The Effect of Retention Trees on the Growth of Norway Spruce

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Master Thesis no. 200

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Bilateral Cooperation

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ABSTRACT

The increased demand for wood and at the same time declining biodiversity, especially in species related to natural forests has brought to attention the need to find ways to maintain natural forest components also in managed stands, not only in specially protected areas. One possible method for increasing the number of species in a production forest is using retention trees. A forest stand in Southern Sweden was investigated to determine the effect of retained trees on the growth of Norway spruce (*Picea abies*). A total of thirty-three plots were established in 5.5 ha stand with retained oaks as plot centers, three oak release treatments (high release, medium release and no release) were carried out on the plots. The results showed a reduction in individual tree Norway spruce growth within the proximity of the retained oak. A larger diameter increment was recorded around the gaps in comparison with no release plots, so some of the loss in Norway spruce growth was compensated. At the whole stand level, there was no significant effect of the retained trees on the growth of the spruce; however, this could be caused by the imposed treatments and thinning in the stand, which might have evened out the total retained tree effect. Further investigation is needed in determining the compensation of growth around gaps and also a wider age range of Norway spruce stands should be evaluated.

Keywords: Retention trees, Norway spruce, (Picea abies) Oak, (Quercus robur), growth, competition

Kokkuvõte

Säilikpuude mõju Hariliku kuuse kasvule

Annika Altmäe

Suurenenud nõudlus puidu järele ning samal ajal kahanev, eriti looduslike metsadega seotud, bioloogiline mitmekesisus on loonud vajaduse leida uusi meetodeid kuidas säilitada looduslike metsade komponente ka majandatud mestades. Üks võimalik meetod liigirikkuse tõstmiseks majandatud metsades on kasutada säilikpuid.

Magistritööga püüti selgitada: 1. Milline on tamme mõju individuaalse kuuse kasvule; 2. Kuidas mõjuvad kuuse kasvule tamme ümber parandatud valgustingimued; 3. Milline on kõikide puistus säilitatud puude üldine mõju Hariliku kuuse kasvule.

Lõuna-Rootsis Asa katsemetsas valiti 5,5 ha suurune metsa ala, et kindlaks teha säilikpuude mõju Hariliku kuuse (*Picea abies*) kasvule. Kokku rajati 33 proovitükki, mille keskmeks olid eelmises lageraies alles jäetud Harilikud tammed (*Quercus robur*). Valitud proovitükkidel raiuti 2007. Aastal tamme vabastamiseks tüvede ümbert kolm erineva suurusega ala: 1. Tüve ümber olev ala raiuti kuuskedest puhtaks võra ulatuses ja 2 m võrast väljas pool. 2. Tüve ümber olev ala raiuti võra ulatuses 3. Tüve ümber oleval alal kuuski ei raiutud.

2010. aasta suve lõpul mõõdeti tamme ümber kasvavate kuuskede ja lehtpuude kaugus ja nurk tammest ning diameeter. Igalt proovitükilt valiti 6 kuuske kõrguse ja kolme viimase aastarõnga mõõtmiseks.

Tulemused näitasid säilitatud tamme negatiivset mõju individuaalse kuuse kasvule. Loodud häilud aga kompenseerisid kadusid mõnevõrra, kuna suuremate häiludega proovitükkidel oli kuuse kasv parem. Statistiliselt ei olnud säilitatud puude üldist mõju kuuse kasvule võimalik tuvastada, see ei tähenda aga et mõju ei ole. Sellise tulemuse põhjuseks on arvatavalt puistus läbi viidud harvendusraie ning ka häilude rajamine tammede ümber, mis on mõjutanud ressursside jaotamist puistus ning seeläbi mõjutas ka esialgseid statistilisi näitajaid. Eeldatavasti enne harvedusraiet ning häilude rajamist oli säilikpuude üldine mõju selles puistus selgem.

Kuna proovitükkide keskel olevatel tammedel oli selge mõju juba üksiku kuuse kasvule, siis metsa majandamise seisukohast oleks soovitatav jätta säilikpuid pigem gruppidena

kui eraldi ükskikpuudena. Antud eksperimendi positiivne tulemusena võib välja tuua kuuskede parema kasvu suuremate häiludega proovitükkidel, mis näitab et õigesti majandatuna ei ole säilikpuude mõju uue metsa kasvule nii negatiivne kui varem arvatud.

Kuna antud magistritöös oli statistiline analüüs eksperimendi ülesehituse tõttu keerukas (plaanitud eksperiment ja reaalsus erinesid üksteisest oluliselt (Appendix A)), siis vajaksid saadud tulemused edasist uurimist. Rohkem uuringuid tuleks teha ka vanemates kuusikutes, mis on küpsusvanusele lähemal.

Tänusõnad

Soovin tänada oma juhendajaid Urban Nilssonit, Bronson Bullockit ja eriti Lee Allenit kogu abi ja toe eest magistritöö tegemisel, Maria Koch Wiederbergi tema juhendamise eest Asa mõõtmiste tegemisel. Lisaks soovin tänada kõiki õpetajaid Rootsi Põllumajandusülikoolis, Helsingi Ülikoolis ja Põhja Carolina Osariigi Ülikoolis huvitavate loengute ja väga hea metsandusliku hariduse eest. Sooviksin tänada ka Atlantise programmi ja Euroforesteri programmi ilma milleta ei oleks minu õpingud välismaal võimalikud olnud.

Ja lõpetuseks tänan südamest oma toetavat perekonda ja kõiki huvitavaid inimesi keda õpingute ajal kohanud olen, tänu teile on need olnud tõeliselt lõbusad ja sündmusterohked aastad.

BIOGRAPHY

Annika Altmae was born on the 2nd of April 1987 in Kullamaa village, Estonia. She graduated from secondary school in Kullamaa in 2002 and from high school in Käina village in 2005. She continued her studies in the same year at the Estonian University of Life Sciences, Tartu, Estonia, where her major was Natural Resources Management. She graduated with a BS degree in 2009 and continued on for her Master's Degree in Sweden at the Swedish University of Agricultural Sciences. Her major during her Master-studies abroad was forestry. After completing the Euroforester Masters-program in Sweden she continued as a student in the Atlantis program first at the University of Helsinki in the fall semester 2010 and then at North Carolina State University starting the spring semester 2011. Her planned graduation from the Atlantis program was on 16th February 2012.

