Development of Single Oak Trees in a Mixed Coniferous Stand

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Abstract

Pedunculate oak (*Quercus robur*) and sessile oak (*Quercus petraea*) are important tree species in the southern half of Sweden. Oak trees house a large biological fauna and can have high value timber. Managing oaks in pure stands is common but a large portion of oak is found in admixed in coniferous stands. The aim of the study was to investigate the growth of single oaks in a multi-layered, conifer-dominated mixed stand in relation to thinning method, competing trees and age.

The study was conducted in Tönnersjöheden experimental forest in southern Sweden on 100-year old pine stand with naturally regenerated spruce and oak. The area was divided into different target diameter harvest treatments and thinned 2008-2009. 90 oaks were sampled for the single tree analyses, 30 trees for the age analyses and data from long-term study was used for thinning comparison.

Results revealed that oak trees in the thinned stands grew significantly more than the control. The difference between various thinning treatments was not significant. Oaks with a higher number of neighbouring Norway spruce grew less than oaks with few or no neighbouring spruce trees. Any effect on growth of the distance to or size of the neighbouring tree was not found. The age of the measured trees was 38-68 years and the age had a positive relation to DBH and tree height.

Due to the light demanding nature of oak, thinning is essential for sufficient growth of suppressed oak trees. How the thinning is conducted was found to be less important in this study. The effect on growth by neighbour trees of different species was noticed while the size or distance to neighbours was not, implying that a focus on the tree species (in this case Norway spruce) is important when thinning to promote oak growth.

Keywords: Oak, growth, competition, mixed species, oak thinning, *Quercus robur, Quercus petraea,* oak management, crown size, Norway spruce, *Picea abies*

Sammanfattning

Ek (*Quercus robur*) och bergek (*Quercus petraea*) är viktiga trädslag i Sverige. Eken hyser en stor biologisk fauna och har ett högt timmervärde. Skötsel av ek i rena bestånd är en vanlig metod, dock finns en stor andel av eken i blandade bestånd. Syftet med studien var att undersöka enskilda ekars tillväxt i en barrblandskog i relation till gallringsmetod, konkurrerade träd samt ålder.

Studien utfördes i en 100-årig barrblandskog med naturligt föryngrad ek i Tönnersjöhedens försökspark i södra Sverige. Området har delats in i olika typer av måldiameterhuggning och gallring utfördes 2008-2009. 90 ekar valdes ut till den enskilda analysen av ek, 30 till åldersanalysen och till behandlingsanalysen användes data från långtids studier på området.

Resultatet visade att ekar i gallrade bestånd växte signifikant mer än de i kontrollytan. Skillnaden mellan måldiameterhuggningarna var dock inte signifikant. Ekar med ett stort antal gran som grannar växte mindre än ekar med få eller inga granar som grannar. Någon effekt på tillväxten av avståndet till eller storleken av grannarna hittades inte. Åldern de mätta träden var 38-68 år och ålder hade en positiv relation till brösthöjdsdiameter samt trädets höjd.

På grund av ekens krav på ljus är gallring av bestånd essentiellt för ekens tillväxt. Hur gallringen utförs är mindre viktigt. En effekt på ekens tillväxt av trädslaget på grannen hittades medan effekten av storleken eller avståndet till grannen inte hittades, vilket visar på att fokus på trädslag är viktigare vid gallring i syfte att gynna ekens tillväxt .

Nyckelord: Ek, tillväxt, konkurrens, blandskog, blandbestånd, ekgallring, *Quercus robur, Quercus petraea*, ekskogsskötsel, kronstorlek, Gran, *Picea abies*

Dedication

To my parents who showed me the beauty of nature

They say a little knowledge is a dangerous thing, but it's not one half so bad as a lot of ignorance.

Terry Pratchett

Contents

1 Introduction

1.1 The oak

The two species of oak in Sweden is pedunculate oak (*Quercus robur*) and the sessile oak (*Quercus petraea*). Both species are similar on many properties like growth and timber quality and are therefore often managed in the same way. One difference is that *Q. robur* prefers more moist and calcareous soils while *Q. petraea* can withstand dryer and more acid soils (Loginov 2012). In general the oak is a sturdy tree and can withstand hard winds, insect attacks and drought but oaks need a good soil to grow well. A high part of clay is preferred and it should not be less than a good spruce site. If left undamaged the oak has a good height growth, but the plants are often browsed which slows the growing (Götmark et al. 2005, Kullberg & Bergström 2001). The top shoot often seeks the light which can result in a crooked stem if shaded from above. The shoot will not try to go through a shading crown (Ståål 1986). A shade from the side will however help the shape and shade the stem which will help against epicolmic branches. In the youth oaks can manage a degree of shading but is considered a light demanding species later (Lüpke 1998).

Even if the oaks only stand for a 1.2 % the standing volume in Sweden (SLU 2014) it is an important species in the forests of Sweden. There are many reasons why the oak is important.

- Ecological importance - Oaks are the tree species with the highest number of associated species in Sweden (Berg 2006). Mature and old oaks in particular hold many different species of beetles and a large part of these are on the Swedish red list (Ranius & Jansson 2000). Oaks also improve the ground conditions around it. As an example the pH is higher in the top soil layers under an oak canopy than one without (Dahlgren et al. 1997).
- Recreational and cultural importance - Oaks have for a long time been a central tree in the Swedish culture and belief. The oak is “the king of trees” (Törnlind 1997) and have had many important uses over time. They have been a symbol for life and death. They were in Norse belief holy and therefore protected and tended. The acorns have also been very important for swine herding (a.a.).
- Economic importance - Oaks have been of economic value for Sweden for a very long time. Both as a wood and a source of food for animals. Since

the 14th century oaks have been protected by law in Sweden, at fist for the importance of the acorns later the wood was more vital for shipbuilding (Törnlind 1997). Today it is still one of the best priced woods in Sweden. Main use today is flooring and furniture (Träcentrum 2015).

1.2 Oak stand management

Oak is commonly managed in pure stands. This type of management often starts with a planting or direct seeding followed by pre-commercial thinnings, in some cases introduction of understory, and many lighter thinnings (Attocchi 2015). The final goal is 50-80 crop trees per ha with a spacing of approximately 14 m between stems (Attocchi & Skovsgaard n.d.). The rotation is normally 120 years in northern Europe (Attocchi 2015).

Another type of oak management is performed in mixed stands. The type of management is different depending on the species in the mixture. In Sweden there is a method where groups of oak are planted in a mixture with spruce (Ståål 1986). The main motivation is an early income from cutting the spruce and a shape improving effect of competition on the oaks (Linden 2003). In the method there are 50-70 groups/ha of oaks with around 10 or more oaks in each. Between the groups, spruce trees are planted and then harvested like a normal spruce stand (2x2 spacing, 2500 ind./ha). The oaks are thinned, eventually there is only one oak left in each group when all the spruce trees are cut. Later on, the management is similar to common pure oak management, 12-15 m (Ståål 1986).

1.3 Oak in mixed stands

In Sweden oaks represent 1.2 % of the standing volume. Most of the oaks are found in the southern part of Sweden especially in the reigon of Götaland (SLU 2014). In Götaland there are around 50000 ha of pure oak stands. But there are also around 170000 ha of forest with oaks mixed with other species, *Table 1* (Drössler et al. 2012 a). Oaks and conifers is a common mixture. One reason for this is the Eurasian jay. The jay nests in the conifer stands but it likes to eat acorns. They gather the acorns and store them in the conifer forest. Some are forgotten and start growing (Götmark et al. 2006). One study shows that if there is a stand of oaks within 4 km of a spruce stand they will spread the acorns there (Lundberg et al. 2008).

The crown size of the oaks is often in direct relation to the growth of the oak (Carbonnier 1951, Assmann 1970). Shade tolerant species in a mixture will help prevent epicormic branches but if competition becomes too severe it will affect the crown of the oak (Lüpke 1998). This is one reason why management of the stand is important for oaks. Mixing broadleaves with conifers can also help against fungi, insects and soil acidification in the whole stand (Götmark et al. 2006).

