable in other parts of Sweden as well, so for this study in Hälsingland, a version of the checklists by the SFA adapted for inventorying in northern Sweden was chosen (see Appendix 2).

The general concept and workflow of the method is the same as for the NW, but the checklists however have lower scoring threshold values for a few elements and characteristics. Nevertheless, the checklists will collect the same data as in the NW. However, fire stumps are only registered when using the checklist for pine-dominated stands and broadleaf-rich coniferous stands. Regarding the scoring, the difference in basic criteria spruce-dominated stands in northern Sweden outside of the area defined as NW is that 20 *Picea* LCT instead of 30 are needed to generate a point. For supporting criteria, at least 15 instead of 20 *Picea* LCT are needed, at least 10 Picea trees older than 220 years instead of 250, and the 50 oldest trees per hectare need to be older than 150 instead of 180 to generate a point. The difference in basic criteria for pine dominated stands is that at least 20 instead of 30 LCT, independent of species, are needed to generate a point. For supporting criteria, at least 15 instead of 20 *Pinus* LCT, *Pinus* trees older than 220 years instead of older than 250 and the 50 oldest trees per hectare need to be older than 160 instead of 180 to generate a point.

In pine-dominated forests and broadleaf-rich coniferous forest, at least 4 basic criteria and/or 7 supporting criteria is needed for a WKH classification, whereas 5 basic criteria and/or 8 supportive are needed in spruce-dominated forests. However, to describe the forest stand characteristics as detailed as possible, both basic and supporting criteria were assessed in this study, regardless of fulfilling the basic criteria or not.

The SFA checklists for northern Sweden with sample plots are suitable for this study as they provide measurable and comparable data on key elements and characteristics, while also providing a holistic natural value assessment of the surveyed stand. This data will be sufficient to answer the research questions and through an established method give a relatively objective estimation of the forest conservational values.

2.3 Inventory method

2.3.1 GIS preparations

Polygon shapefiles of the 30 forest stands were imported to the QGIS 3.16.19 software (QGIS Development Team 2021) for preparations of the field surveying. Google earth aerial photos were included as a base layer. The polygon shapefiles used represents the forest stands as they were in 2002. To objectively place sample plots in the reference forest stands (RFS), a 50x50 meters point grid was created within the polygons using the QGIS software. The distance of 50 meters was chosen as it generated at least 3 sample points within the relatively small forest stands. To use the QGIS-project remotely in the stands, a QGIS-based application called “Input” was used (Lutra Consulting, 2022), that allows easy access and georeferenced field data collection. The Input application was used to navigate the stands and the point grid for sample plot placement.

2.3.2 Field survey procedure

Reference forest stands

As the RFS had an average size of ~6.5 hectares, three sample plots were decided to be sufficient to provide representative data. For sample plot placement within RFS, grid points within the polygon, excluding points bordering the polygon, were given a number starting from the upper left (NW) corner. The numbered points were then randomly chosen using Googles number randomization tool where the number of sample plots included in that stand was stated and a random number was generated. This was repeated three times to obtain three sample plots (see Fig. 1). However, as the SFA method states that deviant biotopes larger than 0,5 hectares should be delineated and separately surveyed, and this resulted in RFS NVA with 2 sample plots and an additional NVA with one sample plot for the deviant biotope. This was the case for two RFS.

If the generated sample plots in RFS was too close to the polygon edge to include a radius of 25 meters from the centre point, the centre point was moved by taking 10 steps away from the grid point inwards the polygon. If the centre point remained too close to the edge, an additional 10 steps were taken away from the edge and repeated until the circle plot fitted inside the polygon. If the stand polygons were too narrow (>25m), the sample plot radius was lowered to fit. If possible, the radius was lowered to 18 meters as it simplifies the upscaling to per hectare. If not possible, the radius was lowered further, and the upscaling was done manually after the field data collection (see section 2.3.3). In one very narrow reference stand, it was difficult to fit larger circular sample plots. Here, two sample plots with a radius of 10 meters was placed and the average number of elements found was used for upscaling to numbers per hectare.

Retention patches

In stands categorized as harvested, the RPs were inventoried. In this study, patches of intact forest left within the surveyed polygon were interpreted as RPs. This includes both stand-alone "islands" of trees as well as forest patches bordering remaining forest outside of the surveyed polygon. Out of all RPs, 14 were connected to a forest stand outside of the surveyed polygons, and 10 were disconnected by surrounding clearcuts. If more than one RP was left within the surveyed polygon, a separate NVA could be done in the separate patches resulting in more than one NVA per harvested stand.

For RPs, one sample plot was deemed to be sufficient, in accordance with the SFA method. However, a few RPs proved to be relatively large and there two sample plots were placed to increase representability (see Fig 1). Sample plot placement in

RPs was done by seeking out the perceived centre of the RP using aerial photos and the stand polygon edges. The placement of the sample plot in the centre of the RP was decided to avoid edge effects possibly influencing the structure and characteristics. After placing myself in the centre of a patch, a nearby object, mainly a stick, was randomly thrown in the air and the place it landed was decided as the centre point.

As for fitting the sample plot of 25 meters in RPs, the procedure was similar as in RFS. Firstly, the radius was lowered to 18 meters. Secondly, if the RP still failed to fit the circle plot, the radius was lowered even further. Finally, another method was used to adapt the sample plot size if it was difficult to fit a circular sample plot. A Garmin 62s GPS device was used to track the outlines of the RP. If the RP was bordering a forest outside of the surveyed polygon, the polygon edge was followed in the Input app and then the outline of the RP towards the clearcut. If the RP was disconnected, outlines of the RP was simply tracked using the GPS. By using the GPS track function, the area of the entire retention patch was obtained. In one case, the only tree retention was a riparian buffer around a natural creek crossing the forest stand. To obtain a sample plot here, I used the Garmin tracking tool and walked 40 steps alongside the outline of the riparian buffer upstream, perpendicularly crossed the riparian buffer and walked 40 steps alongside the outline of the riparian buffer downstream and crossed again to return to the starting point.

The stands categorized as partially harvested were delineated in smaller management units and could thereby be inventoried both as RFS and RPs. If an entirely unharvested subunit was left, clearly delineated by subunit polygon borders, the unit could be inventoried as a RFS. This was done because there were few unharvested stands left. If any RPs were left in the harvested subunit, they could be inventoried as RPs (see Fig. 1). However, the reason for the delineation into subunits is unclear, making it harder to determine if the areas left unharvested within the partially harvested subunit was left as retention or if the forest managers simply altered the stand unit borders. Therefore, this study considers all areas of intact forest left within a harvested unit as a retention patch.

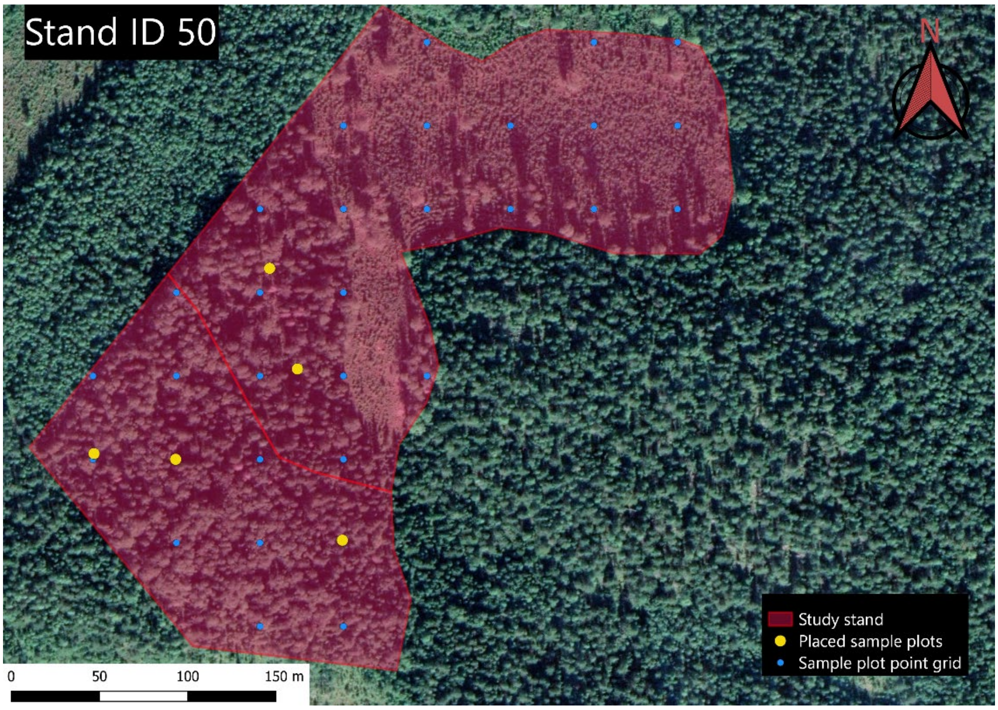

Figure 1. Stand 50 that is partially harvested shows an example of sample plot placement in a RFS (bottom polygon) using the point grid and in a RP (top polygon) using aerial photos and polygon edges.

Many of the surveyed forest stands are placed in remote areas where there was no signal on the smartphone, disabling use of the Input application to locate sample plots and RP. To condition inventorying without a signal, sample plots were placed beforehand using the same procedure as previously described. For RFS, the QGIS point-grid map was used to obtain coordinates for three randomly chosen sample plots and for RP by locating the coordinates of the perceived centre of the retention patch using aerial photos. The coordinates could later be found when inventorying using the Garmin 62s GPS device.

2.3.3 Data collection

To facilitate a quick and simple collection and compilation of data, digitalized checklists for NVAs according to the SFA method for inventorying WKH in northern Sweden were created and imported to the ArcGIS application Survey123 (Esri 2022). Three checklists were used, including the forest types likely to be found (considering the study stand criteria); 1) spruce-dominated forest in northern Sweden, 2) pine-dominated forest in northern Sweden and 3) deciduous-rich coniferous forests in northern Sweden (see Appendix 1). Using the Survey123 application, georeferenced data could be collected and analysed without internet connection using a smartphone, and later easily exported for further analysis.

Firstly, when arriving at the forest stand, I decided on what checklist best corresponds to the stand biotope. As described in section 2.2.1, areas larger than 0,5 hectares that deviates from the dominant biotope type should be delineated for a separate survey. After, a NVA was initiated using the Survey123 application with georeferenced sample plots. As the application was used on a smartphone, recording the exact coordinates of the sample plots was limited by the GPS accuracy and a margin of error was automatically noted by the application. Finally, for each sample plot placed (in this study a maximum of tree sample plots), the application automatically created a stand-wise summary of data on number of elements and stand characteristics. I then used this summary to manually fill in the number of criteria met to obtain a classification of the surveyed forest stand. The Survey123 application enables automatic upscaling of parameters per hectare with sample plot radiuses of 18 or 25 meters. However, when the sample plot size was either lowered to a smaller radius or determined by the tracking of the outlines of a RP, the recalculation was performed by calculating a factor to multiply the sampled elements with to upscale data ha^{-1}. This was done manually in Microsoft Excel (Microsoft Corporation 2018) after the surveys were exported to a computer.

For the default radius of 25 meters, this factor is 5 to obtain number of elements ha^{-1}. With the adapted sample plot sizes, the following function was used:

$$No.of\ elements\ ha^{-1} = \frac{1ha}{Sample\ plot\ size\ in\ ha} * No.of\ elements\ noted\ in\ plot$$

Figure 2. Equation for upscaling of number of elements per hectare

Registering species of conservational interest

According to the method for inventorying WKH by the SFA, the focus should be on registering important structures rather than finding species of conservational interest (Skogsstyrelsen, 2020). In RFSs, indicator- and red listed species were noted in sample plots and whilst moving through the stand. However, the search for species was limited to a maximum of 20 minutes. In RPs, the possibility to observe indicator- and red listed species was limited by the RP edges or forest stand polygon, also here under a time limit of 20 minutes. The number of species searched for is however restrained by the species that I can identify in Skyddsvärd skog ((Nitare 2020). These species are summarized in a list (see Appendix 3). In addition, the indicator- and red-listed species found in this study’s surveys are summarized in another list (see Appendix 4).

