Temporal evaluation of retention patch development

– Retention patches in Swedish forestry

Tidsmässig utvärdering av hänsynsytors utveckling – Hänsynsytor i svenskt skogsbruk

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Abstract

The demands on the world’s forests are increasing rapidly and the different interests are conflicting, often including goals of biodiversity and timber production. Forest management has since the 1990s included a scientifically validated measure known as retention forestry, to better balance conflicting goals of forest management. It is implemented by leaving portions of stands unlogged to maintain continuity of important structural diversity, facilitate organism dispersal and enhance landscape connectivity. Due to retention forestry being relatively new, there is a lack of knowledge regarding retention forestry maintenance over time. We conducted a spatial analysis on isolated retention patches on clear-cuts in near coastal and inland Västerbotten county, examining areal decreases between 2007 and 2017 in the geographics information system QGIS. Locations, forest cover types, original retention patch size, distance to clear-cut edge and clear-cut ID were the basis for a statistical analysis, assessing if the factors influenced retention patch areal decrease. We found that retention patches in Västerbotten had a mean size of 0.11 ha and that they had decreased to 0.08 ha on average. Furthermore, our statistical model showed that original retention patch size was the only significant factor explaining areal decrease. Earlier studies have stated that the main cause for retention patch reduction is wind effects and exposure, something our project did not account for. The results showed that larger retention patches had lower percentage decreases compared to smaller retention patches. For future studies, more data and variables should be used, possibly over a larger timespan and geographical range.

Keywords: Retention forestry, retention patch, inland, near coastal, geographics information systems, orthophotos, Västerbotten

Sammanfattning

Världens behov av skogens nyttor ökar snabbt och olika behov som timmerproduktion och bevarande av biodiversitet är ofta motstridiga. Skogsskötseln har sedan 1990-talet inkluderat vetenskapligt validerad naturhänsyn i skogsbruket för att bättre balansera skogsskötselns motstridiga mål. Detta implementeras genom att lämna delar av bestånd oavverkade för att bibehålla kontinuitet av viktig strukturell diversitet, främja organismers spridning och öka landskapets konnektivitet. Då lämnande av naturhänsyn i skogsbruk är relativt nytt så finns det lite kunskap om skötseln av naturhänsynen över tid. Vi genomförde en rumslig analys på isolerade hänsynsytor på hyggen i Västerbottens inland och nära kusten, där vi utforskade areella minskningar mellan 2007 och 2017 med hjälp av det geografiska informationssystemet QGIS. Områdena, skogstäckena, hänsynsytornas ursprungliga storlek, distansen till närmsta hyggeskant och hygges-ID användes i en statistisk analys för att bedöma om någon av faktorerna påverkade hänsynsytornas areella minskning. Våra resultat visade att Västerbottens hänsynsytor hade en medelstorlek på 0.11 ha och att de i snitt hade minskat till 0.08 ha. Vår statistiska modell visade att hänsynsytornas ursprungliga storlek var den enda signifikanta faktorn som beskrev den areella minskningen. Tidigare forskning har visat att huvudorsaken till hänsynsytors storleksminskning är vindeffekter och vindutsatthet, vilket vårt projekt inte undersökte. Resultaten visade att större hänsynsytor hade lägre procentuella minskningar jämfört med mindre hänsynsytor. Mer data och variabler bör användas i framtida studier, om möjligt över ett längre tidsspann och en bredare geografisk utbredning.

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1 Introduction

1.1 Background

As the demand for forest services and forest-based products are increasing in order to move towards a biobased society, the world's forests need to accommodate for more, which could lead to potential societal and ecological conflicts (Näringsdepartementet 2018). By 2010, 55% of the world's forests had been converted to managed forests and were already being used for wood production as the primary purpose (Food and Agriculture Organization of the United Nation 2010). To halt the decline in biodiversity across the world, solutions like retention forestry can help integrate and preserve the biodiversity better in commercially managed forest stands (Lindblad 2019). Retention forestry has been found to be a very effective conservation measure and can thus contribute worldwide in achieving more multifunctional forestry, balancing both human and ecological needs (Mori & Kitagawa 2014).

Retention forestry was introduced in North-western America 35 years ago and is practised internationally in various regions, taking on different forms and being adaptable to many conditions (Gustafsson et al. 2012). The measure includes creating and/or leaving dead wood, leaving patches of trees on clear cuts and leaving tree buffers around streams (Gustafsson et al. 2016). The practise of leaving live trees on harvested areas has often been referred to as Green-tree retention (GTR) and can be seen as forest disturbances that modify successional patterns and create new habitats for pioneer species. GTR is intended to fulfil three important objectives regarding biodiversity conservation in managed forests. Those three objectives are: 1) to have lifeboating functions for processes and species as the forests regenerate, 2) providing structural features in regenerating forests that are important for preserving biodiversity and 3) improving the forest connectivity throughout the landscape (Franklin et al. 1997). A more detailed description of the three important functions can be found in table 1. Furthermore, Franklin et al. (1997) wrote "Use of structural retention to sustain biological diversity assumes that refugia will provide the inocula for re-establishing species in the harvested area once the new forest stand and other suitable habitat conditions are re-established", emphasising the importance of the lifeboating effect of retention forestry.

Main function of retention patches	Description
Lifeboating (Franklin et al 1997)	Achieved in three ways: 1. Providing structural elements fulfilling habitat requirements for various organisms 2. Ameliorating microclimatic conditions in relation to those that would be encountered under clearcutting, and 3. By providing energetic substances to maintain nonautotrophic organisms.
Structural enrichment (Franklin et al 1997)	After cuttings, important structural features like decadent trees and logs may permanently or temporarily remain absent on the site. Structural retention aims to enrich forest stands with structural complexity, providing suitable habitats throughout the entire rotation for species that are unfavoured in younger forests.
Enhancing landscape connectivity (Franklin et al 1997).	Landscape connectivity impacts species dispersion and migration and is heavily impacted by landscape matrix conditions spatial patchiness. By reducing the size of the non-forested matrix between forest patches or suitable substrates, the matrix can be made less hostile and suitable microclimates can be increased.

Table 1. *Main functions of retention patches and their descriptions. The main functions are "Lifeboating", "Structural enrichment" and "Enhancing landscape connectivity".*

Around 5-10 % of a forest stand is suggested to be used as a minimum for retention and should be distributed throughout the landscape to facilitate organism dispersal (Gustafsson et al. 2012). Although retention forestry is a common practice in various parts of the world, it is still a relatively new silvicultural measure and research within the area has been sparse (Gustafson et al. 2016). However, the field of research is gaining more attention and results have become more available in recent years. Published research regarding effects of applied conservation in forest management practices show positive results. Dead wood in different stages of degradation are key substrates for several species (Nilsson et al. 2021) and the amount of dead wood outside formally protected areas has increased by 53% since the 1990s (Fig. 1).