If the percentage of oak is low the incitement to conduct treatments solely for oak promotion is low. But could a conventional thinning be enough to ensure sufficient DBH growth and vitality of single oak trees, without a focus on oak promotion?

Table 1. *Areal proportion of the 12 most common tree species combinations with oak and number of inventory plots. The minimum proportion of basal area of each species is 10%. Combinations with less than 20 plots the proportion of forest is not guaranteed. (Source: Drössler et al. 2012 a).*

Species	Forest area (1000 ha)	Number of plots
Oak	49.5	82
Spruce/Oak	39.3	56
Spruce/Birch/Oak	21.7	36
Pine/Oak	20.5	34
Birch/Oak	18.1	30
Oak/Beech	15.7	26
Pine/Spruce/Oak	15.1	25
Pine/Birch/Oak	10.3	17
Aspen/Oak	8.5	14
Spruce/Aspen/Oak	7.3	12
Birch/Aspen/Oak	6.6	11
Birch/Oak/Beech	6.6	11

1.4 Aim of the study and hypotheses

The intention with this study is to investigate how oaks was stimulated by a "normal" thinning, performed without the aim to promote oak. This will done by investigating if different thinning alternatives had an effect on the diameter growth and crown size of oak. In addition, I also addressed how competition of neighbouring trees affected the diameter growths and crowns of single oak trees. Based on this information, I wanted to contribute to improvement of future management of oaks in mixed stands.

H1 The diameter growth and crown size of oaks in thinned stands are significantly higher than the oaks in an unmanaged stand.

H2 Oaks with 2 or more spruce trees as closest neighbours will have a smaller crown and a lower diameter growth.

H3 The distance to and size of neighbouring trees has a large effect on the growth of single oak trees.

H4 Smaller oaks are younger than the larger oaks in the study stand.

2 Material and method

2.1 Site and history

The forest site Erikstöp with the study stand is located in Tönnersjöheden experimental forest which is located in the southwest part of Sweden (56°N, 115-140 m a.s.l.). The vegetation period is 215 days, the mean temperature is 6.7°C and the mean annual precipitation is 1050 mm. The stand is located at the transition zone between boreal and nemoral zone and the soil is a podzol on a sandy moraine (Drössler et al. 2012 b). The site was Calluna heath land before it was planted with pine 1912, since then many other species have established naturally on the site. The current stand is mainly composed of Norway spruce (Picea abies) and Scots pine (*Pinus sylvestris*), but there is also sessile oak (*Quercus petraea*), birch (mainly *Betula pendula*) and European beech (*Fagus sylvatica*). The ground flora is mainly *Vaccinium myrtillus* and moss and grass.

Thinnings and commercial thinnigs have been performed on stand focus on the pines year 1947, 1953, 1958, 1974 and 1991 (Drössler et al. 2012 b). A thorough description of the tree species composition, volume and size were made by Balster (2014), corresponding information can be found in appendix 1 (Table 8, 9, 10).

2006 the stand was divided into 4 treatments with 3 areas of each treatment and in each area 4 plots were set up with a radius of 10 m (*Figure 1*).

- T-treatment - 'normal' target diameter cutting (every tree larger or equal to target diameter is cut)
- TS-treatment - 'normal' target diameter cutting and soil preparation and additional silvicultural measures (cleaning/tending if necessary)
- TN-treatment - extra nature values, smaller target diameter for spruce and higher for all other species.
- C-treatment - control area, not managed

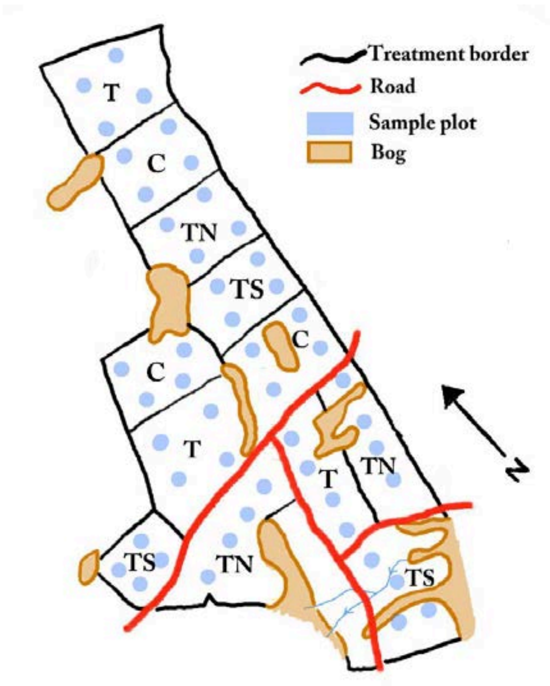

Figure 1. Map of the permanent sample plots in the study stand.

Out of the four treatments, three of them, the control (C), normal diameter thinning (T) and the diameter thinning with extra nature values (TN) were chosen for this study. The target diameter cutting with soil preparation and additional silvicultural measures (TS) was excluded in order to limit the amount of work for this Master thesis.

The target diameter cuttings were made in winter 2008-2009. The target diameters per tree species and treatment are shown *Table 2*. The mean basal areal (BA) of each treatment was estimated by using the mean of all the 12 different plots from that type of treatment. The BA (*Figure 2*) was lower in the TN-treatment than in the other treatments from the start. The thinning interventions were also larger which resulted in an even lower BA in the year 2014 compared to the T-treatment. The C-treatments continued to grow and were now very dense in most cases, with a mean of 43 m²/ha in BA 2014.

Table 2. *Target diameter (in cm) for each species depending on treatment and quality class (class 2 describes trees with forks, spike-knots or branches thicker than 6 cm).(Source Drössler et al. 2012 a)*

Species	Treatment		
	T		TN
	Quality class		
	1	2	
Pine	40	30	40
Spruce	36	26	26
Birch	30	20	30
Oak	60	30	60
Beech	50	30	50

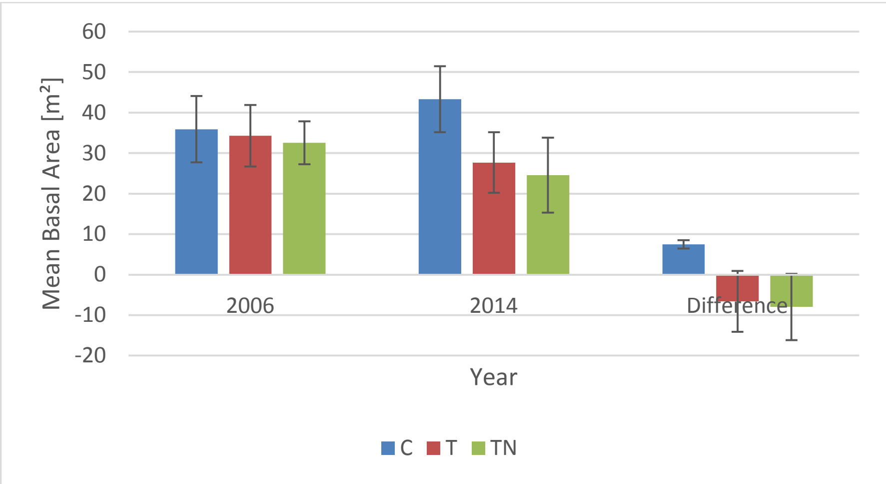

Figure 2. Mean basal area per thinning treatment (C, T and TN) in year 2006 and 2014. The figure also shows the difference between the two measurements.

The mean diameter at breast height (DBH) of the stand differed between Treatments (*Figure 3*). The average DBH of the C-treatment was 10.13 cm which was 1.65 cm smaller than the T-treatment, the difference was significant (p-value < 0.01).