2.3.4 Assessment of physical prerequisites

In addition, an ocular assessment of the physical prerequisites of the plot will be done with the parameter's occurrence of boulders, soil moisture and slope. The parameter slope will be determined in degrees by using a tree height/slope measurer. The parameters occurrence of boulders and soil moisture will be assessed on a three-levelled scale (see *Table 1*). Soil moisture will be categorized by using the definitions by SLU (SLU 2021). All factors will be assessed within the limit of the sample plots. In addition, any traces of forestry that are discovered in the plot will be noted, for example cleaning, thinning or driving.

Table 1. Classification of the physical factors occurende of boulders and soil moisture.

Physical factor	***Category 1***	***Category 2***	***Category 3***
Occurrence of boulders	0-5 large boulders	5-40 large boulders	>40 large boulders
Soil moisture	Dry-mesic	Mesic-moist	Moist-wet

2.3.5 Inventory procedure in short

1. Use the Input application to locate sample plots by using the 50x50 meters grid (in RFS) and randomly select three sample plots using Googles number randomization tool. Alternatively, locate sample plot in a retention patch by seeking out the perceived centre of the retention patch using the aerial photo as guide, and throwing an object to randomly determine the midpoint of the sample plot. Adjust placement or sample plot radius if needed to place sample plots within the polygon edges or RP, as described in section 2.3.

2. Start a new NVA in the Survey123 application and state the stand ID.
3. Mark coordinates of sample plot midpoint by placing a sample plot in the Survey123 application.
4. Determine the physical prerequisites by estimating the number of boulders, assess soil moisture based on ground vegetation, and measure slope with the height measurer.
5. Measure a 25-meter radius circle with a measuring tape.
6. Perform the natural value assessment using the checklists in the Survey123 application.

2.4 Data analysis

Initially, all survey data collected with the Survey123 application was exported into a Microsoft Excel format and using the Excel software they were further organized and categorized to simplify upcoming statistical data analysis. All statistical analyses were performed using the Rstudio software (Rstudio Team 2020) and graphically presented using the R package ggplot2 (Wickham 2016) and Microsoft Excel (Microsoft corporation 2018). The Survey123 data included the total NVA data, together with the corresponding sample plot data.

2.4.1 NVA score

The analysis of the NVA score was limited to spruce-dominated stands as there were an unequal number of possible criteria to be met and the criteria differ between the biotope types. For example, occurrence of silver logs and dry snags were criteria in pine-dominated biotopes whilst spruces with root rot or rough bark structure were criteria in spruce-dominated biotopes. As a result, 10 spruce-dominated RFS and 18 spruce-dominated RPs were included in the NVA score analysis. A Wilcoxon rank sum test with continuity correction was used to analyse differences between RFS and RPs. When analysing the classification of RFS or RPs, the classification was divided into classified as WKH or not, where ONV and LNV was grouped together. This was then analysed in Rstudio with a Pearson's Chi-squared test with Yates' continuity correction since differences between two categorical variables are analysed. The Yate's continuity correction was used to prevent an overestimation of statistical significance when analysing a small dataset.

2.4.2 Deadwood and live conservation trees

There are minor differences in the checklists on both properties of deadwood and characteristics (see section 2.2.2). Therefore, the data available for a comparative analysis was the data on elements registered in all checklists. That is: 1) Live conservation trees (LCT), 2) Lying deadwood (LDW), and 3) Standing deadwood (SDW). The LCT were divided into four categories based on tree species: *Picea*, *Pinus*, *Betula* and *Populus/Salix/Sorbus* grouped together. The deadwood data was divided into three categories based on tree species: *Picea*, *Pinus* and deciduous species. Differences in LCT and deadwood in RFS and RPs was therefore analysed between species or species groups and in total. Coarse deadwood >30 cm in diameter at breast height (CDW) was collected in the checklist for spruce-dominated forests and deciduous-rich coniferous forests, excluding the stands or patches surveyed with the checklist for pine-dominated forest. The analysis on CDW was therefore limited to sample plots in 18 spruce-dominated RPs and sample plots in 11 RFS where 10 were spruce-dominated and 1 was a deciduous-rich coniferous forest. When analysing differences in number of LCT and deadwood, Rstudio was used to perform Wilcoxon rank sum tests with continuity correction.

Diversity in deadwood and live conservation trees

If the occurrence of key elements in sample plots where to be seen as binary, where if an element is present generates a 1 and not present generates a 0, a sum for each stand is given on the number of different elements with a maximum score of 10. A maximum score of 10 corresponds to having *Picea*, *Pinus*, *Betula* and *Populus/Salix/Sorbus* LCT, *Picea*, *Pinus*, deciduous SDW, and *Picea*, *Pinus*, deciduous LDW. A survey having a high score thus indicates a great substrate diversity. The parameter CDW had to be excluded in this analysis as it is not noted in all NVAs. For RFS and larger RPs with two sample plots, an average number of elements in the sample plots were calculated to obtain one value for each NVA survey. This data was analysed with a Wilcoxon rank sum test.

2.4.3 Initial species richness

The studied stands were chosen as they represent relatively homogenous soon to be harvested spruce-dominated stands. However, natural forest ecosystems will include some variations. Therefore, one could argue that the forests initially held varying degrees of conservational values that could affect the outcome of this study. Gustafsson et al. (2004) carried out a complete inventory of number of bryophyte- and lichen species in the forest stands in 2002. The data on total number of species found and number of threatened species found in what in this study was defined as RFS or RPs was now tested in Rstudio with a Wilcoxon rank sum test.

2.4.4 Physical prerequisites

For the analysis of the physical prerequisites with soil moisture and occurrence of boulders Rstudio was used to perform a Pearson's Chi-squared test with Yate’s continuity correction. The Yate’s continuity correction was used to prevent an overestimation of statistical significance when analysing a small dataset.

As the data of the parameters was determined on a three-levelled scale (1-3) in each sample plot, an average for the whole stand or patch was calculated for each RFS or the larger RPs with two sample plots. One sample plot was placed in the RPs, generating only one value for the physical prerequisites. This result was then divided into two categories; <1.9 or >=2, to be able to test the hypothesis that the values for soil moisture and occurrence of boulders differ in RPs. Slope was measured with a height measurer giving an exact value for slope in degrees. As for soil moisture and occurrence of boulders, an average slope was calculated for the

RFS and the large RPs with two sample plots. The slope measured in RPs and the average slope in RFS was analysed in Rstudio with a Wilcoxon rank sum test.

3. Results

3.1 Stand classification and survey results

Upon arrival at the forest stands, it was noted that two of the 30 forest stands that were harvested was left without retention patches within the surveyed polygons, and in two stands the retention patches observed on the aerial photos had been harvested and was not inventoried in this study. Therefore, the number of forest stands included in this study was 26. The field survey of the remaining stands resulted in 15 stands categorized as harvested, 4 as partially harvested and 7 not harvested. Note that in harvested or partially harvested stands, more than one survey could be performed in RPs. Two RPs were inventoried in 6 stands. Moreover, partially harvested stands could result in both surveyed RP and RFS (see Fig. 1), which was the case in two stands. In total, the surveyed stands resulted in 12 NVAs in RFS, where 10 were spruce-dominated and two of these had a deviant forest type in an area larger than 0,5 hectares. There, a separate NVA-survey was created with the corresponding checklist, where one was pine-dominated, and one was deciduous-rich coniferous. For RPs, a total of 24 NVAs were done, where 18 were spruce-dominated and six were pine-dominated. One of the pine-dominated NVAs was done in a pine-dominated area of a larger spruce-dominated RP.

3.2 Natural value assessment

3.2.1 NVA score

The Wilcoxon rank sum test on the NVA score in spruce-dominated stands showed how the number of basic criteria met were significantly different in RFS and RP ($p=0.003$) where the highest median was found in RFS (5) compared to in RPs (4). The number of supporting criteria met were significantly different between RFS and RP ($p=0.0002$), where RFS had the highest median (10.5) compared to RPs (9) (see *Figure 3*). The total NVA score, where the basic and supporting criteria met are summarized, were significantly different in RFS and RP where RFS had a median of 15 criteria whereas RPs had a median of 12 as shown in *Table 2*. RPs met a maximum of 5 basic criteria and RFS reached a maximum of six basic criteria. For supporting criteria, the maximum value for RPs was 10 whereas for RFS it was 14. The maximum total NVA score was 15 in RPs and 20 in RFS.

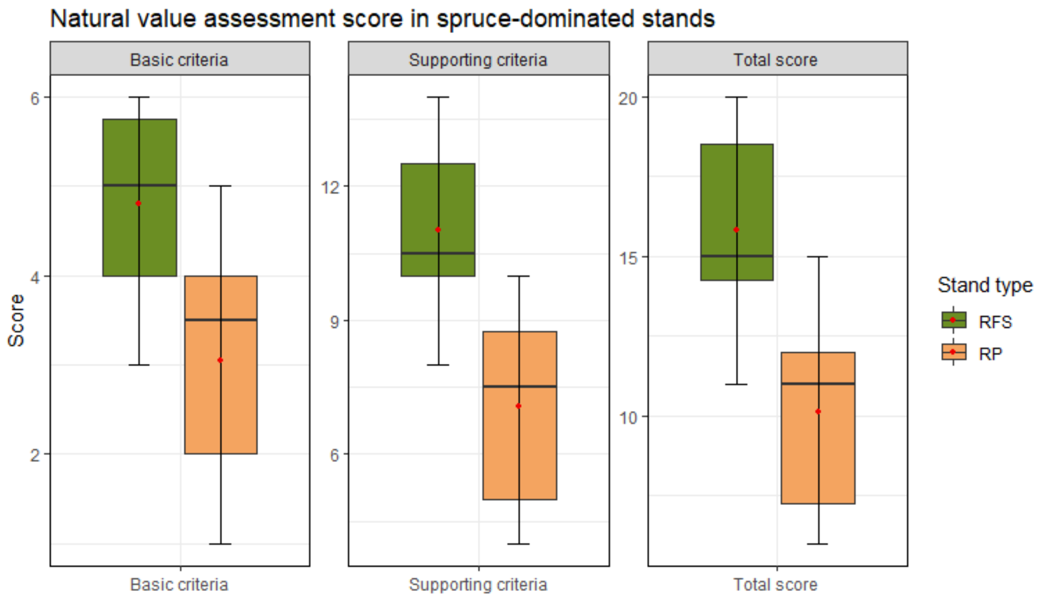

Figure 3. Differences in natural value assessment scores for spruce-dominated retention patches and reference forest stands. Each boxplot pair represents the distribution of the data on basic criteria, supporting criteria and total NVA score. RFS or RP. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show the variability. Black horizontal line represents the median and red dot represents the mean. Note the different scale of the y-axis.

Table 2. Wilcoxon test results on the criteria score in spruce-dominated reference forest stands and in retention patches, α=0,05. n = 10 for reference forest stands and n = 18 for retention patches.

Criteria category	RFS Median	RP Median	P-value	W-statistic
Basic criteria	5	4	0.003	150.5
Supporting criteria	10.5	9	0.0002	166.5
Total NVA score	15	12	0.0004	164

3.2.2 Classification

Figure 4 shows how the dominant classification was as WKH for 92% of the RFS and how all the RFS were classified at least as ONV. 54% of the RPs were classified as WKH, 29% as ONV and 17% as LNV. However, the Pearson's Chi-squared test with Yates' continuity correction showed no significant difference in the number of stands or patches classified as a WKH or not (p=0.06, X^2 = 3.5156).

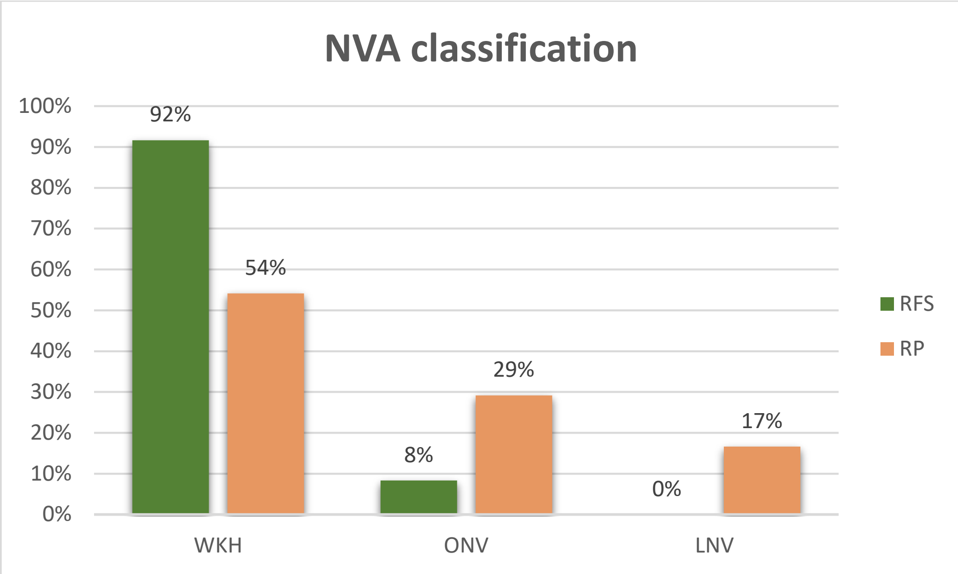

Figure 4. Proportion of RFS (in green) and RPs (in orange) in the final classification categories. Classification is subjective and evaluated by the inventory, guided by the number of basic and supportive criteria met. WKH stands for woodland key habitat, ONV stands for woodland habitat of semi-high conservational value, and LNV stands for lower conservational value.

