A thinning experiment in Oak (*Quercus robur* L.) in Southern Sweden

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Introduction

Thinning experiments in oak with a traditional block design are scarce in Scandinavia. Results from two older Danish experiments (QX and QY) in stands established in the mid-1920s have been reported by Bryndum (1957, 1965 and 1966). These experiments were focused on comparisons between different thinning grades. A few other Danish experiments are described by Attocchi (2015). In Sweden, a tinning experiment was established in Skarhult experimental forest outside Eslöv in 1991 (Agestam, EKö & Johansson, 1993) (Figure 2).

Growth and yield of oak in southern Sweden has been studied by Carbonnier (1975). The constructed yield tables were based on 29 permanent plots. The stands in the study material were all manged according to a uniform model, *i.e.* frequent thinnings with focus on promoting selected main stems (potential crop trees). The number of main trees in the late part of the rotation was often considerably below 100 per ha.

Other strategies for managing oak have been discussed. The dimension and quality demands of oak timber have varied over time, and the demand for small tree dimensions has in earlier times been poor. It has therefore been discussed to mix spruce and oak, where spruce is suggested to be planted at an ordinary spacing together with small oak groups in a sparse pattern. The density of the oak groups should correspond to the number of mains stems in the final stand, app. 50 trees per ha. One oak in each group is early singled out and pruned and the management aims at free growth of the oaks (free of competition) at a time when good timber quality has been established, thus spruce have to be removed at an early stage. To avoid quality deterioration during the thinning period epicormics are controlled manually, if possible annually. The management method is described in detail by Ståål (1986).

An economic comparison was made between silviculture of pure oak stands, pure spruce stands and the above described management of mixed stands (Lindén & Ekö, 2003). The study showed that the LEV (Land Expectation Value) was highest for pure spruce and lowest for pure oak, while the LEV for the mixed stand was in between the pure alternatives. The results were quite dependant on the type of land owner and on current subsidises. Free growth of oak with the aim of reducing the long rotation needed for production of timber with large dimensions has also been discussed in other countries (Evans 1982, 1984).

As said above there is a lack of knowledge of other thinning programmes in oak than the traditional. Could there still be an interest in free growth, possibly combined with a mix of other species, or have the economic prerequisites changed over time? Comparing the Swedish prices for spruce in 1964 and 2014 both levels and patterns over diameter look very similar (Figure 1). However, prices for oak timber are not directly comparable since the grading of oak timber quality has changed over time, *e.g.* today there is no longer a veneer assortment. But, the general price pattern for oak timber looks quite comparable in 1964 and 2014. Thus, a mixed alternative could still be of interest.