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1. Introduction

The increasing demand for wood has led to the expansion of even-aged plantations all over the world (FAO 2011). Growing trees in plantations is a good way to maximize volume production from forests (Hartley 2002). In Sweden, plantations and the clear-cut system was introduced on a broad scale in the second half of the 20th century, which led to vast clear-cut areas and is considered to be a possible cause for faster biodiversity decline (Freedman et al 1996, Palik and Engström 1999). In the 1970's the priorities of the society and the attitude of forest owners started slowly shifting towards aesthetics and conservation, which was expressed in the Swedish Forestry Act of 1979 (Enander 2003). In the beginning of the 1990's species extinction and concern about possible climate change came to global attention, with conferences held in Rio (Anon. 1992) and Helsinki (Anon. 1994). Since the need for changes became evident, forest managers and policy makers started looking for improved forest management methods that would address both production and conservation goals (Niemelä et al 2006).

The Swedish approach to nature conservation is not to set many areas aside (Nature reserves only take up 10% of the area (FAO 2010)), but instead try to use different methods to increase biodiversity all over the country, including production forests.

Using retention trees inside production areas is hypothesized to help improve landscape connectivity and therefore biodiversity, because more suitable habitats are created for a larger number of species (Murcia 1995). Retained trees are used as "lifeboats" (Manning et al. 2006, Franklin 1997). Harvests can be designed to leave behind several mature large-diameter trees as scattered individuals, in clumps or linear strips. An important value of retention trees is that they provide future inputs of coarse woody debris, which is the most conspicuous difference between a natural and managed stand (Hartley 2002). 'Lifeboating' is achieved in at least three ways: by providing structural elements that fulfill habitat requirements for various organisms, (2) by improving microclimatic conditions in relation to those that would be encountered under clear-cutting (3) by providing energetic substances to maintain non-autotrophic organisms (Franklin et al 1997).

Retained trees have been reported to be beneficial for species with limited dispersal abilities (e.g. lychens), invertebrates (Southwood 1961, Petersson et al 1995, Hyvärinen et al 2005), birds (Rosenvald & Lõhmus 2008), ectomycorrhizal fungi (Rosenvald & Lõhmus 2008), herb and shrub species (North et al 1996). For some invertebrates it is also important how the retained trees are managed. Higher numbers of species have been reported to depend on large trunks and open canopy for increased sunlight (Ranius & Jansson 2000). A study by Thelin et al (2002) suggested that keeping a mixture of broadleaves can help keep sustainable nutrient levels in the forest soil. However, another study (Rothe *et al.* 2003) concludes that the positive effect of broadleaves on the nutrient balance of conifer needles is overestimated and no statistically significant evidence was found of a positive effect of broadleaves on conifers.

The main concern with using retained trees in a stand is that they are shown by different studies (Basset & White 2000, Jakobsson 2005) to have a negative impact on the growth of the new stand. A 2 m reduction in height and 0.5 m^2/ha reduction in mean annual basal area increment was found in dense overstory in an investigation by Linden & Ölander (2003). In addition many studies have shown a reduction in height growth of Norway spruce due to overstory (Jaghagen 1997, Dignan et al 1998, Örlander & Karlsson 2000).Given that the RT are economically valuable, leaving them standing may impose a considerable burden to private landowners, existing forestry laws do not provide any compensation for this cost (Koskela *et al* 2007).

The objective of this thesis is to investigate the extent of the competition and possible factors that affect the competition between the retained trees (mainly *Quercus robur*) and the new stand (*Picea abies*)

1. How the growth of Norway spruce is influenced by the retained oaks:
   a) Is there a reduction in growth in the individual trees with the proximity of the oak?
   b) Do the light conditions (spruces angle from the oak) influence the growth of the spruces? Is there a change in the growth-distance relationship in different light conditions?
   c) Is the effect of the oak also evident on per hectare measures?
2. Can the effect of the retained trees be influenced by silvicultural techniques?

   a) Does more available space make more resources available and compensate the growth reduction?
3. What is the total effect of the retained trees in the stand on the growth of the spruces?
   a) How much does the broadleaf basal area influence the spruce diameter, height, basal area and volume growth?

2. Material and methods

2.1 The experimental stand

The data were obtained from a 5.5 ha stand located at the Asa Experimental Forest in southern Sweden (Lat. 57°08'N, Long 14°45'E, altitude 220 m above sea level). The site index (base age 100 years) was 38 m. The mean annual temperature between 1999 and 2009 was 6.7°C and the mean annual precipitation 775 mm.

The site was located on a slope with approximately 10% inclination to the west. The soil texture was sandy loam. on 84%, loam on 12% and sand on 4% of the stand. The soil water conditions were mesic on 90%, moist on 8% and wet on the remaining 2% of the stand (Linden and Örlander 2000)

The stand was a mixed stand, with an understory of Norway spruce and an overstory of various deciduous trees and older Norway spruce that were retained after the final harvest of the previous stand in 1972 that was dominated by Norway spruce. The spruces of the new stand were planted in 1975 with 2m spacing. The oaks averaged 145 years old in the summer of 2010, when the stand growth variables were measured. The dominant deciduous trees in the stand were Pedunculate oak (Quercus robur L.), European aspen (Populus tremula L.) and Norway maple (Acer platanoides L.).