3.3 Live conservation trees

The LCT showed a great difference in frequency, especially for *Picea* and *Pinus* in RPs, visualized by the outliers in *Figure 5* and described as the range in *Table 3*. Note that the y-axis in *Figure 5* differ between the species to visually present the data better.

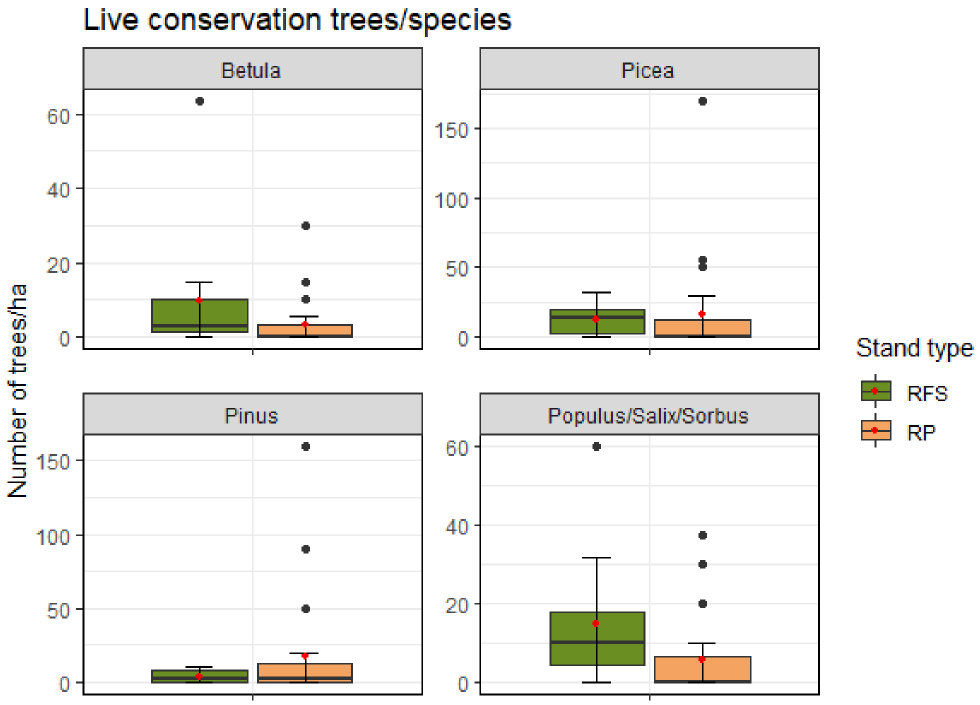

Figure 5. Mean number of Picea, Pinus, Betula and Populus/Salix/Sorbus LCT found in RPs and RFS. Note the different scales on the y-axis. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show the variability. Black horizontal line represents the median and red dot represents the mean.

The Wilcoxon test on differences in number of LCT per hectare and species or species group showed that there was a significant difference in the median number of *Betula* LCT (p=0.03) and *Populus/Salix/Sorbus* LCT (p=0.01) with *α=0.05* (*Table 3*). RFS had a median of 2.9 *Betula* LCT/ha compared to 0 in RPs and 10.0 *Populus/Salix/Sorbus* LCT/ha compared to 0 in RPs. The total showed in *Table 3*. is the summarized value for all live conservation trees in a survey, independent of species or group of species.

Table 3. Descriptive statistics for LCT and p-value and W-statistic from Wilcoxon rank sum test for differences in number of LCT between reference forest stands and retention patches. For reference forest stands n = 12. For retention patches n = 24. Significant p-values shown in bold.

LCT	**RFS** Median (*range*)	**RP** Median (*range*)	**P-value**	**W**
Betula	2.9(*0-63.6*)	0(*0-30*)	**0.03**	203
Picea	14.2(*0-31.6*)	0(*0-170*)	0.18	182
Pinus	2.5(*0-10*)	2.8(*0-160*)	0.54	126
Populus/Salix/Sorbus	10.0(*0-60*)	0(*0-37.2*)	**0.01**	218.5
Total	32.5(5-*111.4)*	22.5(*0-180.0*)	0.37	171

3.4 Deadwood

For lying- and standing deadwood types; n=12 for reference forest stands and n=24 for retention patches, including data from all checklists. For coarse deadwood (CDW); n=11 in reference forest stands, and n=18 in retention patches, as this parameter was not recorded in pine-dominated or deciduous-rich coniferous checklists.

As shown by outliers in *Figure 6* and the range in *Table 4*, there was a great difference in frequency of lying deadwood, most prominent for *Picea* and deciduous deadwood.

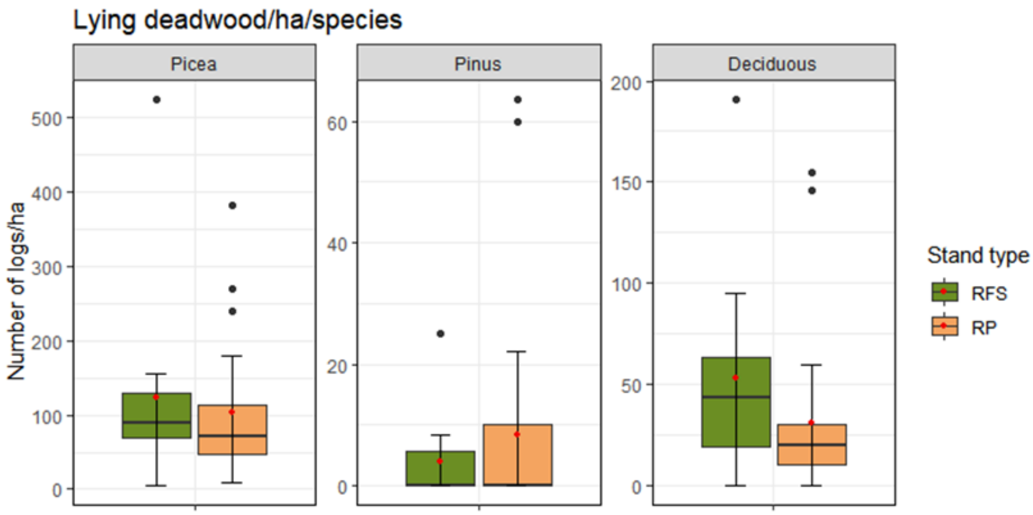

Figure 6. Mean number of Picea, Pinus and deciduous logs >10 cm in diameter found in RPs and RFS. Note the different scales on the y-axis. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show the variability. Black horizontal line represents the median and red dot represents the mean.

Similar to lying deadwood and LCT, standing deadwood showed a large difference in frequency, visualized by the outliers in *Figure 7* and the range in *Table 4*. The largest difference in standing deadwood was found in the *Picea* data. The scale of the y-axis differs also in *Figure 7*, for a better visual presentation.

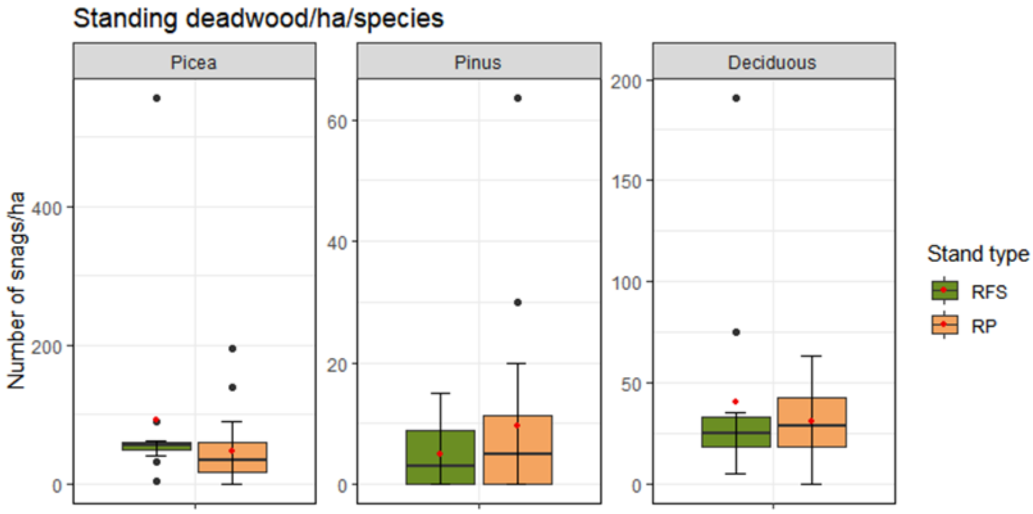

Figure 7. Mean number of standing snags >1.3 meters of height per RP or RFS. Note the different scales on the y-axis. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show the variability. Black horizontal line represents the median and red dot represents the mean.

The Wilcoxon test showed a significant difference in number of CDW logs and/or snags between RFS and RPs (p=0.009, α=0.05). More CDW was found in RFS (median=18.3) compared to in retention patches (median =0) (as shown in *Figure 8* and *Table 4)*.

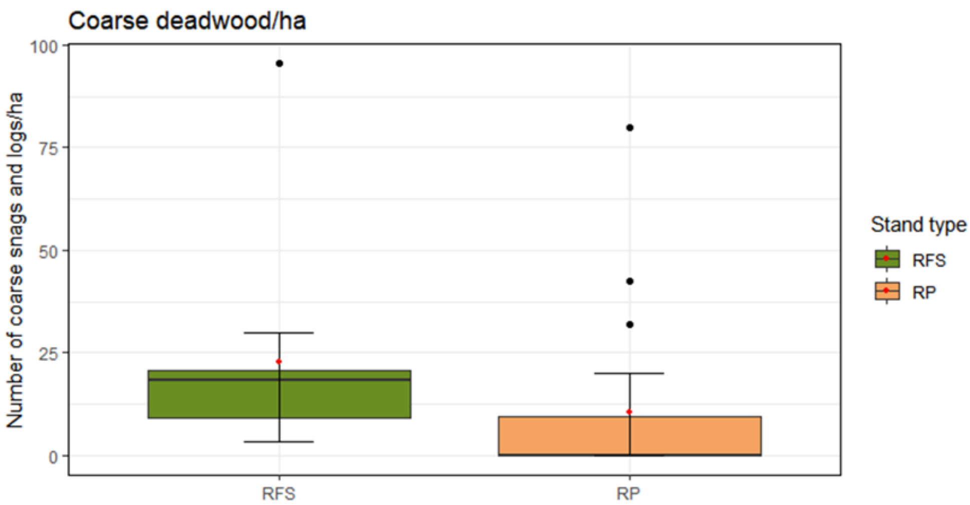

Figure 8. Number of coarse deadwood (>30cm in diameter at breast height) logs and snags/ha. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show variability. Black horizontal line represent the median and red dot represent the mean.

Table 4. Median, minimum and maximum (range) of number of trees/ha for all types of deadwood together with p-value and W-statistic of the Wilcoxon rank sum test on differences in number of deadwood elements between reference forest stands and retention patches, α=0.05. Total LDW and

total SDW is the summarized value for all lying- or standing deadwood in a survey, independent of species or species group.