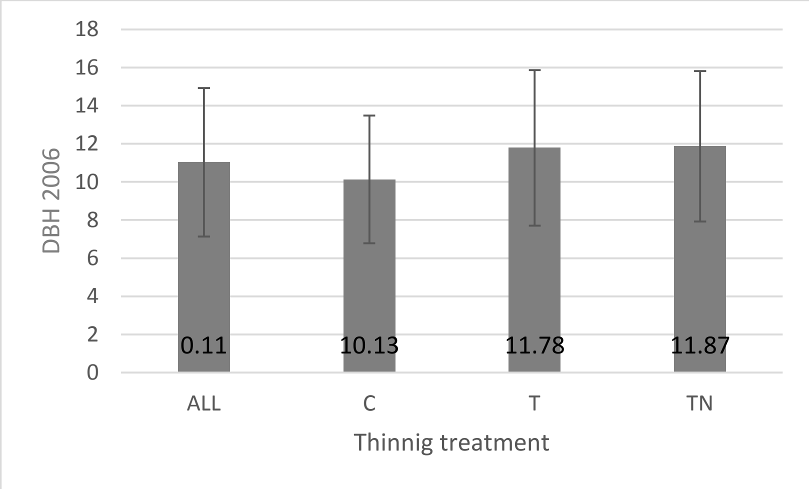

Figure 3. Mean DBH 2006 divided by thinning treatment.

The study was divided into three different parts analysing different aspects; treatment comparison, single tree study and age study.

2.2 Treatment comparison

2.2.1 Selection of sample trees

Oak trees on the long-term plots were used for the treatment comparison. Requirements were that the oaks should have been measured in both 2006 and 2014 and the oaks should be in one of the selected treatments (C-, T- or TN-treatment). All oaks meeting the requirements were selected.

2.2.2 Data collected

Data used for treatment comparison comes from earlier measurements for a long-term study on the study area. There in the selected treatments there are 36 permanent plots with a 10 m radius. Measurements was made 2006 and 2014 and includes; treatment, plot, tree no., plot BA, tree DBH and tree species.

2.2.3 Data analysis

To compare the oaks between 2006 and 2014 the total amount of oaks on the plots were included. Trees occurring in 2006 and not in 2014 were assumed dead and trees occurring in 2014 and not in 2006 are seen as ingrown. Both ingrown and dead trees were discarded.

The data was divided into the three different treatments. When comparing the treatments and plots student t-test (95 % interval of confidence), multiple regression analysis, standard deviation and visual analyses of plotted data were considered.

2.3 Single tree study

2.3.1 Selection of sample trees

The aim for the single tree study was originally 30 trees with the lowest increase of DBH and the 30 trees with the highest DBH increase. The measurements were made in spring 2014. Trees with serious stem or crown damage discarded.

Seeing that the number of trees could limit the analyses it was decided to extend the sample by more 30 trees. The 30 extra trees was chosen from the trees with a DBH increase close to the mean increase of all trees, one additional condition was to not measure more than two trees from the same plot. The reason for choosing trees close to the mean was to make a more balanced picture of the stand.

2.3.2 Data collected

Earlier measurements were made for long-term studies. The values I have used from these studies are DBH values from 2006 and 2014, species of all trees on the plots and BA from 2006 and 2014 of the plot. Other values were measured in the field during spring and late summer 2014 (*Table 3*).

In addition to the selected oaks competitors/neighbouring trees were measured. There are several methods of selecting competing trees, many of these would require a large amount of measurements (Pretzsch 2009). To limit the amount of data and time used only the 3 closest living trees above 5 cm DBH was selected. The maximum distance to a neighbour was 8 m.

Table 3. *Tree and site characteristics measured for single tree study and a description of the characteristics.*

Tree characteristics measured	Description
Height	Tree height from ground to highest part
Crown base	The height to the first living branch, not including epicormic branches
Distance to closest neighbours	The 3 closest one was chosen, trees further than seven meters away was not measured.
Size of the neighbour	If the tree was outside the plot DBH was measured, otherwise the data from 2014 was used.
Species of neighbour	Species of the 3 closest neighbours
Projected crown area	The area was measured as distance and angle (in gon) to six points. The six points was set around the tree at the edge of the crown, and spread so they gave the best possible representation of the crown area.
Site characteristics measured	Description
Topography	With scale: top, upper slope, slope, lower slope or bottom
Soil moisture	With scale: wet, moist, mesic or dry
Base rock	If base rock is visible at the site, Y/N

When measuring the projected crown area six markers was set at the edge of the crown, spread so they gave the best possible representation of the crown. When setting the markers a person holding a stick was used to find the edge with help from a person standing some distance away with a view of the crown. The distance to the markers from the oak stem was measured together with the angle in gon-degrees.

2.3.3 Data analysis

When analysing the data the trees were divided into different groups (Table 4). One tree could be in several groups. When comparing the groups, a group containing a specific tree was not compared to a group containing the same tree.

The following comparisons were made:

Table 4. *Description of groups made for comparison and the figures including the group.*

Name	Description	Figure No.
Total	Includes all trees	*8, 9, 12, 13*
C-treatment	Trees in the C-treatment	*5*
T-treatment	Trees in the T-treatment	*5*
TN-treatment	Trees in the TN-treatment	*5*
0-1 Spruce	Trees with one or no neighbouring spruce	*10, 11*
2-3 Spruce	Trees with two or more neighbouring spruce	*10, 11*
0 Spruce	Trees with no neighbouring spruce	*10*
1 Spruce	Trees with one neighbouring spruce	*10*
3 Spruce	Trees with three neighbouring spruce	*10*
0-1 Shade tolerant	Trees with one or no neighbouring spruce and beech	*11*
2-3 Shade tolerant	Trees with two or more neighbouring spruce and beech	*11*

Initial DBH for treatment and spruce groups can be found in appendix (*Figure 18* and *Figure 19*).

New parameters were calculated for these analyses. Projected crown area was calculated in ArcMap as polygons. In order to calculate the X and Y coordinates from the angle and distance measured in the field, the following formulas were used:

$$X = Distance \times COS\left(\frac{2\pi}{360}(Gon \times 0.9)\right)$$

$$Y = Distance \times SIN\left(\frac{2\pi}{360}(Gon \times 0.9)\right)$$

(Gon = the measured Gon-degree, Distance = Distance from stem to crown edge marker)

There have been many different competition indexes made over the years most containing DBH of competitor and distance to competitor as variables. The best indexes also used a crown measurements of the competitors and a linear expansion function (Biging & Dobbertin 1992). Due to lack of measured variables and time simpler indexes was calculated. Three different indexed values were calculated using the following formulas:

$$I_{distance} = \overline{distance\ to\ neighbour}\ /\ Number\ of\ neigbours$$

$$I_{size} = \overline{size\ of neighbour} \times Number\ of\ neigbours$$

$$I_{competition} = \frac{I_{size}}{I_{distance}}$$

Again, student t-test (95 % interval), multiple regression analysis, standard deviation and visual analyses of plotted data were considered when comparing the groups.

2.4 Age study

2.4.1 Selection of sample trees

The selection of trees for the age studies was made with the goal to have 30 trees which was evenly spread in all DBH classes. The DBH classes were: 5-10, 10-15, 15-20, 20-25 and 25-30+ cm. Another condition was to choose trees that were not very close the long-term study plots and spread over all treatments.

2.4.2 Data collected

For the age study there was no data available from prior studies. Data was collected in the field late summer 2014 (Table 5). In addition to the selected oaks competitors/neighbouring trees were measured. To limit the amount of data collected only the 3 closest living trees above 5 cm DBH was selected. The maximum distance to a neighbour was 8 m.