2.2 Data collection

In 2007 33 retained oaks in the stand were chosen as plot centers, they were divided into 11 blocks (Figure 1) based on the location of the plots in the stand. One of three release treatments was randomly assigned to each plot. The stand was thinned and the treatments carried out in early 2008 as follows:

1. Treatment 1 – heavy release (HR) - the area around the oak was cleared within the border of the oak crown and 2 m outside of the crown.
2. Treatment 2 – moderate release (MR) - the area around the oak was cleared within the limit of the crown.
3. Treatment 3 – no release (NR) - the area around the oak was not cleared. (Figure 2)

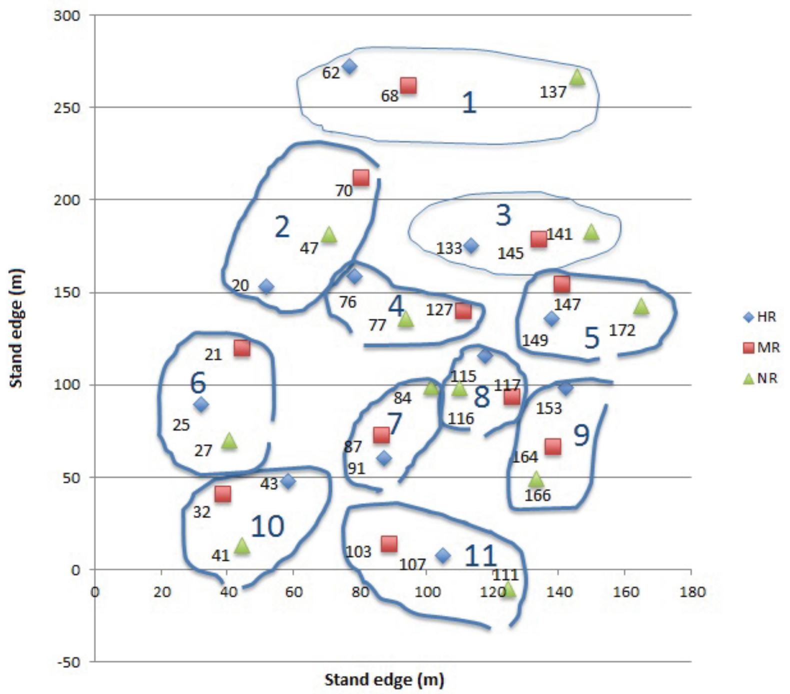

Figure 1. Design of the blocks in the stand (block numbers in blue), blue diamonds mark heavy release treatment plots, red squares mark moderate release treatment plots, blue triangles mark no release treatment plots (plot numbers in black).

In 2010, diameter at breast height (DBH) was measured on the center oaks, all spruce (both current and previous rotations), and all other broadleaves (aspen, alder, hazel, maple, oak, lime, and birch) that were inside the 15m plot radius. In addition distance and direction from the oak were measured on all second rotation spruce (> 5cm). One tree was randomly chosen in each of four quartiles in a sorted diameter list for total height measurement. These same trees were also cored at breast height to determine radial growth during the three last years.

Basal area was distributed between oaks (4.5 m^2/ha), other broadleaves (9.0 m^2/ha), residual spruce (2.3 m^2/ha) and the current rotation spruce (17.1 m^2/ha).

Because of differences in the crown size of the center oaks, the radius of the cleared area (distance from oak to the first current rotation spruce) varied within and between treatments (Figure 2), the number of second generation Norway spruce measured within each plot and their distribution varied (Figure 3) and unfortunately several treatment plots overlapped (Appendix A).

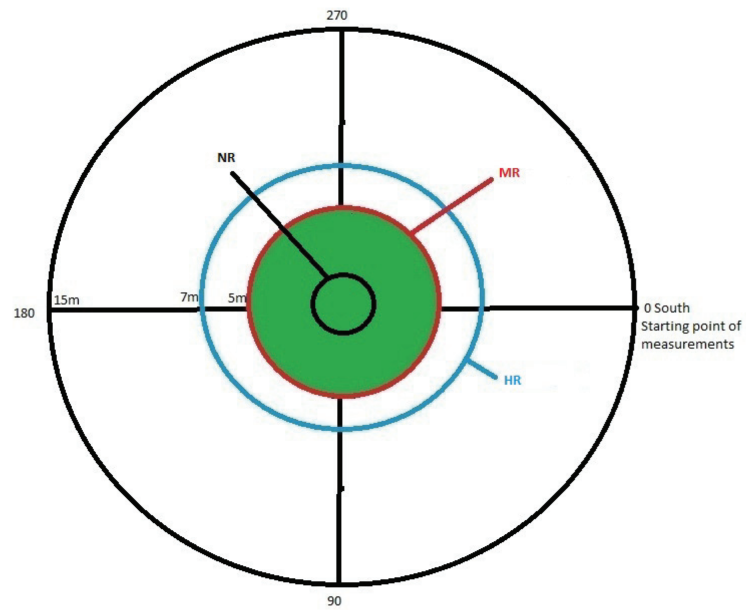

Figure 2. Design of the experimental plots with oak stem as the center. The border for each treatment marks the average distance of the closest spruce to the oak for that treatment. Actual distances vary by plot based on the crown width of the oak.

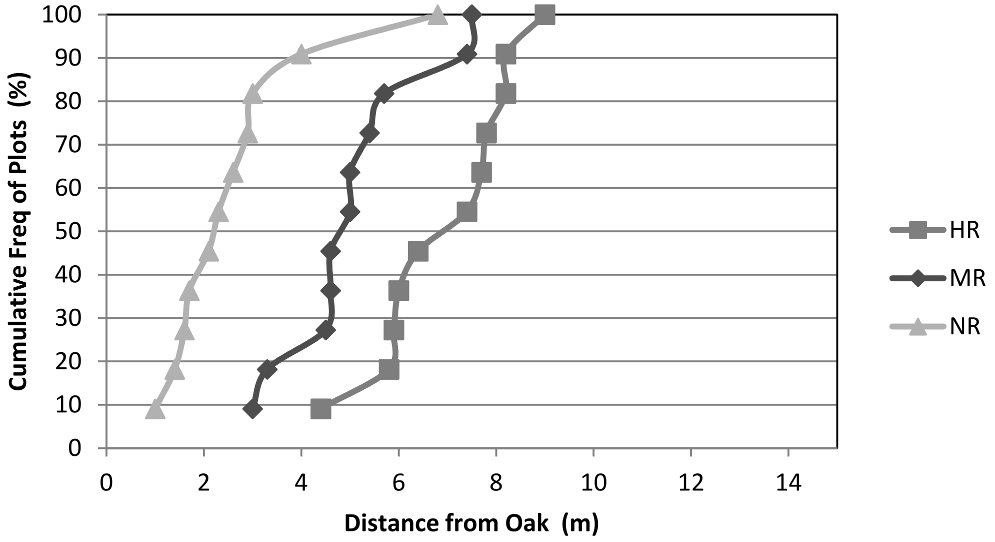

Figure 3. Cumulative distribution number plots by the distance to the closest current rotation spruce from the center oak for each treatment.