Deadwood type	**RFS** Median (*range*)	**RP** Median (*range*)	**P-value**	**W-statistic**
Picea lying deadwood	88.3(*5-525.2*)	70.3(*10-382.0*)	0.41	169
Pinus lying deadwood	0(*0-25*)	0(*0-63.7*)	0.88	139.5
Deciduous lying deadwood	43.3(*0-191.0)*	20.0(*0-154.7*)	0.08	196
Total lying deadwood	132.5(*30-716.2*)	96.6(*15-445.6*)	0.26	178
Picea standing deadwood	55(*5-557.0*)	33.8(0-*196.0*)	0.14	188
Pinus standing deadwood	2.9(*0-15.0*)	5(*0-63.7*)	0.71	133
Deciduous standing deadwood	25(5-*191.0)*	28.8(*0-63.7*)	0.81	136.5
Total standing deadwood	80.8(*20-748.0*)	70.0(*25-229.6*)	0.28	176.5
Coarse deadwood	18.3(*5-95.5*)	0(*0-80*)	**0.009**	155.5

Total number of LCT and deadwood

Figure 9 shows averages of the total number of LDW logs, SDW snags and LCT in RP and RFS, independent of species or species group. The range shown in *Table 4* together with outliers visualized as black dots in *Figure 9* shows the large difference in mean number of elements. For example, the mean for total number of standing deadwood in reference forest stands varies between 20-748. The y-axis differs for the three element categories for a better visual presentation.

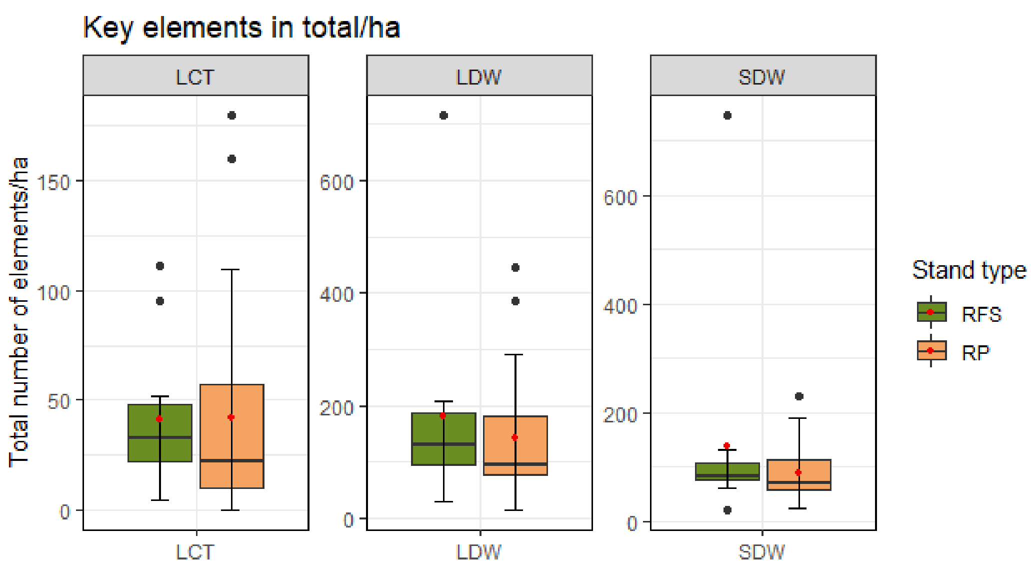

Figure 9. Mean number of live conservation trees (LCT), lying deadwood (LDW) logs, and standing deadwood (SDW) snags/ha per natural value assessment survey in RFS and RPs. Boxplots are green for RFS and orange for RP and cover 50% of observations. Black dots show outliers and whiskers show variability. Black horizontal line represents the median and red dot represents the mean. Note the different scales of the y-axis.

Structural diversity

The most structurally diverse stand was a RFS that had 10 different key elements present whereas the lowest number of elements was 3.5, found in a RP. However, the Wilcoxon rank sum test with continuity correction showed no significant difference in the number of elements found in RFS and RPs (p>0.1, $\alpha=0.05$), where the median number of elements in RFS was 6.5 and 6 for RPs.

3.5 Physical prerequisites and traces of forestry

The statistical tests summarized in *Table 5.* showed no significant difference between the slope (p=0.6969), occurrence of boulders (p=1) or soil moisture (p=0.1559) in RFS and RPs. The median slope was 4.9 degrees with a range of 1.25-27.2 in RFS and the median in RPs was 4.2 degrees with a range of 0.2-36.9. Three RPs and one RFS had traces of forestry. In two separate RPs in the same stand, I found old ditches and in another RP there was a logging road. In one RFS I found stumps from an old thinning.

Table 5. Statistical test results of a stand-wise comparison on slope, soil moisture and occurrence of boulders in reference forest stands and retention patches, α=0,05.

Physical factor	**Statistical test**	**P-value**	**Test statistic**
Slope	Wilcoxon rank sum test	0.6969	162.5
Occurrence of boulders	Pearson's Chi-squared test for count Data	1	0
Soil moisture	Pearson's Chi-squared test for count Data	0.1559	2.0133

3.5.1 Initial species diversity

The Wilcoxon rank sum test with continuity correction analysing differences in initial bryophyte- and lichen species diversity in 2002, in what is classified as RFS and RP in this study, showed that there was no significant difference in total number of species (p= 0.07534) or in number of threatened species (p= 0.08993) in RFS and RP. RFS had a median of 13 species in total and 5 threatened species whereas RP-stands had a median of 11 species in total and 4 threatened species.

4. Discussion

The purpose of this study was to pinpoint differences in structural composition in RPs in comparison with structurally similar RFS, to evaluate the RP pre-harvest representativeness and conditions to fulfil the functional aims with RF. My findings show that RPs does not representatively preserve the biologically important substrate composition that likely existed prior to harvest. The surveyed RPs held either less or indifferent number of substrates found in RFS and met fewer criteria for WKH compared to RFS. This indicates that studied RPs are structurally different from RFS and cannot be considered biodiversity hotspots. These results further implies that the forest that re-establishes after harvest will be structurally poorer and of lower conservational quality, as executed retention does not seem to include areas as rich in biological key elements. Thus, protection of forests with resembling characteristics as the RFS of this study would be recommended to avoid further impoverishment of the forest landscape with biodiversity loss as consequence.

The method used with a natural value assessment was chosen as it includes data collection on LCT and deadwood elements; two substrates that have high importance for biodiversity and structural enrichment of managed forests (Martikainen 2001; Dahlberg & Stokland 2004; Jonsson et al. 2005; Lie et al. 2009; Rudolphi et al. 2014), whilst also providing a holistic assessment of natural values including characteristics that connects to higher biodiversity. The evaluation of if RPs fulfil criteria for a WKH could thus indicate whether forest management succeeded in retaining biodiversity hotspots in a managed forest matrix.

Sweden has a small proportion of untouched natural forests left, but forests similar to in this study, that are unprotected, mature and possibly facing harvest, are more abundant (SLU Riksskogstaxeringen 2021). Therefore, I found it necessary to evaluate how well forest management practiced with RPs mimics the conditions found in these forests pre-harvest to maintain structurally diverse forests and harbour species over the regeneration face, and possible areas of improvement. However, it is worth noting that the RFS are not completely untouched by humans and does not fully represent natural old-growth forest conditions, which was expected based on findings by Dahlberg & Stokland (2004).This implies that even if RPs manage to match the conditions found in the stand prior to harvest, there are still many improvements to make in nature conservation in forestry to re-establish the natural conditions under which many species have developed.

4.1 NVA score and classification

The results for the natural value assessment score of spruce-dominated stands in this study clearly shows how RFS fulfils more WKH criteria in comparison to RPs. The maximum total score for RFS was 20, meaning that almost all criteria possible to meet for a WKH in that biotope was met, whereas the total score in RPs reached 15. The same trend was shown for the criteria separated where RFS met a maximum of 6 basic criteria and 14 supporting criteria, whereas RPs only met a maximum of 5 basic criteria and 10 supporting criteria. These results are quite surprising as one of the targets for RF is to structurally enrich managed forests, e.g. through RPs, so the retained areas would reasonably contain more key elements and enriching structures than randomly placed sample plots in RFS. The lower score in RPs is contradictory to the anticipation of RPs as biodiversity hotspots in managed forest stands. However, RPs have a relatively small area (for spruce-dominated RPs in this study a minimum of 0.0334ha) and were sampled with mostly one sample plot (in two cases with two sample plots) compared to RFS where at least two and mostly three sample plots were used. This means there was a higher probability that more interesting structures and characteristics were encountered in the RFS. Though, the basic criteria score, significantly higher in RFS, was based on elements encountered together with tree- and deadwood continuity. Even if more supporting characteristics could be encountered in RFS, the probability to meet basic criteria was indifferent.

The Wilcoxon test on differences in classifications as WKH I made of the stands showed no significant difference, but the results are close to significant ($p=0.06$) and shows a clear trend where more RFS are classified as WKH compared to RPs. As shown in Fig. 4, no RFS were classified lower than ONV and a dominant proportion was classified as WKH. On the contrary, RPs had a greater variance in classification where 46% were not classified as WKH and a surprisingly high proportion (17%) held lower conservational values (LNV), meaning that a quite large proportion of the RPs were rather trivial in terms of natural values. This trend is concerning since RPs with relatively low conservational values would probably be unsuccessful as lifeboats for species present in the pre-harvest stand.

4.2 Live conservation trees

A prominent target with RF is to retain LCT, being an important current- and future substrate in managed forest (Martikainen 2001; Lie et al. 2009; Claesson et al. 2013). In contrast, there was no significant difference in number of pine nor spruce LCT shown between RPs and RFS. Furthermore, the number of LCT of *Betula* and *Populus/Salix/Sorbus* was significantly higher in RFS. Thus, my results demonstrate that the studied RPs is not preserving a representative amount of LCT found in similar reference stands, despite guidelines and recommendations underlining its importance as a substrate.

However, dispersed retention of LCT is a common practice (Claesson et al. 2013), and this study does not include dispersed LCT outside of RPs. Including this could provide a more detailed data regarding number of LCT left at harvest. Though, the retention of LCT in patches instead of as dispersed trees is a recommended practice (Siitonen 2001; Hyvärinen et al. 2006; Lie et al. 2009) and to place patches where LCT exist will in addition lead to a future enrichment of high quality deadwood (Siitonen 2001).

The results regarding *Betula* and *Populus/Salix/Sorbus* illustrate how forest management in the studied area further maintain a deficiency of deciduous trees in a coniferous-dominated landscape with probable negative consequences for biodiversity. Dahlberg & Stokland (2004) presses the importance of increasing amounts of deciduous deadwood with the ongoing negative trend for saproxylic species (SLU Artdatabanken 2020). It has been shown that *Populus tremula* is of particular importance for maintaining biodiversity in boreal forests (Kivinen et al. 2020), and the proportion of species categorized as CR are highest for *P. tremula* as host tree, concluding that small groups of *Populus* trees can be biodiversity hotspots in boreal forests (Tikkanen et al. 2006). For most RPs, no *Populus*/*Salix*/*Sorbus* LCT were present, whereas RFS had a median of 10 trees per hectare, showing that deciduous LCT trees were present in similar pre-harvest stands but not included in surveyed RPs. Not retaining deciduous trees in RPs will likely impair the lifeboat function for many species and promote the ongoing homogenisation of forest stands.

4.3 Deadwood

The number of deadwood substrates in RPs was not significantly different from in randomly placed sample plots in RFS. This result was unexpected since targets with RF is to maintain biological legacies like deadwood in managed forests and to promote saproxylic species (Gustafsson et al. 2010). Again, no survey was done in the harvested area of the stand, where more deadwood might have been encountered, but with recognised positive effects of leaving deadwood in RPs instead of dispersed placement, it would be reasonable to expect RPs to be deadwood hotspots.

Besides the retention of pre-existing deadwood in RPs, deadwood substrate is in addition to a higher degree created post-harvest. Since tree mortality in stand-alone RPs left in spruce-dominated forests is relatively high due to wind- and pest damages and exposure stress, this normally leads to uncharacteristically high levels of deadwood (Jönsson et al. 2007), conversely to what is observed in this study. However, ~60% of RPs were not stand-alone, so this effect might have been less pronounced. Fortunately, it has been shown that the volume of deadwood outside of formally protected areas have increased in all parts of Sweden over the past 25 years, indicating that retention forestry to some degree has had a positive effect on the deadwood supply (Naturvårdsverket 2015).