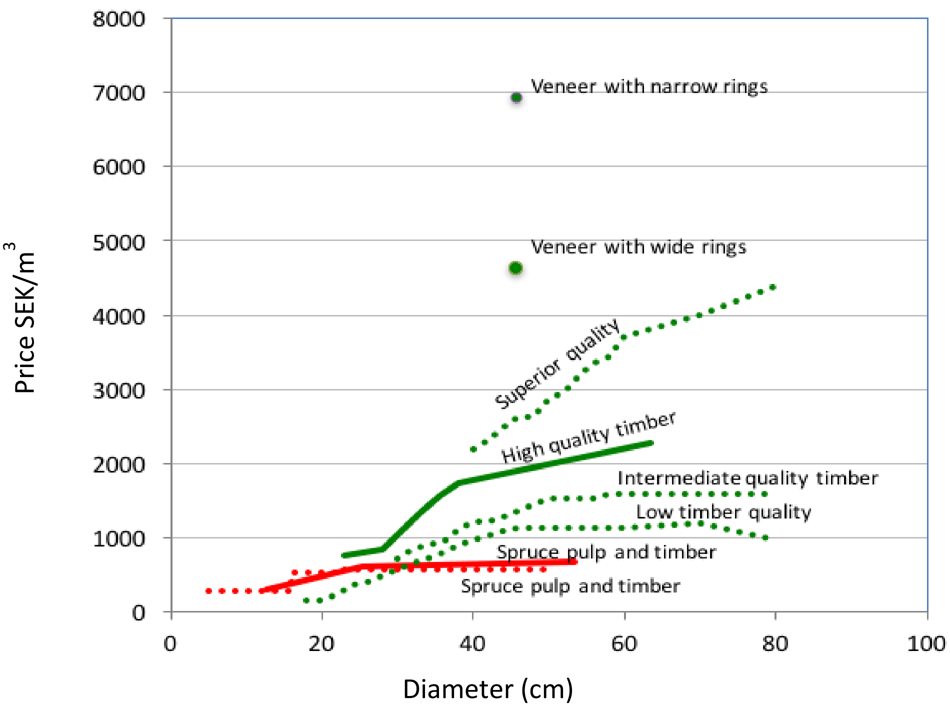


Figure 1. Timber and pulp prices from 1964, dotted lines, and from 2014, solid lines. Red: spruce, Green: Oak. Prices from 1964 corrected with Swedish CPI (Consumer price index).

In the current study a thinning experiment in oak is analysed with the aim of comparing the dominating silviculture model for oak (Carbonnier, 1975) with a heavy thinning programme (free growth) and with silviculture without intervention. Focus is on volume increment, diameter development and timber quality.

Materials and methods

The study stand

The stand is located in Skarhult experimental forest, in a flat and moist area (Figure 2). The soil is deep, consisting of a fine-grained moraine and the soil type is brown earth. The area has previously been used for agriculture and has been ditched. Based on observation in adjacent older oak stands the site conditions are considered to be suitable for growing oak. The experimental area is uniform, reflected by site index, which varies between 25.8 and 27.1 m. Assessments was made with height curves (Carbonnier, 1975) at the establishment of the experiment in 1991, The stand was planted in 1952 with one and two years old seedlings of oak (*Quercus robur* L.), in a density of 13000 per ha^{-1}. The origin is judged to be Dutch, but unfortunately all documentation have been lost. At the establishment, a nurse crop of grey alder (*Alnus incana* L.) was also planted, 3000 seedlings per ha. Supplementary planting was made in 1953 with larch *(Larix decidua* Mill.) and in 1959 with hornbeam (*Carpinus betulus* L.). Pre-commercial thinning was conducted in 1980 and a first tinning was made in 1986, where after a pure oak stand remained.

The area is heavily browsed. A low and sparse understory has established until 2016, mainly consisting of hornbeam and Northern European Hawthorn (*Crataegus sp.)*.