Table 5. *Tree and site characteristics measured for age study and a description of the characteristics.*

Tree characteristics measured	Description
Height	Measured when felled, from cut to top and then adding stump height
Crown base	The height to the first living branch, not including epicolmic branches
DBH	Diameter at 1.3 m height
Distance to closest neighbours	The 3 closest one was chosen, trees further than seven meters away was not measured
Size of the neighbours	
Species of neighbours	
Stem disc	Was cut as close to the ground as possible, use for age determination
Cut height	Height of the cut from the ground.
Site characteristics measured	Description
Topography	With scale: top, upper slope, slope, lower slope or bottom.
Soil moisture	With scale: wet, moist, mesic or dry.
Base rock	If base rock is visible at the site, Y/N
Vegetation type	No/Moss, blueberry, grass, herbs.
Basal area	Measured with a relascope

2.4.3 Data analysis

The year rings on the stem disks were counted manually. After counting the year rings one year were added for each 5 cm from the ground to height of the cut. The average growth of seedlings are 6±0.8 cm/year (Drössler et al. 2015). Age, DBH, height and growth/year were compared to other tree characteristics to find any correlations. The trees were also divided into groups with 0-1 or 2-3 spruces as neighbours. The groups were tested with students T-test (interval 95 %). When calculating the mean growth/year variable the DBH of the tree was divided by the total age.

3 Results

The total number of oaks measured in the three selected treatments was 337 trees. After sorting out all dead trees and the ingrowth from 2006 to 2014, there were 281 oak trees to perform the comparison.

3.1 Difference between treatments

The mean DBH growth of all 281 trees was 2.2 cm between the year 2006 and 2014, per year the growth was 2.75 mm. The DBH growth of the C-treatment was lower than the other two treatments (*Figure 4*). The difference of 1.09 cm was significant between the TN- and the C-treatment (P-value < 0.01). The percentage growth of initial DBH (*Figure 3*) for C-treatment was 14 % and for the TN-treatment it was 21%. The differences between T- and C-treatment was even larger. However, the difference between the T- and TN-treatment was not significant (P-value 0.42). The growth was slightly higher in the T- than the TN-treatment but the variation within the treatments was large.

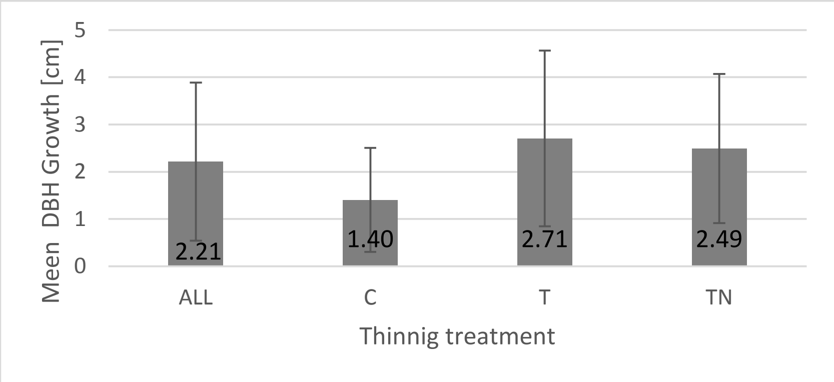

Figure 4. Mean total DBH growth between years 2006-2014 depending on thinning treatment of stand.

Comparing crown size, among single tree selection, the pattern was different from the DBH growth. The TN-treatment had a larger crown size and a higher DBH than the other treatments. The crown size (*Figure 5*) was 78% larger for the TN-treatment compared to the C-treatment (P-value < 0.01). The difference between T- and TN-treatment concerning crown size and DBH was not significant (P-value 0.46).

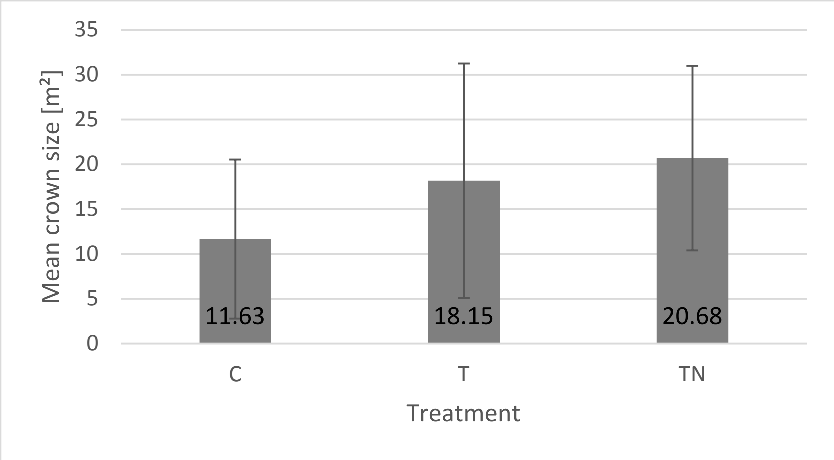

Figure 5. The mean crown sizes of single tree selection depending on the thinning treatment.

When the BA was plotted against the mean DBH growth (*Figure 6*) a negative relation could be seen between the DBH growth and the BA. In general the C-treatment plots had a higher BA and a lower DBH growth. Among the exceptions are two plots with only one oak which both scored well below expected values. One plot scored much higher than expected with a mean DBH growth of 5.7 cm. This plot contains the oak with the highest measured DBH growth of all oaks and the rest of the oaks on the plot also had above average DBH growth.

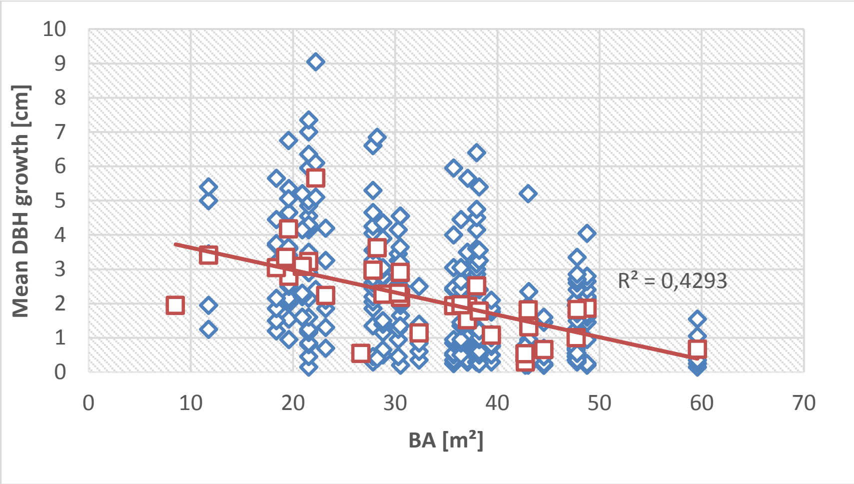

Figure 6. Mean Basal Area 2014 plotted against the Mean DBH growth 2006-2014. Blue squares symbolise a single tree and orange squares are the plot average.

Instead of only using BA from 2014 the difference in BA between 2006 and 2014 can be used. The difference will describe the ingrowth of BA or the BA lost when thinning. The effect of thinning can be seen by plotting the difference of BA to the DBH growth (*Figure 7*). A difference between treated and untreated stands can be distinguished. The thinned groups have in general a higher DBH growth than the control.