4.3.1 Coarse deadwood

This study showed that less CDW (>30cm in diameter) was found in RPs than in RFS. Previous studies on deadwood availability has shown that a mean of 55.8 CDW elements ha^{-1} are found in boreal old-growth spruce forests (Jonsson 2000), which is far more compared to amounts in this study with a mean of 22.9 in RFS and 10.7 in RPs. There is a general deficiency in CDW in Sweden's managed forests, where less than 10% of deadwood exceed 30 cm in base diameter (Jonsson et al. 2016), similar to what I found where 6.6% of the deadwood exceeds 30 cm in diameter in RFS and 3.4% in RPs.

Considering the expected increased mortality connected to RPs, most prominent the first years after harvest (Jönsson et al. 2007), there should be a notable increase in CDW by now. These results show how current methods for CDW retention are likely insufficient with highly negative outcomes for preservation of saproxylic species, since a vast majority prefer deadwood with larger diameters and more than 15% of species prefer deadwood >40 cm in diameter (Dahlberg & Stokland 2004). Comparing the results from this study with results on amount of CDW found in old-growth forests in Sweden show that both RFS and RP deviate in terms of CDW amount.

The lack of CDW in RPs that evidently exist in RFS indicates that forest management does not capture representative forest patches that will have sufficient capacity to harbour all species over the clear-cut phase. This may indicate that other values than natural values were prioritized. Forest owners has shown to have a general positive attitude towards setting aside parts of their forest estate for nature conservation purposes, but this attitude was less positive if it leads to a greater loss in revenue (Westerström & Frick 2013). Therefore, operations during final harvest may have prioritized a higher profit, meaning that valuable timber was disadvantageous to leave in RPs. The consequences would be RPs with a deviating diameter distribution than previously found in the harvested stand and decreased recruitment possibilities of CDW. However, there is a discrepancy in leaving large diameter trees in RPs, since it eventually creates CDW, but large trees also face a higher risk of wind damage, and if many large trees in a RP disappear due to wind damage, the microclimate would not be sustained, which is a requirement for lifeboating of species (Franklin et al. 1997).

4.3.2 Total number of LCT and deadwood

As demonstrated in Fig. 8, there was no difference in total number of substrates for each substrate category. Fig. 8 also demonstrate the wide range of observed values with many outliers. Instead, it shows that the median number of substrates were higher in RFS in comparison to RPs for all substrate categories, and a higher mean for lying- and standing deadwood in RFS. The natural conclusion from this dataset would be that the RPs in general hold fewer substrates than RFS.

4.3.3 Substrate diversity

The tests for substrate diversity, including both deadwood and LCT, showed no difference between RPs and RFS. Having a high substrate diversity would give some indication on a RPs ability to harbour a wide array of species, as species can be very specific in their substrate preferences (Jonsson et al. 2005). Having a low substrate diversity where only one or a few substrate types are present does not necessarily need to be negative, as this means that there would be an abundance of substrate for the species that is linked to that type of substrate. On a larger scale, RPs with dissimilar but homogenous substrate quality would thus sustain substrate diversity. However, nature consideration in Swedish forestry is mainly focused on smaller management units, so to ensure a provision of substrates that meets species demands would require retaining a heterogenous substrate composition in RPs (Jonsson et al. 2005). The insignificant difference between RPs and RFS show that RPs generally seem to have captured a similar substrate diversity to what is found in RFS. However, these results does not disclose the quality of substrates found, where stands can have similar substrate diversity and composition but different substrate quality.

A point of concern was whether the stands chosen in 2002 had a different pre-existing species diversity, that might indicate pre-existing differences in natural values. However, the tests showed that no difference was found in initial species diversity, that can be seen as an indicator that the original stands held congruous conservational values with similar levels of biodiversity. Testing initial species richness was simply done to further strengthen the assumption of homogenous study stands.

4.4 Physical prerequisites

The physical prerequisites in the studied RFS and RPs were investigated as a hypothesis of mine was that the placing of RPs is influenced by the area's operational difficulty to harvest. The influence of the physical factors is significant to investigate, since choosing areas with a deviant composition, like wetter areas or areas covered with boulders, will not meet the condition of representing the preharvest stand (Franklin et al. 1997) and likely have a deviant species composition. However, the analysis of the data collected showed no differences between RFS and RPs in slope, soil moisture or occurrence of boulders. Though, the variation of these factors within the stands was not determined in this study. If the variation was low with no patches having deviated physical prerequisites making them difficult to harvest, the influence of these factors would be harder to detect.

Although, two RPs visible from the aerial photos were completely removed when data collection took place, and three others had traces of forestry like drainage ditches and a logging road. This complete removal or degradation of RPs opposes forest certification recommendations and counteract the function of RF with increased connectivity and habitat preservation in a longer time-perspective (Saura et al. 2014). RPs remain a significant complement to formally protected areas (Perhans et al. 2009; Simonsson et al. 2016), and to fulfil their function, they need to be of high quality and remain untouched until the next forest stand reaches maturity (Martínez Pastur et al. 2020). This function would likely be counteracted if RPs are affected by forestry operations.

4.5 Implications for forest management

To summarize the results of this study, forest management has created RPs with a structure that does not match the quality in RFS, where CDW and deciduous LCT are more abundant. Further, no difference in deadwood amounts show that RPs does not constitute deadwood hotspots. Expected was RPs that encapsulate the structure found in RFS while also providing an abundance of substrates needed to lifeboat species until the subsequent forest stand is established. Instead, my results show that RPs constitute areas of lower or indifferent conservational quality than randomly selected samples in RFS, and the conclusion that other values than conservational are prioritized is not far-fetched. Based on the results in this thesis, I would argue that the nature conservation approach in Sweden need to be revised to ensure future forests of high conservational quality.

There are many areas of improvement and management options that are essential for long-term species survival in the managed forest landscape. Firstly, what to retain need to be evaluated to in the best manner capture a representative forest composition while also providing required substrates by threatened species. As shown, the amount of deciduous LCT was lower in RPs so some attention needs to be directed to ensure that deciduous trees (preferably LCT) are retained in retention patches where they are part of the species composition in the pre-harvest stand. This would counteract the homogenisation of boreal coniferous forests and benefit a wider range of species. A diverse patch composition is preferred with varying species and diameters. More wind-resistant smaller trees and deciduous trees is recommended, together with larger trees that can help provide deadwood for saproxylic species (Jönsson et al. 2007; Ylisirniö & Hallikainen 2018).

Many researchers agree that RPs should be placed in areas with a pre-existing higher density of deadwood to fulfil the lifeboat function (Vanha-Majamaa & Jalonen 2001; Hautala et al. 2004; Jonsson et al. 2005). Large amounts of deadwood often coincide with wetter areas, also enriched by *P. tremula* trees (Vanha-Majamaa & Jalonen 2001), indicating that wetter areas are suitable for retention. It has also been suggested to move logs from clear-cut areas into RPs as a good practice to prevent further damage to the deadwood and promote exposure-sensitive species (Rudolphi et al. 2014). However, the shortage of deadwood in managed forests will likely not be resolved only by retaining existing deadwood legacies, but to meet the requirements for saproxylic species, active creation of deadwood during management operations is likely needed to quicker reverse the shortage (Jonsson et al. 2005, 2016). In addition to high quality RPs, there is a need for increasing the quality of the managed forest matrix to promote species dispersal and thus long-term survival (Fahrig 2001). A suggested way to promote higher matrix quality is to through forest certification prescribe a higher level of retention of dying- and living trees and creation of high stumps (Jonsson et al. 2006). On a different note, the stand-level standard retention approach used in Sweden today mainly focuses on substrates and structure, and an obvious way to improve management is a more thorough species inventory prior to harvest, to identify biodiversity hotspots and concentrate retention efforts there (Vanha-Majamaa & Jalonen 2001; Rudolphi et al. 2014).

A second important management improvement is the spatial arrangement of RPs. It has been suggested that larger aggregates are to prefer over smaller ones, due to the extensive exposition to edge-effects (Esseen 1994; Aune et al. 2005; Ylisirniö et al. 2016). Having larger RPs also links to a desired diverse patch composition as it would be more likely to include structures and characteristics of a WKH, and thus have a higher ability to harbour a larger diversity of species (Jönsson et al. 2007). Though small RPs, like those included in this study, will structurally enrich managed stands, they are highly unsuccessful in maintaining forest interior conditions and it is therefore unlikely that small RPs will successfully lifeboat disturbance sensitive species (Jönsson et al. 2007). Retaining larger aggregated areas than the RPs in this study is therefore advised.

The operational aspect is hard to look past for future forest management, where many areas are operationally impossible to harvest with methods used in Sweden. These areas are also known to often coincide with higher species diversity (Vanha-Majamaa & Jalonen 2001) so it would be wise to continue retaining them. However, a method to both create larger RPs and include a physical setting that is representative of the forest stand is to expand RPs around areas presenting operational difficulties to also include a representative forest setting. An additional way that the spatial arrangement could improve is placing of RPs in shaded areas, to sustain a protected microclimate that will benefit exposure-sensitive species, e.g. by placing patches facing north (Rudolphi et al. 2014).

A third consideration to be made in management is the spatial scale of nature consideration. If retention is to be performed in a standard fashion, retaining similar biotopes and substrates in all management units, what will the consequences be if the retention is viewed on a landscape level? An important step nature consideration in forestry need to take is a shift to a more holistic perspective, where natural values are considered on a landscape level and RPs are representative of the landscape as a whole (Perhans et al. 2009). In addition to spatial consideration, temporal consideration should be made to ensure that there is a continuous structural enrichment by RPs (Jonsson et al. 2005; Rosenvald & Lõhmus 2008; Roberge et al. 2015) and that RPs continue fulfilling their function as stepping stones (Saura et al. 2014) in a longer time perspective. Overall, what is needed from forestry stakeholders is a will to compromise profit and adjust yield expectations to meet biodiversity preservation targets (Mitchell & Beese 2002).

Nonetheless, economic values are central in forest management and the cost-effectiveness need to be assessed for all management operation, including nature considerations. If a tree is to be retained from harvest, it is naturally important that factors that can maximize the benefit is considered (Jonsson et al. 2005). It is inevitable to face trade-offs in management as it is not likely that operations that maximize biological diversity will also maximize production (Mitchell & Beese 2002). Consequently, forest managers should prior to harvest consider the current trade-offs to find the best alternatives, but with the prevailing focus on financial values with negative consequences for biodiversity (Lindahl et al. 2017), a loss in revenue due to nature consideration should be accepted.

To conclude, a larger perspective is required to promote all forest dwelling species, where the narrow perspective the Swedish model with general stand-level nature consideration brings may forego some of the functions described by Franklin et al. (1997) and Gustafsson et al. (2012). The problem with the stand-level focus on nature consideration and prioritizing of profit in forest management is that it may be incompatible with including requirements of a broader set of species and with creating heterogeneity on a landscape level. To achieve RF goals, forest management should consider a larger geographic scale (Perhans et al. 2011) and temporal scale to ensure long-term structural enrichment (Jonsson et al. 2005; Rosenvald & Lõhmus 2008) identify areas with the highest species richness (Vanha-Majamaa & Jalonen 2001; Rudolphi et al. 2014), and protect a wider array of biotopes with different site characteristics (Fridman 2000).

4.6 Possible improvements and sources of error

The set of stands that was chosen for this survey was in many ways beneficial as it was relatively homogenous and structurally similar spruce-dominated stands, but since a few of the stands were excluded from the beginning due to not having any RPs or due to harvested RPs, the sample size turned out relatively small. To include a larger dataset with similar stands would provide a sounder statistical analysis of the parameters in this study. Nevertheless, the homogeneity of the surveyed stands included in this study ensures a solid basis for a comparative structural analysis. However, this study could be improved with a larger sample size and elimination of sources of error.

The method used in this study requires a higher level of experience with evaluating natural values in forest biotopes. Thus, a more experienced inventory would likely make a more well-grounded assessment of natural values, with more references to compare prevailing conditions to. Further, this method includes species of conservational interest, thus requiring a comprehensive species knowledge to fully utilize the species dimension of the assessment in addition to structural parameters. In conclusion, the method was designed to minimize subjectivity but the ability to assess natural values increase with experience, so whomever using this method should preferably be familiar with assessing natural values in the current biotope.

Although, the method provides concrete measurements on elements important for biodiversity and this objectively collected data enables making a valid comparison and draw well-based conclusions on structural differences between the RPs and the RFS.