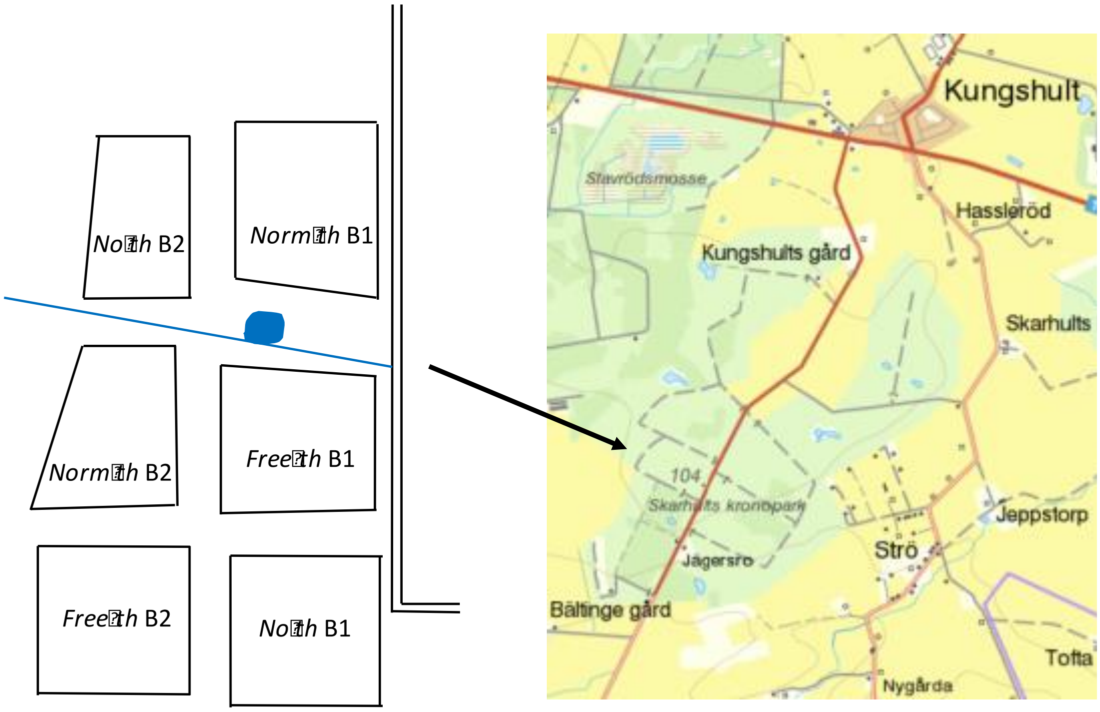


Figure 2. Location and design of the oak thinning experiment (55°50'N 13°23´E).

Treatments

1) No thinning (*No th*)

It should be noted that one thinning was already made 5 years before establishment of the experiment. No further interventions are planned. Main trees (potential crop trees) were selected at the establishment, according to the same principals as in the normal thinning treatment.

2) Normal thinning (*Norm th*)

The treatment represents the dominating programme for well managed oak stands in Sweden. The thinning programme applied corresponds to the A programme as outlined by Carbonnier (1975). The interval between thinnings should be about 5 years in the first part of the rotation and about 10 years in the late part. The basal are in the late part is targeted at 18 – 20 m^2ha^{-1}. Thinnings are aimed at promoting growth of dominant trees with good timber quality. About 60 – 70 trees per ha are supposed to remain in the late part of the rotation. If needed, emerging epicormics should be controlled manually.

3) Extra heavy thinning with free growth of main trees (*Free th*)
Main trees were selected amining at a distance of about 15 m, app. 50 trees per ha. The distance was decided based on observation of crown development by Ståål (1986). Thinning should be made at the same time as in *Norm th,* or more frequent, aiming at keeping the crowns of the main trees fully expeosed, thus trying to maximize individual tree growth. Emerging epicormics should be controlled manually.

At the establishment of the experiment half of the selected main trees in *No th* and *Free th* were pruned up to 4 m height.

Experimental design
The experiment was established in 1991, in a randomized block design, with two blocks, B1 and B2 (Figure 2). The plot size varied between 0.36 and 0.49 ha. The establishment was made according to the routines for permanent plots at SLU (Institutionen för skogsproduktion, 1992). In addition, tree coordinates were collected using a theodolite on the two plots where *Free th* was applied.

Measurements
Inventories were made in 1991/1992, 1996, 1999, 2004, 2010 and 2017. At the first inventory trees with a dimeter at breast height (*dbh*) greater than 100 mm were permanently number in the field. Smaller trees were measured but without identification, as was the case in all inventories except for the inventory in 2004, when only numbered trees were measured. The inventory in 1999 just included the two plots with *Free th*.

Measurements were made according to the routines for permanent plots at SLU (Institutionen för skogsproduktion, 1992). This means that the diameter of each trees was measured, while crown height and tree height were only measured on sample trees. In addition, on the two plots with *Free th*, measurements of the crown diameter on main trees were made in 1991, 1994, 1996, 1999 and 2017. Assessment of the crown projection was made in 8 directions with the help of a vertically held pole pointing at the periphery of the crown.