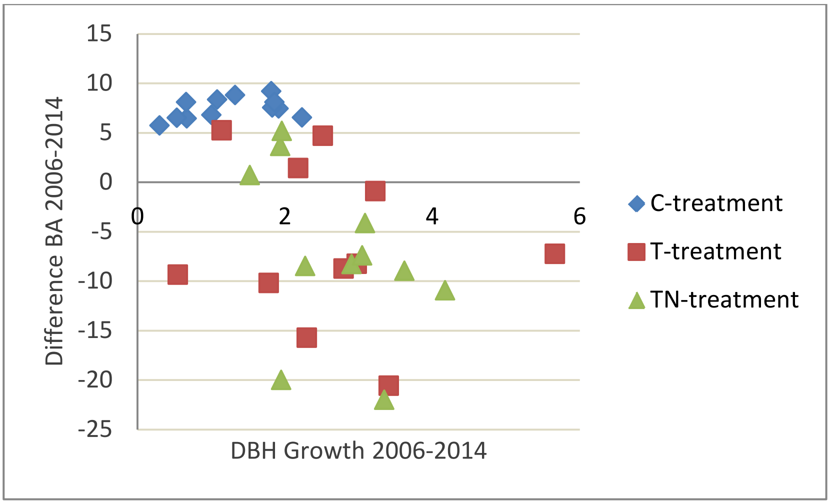

Figure 7. The difference in BA between 2006 and 2014 for each plot plotted against mean DBH growth 2006-2014 of each plot. Blue squares symbolises C-treatment plots, red squares T-treatment plots and green triangles TN-treatment plots.

3.2 Single tree growth and competition

Changing focus from treatment to single trees the competition could be investigated closer by observing how the species of, distance to and size of the competitor related to the DBH, DBH growth and crown size.

Investigating the relations between initial DBH (2006) and crown size it was clear that the DBH have a positive relation to the size of the crown (*Figure 8*). However, when plotting initial DBH and DBH growth (*Figure 9*) relation was less clear and had a much lower R^2-value.

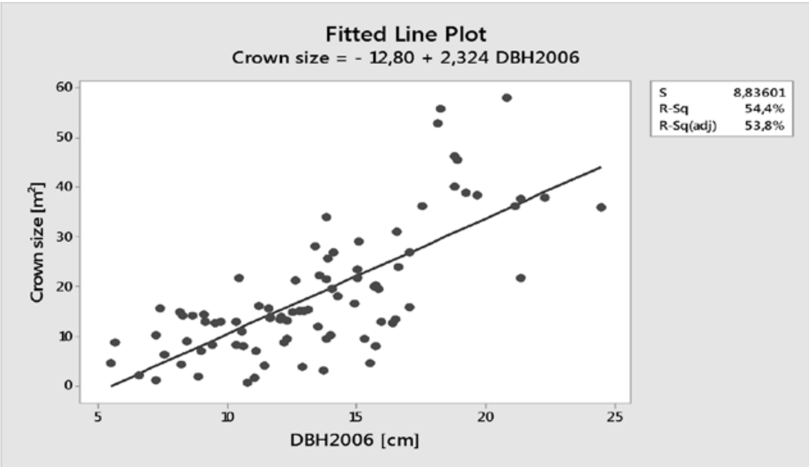

Figure 8. A plot of all single tree selection trees showing the size of the crown depending on the DBH 2006.

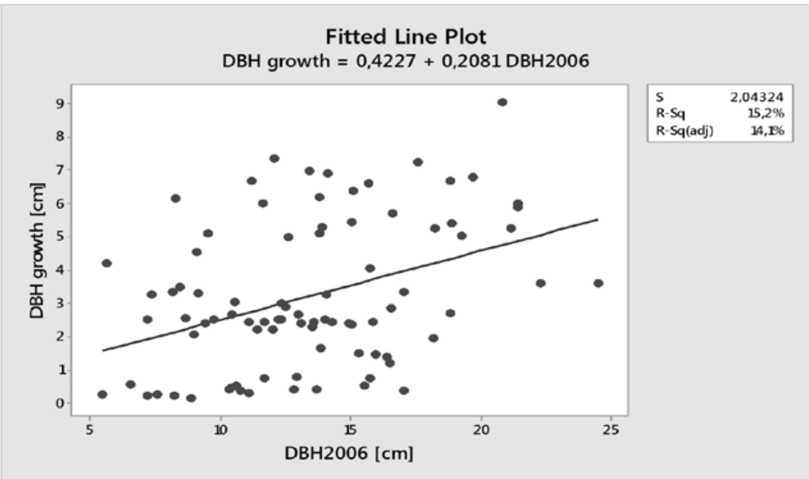

Figure 9. A plot of all single tree selection trees showing the DBH growth 2006-2014 depending on the DBH 2006.

3.2.1 Competing tree species

Comparing the DBH growth of groups with a varying numbers of neighbouring Norway spruce (Table 4) revealed a negative relation between the number of spruce trees and oak DBH growth. Oak trees with 0-1 spruce tree among its close neighbours (*Figure 10*) had grown 12% more than the other group with more spruce trees as close neighbours, however the difference was not significant (P-value = 0.47). The difference was larger when looking at the groups with no spruce trees and 3 spruce trees. The growth of trees with no spruce trees as neighbours increased by 169% compared to the group with tree spruce trees (P-value < 0.01). Even when comparing the groups with only one spruce tree to the group with no spruces there was a noticeable difference of 1.08 cm in mean DBH growth between the two.

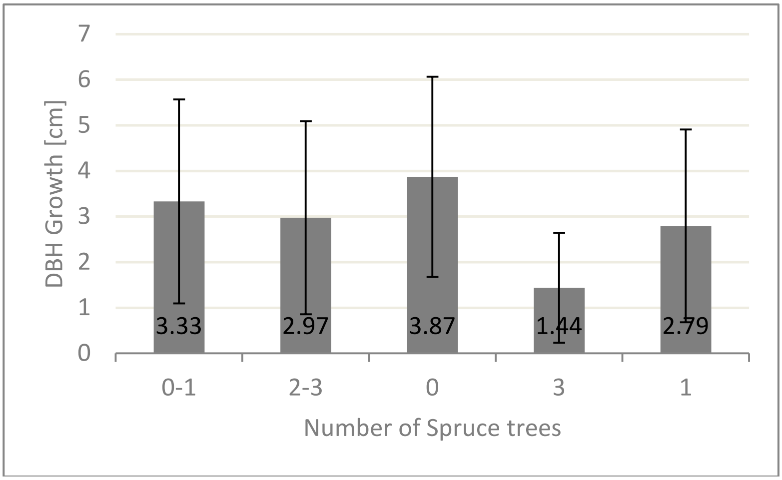

Figure 10. The mean DBH growth 2006-2014 depending on the number of neighbouring spruce trees.

The crown size was also affected by the species but the difference of 7 % is less than the DBH difference and was not significant (P-value 0.67). If beech (*Fagus sylvatica*) was included with spruce in the groups (Table 4) of shade tolerant neighbours the difference was minor (*Figure 11*). The difference of crown size between the groups was 2.9 m² instead of 1.3 m² for the spruce groups (P-value 0.31). Comparing growth of groups with no shade tolerant neighbours and with 3 shade tolerant neighbours was similar to the groups with spruce (*Figure 10*). However, the group with no shade tolerant neighbours had grown 136 % more instead of 169 %.

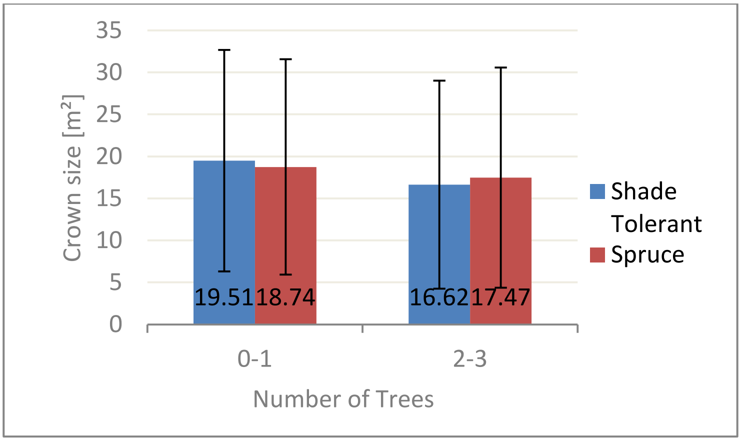

Figure 11. The mean crown size depending on the number of shade tolerant neighbors (Beech and Spruce) or Spruce trees.