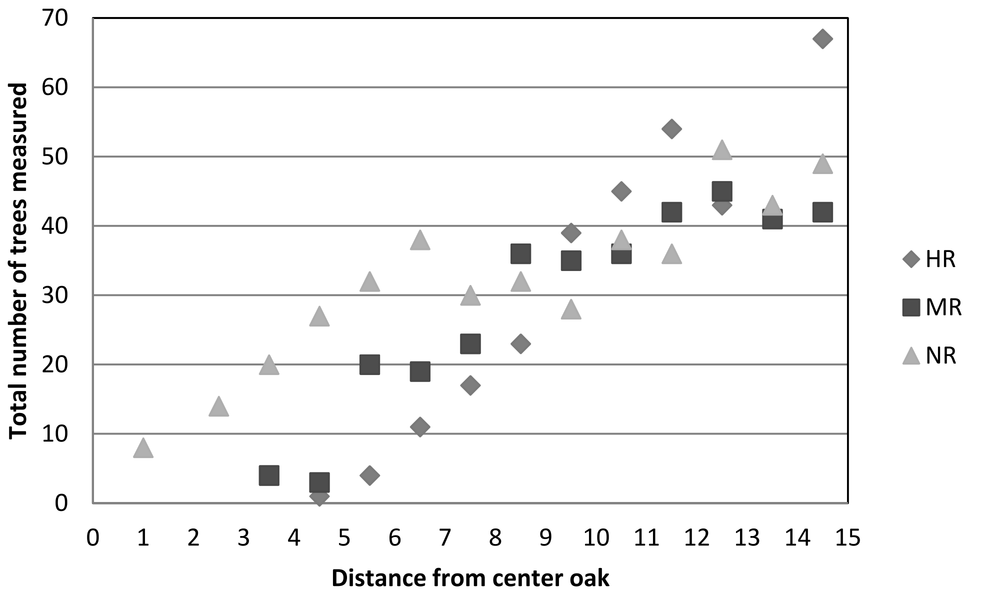

Figure 4. Total number of measured trees within a 1 m band centered at a given distance from the center oak.

2.3 Previous data collection

This stand was also measured in 2007, before the stand was thinned and the treatments imposed. Only the diameters of spruce and broadleaves on medium and high release plots were measured, heights were not measured and trees were not cored. The maximum radius of a sample plot was 10 m, the angle of the measured spruce from the oak was not measured. It was not possible to identify the trees that were measured in 2007 as was the initial plan, because most of the trees that were measured in 2007 were cut when the stand was thinned and the areas around the oaks cleared in early 2008. These differences made it very difficult to make comparisons between the two data sets. After careful consideration the 2007 data were still used for analysis, however only to investigate the individual spruce diameter in relation with distance from the oak.

2.4 Statistical analysis

To determine how the growth of the current rotation spruce was influenced by the retained oaks five aspects were analyzed:

All individual-tree spruce growth variables (2010 height, 2010 DBH, 2007 DBH, 3 year DBH increment (2007 to 2010), 2010 basal area, 3 year basal area increment, and 2010 volume) were regressed against distance from the center oak. Both 2010 and 2007 measured data were used in the DBH regression. Diameter increments (DBHI) were measured on 173 trees in 2010 and were used to predict diameter increments for all trees. Based on the estimated data the basal area in 2007 and the 3-year basal area growth were also estimated. Individual-tree basal area was calculated according to the following formula:

$$BA=DBH^2*0.00007854$$

The volume of the trees was calculated according to Brandel (1990)

$$Volume = 10^{-0.972} *DBH^{12.03084} * (DBH+20)^{-0.51807} * H^{2.91197}*(H+1.3)^{-1.662}$$

Spruce growth variables were regressed against distance (DIST) using SAS 9.2 general linear model process with the following model statements:

- Model DBH10 DBH07 DBHI H10 BA BAI VOL=DIST
- Model DBHI= dbh07 treatm dbh07*treatm

The spruces were divided into four directional angle groups: south 315-45°, west 45-135°, north 135-225° and east 225-315°. The measurements were started at 0° south as shown in Figure 1. In SAS diameters in 2007 (DBH07) and 2010 (DBH10), diameter increment, (DBHI), height (H10), basal area 2010 (BA), basal area increment (BAI) and volume of individual trees were regressed against the distance and direction from the oak:

- Model DBH10, DBH07, DBHI, H10, BA, BAI=Dist Direction Dist*Direction

The spruces were divided into groups according to their distance class. There were 15 distance classes (plot radius 15m – each distance class is a 1 m concentric ring around the oak). The regression analysis was done on the first 10 m away from the center oak (potentially higher gap influence) and on the whole plot. The estimated DBH increment data (Step 1) was used to calculate basal area increment. In SAS basal area 2010 (BAH), basal area increment (BAIH) and volume (VOLH) per hectare were regressed against concentric distance groups (DIST1):

- Model BAH BAIH VOLH=DIST1

The data were divided into 3 groups according to the imposed treatments and the growth variables were compared between treatments using Analysis of Variance. Also the effect of directional angle and the effect of oak proximity were compared between treatments. In SAS diameter (DBH) 2010, diameter increment DBHI, height (H10) of individual trees and basal area 2010 (BA), basal area increment (BAI) and volume (VOL) were regressed against distance, treatment and angle:

- Model DBH DBHI H10 BA BAI VOL = dist direction treatm block dist*direction dist*treatm direction*treatm dist*direction*treatm

The average basal area and basal area increment of the plots were compared on 0-15 m (BA1), 0-5 m (BA2), 5-10 m (BA3) and 10-15 m (BA4) between treatments.