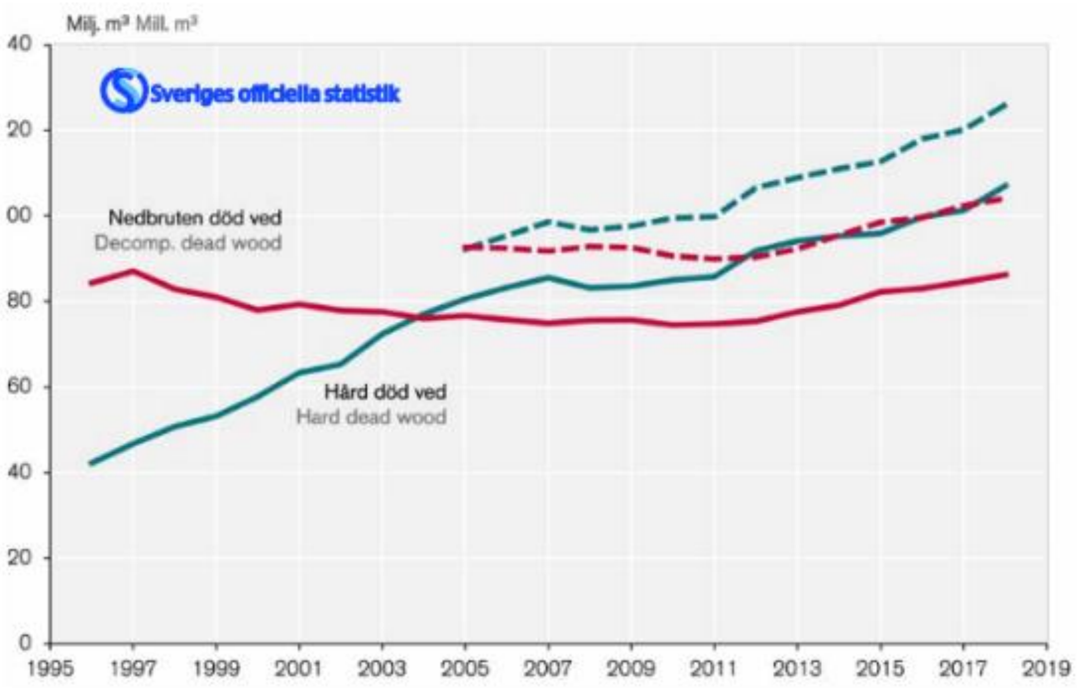

Figure 1. *Dead wood volume by decay class. 1996–2018. Solid lines: Productive forest land outside formally protected areas as of 2019. Broken lines: All productive forest land. Moving five year average (Nilsson et al. 2021).*

The 1993 revision of the Swedish forestry act initiated a change in Swedish forestry, stating that production and environmental goals should be equally prioritized (SFS 1993:553). Since then, these new methods of nature conservation have been incorporated as a natural part of forest management practices. This approach, although not required by law, is a way to achieve the goals set by the Swedish forestry act and is included in the certification systems FSC and PEFC, used by most Swedish forest owners and forestry companies (Lehtonen et al. 2021). Clear-cuts in Sweden today contain both dispersed and aggregated trees left as retention. The aggregated tree patches are ideally meant to have lifeboating functions for species on a local scale and reduce fragmentation on a landscape level. The lifeboating objectives have been achieved for certain species groups where significant improvements of survival was reached (Rosenvald & Lõhmus 2008). There have been several studies conducted on forest patches, examining both species survival and how forest patch longevity is affected over time by abiotic and biotic factors. One study found that greater species composition is found in retention patches compared to surrounding clear-cuts (Rudolphi et al. 2014). Another study by Mori and Kitagawa (2014) reviewed the results on retention logging from many other studies in a meta-analysis. They showed that retention patches can preserve species richness to the same extent as unmanaged forest types, with some differences between different taxa, often correlating with the mobility and dispersal potential of individual species. The expectation is that species in retention patches should be able to recolonise the area surrounding the retention patches after the forest re-establishes. This has been confirmed in a study by Rudolphi & Gustafsson (2011), that showed that the potential for sensitive species to occur in young production forests is dependent on the history of the forest landscape and the structures left as retention, such as deciduous trees and dead wood. There is no formal protection status for retention forestry, and isolated patches often face disturbances such as windthrows, due to often being exposed on clear-cuts. The available research indicate that the smaller the retention patch the greater risk for wind throws and edge effects (Gustafson et al. 2016). A study conducted by Rosenvald et al. (2008) showed that 35% of the retention trees disappeared over 6 years. Of these tree deaths, 89,6 % were caused by wind throws. In another study Jönsson et al. (2007) looked at different spruce retention patch sizes in the mountain region of Västerbotten county in Sweden and found that most of the trees were wind felled within the first 5 years. Tree death on retention patches decreased considerably after 5 years and patches smaller than 1 ha in size continued to maintain lifeboating functions for species that would otherwise go extinct on clear-cuts. There are several factors that can influence the tree longevity of a retention patch, such as tree species composition, distance from the patch to the nearest forest edge and soil properties. Knowledge about a stand's characteristics and biodiversity could allow for a more custom made and cost-effective nature conservation planning (Gustafson et al. 2016; Rosenvald et al. 2008; Hautala & Vanha-Majamaa 2006).

1.2 Aims of the study

The aim of this study was to assess if and by how much retention patches decrease in size over a selected timespan and in different geographical locations. We hypothesized that areal decreases would be observable and that these changes would be influenced mainly by distance to clear-cut edges, tree species composition and geographical location.

2 Materials and methods

2.1 Selecting area of study and data collection

The area of study was concentrated to the county of Västerbotten in Sweden. A previous study conducted by Svensson et al. (2019) has found that continuous forest patch size, patch abundance and total land area differ among the alpine regions, inland regions, and coastal regions of northern Sweden. In order to capture and examine regional difference in retention patch evolution over time, orthophotos (aerial flight photos) in raster format were downloaded for one area in the western inland region and one area near the coastal region of Västerbotten. The orthophotos were downloaded from “The National Land Survey” in Sweden on 2/3 2022 to be examined in the open-source geographic information system QGIS. The downloaded photos covered an area of 25 km^2 or 2500 ha with a resolution of 0.5 m/pixel, covering an RGB (red, green, blue) colour span and were adapted to the EPSG:3006 (SWEREF 99 TM) reference system. Four orthophotos were chosen from both 2007 and 2017 for the inland area and four additional ones from 2007 and 2017 for the near coastal area. The time-period was chosen due to limited access to orthophotos over longer timespans. The areas of study covered 10 000 ha each and were each made up of 4 orthophotos, as seen in figure 2, with the top left area being the inland region and the bottom right area being the near-coastal region. A vector layer called “Performed final fellings” (© Swedish Forestry Agency, 2022) containing polygon data on performed final fellings done in Västerbotten between 1998 and 2021 was downloaded. This vector layer was trimmed to remove all final fellings performed after 2007 from the vector layer. The area of study in each orthophoto was then limited to the areas with vector polygons showcasing registered final fellings and that coincided with clear-cuts on the orthophotos. The raster layer AC_lan_nmd2018bas_ogeneraliserad_v1_1 from “The National Land Cover Data” (© Swedish Environment Protection Agency, 2018) was then downloaded, with land cover data from 2018 covering Västerbotten. This was done in order to later assess the main forest cover type for each retention patch. The collected data is found in table 2.