3.2.2 Size of and distance to competitors

When ignoring the species the effect of closest competitor's on the DBH growth, the DBH or the crown size was not clear. There was no clear correlation between size of and distance to the neighbouring trees on DBH growth or crown size. Plotting mean distance of the tree closest competitor showed that the correlation to growth (*Figure 12*) or crown size was low. An indexed value of competitor distance, where the mean distance is divided by number of competitors, gave similar results (R^2=0.03). None of the regressions was significantly different from zero. An extreme value occurred in the indexed values because of one tree with only one neighbour which in turn was far away. Without the extreme the correlation was slightly higher (R^2=0.06), but still very small. Comparing the results to plots using size instead of distance the differences was negligible. However if the size and distance index was combined into a competitor index the R^2-value increased slightly (*Figure 13*).

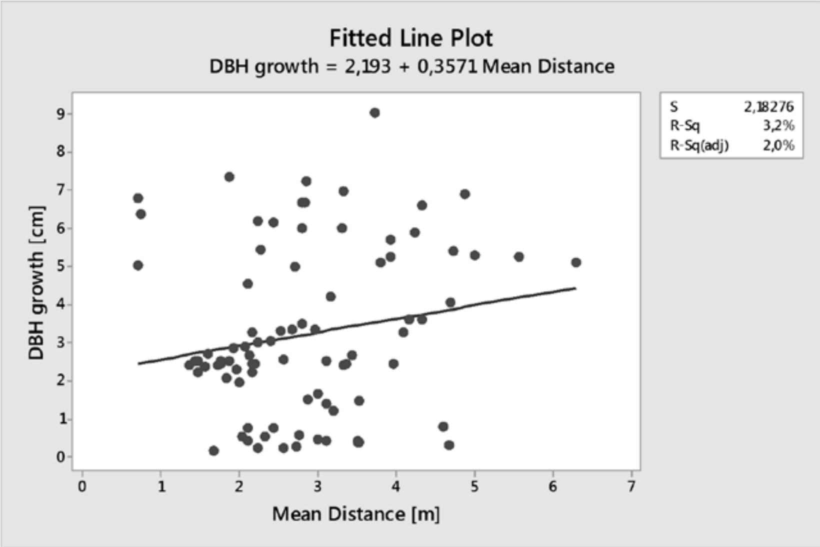

Figure 12. The relationship between DBH growth 2006-2014 and mean distance to the closest competitors of the selected single oak trees.

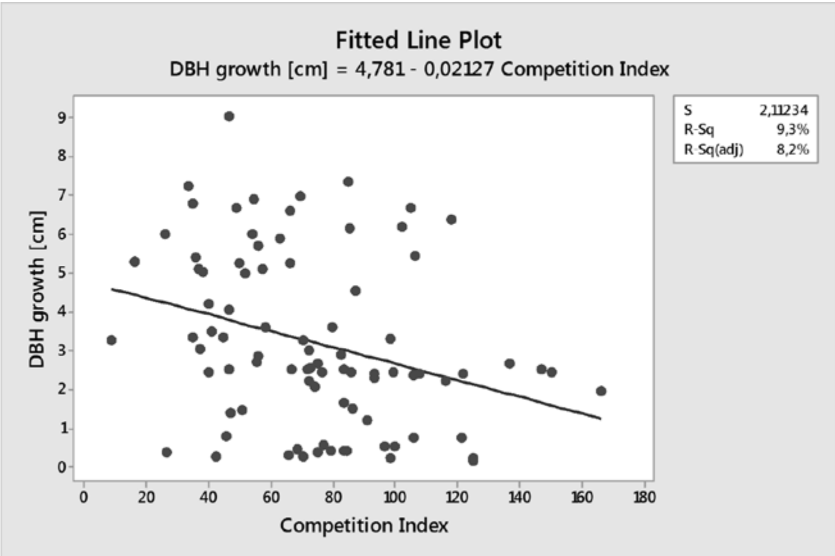

Figure 13. The relationship between the DBH growth 2006-2014 and Competition index.

Performing a multiple regression with Indexed Distance and Size as predictors and DBH growth as response (*Table 6*) gave an R^2-value of 0.07 and none of the coefficients was significantly different from zero.

Table 6. *Regression between response variable DBH growth [cm] and predictors Size index, Distance index. Model P-value 0.057.*

Variables	Coef	SE Coef	T-Value	P-Value
Constant	3.459	0.853	4.06	0.000
Size index [cm]	-0.0173	0.0107	-1.61	0.110
Distance index [m]	0.871	0.453	1.92	0.058
Model summary	S	R^2	R^2(adj.)	R^2(pred.)
	2.15597	6.66 %	4.41 %	0.00%

The multiple regression did not give a higher correlation to DBH growth than the competition index did. The correlation between competition index and DBH growth could be improved from R^2-value of 0.09 to 0.22 if the DBH 2006 was added to the regression (*Table 7*).

Table 7. *Regression between response variable DBH growth [cm] and predictor variables Competition index, DBH 2006 [cm]. Model 1 only containing Competition index. Model 2 containing both variables. Model 2 P-value <0.01.*

Variable	-----Model 1----		-----Model 2----	
	Coef	P-value	Coef	P-value
Constant	4.781		2.003	
Competition Index	-0.02127	0.004	-0.01872	0.007
DBH2006 [cm]			0.1935	0.000
Model summary				
S	2.11234		1.96704	
R^2	9.32%		22.30%	
R^2(adj)	8.24%		20.43%	
R^2(pred)	5.42%		17.47%	

3.3 Age of the oaks

After selecting trees for the age study there was slightly more trees cut in the middle classes and less in the largest. Spatially a few more were cut from the TN-plots than the other plots.

As with the single tree studies there was no clear relation between the DBH (*Figure 14*) or Age and the distance to competitors, size of competitors or BA of the plot. Using the mean DBH growth per year was slightly better (plotted against distance to neighbour R^2=0.15) but still the correlation was low. The difference of growth per year between trees with 0-1 or 2-3 spruces as neighbours was 10 % higher with low amount of spruce but it was not significant (p-value=0.45).

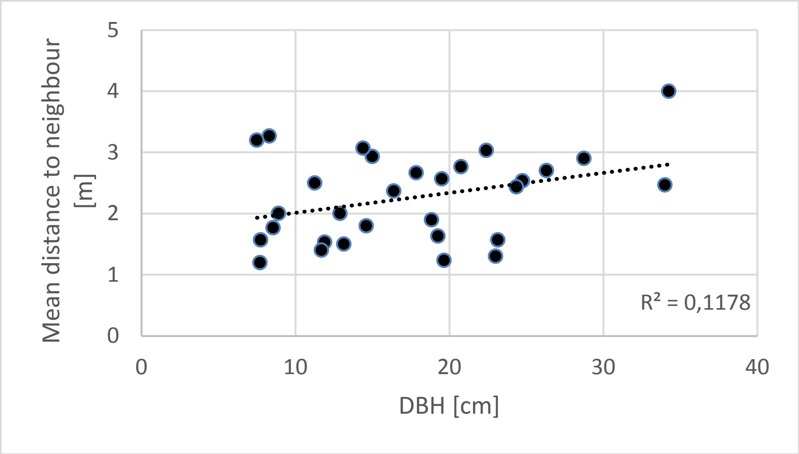

Figure 14. Mean distance to neighbours plotted against DBH of oaks in age studies.

Counting the rings of the stem discs revealed that all 30 trees were between 38 and 68 years old. When plotting the age and the DBH in *Figure 15*, there was a positive correlation. A tree with a high DBH was in most cases older than a tree with low DBH. Mean DBH growth per year was 3.26 mm which was slightly more than the average 2.75 mm/year in the single tree study 2006-2014. Another measurement of tree size is height and when using tree height instead of DBH the pattern was very similar (*Figure 16*). The mean height growth per year was 0.26 m.