- Model BA2 BA3 BA4 BAI2 BAI3 BAI4 = treatm
- Model BA1 BAI1 = treatm block treatm * block

The individual-spruce growth variables were regressed against the retained tree basal area. The retained tree basal area was compared between treatments. Diameter (DBH) 2010, diameter increment DBHI, height (H10) of individual trees and basal area per hectare 2010 (BAH), basal area increment per hectare (BAIH) volume per hectare (VOLH) were regressed against total retained tree basal area (RT)

- Model DBH DBHI H10 BAH BAIH VOLH= RT treatm RT*treatm

3. Results

3.1 Oak influences on individual Norway spruce growth

Individual tree DBH, DBHI, height, basal area, basal area increment and volume were significantly greater with increasing distance from the oak (Table 1). The R^2 values were low and the variation in the data were high – for DBH 2010, DBH 2007 and DBHI the coefficients of variation were over 30%, for basal area 78%, basal area increment 53% and for volume 66%. The slope parameters (Table 2) can be interpreted as follows: DBH of spruce increased by 4 cm, DBHI by 1 mm and height by 2.6 m, for a 10 m increase in distance from the center oak which in practical forestry is a substantial increase. However, the results were also influenced by how the treatments were imposed: the small trees close to plot centers remained on the no release plots but they had been removed in the high and medium release plots which caused an additional effect on the growth-distance relationship.

Table 1. Summary of the regression analysis between individual spruce characteristics and distance from the center oak. (p-value < 0.05)

Distance	**DBH 2010 (cm)**	**DBH 2007 (cm)**	**DBHI (cm)**	**Height (m)**	**BA2010 (m^2 /tree)**	**BAI (m^2 /tree)**	**Volume (m^3 /tree)**
Number of trees	1154	437	159	159	1154	159	159
p-values for regression parameters	<.0001	0.349	0.011	0.009	<.0001	0.012	0.022
R^2	0.037	0.02	0.041	0.042	0.031	0.04	0.033
Coefficient of variation	35.4	35.1	32.2	20.8	78.1	53.6	66.0
Slope parameters with distance	0.433	0.11	0.015	0.262	0.001	0.0001	0.017

The regression slopes between individual-spruce DBH, BA and distance from center oak were different on the south and east side of the oak (Table 2). For the other individual-spruce growth characteristics there were no differences in the regression slopes between the directional angles.

Table 2. Summary of the regression analysis of how Norway spruce growth is influenced by distance from the oak and the directional angle from the oak. Values with different letters are significantly different (p-value < 0.05)

Distance	**DBH**	**DBHI**	**Height**	**BA2010 (m^2/ha)**	**BAI (m^2/ha)**	**Volume (m^3/ha)**
Number of trees	1154	159	156	1154	159	156
p-values for regression parameters						
Distance	<.0001	0.035	0.0272	<.0001	0.074	0.152
Direction	0.316	0.933	0.857	0.283	0.855	0.840
Distance*Angle	0.036	0.956	0.972	0.016	0.799	0.820
R^2	0.054	0.066	0.081	0.045	0.077	0.062
Coefficient of Variation	36.5	33.1	20.9	81.7	61.0	82.9
Slope parameters with distance						
Direction North	0.334a	-0.003a	0.255a	0.001a	0.0001a	0.023a
Direction East	0.635b	0.011a	0.032a	0.002b	0.0003a	-0.003a
Direction South	0.164c	-0.431a	0.522a	0.0004c	0.0002a	0.056a
Angle West	0.404a	-0.136a	0.428a	0.038a	0.025a	0.024a

On the east side of the oak the influence of the oak proximity on the spruce DBH was stronger than on the south or north side (Figure 5.). On the east side the DBH of the individual spruces were 9.45 cm larger 15 m away than the spruces close to the center oak, which in practical forestry is a very remarkable difference. On the South side, the

DBH of individual spruces were 2.4 cm larger 15 m outside of the center oak compared with the ones close to the center. In all aspects the DBH was larger as the distance from the oak increases. For basal area the relationship was also strongest on the east side and weakest on the south side of the center oak. For all the other individual tree growth variables there were no statistically significant differences between the four directional angles.

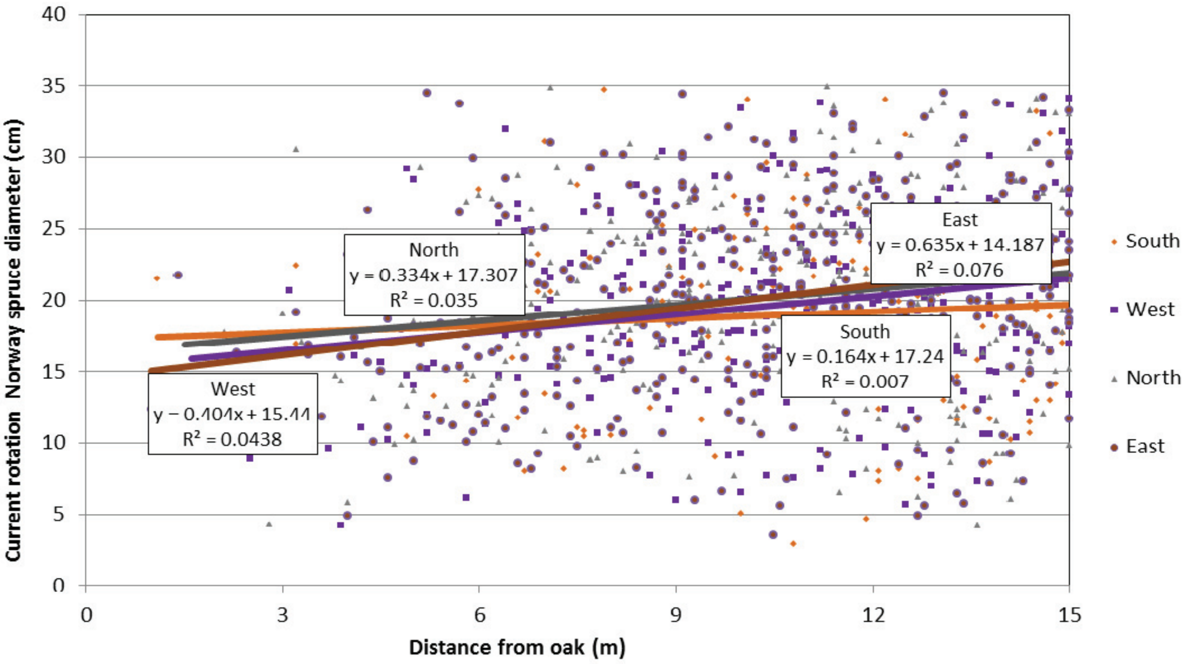

Figure 5. Relationship between individual tree DBH measured in 2010 (DBH2010) and distance from the center oak for four directional angles (South, West, East, and North)