__Fig 2.__ The QGIS canvas with the selected areas of study in Västerbotten. The darker squares are the 10 000 ha large study areas, consisting of 4 orthophotos each. The top left area is the inland area (coordinates: 726_63_00, 726_63_05, 726_63_50 and 726_63_55) and the bottom right area is the near coastal area (coordinates: 709_69_00, 709_69_05, 709_69_50 and 709_69_55), based on OrtoRgb050 epsg3006, © The National Land Survey. Background picture: "The National Land Cover" data layer for Västerbotten county in Sweden, 10x10m, © Swedish Environmental Protection Agency (2018).

2.2 Data analysis

Based on what was visible in the orthophotos, we digitised clear, visible and isolated retention patches, outlining them as polygon features in a new vector map-layer using a "vector-polygon" function (Fig. 3). This was conducted in order to get a layer showcasing all retention patches in the covered areas. This was done once for the 2007-photos and once for the 2017-photos, making sure to give the same retention patches the same IDs for both periods. We then calculated the area for each retention patch using an area-calculating function based on the coordinate settings. Both map layers were then combined using a combination function. We then calculated the change in size for each retention patch by taking the area for one retention patch from 2007 and subtracting its area from 2017. This difference was then transformed into a percentage difference based on the original size of the retention patch. The total amount of retention patches digitised in our study ended up being 179 across the two geographical locations.

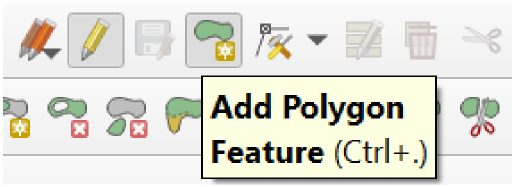

Fig. 3. *Vector-polygon function in QGIS called "Add Polygon Feature".*

For the final steps, additional information was added to the combined retention patch layer by using an overlay function to overlay the layer with registered final fellings. We added data on the final felling ID from the Swedish Forestry Agency and calculated the closest distance between the 2007 retention patch polygons and the final felling polygon edges. After that we overlaid the national land cover layer on top of our combined retention patch layer in order to identify the main forest type covering each retention patch. As the forest cover types were presented by ID-codes in the data-layer, they had to be manually translated and corrected where needed in order to identify the correct forest cover type for each retention patch.

All spatial analyses were done in QGIS Desktop 3.10.12 with GRASS 7.8.4.

2.3 Statistical analysis

Next, we used the data from the combined retention patch layer with data from 2007, 2017, final felling information and forest cover data to test whether the size of the retention patches had changed between the two timestamps and what factors that could have affected the results. Some of the forest cover categories did not have enough sampled data to be statistically relevant in the analysis, hence the data with those forest covers were removed. To account for possible areal errors when digitising the polygons, we excluded all pairs of retention patches with an areal difference of less than 10%. The total amount of retention patches then went from 179 to 103 to be used in the statistical analysis.

We applied a linear mixed model because the data obtained was not fully independent due to many retention patches belonging to the same clear-cuts as well as many variables being able to explain the change in area for each retention patch. A model was created using the variables *retention patch area from 2007* (m^2), *distance to closest clearcut edge* (m), *location in Västerbotten* (inland, near coastal), *forest cover type* (deciduous forest, mixed coniferous, mixed forest, pine forest, spruce forest) and *final felling ID* (random effect) in order to explain the area-difference between 2007 and 2017 (m^2). Our first model had a high and uneven distribution and residual variance and therefore a new model was made with log10-transformed area-variables, which improved the model. The data gathered from QGIS, the transformed data, data variables used in the model and their descriptions are found in Table 2. This is the final model that was used:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \cdots + \beta_7 X_{7i} + \beta_8 u_{8i} + \epsilon$$

Y_i: log10 area difference for observation i, X_{1i}: log 10 area of retention patches from 2007 (m^2) for observation i, X_{2i}: distance to closest clear-cut edge (m) for observation i, X_{3i}: geographical location (Inland) for observation i, $X_{4\text{-}7i}$: forest cover type (deciduous forest, mixed coniferous, mixed forest, pine forest) for observation i, u_{8i}: random effect of final felling ID with mean E(u) = 0 and variance var(u) = G for observation i, ϵ: random errors with mean $E(\epsilon) = 0$ and variance $var(\epsilon) = R$, β_0: intercept, β_{1-8}: effect of variable 1-8.

When we performed the statistical analysis in the statistics software RStudio 4.1.3, we wrote the model as the following: lmer(Log10(area-difference) ~ log10(area 2007) + distance to clear-cut edge + forest cover type + geographical location + random effect).

Null- and alternative hypotheses were chosen for the statistical analysis. The null hypothesis (H_0) was that there would be no statistically significant relationships between area difference and the variables. The alternative hypothesis (H_A) claimed there would be a statistically significant relationship between at least one variable and area difference. A significance level of 5% was chosen for the analysis.