In 2017 assessments of parameters having impact on the timber quality was made. The assessments considered main stems up to a height of 3 m and included number of branches, branch diameter and vitality. Distinction was made between ordinary branches and epicormics. The thickest branch below 3 m was selected for measuring of diameter under bark, 30 mm from the stem surface. Epicormic shoots were counted separately in three diameter classes. <5 mm, 5-10 mm and >10 mm. Furthermore, an experienced scaler graded the bottom log into current commercial timber qualities classes. Grading was made on 12 randomly selected main trees per plot. The assessment was made on the bottom log with a length of 3.1 m. Two system of quality grading were applied an internationals system and a system used by the Kährs company. (The Kährs company is the greatest consumer of oak timber in Sweden). The international grading system includes the following classes: Veneer, A-grade, B-grade, C-grade and reject. Kährs grading system contains the classes: Veneer (Diamond), Block log, and Kährs log.

Analyses

Stand parameters were calculated based on the individual three measurements. Individual tree volumes were estimatd by functions by Matérn (1975). Diameter increment was correlated with diameter and with crown size. Main focus was on main stems when analysing diameter development and timber quality. Two-way ANOVA tests were used to assess statistical significance of pre-planned contrast. No attempt was made to generalize the results beyond the current experiment, therefore all parameters in the ANOVA model were set as fixed. Thus the study should be regarded as a case study.

Results

Stand development

Top height

The top height at establishment varied between 15.7 and 16.7 m. The variation at the end of the observation period was somewhat greater 21.9 to 23.6 m (Figure 3). At age 61 there is a strange deviation of height compared to the general height development patterns on the plots.

Average site index (Johansson *et a*l 2013) assessed at the establishment of the experiment was 26.3 m and at the end of the observation period 27.1 m.

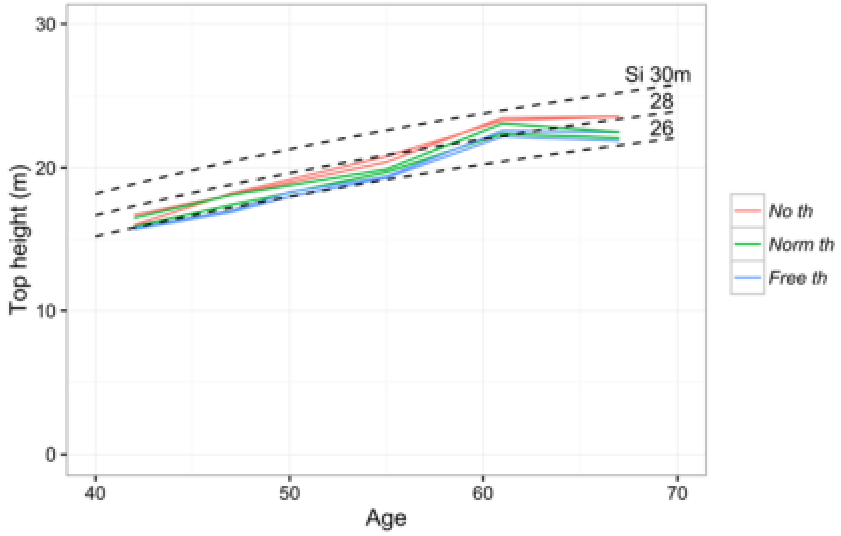


Figure 3. Top height development during the observation period. Site index curves for oak (Johansson *et a*l 2013), indicating top height at 100 years, included for comparison (dashed lines)

No of stems

The number of stems with a *dbh* greater than 100 mm at the start of the experiment varied between 644 and 984 per ha, with a mean of 773 (Figure 4). Mortality and ingrowth are the only factors having influenced the reduction of number of stems in the *No th* treatment. At the latest inventory the number of stems per ha were almost equal on these two plots, 499 and 503. The stem density on the actively thinned plots were smaller on this occasion and varied between 195 and 317 per ha. The number of trees with a *dbh* smaller than 100 mm at the last thinning was on average 194 per ha and varied among plots (*No th*: 97, 90 *Norm th*: 378, 169 and *Free th*: 400, 28)

Basal area

The variation in stand density at the start of the experiment was small and the basal area varied between 18.1 and 20.5 m^2ha^{-1} (Figure 3). At the end of the observation period the average basal area in *No th* had increased to 30.4 m^2ha^{-1}. The average basal area on the *Norm th* plots was at the same time 18.4 m^2ha^{-1}, which in turn was 2.4 m^2ha^{-1} higher compared to in *Free th*.