Spruce basal area and volume per hectare calculated within concentric rings around the center oak were not influenced by the oak proximity, but basal area growth was (Table 4). The coefficient of variation was somewhat lower for basal area per hectare and basal area increment per hectare than for individual tree basal area and basal area increment, but higher for volume. There was a very weak slope for basal area increment when all rings out to 15 m were considered. The gap effect was higher within the first 10 m away from the center oak - the slope value for the basal area increment was doubled.

Table 3. Summary of regression analysis for spruce growth variables on a per hectare basis on the whole plot and first 10 m away from center oak. (p-value < 0.05)

Dependent variables	**BAH (m^2/ha)**	**BAIH (m^2/ha)**	**VolH (m^3/ha)**
Distance up to 15 m			
p-values for regression parameters	0.303	<.0001	0.156
R^2	0.003	0.082	0.015
Coefficient of variation	63.0	43.1	93.3
Slope with distance	0.238	0.001	-3.825
Distance up to 10 m			
p-values for regression parameters	0.155	0.0873	0.194
R^2	0.036	0.052	0.03
Coefficient of variation	75.8	58.9	78.2
Slope with distance	-0.099	0.002	-4.880

3.2 Treatment effects on Norway spruce growth

Initially only Norway spruce DBH significantly differed between treatments (Table 6). The no release treatment had significantly lower DBH than medium and high release treatments, at 18 cm, 20.9 cm and 21.2 cm, respectively (Table 5). Spruce DBH was also affected by distance and angle from the center oak. However since there was a substantial amount of variation in the stand and the plots were overlapping between treatments (Appendix A), it was expected that there was no significant statistical effect of the oak release treatments evident for the other Norway spruce growth variables.

Table 4. Means for second generation spruce growth characteristics for the three oak release treatments. Values with different letters are significantly different (p-value < 0.05)

Treatment	**Number of trees**	**DBH10 (cm)**	**DBH07 (cm)**	**DBHI (cm)**	**BAH (m^2/ha)**	**BAIH (m^2/ha)**	**VolH (m^3/ha)**
HR	353	21.2a	19.7a	1.5a	18.62a	2.48a	174.0a
MR	355	20.9a	19.3a	1.6a	18.34a	2.55a	164.2a
NR	462	18.0b	16.8a	1.2a	20.16a	0.96a	170.3a

Table 5. Summary of multiple linear regression analysis of how Norway spruce growth is affected by the treatments, distance from the oak and directional angle from the oak (p-value < 0.05)

	DBH	**DBHI**	**Height**	**BA (m^2)**	**BAI (m^2)**	**Vol (m^3)**
N	1154	159	159	1154	159	159
R^2	0.52	0.84	0.65	0.66	0.89	0.45
Coefficient of variation	34.8	29.3	20.5	77.3	48.9	62.6
p-values for regression parameters						
Distance	0.002	0.165	0.112	0.006	0.051	0.055
Direction	0.350	0.585	0.142	0.833	0.222	0.067
Treatment	0.011	0.168	0.803	0.131	0.277	0.483
Distance*Direction	0.072	0.701	0.725	0.712	0.551	0.225
Direction*treatment	0.780	0.831	0.573	0.129	0.173	0.381
Distance*treatment	0.061	0.202	0.760	0.457	0.811	0.278
Distance*Direction* treatment	0.043	0.343	0.484	0.081	0.062	0.130
Block	0.860	0.059	0.158	0.005	0.085	

The imposed treatments have influenced the diameter of the current rotation Norway spruce (Figure 5). With the oak release treatments the small diameter Norway spruces were removed from under the oak crown (the plot center) making the slope of the distance effect less steep than it was for the no release plots where the small spruces are still standing.