Finally, the retention patches were sorted into five distinct reduction classes (10-20%, 20-40%, 40-60%, 60-80% and 80-100%) to investigate the distribution of decrease across the retention patches.

a) Data collected for QGIS analysis	Source
Orthophotos inland Västerbotten 2007 and 2017 **Coordinates**: 726_63_00, 726_63_05, 726_63_50, 726_63_55	EPSG:3006 (SWEREF 99 TM), RGB, 0.5m © The National Land Survey (2007, 2017)
Orthophotos near coastal Västerbotten 2007 and 2017 **Coordinates**: 709_69_00, 709_69_05, 709_69_50, 709_69_55	EPSG:3006 (SWEREF 99 TM), RGB, 0.5m © The National Land Survey (2007, 2017)
Performed final fellings sksUtfordAvverk24	© Swedish Forestry Agency (2022)
The National Land Cover data AC_lan_nmd2018bas_ogeneraliserad_v1_1	Västerbotten county, 10x10m, © Swedish Environmental Protection Agency (2018)
b) Data produced in QGIS	**Data description**
Geographical location	Categorical
Retention patch area 2007	Numerical (m^2)
Retention patch area 2017	Numerical (m^2)
Retention patch area difference 2007-2017	Numerical (m^2)
Retention patch area difference 2007-2017, %	Numerical (%)
Final felling ID	Categorical
Distance to closest clear-cut edge	Numerical (m)
Forest cover type	Categorical
c) Data-variables in statistical analysis	**Variable description**
Total amount of retention patches	179
Retention patches with at least 10% reduction	103
Log10-transformed area 2007	Numerical (log10)
Log10-transformed area difference	Numerical (log10)
Distance to closest clear-cut edge	Numerical (m)
Geographical location	Västerbotten (Inland, near coastal)
Forest cover type	Categorical
Final felling ID	Categorical (random effect)

***Table 2**. a) Data collected for the QGIS analysis and the sources. b) Data gathered from the QGIS analysis and the description of the data with its unit. c) Data-variables used in the statistical analysis and the descriptions of the data-variables used in the statistical analysis.*

3 Results

The 103 of the 179 retention patches used for the results had all decreased in size of at least 10%. Our main results were that mean percentage area decrease between 2007 and 2017 was 33.34% in total, with 34.11% being the mean decrease for near coastal retention patches and 32.53% being the mean decrease for inland retention patches. The mean retention patch area in 2007 was 1064 m^2, whereas it had decreased to 766.9 m^2 in 2017 (Fig 4, Table 3). In total, the retention patches decreased 297.5 m^2 on average, with the inland mean being 273.5 m^2 and the near coastal mean being 320 m^2. Table 3 also shows the mean and median values for the retention patches. Overall, the near coastal retention patches had slightly higher mean sizes as well as having a higher median value than the inland retention patches (Fig. 5).

Location	**Area 2007 Mean (m^2)**	**Area 2007 Median (m^2)**	**Area 2017 Mean (m^2)**	**Area 2017 Median (m^2)**	**Area 2007 (Ha)**	**Area 2017 (Ha)**	**Difference 2007-2017 Mean (%)**	**Difference 2007-2017 Std. (%)**
Inland	991.5	577	718	378.5	0.09	0.07	-32.53	-21.38
Near Coastal	1133	730	813	502	0.11	0.08	-34.11	-19.19
Total	1064.4	680	766.9	476	0.11	0.08	-33.34	-20.20

Table 3*. Median and mean areas in m2 and mean areas in Ha of isolated retention patches with at least 10% area reduction for the two study locations in Västerbotten county in 2007, 2017 and mean and standard deviations in % change for the period 2007-2017.*

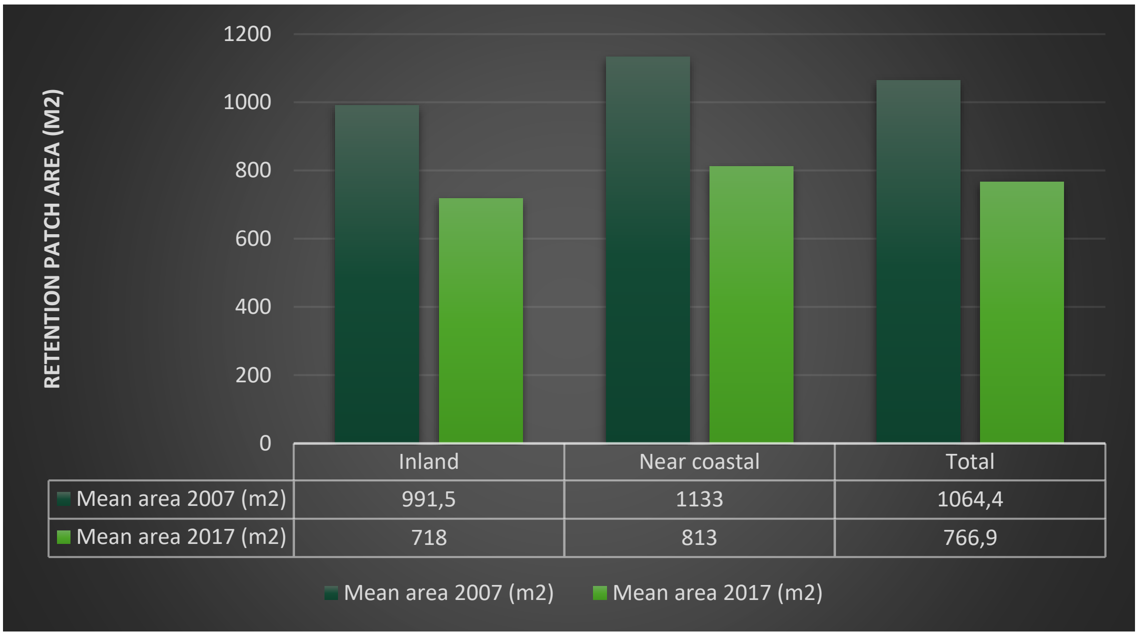

Fig. 4. *Mean retention patch area (m^2) of isolated retention patches with at least 10% area reduction for the two study locations in Västerbotten county and in total for both 2007 and 2017. The average area reduction for the inland study location amounted to 273.5 m^2. The average area reduction for the near coastal study location amounted to 320 m^2. In total, the average area reduction amounted to 297.5 m^2*