Since many of the sample plots were relatively small in size and surrounded by a clear-cut, they were likely influenced by disturbances creating unrepresentative amounts of deadwood (Jönsson et al. 2007). This in turn, with a small RP area led to unrealistic amounts of deadwood per hectare when upscaling using the equation in Fig. 2. The consequences were similar for LCT, where small sample plot area resulted in unrealistic outlier data. Regardless, the high density of deadwood and LCT often observed in RP will benefit saproxylic species and retain deadwood structures in the developing forest stands (Jönsson et al. 2007), but the data observed may not be representative of the actual pre-harvest conditions.

The physical prerequisites were in this study noted in RFS and in RPs, excluding the harvested area in which the RPs were placed. To collect data on the physical setting within RPs and in the associated harvested stand would provide a better basis for a comparative analysis than the method used in this study. Collecting data within harvested units would give clearer results and better answer the research question on if the physical factors influence the RP placement.

An issue discussed with the method used was the assumption of independency between surveys done in the same management unit, in cases with more than one RP or as described in Fig. 1. This might be questionable, as the management unit may have the same historical influence and the close geographic location suggests stand development under similar climatic conditions. However, the separate surveys done in the same stand but in delineated subunits have been considered independent samples and this assumption might be faulty.

4.6.1 Future studies

My results show that studied RPs were not structurally richer with more deadwood or LCT in comparison to RFS, but rather the opposite, so the question of why these patches were retained remains. The limited time for designing and executing the data collection for this study led to both inclusion of unnecessary parameters and exclusion of possibly interesting parameters. For future studies, it would be preferable to survey a set of stands pre- and post-harvest that also includes surveying of the harvested area to get detailed data on what elements are left in RPs and what elements are left on the harvested area. This would provide element data for the whole stand and an improved image of how representative the RPs are of the pre-harvest conditions.

Furthermore, the preparatory work could have been more excessive to improve the data collection. For example, the acceptable range in size and placement of the RPs could have been delimitated beforehand to minimize sample variation. These factors could possibly show interesting patterns with different RP size and stand-alone or RPs bordering standing forest, connected to edge effects that probably have influenced both microclimatic conditions and substrate supply (Jönsson et al. 2007; Ylisirniö et al. 2016). In addition, information on whether the patches left within the surveyed stand that bordered standing forests were left as retention or if the delineation of the management units have been changed could have been gathered to improve the study.

Another restriction that could help improve the evaluation of nature consideration would be to delimitate the study to RPs with similar time since harvest, as this sample of stands vary greatly in when they were harvested. The temporal aspect of RPs should be considered as changes to the forest structure will occur over time that makes the actual management actions harder to evaluate. For example, wind uprooting is a prominent reason for tree death in RPs (Jönsson et al. 2007), and to investigate the proportion of uprooted trees in a RP could imply how much of the dead wood was added post-harvest and how much was retained during harvest. This would give a more precise image of how much dead wood was left intentionally and how much that was coincidental.

Unfortunately, the amount of CDW was only registered in spruce-dominated stands. If this variable were to be included for data collection in all biotope types and if the sample size was larger, interesting comparisons on differences between biotope types could be made. A few RPs were pine-dominated, and these might differ in terms of CDW compared to spruce-dominated RPs.

For future evaluations of operational or economic aspects influencing patch placement, it would be useful to gather information on the physical prerequisites of the harvested area and of the retained area to evaluate if potential differences influenced the placement of patches. An additional method of examining the economic aspects influence on RP placement would be to study if site productivity of the retained areas deviates from the remaining stand. Moreover, to follow up on the results for CDW, it would be interesting to study if the economic value of the timber left in RPs deviate from the remaining stand, as a consequence of a possible disinclination to leave areas of a higher monetary value for conservational purposes. The possible influence of physical prerequisites, site productivity and timber value could also be investigated by including the harvest operational instruction to in that way evaluate what RP placement was based on. Including different forest owners is an additional aspect that could provide insight into possible differences between to what degree nature consideration is prioritized. It is possible that interests and nature consideration left vary depending on if the forest is owned by a forest company, private owners, or the state.

The quality of deadwood substrates is an important aspect identified when discussing how retention of deadwood will contribute to biodiversity preservation (Dahlberg & Stokland 2004; Jonsson et al. 2016). It has been shown that deadwood types found in managed Swedish forests are homogenous (Jonsson et al. 2016), so it could therefore be of interest to also collect data on the deadwood quality like age, diameter class and stage of decomposition, to further evaluate the substrate diversity in RPs. A patch with freshly dead wood of the same age and species is not likely to have the same value for biodiversity preservation as patches including heterogenous deadwood (Jonsson et al. 2005). In this study, the substrate diversity analysis focused on substrates present without considering frequency, which might have been interesting to include. My results do not show if there was a similar substrate diversity but a higher substrate frequency in RPs or RFS. Furthermore, an issue previously described was the unrealistic substrate amounts generated by the upscaling of number of elements in smaller RPs. For future studies, a requirement should be that the surveyed forest stands contain RPs of a sufficient size to place sample plots with a radius of at least 18 m, to get a more realistic representation of elements per hectare.

4.7 Conclusion

I studied structural differences in retention patches and structurally similar reference forest stands to evaluate the composition and conservational quality of retention left, considering the functional aims of retention forestry where retention patches constitute biodiversity hotspots. The results of this study show how retention patches are structurally different from the reference forests with indifferent or lower conservational quality. The retention patches scored lower in the natural value assessment, contained less *Betula* and *Populus/Salix/Sorbus* live conservational trees and less coarse deadwood. The lower quality of retention left implies that the subsequent forest stand will be structurally poorer than the previous stand and this in turn, will on a larger scale lead to an impoverishment of the forest landscape. No difference was found in the physical prerequisites in the reference stands and retention patches.

Based on these results, the Swedish method for nature conservation in forestry needs to improve to ensure a structural enrichment of managed forests and long-term survival of forest dwelling species. Improvements can be made by 1) increasing the diversity and quality of substrates in retention patches to promote lifeboating of species, 2) thorough inventories of species and substrates prior to harvest to identify most beneficial retention patch placement, 3) increasing retention patch size to include a representative and diverse forest composition and sustain forest interior conditions, 4) generally increasing the quality of the managed forest matrix to facilitate species dispersal, and 5) consider conservational values on a landscape level to ensure continuous and complementary provision of habitat and substrate. Today's stand-levelled focus in retention planning could forgo many of the goals with retention forestry that considers a landscape perspective like connectivity and biotope representativeness.

There is uncertainty in how much retention forestry and stand-level nature consideration contributes to long-term biodiversity preservation. Nevertheless, retention forestry is acknowledged as an important complement to formally protected areas and as an important tool in enriching managed forests. However, to maximise the benefit for nature conservation, future studies are required to gain more knowledge. Areas in need of further studies are how well retention patches represent pre-harvest conditions, what interests and factors that influence retention patch placement and what future forests retention forestry creates.

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Appendix 1 – Natural value assessment checklists for north-western Sweden

NB-checklista 2019-07-01

Granskog (nordvästra sverige)

OBS! Gäller för biotoptyperna Barrskog, Barrnaturskog, Lövrik barrskog, Lövrik barrnaturskog och Myr- och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden

Se andra sidan om provytor

Naturvärdesträd (gran)	............../ha
Naturvärdesträd (övriga)	............../ha
Liggande död ved > 10 cm	............../ha
Stående död ved > 10 cm	............../ha
NB	☐
ONV	☐
Lägre naturvärden	☐
NO	☐
NS	☐
PF	☐

Kriterier Spår 1

Hela nordväst: Sannolikt NB om 5 Spår 1-kriterier uppfylls.

- ☐ Minst 20 /ha naturvärdesträd (alla trädslag)
- ☐ Minst 30 /ha naturvärdesträd (gran)
- ☐ Minst 60 /ha dödved >10 cm
- ☐ Minst 30/ ha rötbrutna lågor >10 cm (gran)
- ☐ Trädkontinuitet
- ☐ Lågakontinuitet

Skötsel:

Kriterier Spår 2

Delområde 1,2,3 <20 hektar: Sannolikt NB om 9 kriterier uppfylls.
Delområde 1,2,3 >20 hektar: Sannolikt NB om 8 kriterier uppfylls.
Delområde 4 <20 hektar: Sannolikt NB om 10 kriterier uppfylls.
Delområde 4 >20 hektar: Sannolikt NB om 9 kriterier uppfylls.
Hela nordväst: Sannolikt ONV om 4 kriterier uppfylls.

Träd	☐ Minst 20/ha naturvärdesträd (gran)
	☐ Minst 10/ha granar med grov barkstruktur
	☐ Minst 10/ha granar med hög ålder > 250 år
	☐ Minst 5 /ha naturvärdesträd av tall och/eller björk
	☐ Minst 5 /ha naturvärdesträd av asp/sälg/rönn
Död ved	☐ Minst 50/ha dödved >10 cm
	☐ Minst 20 /ha rötbrutna lågor >10 cm (gran)
	☐ Minst 10/ha grov död ved > 30 cm (gran)
	☐ Lågor i olika nedbrytningsstadier
Karaktärsdrag	☐ Flerskiktat/stor diam.spridning
	☐ Senvuxet bestånd
	☐ Över 160 år - 50 äldsta träden
	☐ Pågående självgallring
	☐ Luckdynamik
	☐ Hänglavsrikt
	☐ Äldre betespräglad skog
	☐ Markvegetation domineras av hög/lågörter
Art	☐ Hög frekvens av signal- och/eller rödlistade art
	☐ Fynd av art med hotkategori VU, EN och/eller CR
	☐ Minst 6 olika signal- och/eller rödlistade arter*
	☐ Andra kvalitetshöjande inslag..................................
	☐ Andra kvalitetshöjande inslag..................................

OBS! Checklistan ska vara starkt vägledande för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan för NV

Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Barrskogar - nyckelbiotoper i Sverige*, broschyren *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd gran															
	NV-träd tall															
	NV-träd björk															
	NV-träd asp/sälg/rönn															
	Total antal naturvärdesträd															
	Granar m grov bark struktur															
	Granar m hög ålder > 250 år															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	rötbrutna lågor > 10 cm (gran)															
	Grov död ved > 30 cm (gran)															
	Lågor i olika nedbrytningsstadier															
Karaktärsdrag	Flerskiktat/stor diam.spridning															
	Senvuxet bestånd															
	Över 160 år - 50 äldsta träden															
	Pågående självgallring															
	Luckdynamik															
	Hänglavsrikt															
	Äldre betespräglad skog															
	Markvegetation domineras av hög/lågörter															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

NB-checklista 2019-07-01

Tallskog (nordvästra sverige)

OBS! Gäller för biotoptyperna Barrskog, Barrnaturskog, Lövrik barrskog, Lövrik barrnaturskog och Myr- och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden

Se andra sidan om provytor

- Naturvärdesträd (tall) .... /ha
- Naturvärdesträd (övriga) .... /ha
- Liggande död ved > 10 cm .... /ha
- Stående död ved > 10 cm .... /ha

- NB ☐
- ONV ☐
- Lägre naturvärden ☐

- NO ☐
- NS ☐
- PF ☐

Kriterier Spår 1

Hela nordväst: Sannolikt NB om 4 Spår 1-kriterier uppfylls.

- ☐ Minst 20 /ha naturvärdesträd (alla trädslag)
- ☐ Minst 30 /ha naturvärdesträd (tall)
- ☐ Minst 50 /ha dödved >10 cm
- ☐ Minst 15 /ha silverlågor/torrakor (tall)
- ☐ Trädkontinuitet
- ☐ Lågakontinuitet

Skötsel:

Kriterier Spår 2

Delområde 1,2,3 <10 hektar: Sannolikt NB om 8 kriterier uppfylls.
Delområde 1,2,3 >10 hektar: Sannolikt NB om 7 kriterier uppfylls.
Delområde 4 <10 hektar: Sannolikt NB om 9 kriterier uppfylls.
Delområde 4 >10 hektar: Sannolikt NB om 8 kriterier uppfylls.
Hela nordväst: Sannolikt ONV om 3 Spår 2-kriterier uppfylls.