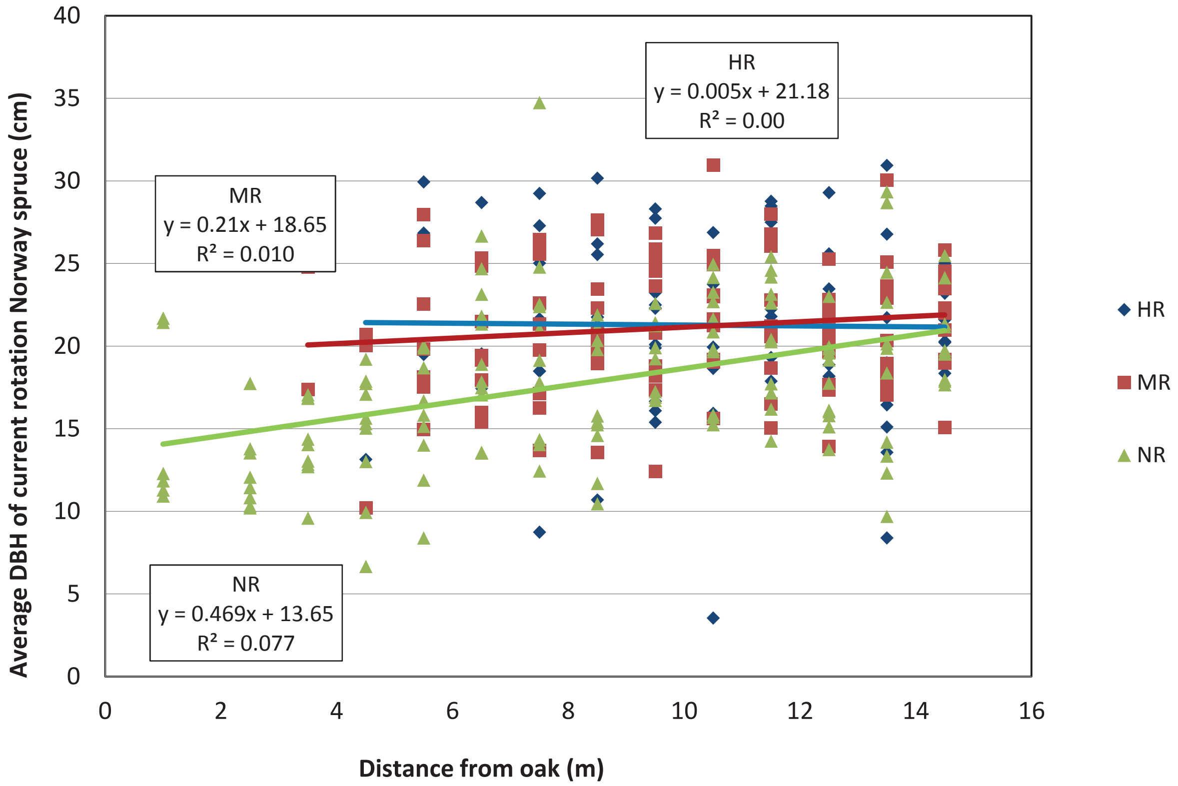

Figure 6. The relationship between Norway spruce diameter and different distances from the oak for the three release treatments.

In each treatment, the regression slope between spruce diameter and distance from the oak was different. In the high release treatments with the largest gaps, the slope was weak 0.005, in medium release it was 0.210 and in the no release treatment it was the steepest 0.487 (Table 6, Figure 6). In medium and high release treatments the distance effect was not statistically significant and in no release the distance from the center oak was highly significant.

Table 6. Summary of the regression analysis on how Norway spruce DBH is influenced by the distance from oak in each treatment (p-value < 0.05).

	HR	MR	NR
p-values of the regression parameter (DBH)	0.969	0.0562	<.0001
R^2	0.00	0.010	0.077
Slope with distance	0.005	0.21	0.469
Coefficient of Variation	30.6	28.7	33.7

On the no release plots, there was little change in Norway spruce basal area or basal area increment with distances from the oak, while in the high and medium release plots, there were changes in both basal area and basal area increment between 0-5 meters and 10-15 meters away from the oak (Table 8). In high release plots, the basal area increment was higher on 10-15 m away from the oak than in the other plots, while in total the increment was highest on the no release plots: 5.8 m^2 compared to 4.74 m^2 in high release and 5.66 m^2 in medium release. The treatment differences were significant for basal area and basal area increment within the 0-5 m distance from the oak, and for basal area increment also within the 10-15 m distance from the oak. On the whole plot (10 – 15 m) both treatment and blocking had a significant effect on Norway spruce basal area and basal area increment.

Table 7. Average basal area and basal area increment of Norway spruce in 0-15, 0-5, 5-10 and 10-15 meters away from oak (2010) between treatments (p-value <0.05).

	N	BA 0-5 m (m2/ha)	BA 5-10 m (m2/ha)	BA 10-15m (m2/ha)	BA 0-15 m (m2/ha)	BAI 0-5 m (m2/ha)	BAI 5-10 m (m2/ha)	BAI 10-15m (m2/ha)	BAI 0-15 m (m2/ha)
HR	11	0.16	14.14	22.21	36.51	0.03	1.85	2.86	4.74
MR	11	3.19	18.27	18.18	39.64	0.48	2.64	2.54	5.66
NR	11	15.47	16.9	16.3	48.67	1.98	1.99	1.85	5.82
p-values for regression parameters									
Treatment		<.0001	0.431	0.105	0.001	<.0001	0.157	0.02	0.001
Block					0.01				0.043

After three growing seasons it was very hard to assess Norway spruce growth response to the release treatments because the only variable assessed that could provide information on actual tree growth response for the past three years was the diameter increment (Figure 7).

The multiple linear regression analysis between DBHI and treatment showed a significant difference. The trees in the no release plots had lower growth rates than in high release and medium release. The highest growth was recorded in medium release plots.

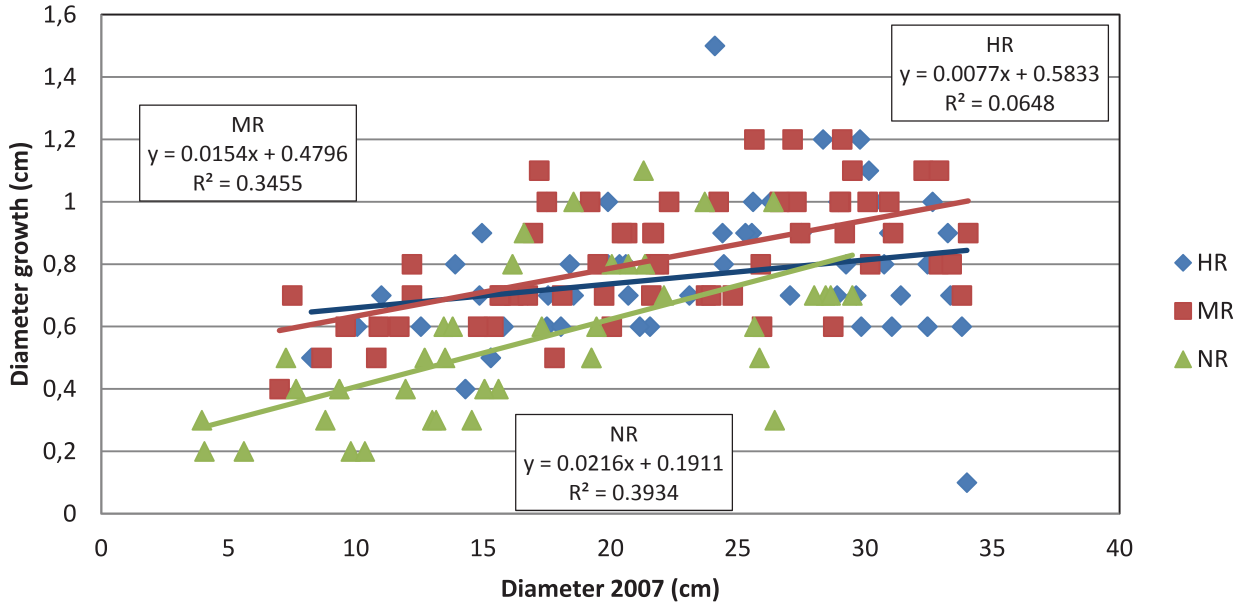

Figure 7. Relationship between current rotation Norway spruce diameter increment and 2007 diameter for each release treatment.