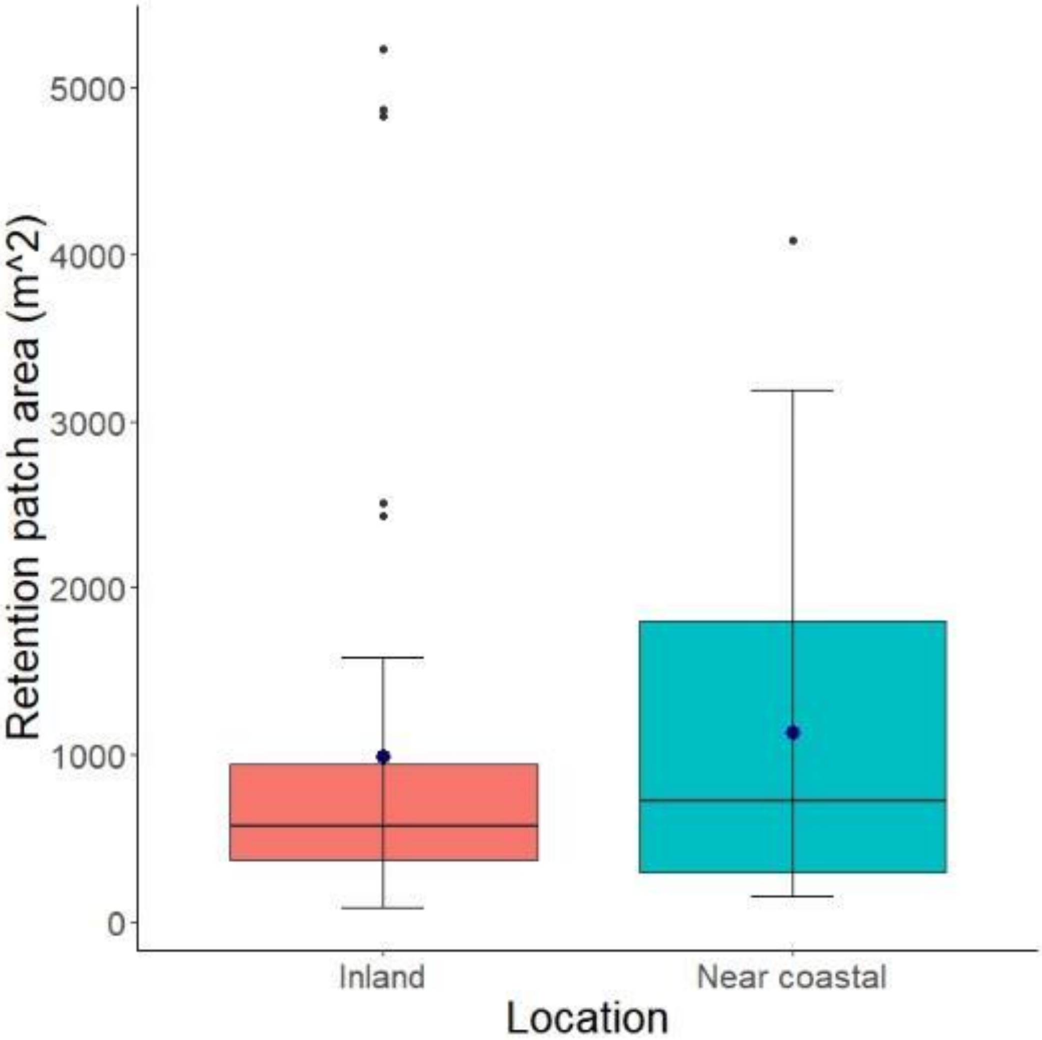

Fig. 5. *Range of retention patch area from 2007 (m^2), mean (dot) and median (midline) retention patch size of isolated retention patches with at least 10% area reduction for the inland and near coastal retention patches in Västerbotten county. The inland mean area is 992 m^2, median being 577 m^2. The coastal mean area is 1133 m^2, median being 730 m^2.*

We also found that the size range of the near coastal retention patches is much higher compared to the inland retention patches, except for a few outliers. Moreover, the area reduction in percentage differed between near coastal and inland retention patches (Fig. 6), highlighting a much greater range in percentage reduction between near coastal and inland retention patches, despite the mean and median values being similar.

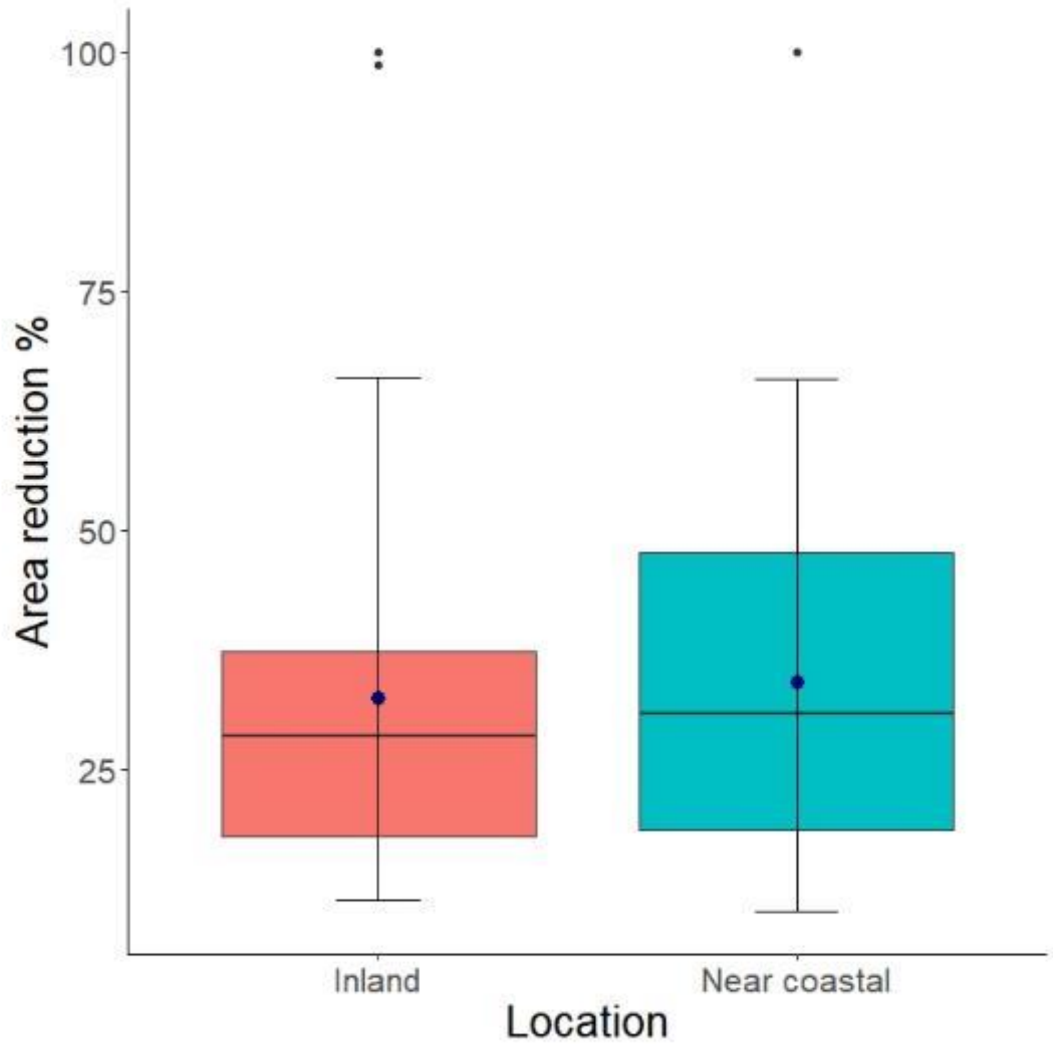

Fig. 6. *Mean (dot) and median (midline) area reduction (%) of isolated retention patches with at least 10% area reduction for the two study locations in Västerbotten county. The inland mean reduction is 32,5%, median being 28,4%. The coastal mean reduction is 34,1%, median being 30,9%.*

In our mixed effect model, we only found a relationship between the log10 values of retention patch areas from 2007 and the log10 values of retention patch area difference (Table 4, $n = 103$, $P < 0.05$). We found a significant relationship between retention patch area in 2007 and the decline in retention patch size between 2007 and 2017. We found in our results that larger portions of the retention patches have decreased in smaller retention patches compared to larger ones (Fig. 7).