Träd
- ☐ Minst 20 /ha naturvärdesträd (tall)
- ☐ Minst 5 /ha tydlig pansarbark eller >250 år (tall)
- ☐ Minst 5 /ha naturvärdesträd gran
- ☐ Minst 5 /ha naturvärdesträd björk
- ☐ Brandljud i levande träd
- ☐ Naturvärdesträd av asp/sälg/rönn

Död ved
- ☐ Minst 30 /ha dödved >10 cm
- ☐ Minst 10 /ha brand/silverstubbar
- ☐ Minst 5 /ha torrakor
- ☐ Minst 5 /ha silverlågor

Karaktärsdrag
- ☐ Flerskiktat/stor diam.spridning
- ☐ Senvuxet bestånd
- ☐ Över 180 år - 50 äldsta träden
- ☐ Pågående självgallring
- ☐ Hänglavsrikt
- ☐ Hällmark/lodyta/blockrikt

Arter
- ☐ Hög frekvens av signal- och/eller rödlistad art
- ☐ Fynd av art med hotkategori VU, EN och/eller CR
- ☐ Minst 5 olika signal- och/eller rödlistade arter*

- ☐ Andra kvalitetshöjande inslag..................................
- ☐ Andra kvalitetshöjande inslag..................................

OBS! Checklistan ska vara starkt vägledande för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan för NV

Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Åtgärdsprogram för kalktallskogar*, *Svampar i sandtallskogar (lavtallhedar)*, *Barrskogar - nyckelbiotoper i Sverige*, broschyrerna *Sandtallskogar*, *Kalktallskogar* och *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd tall															
	NV-träd gran															
	NV-träd björk															
	NV-träd asp/sälg/rönn															
	Total antal naturvärdesträd															
	Brandljud i levande träd															
	Minst 5/ha tydlig pansarbark eller >250 år (tall)															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	Torraka															
	Silverlåga															
	Brand/silverstubbar															
Karaktärsdrag	Flerskiktat/stor diam.spridning															
	Senvuxet bestånd															
	> 180 år - 50 äldsta träden															
	Pågående självgallring															
	Hänglavsrikt															
	Hällmark/lodyta/blockrikt															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

NB-checklista 2019-07-01

Barrskog med höga lövvärden (nordvästra sverige)

OBS! Gäller för biotoptyperna: Barrskog, Barrnaturskog, Lövrik barrskog, Lövrikbarrnaturskog och Myr- och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden
Se andra sidan om provytor

Naturvärdesträd (löv) .... /ha
Naturvärdesträd (övriga) .... /ha

Liggande död ved > 10 cm .... /ha
Stående död ved > 10 cm .... /ha

- ☐ NB
- ☐ ONV
- ☐ Lägre naturvärden

- ☐ NO
- ☐ NS
- ☐ PF

Kriterier Spår 1

Hela nordväst: Sannolikt NB om 4 Spår 1-kriterier uppfylls.

- ☐ Minst 20 /ha naturvärdesträd (alla trädslag)
- ☐ Minst 20 /ha naturvärdesträd (asp, sälg och rönn)

- ☐ Minst 60 /ha död ved >10 cm (alla trädslag)
- ☐ Minst 30 /ha död ved > 10 cm (löv)

- ☐ Trädkontinuitet bland lövträden
- ☐ Lövbrännelik

Skötsel:

Kriterier Spår 2

Hela nordväst: Sannolikt NB om 7 Spår 2-kriterier uppfylls.

Hela nordväst: Sannolikt ONV om 5 Spår 2-kriterier uppfylls.

Träd
- ☐ Minst 20 /ha naturvärdesträd (löv)
- ☐ Minst 10 /ha lövträd med grov barkstruktur
- ☐ Minst 10 /ha naturvärdesträd (asp/sälg/rönn)
- ☐ Minst 10 /ha lövträd med synliga tickor
- ☐ Brandljud i levande träd
- ☐ Träd m bohål /håligheter (alla trädslag)

Död ved
- ☐ Minst 50 /ha död ved >10 cm (alla trädslag)
- ☐ Minst 10 /ha grov död ved >30 cm (alla trädslag)
- ☐ Minst 20 /ha död ved >10 cm (löv)
- ☐ Lågor i olika nedbrytningsstadier
- ☐ Död ved med brandspår

Karaktärsdrag
- ☐ Flerskiktat/stor diam.spridning
- ☐ Pågående självgallring
- ☐ Markvegetation domineras av hög/lågörter
- ☐ Förekomst av småvatten
- ☐ Lövträdens ursprung kan kopplas till brand
- ☐ Hällmark/lodyta/blockrikt

Art
- ☐ Hög frekvens av signal- och/eller rödlistade art
- ☐ Fynd av arter med hotkategori VU, EN och/eller CR
- ☐ Minst 6 olika signal- och/eller rödlistade arter*

- ☐ Andra kvalitetshöjande inslag..................................
- ☐ Andra kvalitetshöjande inslag..................................

OBS! Checklistan ska vara starkt vägledande för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan för NV
Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Åtgärdsprogram för kalktallskogar*, *Svampar i sandtallskogar (lavtallhedar)*, *Barrskogar - nyckelbiotoper i Sverige*, broschyrerna *Sandtallskogar*, *Kalktallskogar* och *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd björk															
	NV-träd asp															
	NV-träd sälg															
	NV-träd rönn															
	NV-träd tall															
	NV-träd gran															
	Summa naturvärdesträd															
	Brandljud i levande träd															
	Träd m bohål/ håligheter (alla trädslag)															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	Grov död ved > 30 cm (alla trädslag)															
	Lågor i olika nedbrytningsstadier															
	Död ved med brandspår															
Karaktärsdrag	Markvegetation domineras av hög/lågörter															
	Pågående självgallring															
	Flerskiktat/stor diam.spridning															
	Förekomst av småvatten															
	Lövträdens ursprung kan kopplas till brand															
	Hällmark/lodyta/blockrikt*															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

Appendix 2 – Natural value assessment checklists for northern Sweden

Datum: 2020-05-15 | **Nyckelbiotop-checklista bedömningsstöd** | Bilaga

Granskog (Norra Sverige)

OBS! Gäller för biotoptyperna: Barrskog, Barrnaturskog, Lövrikbarrnaturskog och Myr och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden

Se andra sidan om provytor

Naturvärdesträd (gran)	______/ha
Naturvärdesträd (övriga)	______/ha
Liggande död ved > 10 cm	______/ha
Stående död ved > 10 cm	______/ha
NB	☐
ONV	☐
Lägre naturvärden	☐
NO	☐
NS	☐
PF	☐
PG	☐

Kriterier Spår 1

Finns minst 5 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 2 inte uppfylls.

- ☐ Minst 20 /ha naturvärdesträd (alla trädslag)
- ☐ Minst 20 /ha naturvärdesträd (gran)
- ☐ Minst 60 /ha dödved >10 cm
- ☐ Minst 30/ ha rötbrutna lågor >10 cm (gran)
- ☐ Trädkontinuitet
- ☐ Lågakontinuitet

Skötsel:

Kriterier Spår 2

Finns det minst 8 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 1 inte uppfylls.

Träd	☐ Minst 15/ha naturvärdesträd (gran)
	☐ Minst 10/ha granar med grov barkstruktur
	☐ Minst 10/ha granar med hög ålder > 220 år
	☐ Minst 5 /ha naturvärdesträd av tall och/eller björk
	☐ Minst 5 /ha naturvärdesträd av asp/sälg/rönn
Död ved	☐ Minst 50/ha dödved >10 cm
	☐ Minst 20 /ha rötbrutna lågor >10 cm (gran)
	☐ Minst 10/ha grov död ved > 30 cm (gran)
	☐ Lågor i olika nedbrytningsstadier
Karaktärsdrag	☐ Flerskiktat/stor diam.spridning
	☐ Senvuxet bestånd
	☐ Över 150 år - 50 äldsta träden
	☐ Pågående självgallring
	☐ Luckdynamik
	☐ Hänglavsrikt
	☐ Äldre betespräglad skog
	☐ Markvegetation domineras av hög/lågörter
Art	☐ Hög frekvens av signal- och/eller rödlistade art
	☐ Fynd av art med hotkategori VU, EN och/eller CR
	☐ Minst 6 olika signal- och/eller rödlistade arter*
	☐ Andra kvalitetshöjande inslag................................
	☐ Andra kvalitetshöjande inslag................................

OBS! Checklistan ska vara ett stöd för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan i Handledningen Naturvärden i skog

Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Barrskogar - nyckelbiotoper i Sverige*, broschyren *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd gran															
	NV-träd tall															
	NV-träd björk															
	NV-träd asp/sälg/rönn															
	Total antal naturvärdesträd															
	Granar m grov bark struktur															
	Granar m hög ålder > 220 år															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	rötbrutna lågor > 10 cm (gran)															
	Grov död ved > 30 cm (gran)															
	Lågor i olika nedbrytningsstadier															
Karaktärsdrag	Flerskiktat/stor diam.spridning															
	Senvuxet bestånd															
	Över 150 år - 50 äldsta träden															
	Pågående självgallring															
	Luckdynamik															
	Hänglavsrikt															
	Äldre betespräglad skog															
	Markvegetation domineras av hög/lågörter															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

Datum: 2020-05-15 **Nyckelbiotop-checklista bedömningsstöd** Bilaga

Tallskog (Norra Sverige)

OBS! Gäller för biotoptyperna: Barrskog, Barrnaturskog, Lövrikbarrnaturskog och Myr och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden

Se andra sidan om provytor

Naturvärdesträd (tall) ______ /ha
Naturvärdesträd (övriga) ______ /ha

Liggande död ved > 10 cm ______ /ha
Stående död ved > 10 cm ______ /ha

NB ☐
ONV ☐
Lägre naturvärden ☐

NO ☐
NS ☐
PF ☐
PG ☐

Kriterier Spår 1

Finns minst 4 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 2 inte uppfylls.

- ☐ Minst 20 /ha naturvärdesträd (alla trädslag)
- ☐ Minst 20 /ha naturvärdesträd (tall)
- ☐ Minst 50 /ha dödved >10 cm
- ☐ Minst 15 /ha silverlågor/torrakor (tall)
- ☐ Trädkontinuitet
- ☐ Lågakontinuitet

Skötsel:

Kriterier Spår 2

Finns det minst 7 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 1 inte uppfylls.

Träd
- ☐ Minst 15 /ha naturvärdesträd (tall)
- ☐ Minst 5 /ha tydlig pansarbark eller >220 år (tall)
- ☐ Minst 5 /ha naturvärdesträd gran
- ☐ Minst 5 /ha naturvärdesträd björk
- ☐ Brandljud i levande träd
- ☐ Naturvärdesträd av asp/sälg/rönn

Död ved
- ☐ Minst 30 /ha dödved >10 cm
- ☐ Minst 10 /ha brand/silverstubbar
- ☐ Minst 5 /ha torrakor
- ☐ Minst 5 /ha silverlågor

Karaktärsdrag
- ☐ Flerskiktat/stor diam.spridning
- ☐ Senvuxet bestånd
- ☐ Över 160 år - 50 äldsta träden
- ☐ Pågående självgallring
- ☐ Hänglavsrikt
- ☐ Hällmark/lodyta/blockrikt

Art
- ☐ Hög frekvens av signal- och/eller rödlistad art
- ☐ Fynd av art med hotkategori VU, EN och/eller CR
- ☐ Minst 5 olika signal- och/eller rödlistade arter*

- ☐ Andra kvalitetshöjande inslag.................................
- ☐ Andra kvalitetshöjande inslag.................................

OBS! Checklistan ska vara ett stöd för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan i Handledningen Naturvärden i skog

Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Barrskogar - nyckelbiotoper i Sverige*, broschyren *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd tall															
	NV-träd gran															
	NV-träd björk															
	NV-träd asp/sälg/rönn															
	Total antal naturvärdesträd															
	Brandljud i levande träd															
	Tydlig pansarbark eller >220 år (tall)															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	Torraka															
	Silverlåga															
	Brand/silverstubbar															
Karaktärsdrag	Flerskiktat/stor diam.spridning															
	Senvuxet bestånd															
	> 160 år - 50 äldsta träden															
	Pågående självgallring															
	Hänglavsrikt															
	Hällmark/lodyta/blockrikt															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

Datum: 2020-05-15 **Nyckelbiotop-checklista bedömningsstöd** Bilaga

Barrskog med höga lövvärden (Norra Sverige)

OBS! I biotoptyperna: Barrskog, Barrnaturskog, Lövrikbarrnaturskog, Lövrikbarrskog och Myr och skogsmosaik

Antal strukturer/ha

Använd 25*5 eller 18*10 metoden
Se andra sidan om provytor

Naturvärdesträd (Löv) ______/ha
Naturvärdesträd (övriga) ______/ha

Liggande död ved > 10 cm ______/ha
Stående död ved > 10 cm ______/ha

NB ☐
ONV ☐
Lägre naturvärden ☐

NO ☐
NS ☐
PF ☐
PG ☐

Kriterier Spår 1

Finns minst 4 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 2 inte uppfylls.