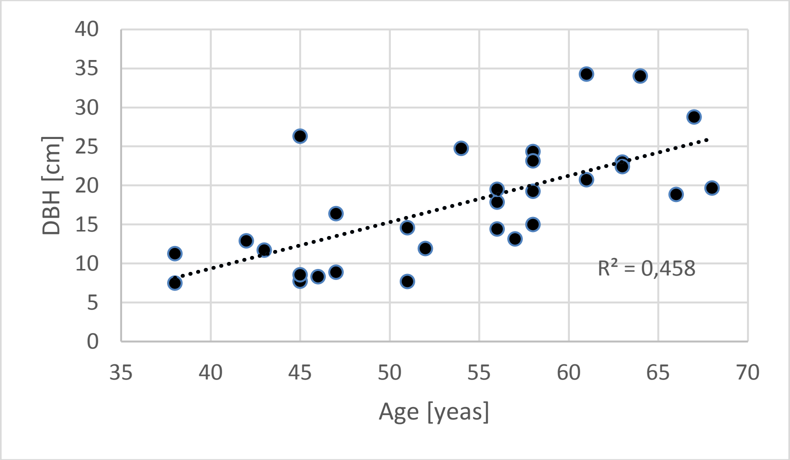

Figure 15. Age of the oaks plotted against the DBH.

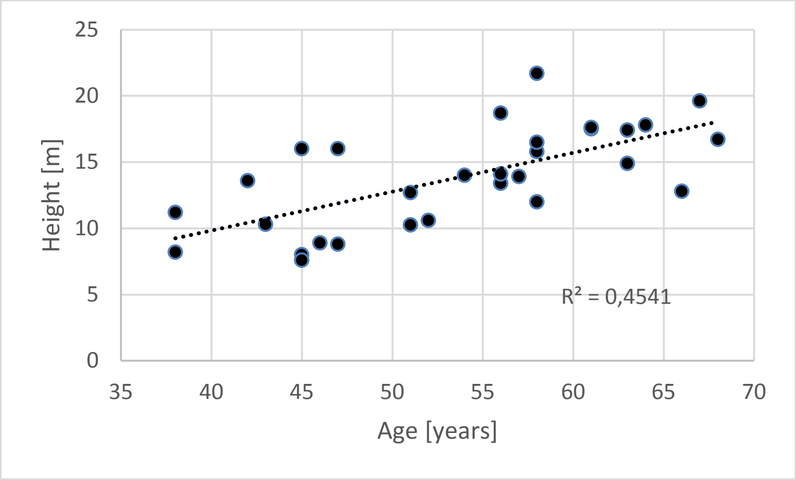

Figure 16. Age of the oaks plotted against the height.

4 Discussion

4.1 Comparison between treatments

The main purpose when comparing the treatments was to assess if the thinning intervention in 2009 had an effect on the growth of the oak trees. By comparing the BA and change in BA between 2006 and 2014 to different characteristics the thinning effect could be illustrated. After dividing the oaks into the different treatments it was clear that the C-treatment had the lowest growth (*Figure 4*) and the smallest crown size (*Figure 5*) of the three treatments. This was expected when the BA of the C-treatment was much higher than in the other treatments (*Figure 2*). Oak is not a very shade tolerant species (Ståål 1986, Lüpke 1998) and high BA of canopy trees can therefore reduce growth and crown development.

When comparing DBH growth to the mean BA (*Figure 6*) of the plots in 2014 there was a clear negative relation. Oak trees on one plot with a high BA did not grow as well as oak trees on another plot with low BA. One problem with the comparison was that all trees on a particular plot were assigned to one BA value which was not directly related to the growth of a single oak tree on the plot. In fact, it was only a rough estimator as single oak tree may be located on the edge of the plot, for instance.

DBH growth was also related with the change of BA on the plots (*Figure 7*). If BA on the plot increased, the oaks DBH growth was lower than if the BA of the plot had decreased i.e. thinned. Both results (*Figure 6* and *7*) demonstrate a positive effect of oak to thinning and that the effect can be reduced for the oaks if there was no management during recent years. Those finding are in line with Ståål (1986) and Lüpke (1998) who pointed out that growth can be reduced without silvicultural promotion.

Comparing the C- with the TN-treatment the TN-treatment had a significantly higher DBH growth and crown size. The growth in the treated stands are comparable to a conventional oak stand (Sjölin 2009). It is important to notice that there was a difference between the two treatments in initial DBH (17 %) which could give the larger oaks (TN-treatment) a higher DBH growth. However, the DBH growth of TN-treatment was 78% higher than the C-treatment DBH growth and the percentage growth of initial DBH for the TN-treatment (21%) was higher than for the C-treatment (14%). The differences to the T-treatment was even larger. A regression of initial DBH and DBH growth on the single tree study selection showed that a very low R^2-value (0.15) which also indicates that the initial DBH is not the reason for the difference in DBH growth between the treatments.

The results are in line with **H1** and **H1** should therefore not be discarded. The difference between treated and untreated stands was found, but a significant difference between treated stands was not found.

4.2 Singe tree study

Conducting the measurements of selected, single oak trees, neighbouring trees was included. The purpose was to explore the relation between the closest neighbours and a single oak tree. Comparing the DBH 2006 of the oaks to the crown area there was a clear positive correlation between those two tree features (*Figure 8*). The correlation between DBH 2006 and the DBH growth was unclear (*Figure 9*) and DBH could not be considered a reliable indicator of growth.

4.2.1 Tree species competition

Oaks in mixed stands with other species are common in Sweden and a mixture with spruce is the most common one according to the national forest inventory (Drössler et al. 2012 a). However, Norway spruce is more shade-tolerant and a strong competitor for oak (Ståål 1986, Lüpke 1998). By dividing the selected oak trees into two groups with 0-1 and 2-3 spruce trees as the three closest neighbours, some differences between the two groups concerning the DBH growth and crown size were observed, but the result was not significant, and **H2** is still possible and cannot be discarded. The study results are also in line with findings by Loginov (2012) and Mason and Conolly (2013) in younger forest (16 to 28 years) where spruce mixtures lowered the DBH growth of oak trees.

Comparing the group Oak trees with no spruce as closest competitors against the group Oak with 3 spruce trees a significant difference could be detected. Oak trees with no spruce had a 169 % higher DBH growth than the other group which finally demonstrated that spruce had a strong effect on the growth of single oaks. A tendency towards better growth was still noticeable when comparing the group with no spruces to the group with one spruce (although not significant).

As with the treatment comparison there was small difference between the groups in DBH 2006. The largest DBH difference (8 %) is between the group with no spruce trees and 3 spruce trees. The difference in DBH growth between the two groups is 169%

In the study stand, spruce was not the only shade tolerant species, but when considering the small number of single beech trees in the comparison of groups with different number of shade tolerant neighbours, the difference to previous findings was small (*Figure 11*). In detail, when comparing the group with no shade tolerant neighbours to the group with 3, the difference was similar to the previous comparison with spruce only. However, the difference in DBH growth between the groups was smaller than the difference between the same groups using only spruce trees which indicated that spruce has a larger effect on growth than beech. The proportion of beech was not enough to compare the effect separately from spruce, therefore the difference of the effect between the two shade-tolerant tree species on oak remains unclear after this study.

4.2.2 Size of and distance to competitors

To assess **H3** the effect of size of and distance to the competitors was studied. The expectation was that an oak tree with a large competitor would grow less than an oak with a small competitor. Another expectation was that an oak with a short distance to competitors would grow less than an oak tree with a long distance to competitors. However, the distance index and size index did not reveal any relationship with DBH growth or crown size. The competition index has a larger correlation to growth but still too small see a clear relation. Neither distance nor size seems to effect the DBH growth or crown size of the oaks largely in this study. Hence, detecting growth differences depending on distance to or size of competitor was not possible. Therefore, solely using size or distance to anticipate the DBH growth or crown size of oaks seems not advisable.