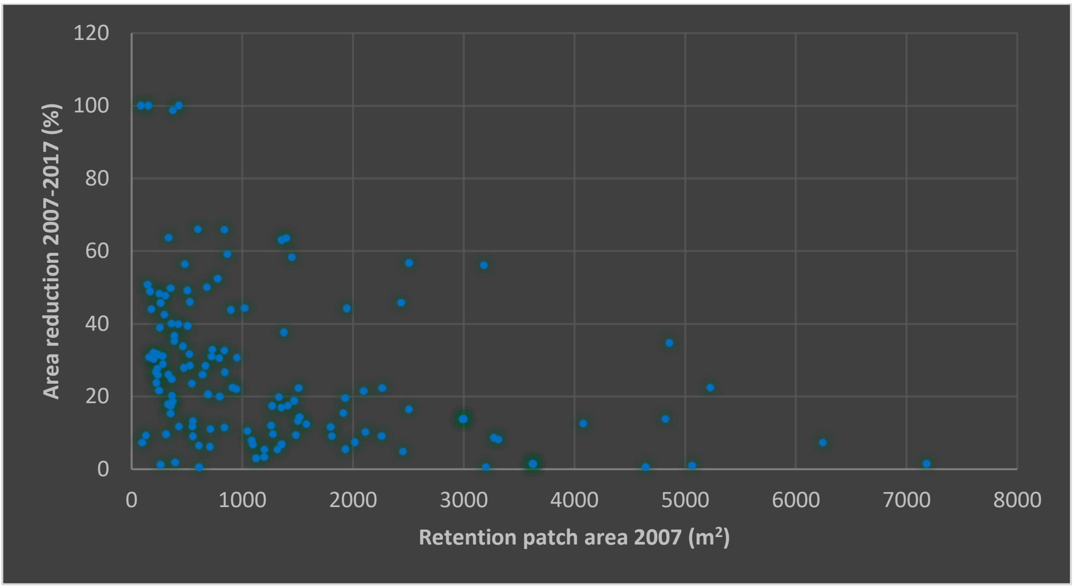

Fig 7. *Retention patch area in 2007 (m^2) of isolated retention patches with at least 10% area reduction between 2007 and 2017 on the x-axis and the % area reduction between 2007-2017 on the y-axis.*

Linear mixed model fit by REML. T-tests use Satterhwaite's method ['lmerModLmerTest']		
Formula: logAreaDiff. ~ DistanceClearcut + logArea2007 + Local + LandCover + (1|ClearcutID)		
Scaled residuals:		
	t value	Pr(>|t|)
(Intercept)	0.399	0.691
DistanceClearcut	0.279	0.789
logArea2007	11.313	<2e-16
LocalNearCoastal	-0.420	0.677
LandCoverMixedConiferous	0.498	0.620
LandCoverMixedForest	-1.229	0.222
LandCoverPineForest	-0.889	0.377
LandCoverSpruceForest	-1.297	0.198

Table 4*. Statistical summary from our linear mixed effect model on isolated retention patches within the study areas with at least 10% area reduction between 2007 and 2017, performed in RStudio 4.1.3. Only the variable logArea2007 has a statistically significant p-value ($p < 0.05$).*

Area reduction varied between the different forest cover types with differing ranges, means and median values (Table 5, Fig. 8), however forest cover types had no statistically significant influence on retention patch areal decrease. Among these differences, pine-dominated forests had the lowest median value of 22.17% reduction, but spruce-dominated forests had the lowest mean reduction in 24.09%, ranging from 11.63% and 34.67%. Deciduous forests had the highest mean reduction in 42.28% and the second highest median reduction in 35.46%. Pine forests had the highest had the highest number of sampled retention patches in 44 and also lowest median reduction in 22.17%.

Forest cover type	**Pine forest**	**Mixed forest**	**Spruce forest**	**Deciduous forest**	**Mixed coniferous forest**
Sample size (n)	44	15	5	16	23
Mean reduction (%)	28.34	31.2	24.09	42.28	39.37
Median reduction (%)	22.17	26.6	30.2	35.46	40.11

Table 5. Sample size (n), mean area reduction (%), median area reduction (%) for the different forest cover types present on each isolated retention patch within the study areas with at least 10% area reduction between 2007 and 2017. The total amount of retention patches was 103.

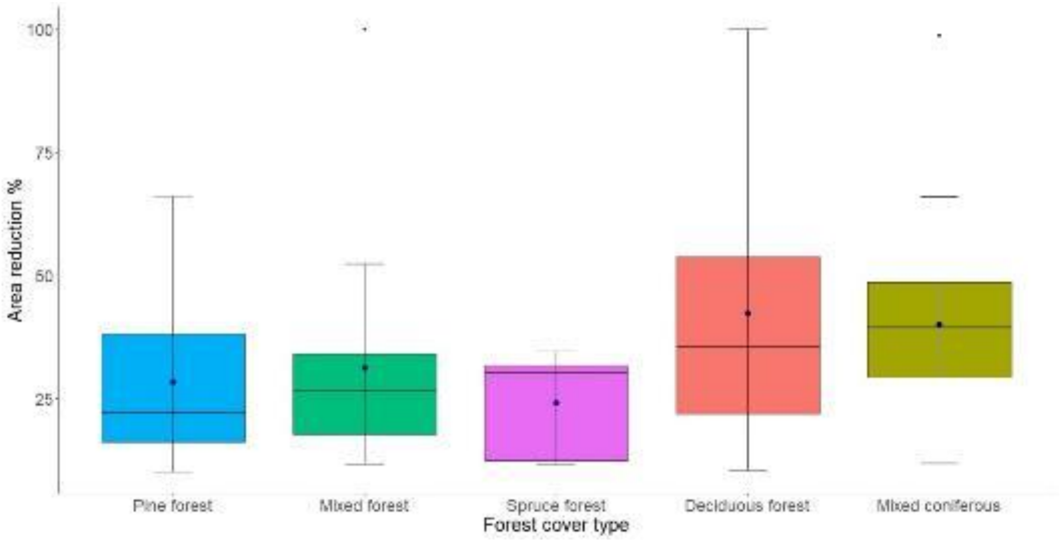

Fig 8. *Area reduction (%) for the different forest cover types on each isolated retention patch within the study areas with at least 10% are area reduction between 2007 and 2017. Midline represents median values and dots represent mean values.*

After sorting the retention patches into five distinct reduction classes of 10-20%, 20-40%, 40-60%, 60-80% and 80-100% reduction, we found that the greatest number of changes in retention patch area occurred in the 20-40% reduction patch (Fig. 9).