3.3 Effect of all retained trees on the growth of current rotation Norway spruce

Since the other broadleaves and residual spruces make up 53% and 7% of the total measured basal area, their influence together with the oaks (13.5% of the basal area) on the total stand was investigated. No statistically significant relationship was found between Norway spruce growth and the total retained tree basal area (Table 8). A difference in the intercept was found for all the growth variables between treatments (Table 8). Norway spruce DBH and volume intercepts were highest in high release treatment. Diameter and basal area increment were highest in the medium release treatment. Basal area per hectare and height were significantly lower in the no release treatment, there was no difference in basal area per hectare between the medium and high release treatments.

Table 8. Summary of the regression analysis on how Norway spruce growth is affected by all the retained trees in the stand and the differences of the retained tree basal area between treatments. Values with different letters are significantly different (p-value <0.05)

	DBH	**DBHI**	**Height**	**BAH (m2/ha)**	**BAIH (m2/ha)**	**VolH (m3/ha)**
Number of plots	33	33	33	33	33	33
p-value of the regression parameters						
Retained trees BA	0.798	0.72	0.853	0.976	0.484	0.321
R^2	0.322	0.671	0.392	0.116	0.704	0.738
Coefficient of variation	11.3	12.4	6.9	31.1	26.5	23.8
Intercept						
HR	23.7b	1.4a	19.8a	16.9a	2.0a	232.5a
MR	20.8a	1.6b	19.5a	21.5a	3.0b	210.9b
NR	17.8a	1.1c	18.3b	15.8b	1.0c	173.2c

4. Discussion and conclusions

This stand gave a good opportunity to investigate the effect of retained trees on an older Norway spruce on a good site. It provided a good balance between production goals and nature values – with Norway spruce being an economically important species in Sweden and the oak in the stand was over 140 years old. However there were some challenges – the treatments were imposed the best way possible, when looking at the initial map of the stand. But after using the actual coordinates of the stand and creating a more precise map it was evident that many of the treated plots were too close, leaving many of the measured spruces under the influence of two or more oaks. This made the estimation of the overall effect of retained trees difficult from this stand.

The most important finding was the effect of the oaks on individual-tree Norway spruce attributes. Most studies have concentrated on general effects on the whole stand or per hectare basis. While there was a substantial amount of variation when estimating the growth of individual trees, statistically the influence of the oaks was still evident and the reductions in growth are practically important. The reduction in height and diameter has also been reported by Linden and Örlander (2003). The effect on basal area, basal area increment and volume was significant but rather small on individual trees, the effect was lost on per hectare measures. The light conditions (directional angle from the oak) had an effect on the competition between the spruce and oak. The effect of aspect on tree growth has previously been addressed by Stage (1976) and by Zenner (2000). Zenner found the strongest influence on the east aspects, which can also be seen in this study - on the east side the distance from the retained oak has the strongest influence on spruce DBH, on the south side the lowest. Since light is a limiting resource in Nordic conditions, it is hypothesized that the south aspects have more light and the competition is less strong (Zenner 2000).

Diameter was significantly different between the different gap sizes around the oaks, but this result could be misleading because of the way the treatments were imposed. It was clearly shown that this effect was caused by small trees that were removed from the treated plots but were left growing on the control plots (Table 6, Figure 4). However when the diameter increment was analyzed the same result was evident – growth was largest in the medium release treatment followed by high release. There were also significant differences in the basal area and basal area increment on different distances from the center oak between treatments, so it was concluded that the gaps have enhanced Norway spruce growth around the edges and this compensated for the loss in production due to retained trees.

On the whole stand level the retained tree basal area did not show a negative impact on the growth variables of the Norway spruce, while in a previous study in the same stand conducted by Linden and Örlander (2003) a reduction in Norway spruce basal area and crown projection area with increased retained tree basal area was recorded. Also reductions in growth of Norway spruce in shelterwood stands have been reported by Linden (2003), Holgen *et al*. (2003), Rose and Muir (1997). One possible reason why the overall effect was not evident could be that the whole stand was thinned when the treatments were imposed, which could have caused differences in tree growth response (Mäkinen and Isomäki 2004) by making the stand more unified because there is more space available which in turn may reduce the evidence of the RT effect. Also as mentioned above, many of the treated plots were too close to each other, so a number of the measured spruces were always influenced by at least two retained oaks - in this case it is not a comparison between spruce with competition and spruce without competition, but a comparison of spruce with more and less competition, which most likely made the results less clear.

The r^2 values were low for the whole analysis, only after blocking effect was added the r^2 values were substantially higher, however this did not change the results in the analysis.

Overall the negative effect of retention trees on the growth of the new stand is not as negative as expected at the beginning of this experiment. The compensation in growth needs more investigation but is an aspect to consider.

Since the oaks had a significant influence on the individual Norway spruce growth characteristics on the production point of view aggregated retention would be more advised than dispersed retention. From biodiversity point of view it depends on the species (Rosenvald & Lõhmus 2008) and one cannot be preferred to the other.

The effect of retention trees on an older Norway spruce stand needs more investigation. To date, the studies conducted have concentrated more on the retained tree effects on Norway spruce regeneration. The effects on regeneration have been reported to be positive (Basset & White 2000, Holgén et al. 2003), but the studies conducted on

Norway spruce stands that are up to 25 years old have been reported to be negative (Jakobsson 2005, Linden & Örlander 2003). The results of this study imply that the older stands (close to maturity) with retained trees and also the possible growth compensation need to be investigated further.

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APPENDICES

Appendix A