A limitation to the study is that spatial distribution of competitors was not measured. If the closest competitors stood in a line away from the oak they would have a different effect on the oak compared to if they surrounded the oak.

Only small effects of size of and distance to competitor was found and **H3** should therefore be discarded.

The practical implications of this is that when thinning it is most likely better to focus on the species of the competing trees instead of the size or the distance to the oaks. E.g. cutting a spruce instead of the pine which was closer to the oak. However, high DBH growth is not equivalent to high quality and spruce can be used for shading of the stem which is a good way to decrease epicormic branches (Ståål 1986, Lüpke 1998).

4.3 Age studies

Because oak was not planted in the study area the age of the oak trees was unknown. After determining the age of the 30 cut oak trees results showed that these oak individuals were 38 to 68 years old. The oldest oak of this sample germinated in the stand when the pine trees were 34 years old. According to some authors (Mosandl 1998, Lundberg et al. 1998) and the age distribution, it seems likely that the first oaks was established at that time was the Eurasian jay. When the stand was 34 years the pine and the spruce could be grown enough for the jay to use as a habitat and they would bring acorns from nearby oak stands (Lundberg et al. 2008, Götmark et al. 2006). The youngest tree was established when the stand was 64 years old. Why we did not find a younger tree (over 5 cm) is unclear. One reason could be that it takes over 30 years to reach 5 cm. Another reason can be that the stand at the age of 64 was too dense for seedlings to establish and survive. The seedlings are a bit shade tolerant in the youth but later require light to grow (Lüpke 1998). Thinning's could have improved the recruitment of oaks in the stand later (Götmark 2007)

A common assumption is that larger trees are older than smaller trees. This is also what was stated in **H4**. To test the hypothesis the age oaks was plotted with DBH and height. The plots revealed that there was a positive relationship of age to both height and DBH. The result supported **H4**.

However, determining the age by DBH or height in a mixed species stand can result in large deviation and is therefore not advisable for scientific studies. The correlation was very low e.g. a tree with 26 cm DBH had the same age as trees with 7.5 cm DBH (see *Figure 15*). This is normal in a conventional stand too but then you know when the oaks were planted and there is no need to determine the age by size.

4.4 Conclusion

If vital oak trees with sufficient growth in mixed, conifer-dominated stand are desired, silvicultural interventions have a considerable potential. Both, stand-wise thinning or specific release of single oak trees are feasible. On this site, the target diameter cutting, comparable to a very late thinning, without a focus on single oak trees was enough to ensure sufficient DBH growth of oak. Without management, both tree growth and vitality was insufficient.

Oak trees with more than one Norway spruce tree as closest competitor grew less than oak trees with other tree species as closest competitors. No effect of the distance to competitors or of the size of competitors on growth was found due to methodological limitations of this study. From this case-study, I conclude that the competing tree species is a more important factor than distance to or size of competitor to promote oak growth by thinning.

Determining the age of oak trees by using DBH or height was found to be not very precise but it can be used as indication when comparing trees. The oaks in the study area had germinated within a limited time period, a stand age of approximately 35 – 65 years.

4.5 Future studies

The effect of thinning was clear in this study. However, the thinning was not made to promote oaks. Comparing a thinning with a focus on promoting oaks could potentially have an even greater effect and comparing such a treatment with a conventional thinning in a mixed species stand would be interesting.

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5 Appendix

Table 8. *General stand description of C-treatment 2014 describing stand characteristics depending on species. Characteristics described are: volume per ha [m³/ha], basal area per ha [*m²/ha*], trees per ha (*N/ha*), and average DBH [mm]. (Source: Balster 2014)*

Tree species	Vol [m³/ha]	BA [m²/ha]	N/ha	DBH [mm]
Spruce	227.1	20.8	666	178
Pine	179.1	16.4	167	349
Oak	36	3.3	265	116
Beech	7,6	0.7	21	200
Birch	25.1	2.3	40	249
Total	474.9	43.5	1159	

Table 9. *General stand description of T-treatment 2014 describing stand characteristics depending on species. Characteristics described are: volume per ha [m³/ha], basal area per ha [m²/ha], trees per ha (N/ha), and average DBH [mm]. (Source: Balster 2014)*

Tree species	Vol [m³/ha]	BA [m²/ha]	N/ha	DBH [mm]
Spruce	126.9	11.2	382	177
Pine	114.5	10.1	103	347
Oak	64.6	5.7	318	141
Beech	4.5	0.4	16	152
Birch	3.4	0.3	27	114
Total	313.9	27.7	846	

Table 10. *General stand description of TN-treatment 2014 describing stand characteristics depending on species. Characteristics described are: volume per ha [m³/ha], basal area per ha [m²/ha], trees per ha (N/ha), and average DBH [mm].*

Tree species	Vol [m³/ha]	BA [m²/ha]	N/ha	DBH [mm]
Spruce	193.4	9.6	273	189
Pine	181.0	8.0	85	344
Oak	49.5	3.6	212	138
Beech	15.6	1.0	40	159
Birch	50.7	2.3	48	218
Total	490.2	24.6	658	

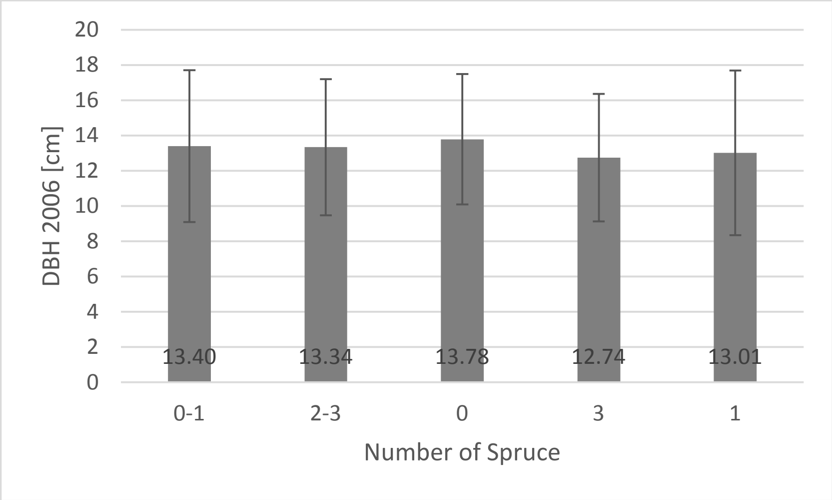

Figure 17. DBH 2006 of oaks in single tree study depending on the number of spruce trees as neighbours.

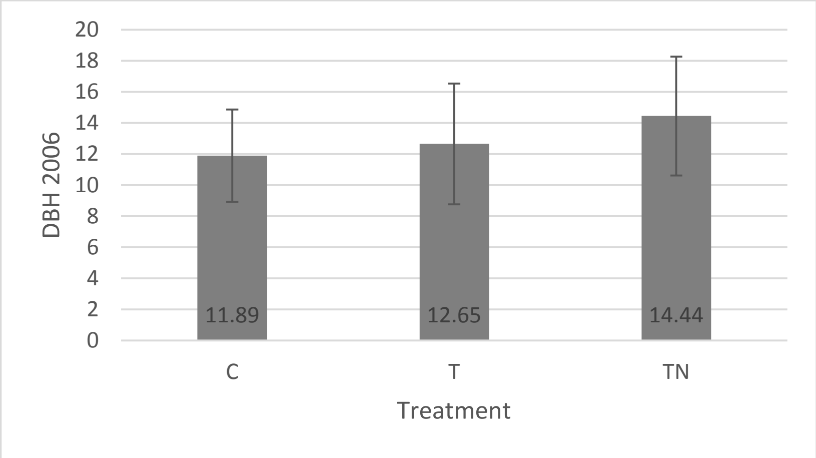

Figure 18. DBH 2006 of oaks in single tree study depending on the stand treatment.

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