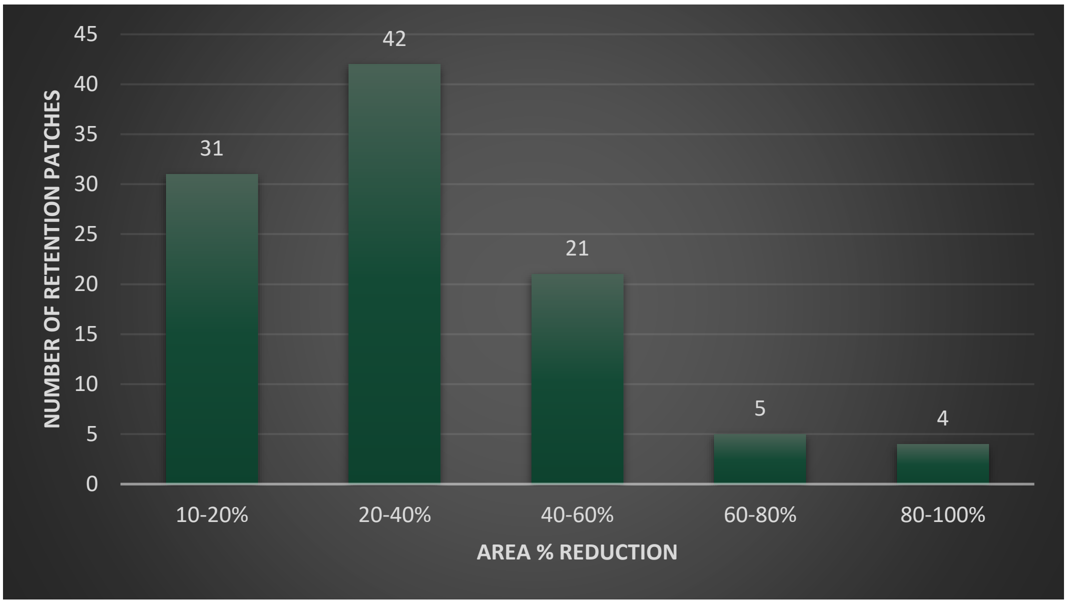

Fig 9. *The amount of isolated retention patches within the study areas with at least 10% area reduction between 2007 and 2017 in reduction classes. The classes are split into 10-20% reduction, 20-40% reduction, 40-60% reduction, 60-80% reduction and 80-100% reduction. The total amount of retention patches was 103.*

4 Discussion

The aim of this study was to assess if and by how much retention patches decrease in area over a selected timespan and in different geographical locations. We hypothesised that areal decreases would be observable and that these changes would be influenced mainly by distance to clear-cut edges, tree species composition and the geographical location. Our results show that there has been a general decrease in retention patch size in both the inland and coastal regions of Västerbotten county, which coincides with our hypothesis for this study. The near coastal region shows a slightly higher area reduction than the inland region (Fig. 6) as well as greater retention patch size compared to the inland region (Fig. 5). We observed a slight relationship between increased patch size and decreased percentage area reduction (Fig. 7). Based on the mixed effect model conducted on our results, original patch size was the single factor explaining area reduction in the retention patches between the two timestamps. This is in line with previous studies as Hautala & Vanha-Majamaa (2006) found that greater uprooting was observed on small retention patches of 0.09-0.14 ha in size compared to large patches of 0.16-0.55 ha, with *p. Abies* as dominant tree species. The results came from paludified (swamp forests) biotopes, concluding that uprooting was more affected by biotope rather than retention patch size. However, a report by Gustafson et al. (2016) states that larger retention patches are more resistant to uprooting and have reduced edge effects compared to smaller patches. This is further established by Esseen (1994) who showed, total tree mortality increased steeply after approximately 5-6 years as a result of decreasing forest patch area, for isolated forest fragments from 1986 in north-western Sweden. In these studies, windthrows were the main cause of decline in forest patch size, which we also assume to be the main cause behind the area reduction in our study.

Further we hypothesized that the factors distance to clear-cut edges, tree species composition and geographical location would influence the retention patch area reduction. Our model variable *distance to clear cut edge* is highlighted in the literature as a key factor affecting areal decrease in retention patches (Rosenvald et al. 2008). However, our statistical analysis showed no significance for that specific variable. Neither did we find any trends indicating a relationship between areal decrease and distance to clear cut edge. One possible explanation as to why an otherwise confirmed variable from other studies did not show any significance, is that the variable was not as accurate as we had hoped for. Using the registered cleat cut polygon in QGIS we roughly received the edge of the management unit, but this was not indicative of the actual closest mature forest. In some cases, the edge of the registered clear-cut polygon bordered another clear cut or open area instead of grown forests, causing the retention patches to remain exposed from that direction as well. This led to an even further distance to closest mature forest than what was registered. In retrospect, the model could have been expanded even further with additional variables that we have come to understand are important for explaining our hypothesis. These include but are not limited to; soil properties, soil moisture, topography and perhaps most importantly; wind direction and wind velocity.

The reason why we examined two regions in Västerbotten county was due to the potential difference in wind exposure (Siyal et al. 2015), as well as comparing how the degree of forestry would affect our results since inland Västerbotten has been subject to more intense forestry than coastal Västerbotten (Svensson et al. 2019). However, the location variable in our model showed no significance in explaining area reduction. Initially we wanted to include a third location in Västerbotten, being the mountain region, which would have resulted in a more holistic and interesting landscape gradient. However, we were not able to find orthophotos over the same timespan for all three regions and therefore had to settle with only the inland and near coastal regions. Our study was only conducted on orthophotos in Västerbotten, but it could be expanded to cover more of Sweden, given that enough orthophotos for the selected timespan exist.