☐ Minst 20 /ha naturvärdesträd (alla trädslag)
☐ Minst 20 /ha naturvärdesträd (asp, sälg och rönn)

☐ Minst 60 /ha död ved >10 cm (alla trädslag)
☐ Minst 30 /ha död ved > 10 cm (löv)

☐ Trädkontinuitet bland lövträden
☐ Lövbrännelik

Skötsel:

Kriterier Spår 2

Finns det minst 7 kriterier är det sannolikt en nyckelbiotop, trots att nivån i Spår 1 inte uppfylls.

Träd
☐ Minst 20 /ha naturvärdesträd (löv)
☐ Minst 10 /ha lövträd med grov barkstruktur
☐ Minst 10 /ha naturvärdesträd (asp/sälg/rönn)
☐ Minst 10 /ha lövträd med synliga tickor
☐ Brandljud i levande träd
☐ Träd m bohål /håligheter (alla trädslag)

Död ved
☐ Minst 50 /ha död ved >10 cm (alla trädslag)
☐ Minst 10 /ha grov död ved >30 cm (alla trädslag)
☐ Minst 20 /ha död ved >10 cm (löv)
☐ Lågor i olika nedbrytningsstadier
☐ Död ved med brandspår

Karaktärsdrag
☐ Flerskiktat/stor diam.spridning
☐ Pågående självgallring
☐ Markvegetation domineras av hög/lågörter
☐ Förekomst av småvatten
☐ Lövträdens ursprung kan kopplas till brand
☐ Hällmark/lodyta/blockrikt

Art
☐ Hög frekvens av signal- och/eller rödlistade art
☐ Fynd av arter med hotkategori VU, EN och/eller CR
☐ Minst 6 olika signal- och/eller rödlistade arter*

☐ Andra kvalitetshöjande inslag.................................
☐ Andra kvalitetshöjande inslag.................................

OBS! Checklistan ska vara ett stöd för den samlade bedömningen, men ska inte användas för att "bevisa" nyckelbiotopsstatus eller inte.

Anteckningar:

*) Från artlistan i Handledningen Naturvärden i skog

Övriga biotoptyper se *Handbok för nyckelbiotopsinventering*, indikatorarter (t.ex. boken *Skyddsvärd skog*), *Barrskogar - nyckelbiotoper i Sverige*, broschyren *Taggsvampskogar*, m. fl.

	Struktur	Provyta (antal av substrat i varje, *JA/NEJ i vissa karaktärsdrag)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	Summa	/ ha
	X-koordinat															
	Y-koordinat															
Träd	NV-träd björk															
	NV-träd asp															
	NV-träd sälg															
	NV-träd rönn															
	NV-träd tall															
	NV-träd gran															
	Summa naturvärdesträd															
	Brandljud i levande träd															
	Träd m bohål/ håligheter (alla trädslag)															
Död ved	Tall liggande död ved > 10 cm															
	Gran liggande död ved > 10 cm															
	Löv liggande död ved > 10 cm															
	Summa liggande död ved															
	Tall stående död ved > 10 cm															
	Gran stående död ved > 10 cm															
	Löv stående död ved > 10 cm															
	Summa stående död ved															
	Grov död ved > 30 cm (alla trädslag)															
	Lågor i olika nedbrytningsstadier															
	Död ved med brandspår															
Karaktärsdrag	Markvegetation domineras av hög/lågörter															
	Pågående självgallring															
	Flerskiktat/stor diam.spridning															
	Förekomst av småvatten															
	Lövträdens ursprung kan kopplas till brand															
	Hällmark/lodyta/blockrikt*															
Arter	Hög frekvens av signal- och/eller rödlistad art															
	Signal och Rödlistade arter															

Appendix 3 – List of conservational species included

Table 6. Red listed-, protected- and indicator species that I have sufficient knowledge about to identify. These species were searched for during the field study. Protected species are indicated by a "§", indicator species by an "I" and for red listed species, the conservation status is stated.

Species	*Status*	*Swedish name*
Old trivial deciduous trees and trivial deciduous forests:		
Antrodia pulvinascens	NT	Veckticka
Artomyces pyxidatus	NT	Kandelabersvamp
Haploporus odorus	VU §	Doftticka
Inonotus rheades	I	Rävticka
Lobaria pulmonaria	NT	Lunglav
Lobaria scrobiculata	NT	Skrovellav
Nephroma bellum	I	Stuplav
Nephroma parile	I	Bårdlav
Nephroma resupinatum	I	Luddlav
Pannaria conoplea	EN	Grynlav
Parmeliella triptophylla	I	Korallblylav
Ramalina sinensis	NT	Småflikig brosklav
Dry sandy pine forests:		
Diphasiastrum complanatum	I, §	Plattlummer

Hydnellum aurantiacum	NT	Orange taggsvamp
Hydnellum caeruleum	NT	Blå taggsvamp
Hydnellum ferrugineum	I	Dropptaggsvamp
Hydnellum fuligineoviolaceum	EN	Lilaköttig taggsvamp
Hydnellum peckii	I	Skarp dropptaggsvamp
Hydnellum roseviolaceum	I	Rosaköttig taggsvamp
Hygrophoropsis olida	VU	Smultronkantarell
Pulsatilla vernalis	EN	Mosippa
Sarcodon squasmosus	NT	Motaggsvamp
Tricholoma matsutake	VU	Goliatmusseron
Limestone coniferous forests:		
Bankera violascens	NT	Grantaggsvamp
Clavariadelphus truncatus	NT	Flattoppad klubbsvamp
Cortinarius harcynicus	NT	Barrviolspindling
Daphne mezereum	I §	Tibast
Dactylorhiza sp.	I §	Fläcknycklar sp.
Gomphus clavatus	VU	Violgubbe
Hepatica nobilis	§	Blåsippa
Hydnellum suaveolens	NT	Dofttaggsvamp
Hypocrea nybergiana	NT	Rödbrun klubbdyna
Platanthera bifolia	I	Nattviol
Ramaria spp.	I	Fingersvampar
Sarcodon imbricatus	NT	Fjällig taggsvamp
Coniferous wet forests, stream environment and		

spring affected environments:		
Alectoria sarmentosa	NT	Garnlav
Craterellus lutescens	I	Rödgul trumpetsvamp
Matteuccia struthiopteris	I	Strutbräken
Moneses uniflora	I	Ögonpyrola
Neottia cordata	I §	Spindelblomster
Sphagnum wulfianum	I	Bollvitmossa
Neottia cordata	I §	Spindelblomster
Primary coniferous forests:		
Amylocystis lapponica	VU	Lappticka
Artomyces cristatus	CR	Liten kandelabersvamp
Bryoria nadvornikiana	NT	Violettgrå tagellav
Callidium coriaceum	I	Bronshjon
Climacocystis borealis	I	Trådticka
Crossocalyx hellerianus	NT	Vedtrappmossa
Dactylorhiza maculata sp. Fuchsii	I	Skogsnycklar
Formitopsis rosea	NT	Rosenticka
Goodyera repens	VU	Knärot
Laurila sulcata	VU	Tajgaskinn
Leptoporus mollis	NT	Kötticka
Meruliopsis taxicola	I	Blodticka
Pelloporus leporinus	NT	Harticka
Phellinus abietis	NT	Granticka
Phellinus ferrugineofuscus	NT	Ullticka

Phellinus pini	NT	Tallticka
Phellinus viticola	I	Vedticka
Phlebia centrifuga	VU	Rynkskinn
Picoides tridactylus	NT	Tretåig hackspett
Pseudographis pinicola	NT	Gammelgranskål
Pseudomerulius aureus	I	Gullgröppa
Pycnoporellus alboluteus	CR §	Storporig brandticka
Pycnoporellus fulgens	I	Brandticka
Rhodonia placenta	VU	Laxporing
Skeletocutis odora	VU	Ostticka
Sparassis crispa	I	Blomkålssvamp
Tomicus minor	I	Mindre märgborre
Trichaptum laricinum	NT	Violmussling
Usnea longissima	VU	Långskägg

Appendix 4 - Species observations

Table 7. Species observations from all NVA surveys. Stands without any species observations are excluded.

Stand/Survey ID	Stand type	Species
10	RFS	*Phellinus ferrugineofuscus*
50A	RFS	*Phellinus viticola*, *Dactylorhiza sp.*
68A	RFS	*Phellinus ferrugineofuscus, Alectoria sarmentosa*, *Nephroma bellum*.
190	RFS	*Phellinus ferrugineofuscus*, *Formitopsis rosea*, *Phlebia centrifuga*, *Phellinus abietis*, *Lobaria pulmonaria*, *Alectoria sarmentosa*.
135	RFS	*Alectoria sarmentosa*, *Goodyera repens*, *Phellinus ferrugineofuscus*, *Lobaria pulmonaria*, *Parmeliella triptophylla*, *Phellinus abietis*, *Formitopsis rosea*.
134	RFS	*Goodyera repens*, *Lobaria pulmonaria*, *Alectoria sarmentosa*, *Nephroma bellum*, *Parmeliella triptophylla*, *Hydnellum aurantiacum*, *Phellinus ferrugineofuscus*, *Hypocrea nybergiana*.
59	RFS	*Goodyera repens*, *Platanthera bifolia*, *Phellinus ferrugineofuscus*, *Alectoria sarmentosa*, *Formitopsis rosea*, *Sarcodon imbricatus*, *Phellinus abietis*, *Nephroma bellum*, *Bankera violascens*.
56A	RFS	*Alectoria sarmentosa*, *Phellinus ferrugineofuscus*, *Lecanactis abietina*
224	RFS	*Phellinus ferrugineofuscus*, *Phellinus abietis*, *Phellinus viticola* , *Lobaria pulmonaria*, *Picoides tridactylus (traces)*.
135	RFS	*Alectoria sarmentosa*, *Goodyera repens*, *Phellinus ferrugineofuscus*, *Lobaria pulmonaria*, *Parmeliella triptophylla*, *Phellinus abietis*, *Formitopsis rosea*.
116	RFS	*Callidium coriaceum*, *Phellinus viticola*, *Sarcodon imbricatus*, *Phellinus ferrugineofuscus*, *Nephroma bellum*.

151	RP	*Hepatica nobilis*, *Ramaria spp.*, *Craterellus lutescens*, *Osteina undosa*.
50B	RP	*Phellinus ferrugineofuscus*.
163A	RP	*Clavariadelphus truncatus*, *Pycnoporellus fulgens*, *Phellinus viticola*.
75A	RP	*Alectoria sarmentosa*, *Phellinus viticola.*
75B	RP	*Callidium coriaceum*.
68B	RP	*Alectoria sarmentosa*, *Callidium coriaceum*, *Phellinus abietis*.
68C	RP	*Alectoria sarmentosa*, *Bryoria nadvornikiana*.
99A	RP	*Tomicus minor*, *Alectoria sarmentosa*.
195A	RP	*Phellinus viticola*
195B	RP	*Phellinus viticola*, *Alectoria sarmentosa*
183	RP	*Callidium coriaceum*, *Phellinus viticola, Meruliopsis taxicola*
61	RP	*Lobaria pulmonaria*, *Alectoria sarmentosa*, *Pseudographis pinicola.*
251	RP	*Alectoria sarmentosa*, *Callidium coriaceum*, *Sarcodon imbricatus*.
237	RP	*Alectoria sarmentosa.*
34	RP	*Alectoria sarmentosa*, *Phellinus ferrugineofuscus*, *Phellinus abietis*, *Artomyces pyxidatus*.
52	RP	*Phellinus abietis*.
99B	RP	*Hydnellum suaveolens*.
56B	RFS	*Sarcodon imbricatus*, *Alectoria sarmentosa.*
239	RP	*Alectoria sarmentosa*, *Hydnellum ferrugineum ,Pseudographis pinicola*.
135	RFS	*Lobaria pulmonaria*, *Nephroma bellum*, *Parmeliella triptophylla*, *Callidium coriaceum*.

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