A variable that we thought would prove significant in our model was *forest cover type* in the retention patches. Based on our results, mixed coniferous forests followed by deciduous forests had the highest mean and median decreases in area, whereas pine forests had the lowest median and spruce forests had the lowest mean areal decrease (Fig. 8). Although the results showed observable differences in area reduction, forest cover type was not a significant variable in explaining areal decrease in our model. Rosenvald et al. (2008) showed that tree species and location of trees relative to clear cut edges are key variables to consider in retention practices. In their study they found that hardwood deciduous trees had the highest survival, followed by softwood deciduous trees. Among conifer species *P. Abies* has been shown to be more susceptible to wind damage compared to *P. Sylvestris* and other tree species due to its shallower root-system (Hautala & Vanha-Majamaa 2006; Rosenvald et al. 2008). Interestingly, spruce forests showed the lowest range and mean value regarding areal decrease in our study. A possible explanation for this could be that the amount of retention patches dominated by spruce in our study (n = 5) were much fewer compared to the other forest cover types. Another possible source of error that could help explain our spruce patterns would be the time between the forest was harvested and when the orthophoto was taken. Therefore, there is a risk that spruce trees on the retention patches had already blown down before we could analyse the photos. To make a better conclusion regarding the areal decrease of spruce-dominated retention patches, we would need more data and more precise knowledge of when the forests were harvested. The mixed coniferous forest could be assumed to consist primarily of spruce due to its high area reduction and wide range in area reduction, but we have no data to back it up. Just like pine and spruce trees having different characteristics that make them more or less prone to wind damage, deciduous trees can also have varying susceptibilities. Deciduous forests in Västerbotten county are made up of birch (*Betula pendula* and *B. pubescens*), alder (*Alnus incana*) and European aspen (*Popoulus tremula*). The birch species have been found to be more prone to uprooting on non-wetland areas compared to European aspen and alder (Hautala & Vanha-Majamaa 2006), which can help explain the high variation in area reduction for deciduous forest in our results. A deeper analysis becomes difficult though due to lack of information about the exact species composition of the retention patches. We can interpret the results however, like deciduous retention patches with higher percentage area reduction most likely having a higher abundance of birch and those with lower percentage area reduction having a higher abundance of aspen and alder.

Most of the retention patches assessed in our study had anywhere between 10-60% area reduction over the 10-year span of the orthophotos, with the remaining patches with even further reduction (Fig. 9). This coincides with findings from Rosenvald et al. (2008) that showed that many retention trees left on clear-cut sites die shortly after. Though some species such as fungal polypores may still be able to colonise the snags and dead logs, it may affect others negatively due to less time for retained trees to grow in size and thus eventually provide larger trunks for longer decaying periods and more available substrates (Runnel et al. 2013). Species requiring shaded habitats can also be negatively impacted by decreasing retention patch area as the canopy cover opens (Lõhmus & Lõhmus 2011). Although 71% of the retention patches examined in our study only decreased with a maximum of 40% in area, this reduction may be enough to impact the lifeboating effect and recolonisation of species otherwise dependant on unharvested forest climates. A study by Esseen (1994) has found that forest patches should be around 5-10 ha large in order to maintain unaffected microclimates and an undisturbed core. The opinion on the matter is conflicting however since there are studies also stating that areas as low as 0.8 ha is enough for maintaining an undisturbed microclimate (Matlack 1994). None of our measured retention patches were anywhere close to even 0.8 ha in size, although our study was biased, and we only examined easily distinguishable and isolated retention patches on clear-cuts. Given the distribution of percentage area decrease as seen in figure 9, it may be enough to severely alter the established microclimates in the retention patches. Even with altered microclimates however, the forest patches may still achieve their dedicated lifeboating function for certain organisms, depending on their habitat and substrate preferences.

Another aspect of the model to take into consideration is the data availability and the percentage change over time. The initial dataset collected in our QGIS analysis of the orthophotos had 179 retention patches, but only 103 of them were used as much data had a percentage reduction of less than 10%, or sometimes a percentage increase instead. This large reduction in datapoints were thought of as potential human errors in digitising the retention patches as we often had difficulties perfectly identifying the retention patch edges from the photos. The different shades and upcoming regeneration around the retention patches often gave errors in making out the exact size in retention patches, which often led to vastly different areas between the two timestamps as well as some retention patches growing over the period. Despite the removal of data with less than 10% areal reduction, some of the retention patches could have had such small areal changes over the timespan, something our model did not consider. The uneven distribution across original sizes for the retention patches made the model less accurate at predicting changes on larger retention patches compared to smaller. To improve the model in this regard, more data would be needed with a more even distribution. Particularly, more data would be needed for larger retention patches and those with greater areal decreases over the timespan, reliable data for retention patches with very small areal decreases. However due to insufficient time, we were forced to settle with our initial variables, but it gives further incentives to improve the model for future projects.

We settled on a 10-year timespan since orthophotos covering a longer time frame were unavailable. A longer time frame would have strengthened our basis for answering our hypothesis. One of the major gaps in this line of research is the absence of long-term studies on how retention patches change in size and function over time (Gustafson et al. 2016). Ideally, orthophotos from clear cuts from when retention practices were first implemented should have been used. Our limited time frame could potentially have resulted in less accurate results compared to a longer time frame. However, some studies indicate that most retention tree mortality occurs within the first decade after clearcutting (Jönsson et al. 2007; Rosenvald et al. 2008). To our knowledge a study like the one we have performed, evaluating retention patches through geographic information systems, has not been done before. We encountered several setbacks during the project progression, some of which we managed to overcome, which can allow for further studies.

4.1 Conclusion

We examined retention patches on clear-cuts in two locations in Västerbotten county within the timestamps 2007 to 2017 and found that there has been a decrease in retention patch area. Furthermore, we explored potential variables that would explain the areal decrease and our statistical model showed that the only variable that explained the areal decrease was the original retention patch size from 2007. Due to the project's risk of potential human error, digitising polygons by hand, inaccurate data that showed an increase or a very small decrease in retention patch area had to be filtered out. This led to a loss of data which in turn might have affected the representativeness of the different variables in our statistical model. Furthermore, there are potential errors in the varied precision of used layers and functions in QGIS that may have affected the outcome, such as the represented forest cover type that might differ from reality. However, our study confirms our hypothesis that retention patches in Västerbotten county have had areal decreases over the selected timespan. A larger time span could be examined to achieve a more robust basis for explaining how much retention patches change in size over time. Prior studies have however found that most changes in retention maintenance occur within the first decade. Studies have confirmed that retention patches fulfil important functions where they are implemented, but depending on where in Sweden they are, different variables will impact their size and distribution in different ways. This could call for adaptations and different combinations of forestry management, forest protection and retention forestry in order to improve species lifeboating and enhance landscape connectivity. Furthermore, there is reason to examine larger retention patches than what was investigated in this study as other studies have confirmed that larger retention patches maintain their microclimates better. This QGIS project and our statistical model could be expanded further with additional variables such as wind exposure and velocity, soil properties and topography, which could lead to a better understanding of planning and maintenance of retention forestry and isolated retention patches. Since this area of research is currently rather limited, there is a need of more studies covering both longer time spans and larger spatial scales.

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