Volume

The patterns of basal area and volume development are similar (Figure 3). The average volumes at the end of the observation period were for *No th*, *Norm th* and *Free th*. 310, 171 and 148 m^{3}ha^{-1}.

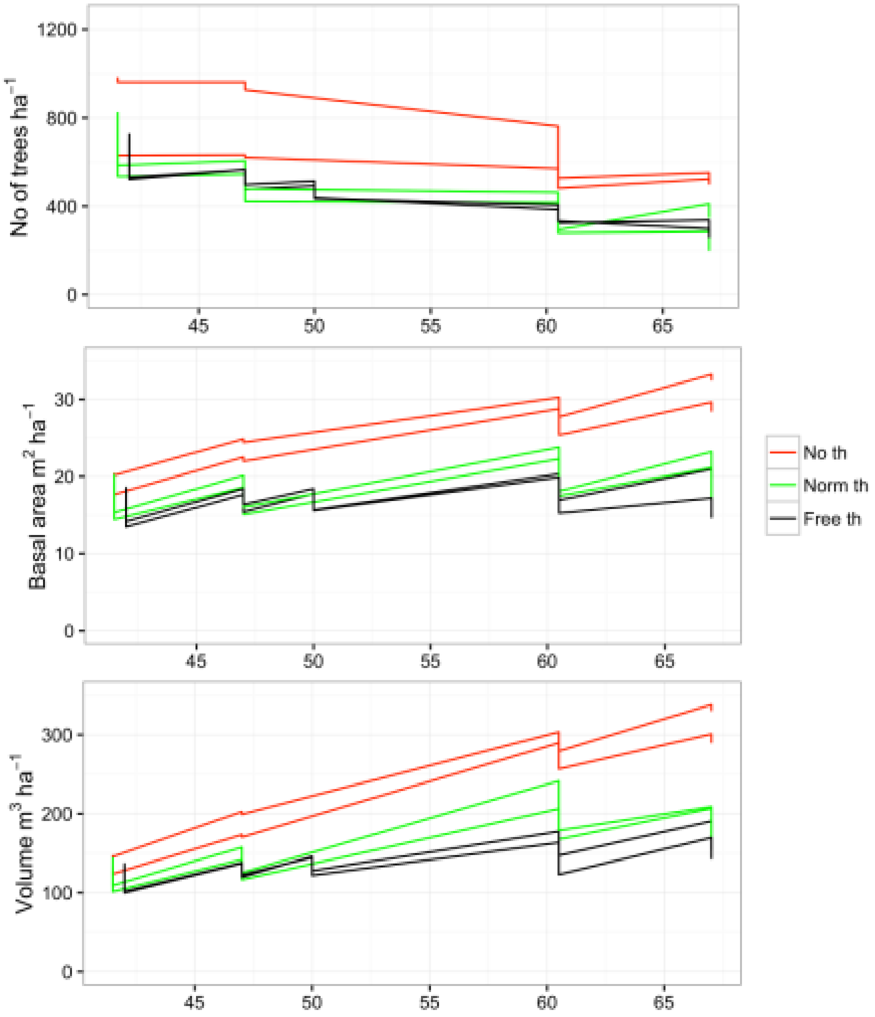


Figure 4. Development of stem number (only trees with a *dbh* greater than 100 mm counted), basal area and stem volume, on the different plots

Mortality and volume increment

The mortality during the observation period was substantial, particularly in *No th* where the annual mortality was 2.2 m^{3}ha^{-1}, compared to 0.6 and 0.1 m^{3}ha^{-1} in *Norm th* and in *Free th*. The mortality was unevenly distributed over age and also unevenly distributed over plots. Severe mortality occurred at age 55 and 61 (Figure 5), the most severe in *No th* Block 1 were 31 m^{3}ha^{-1} were lost.

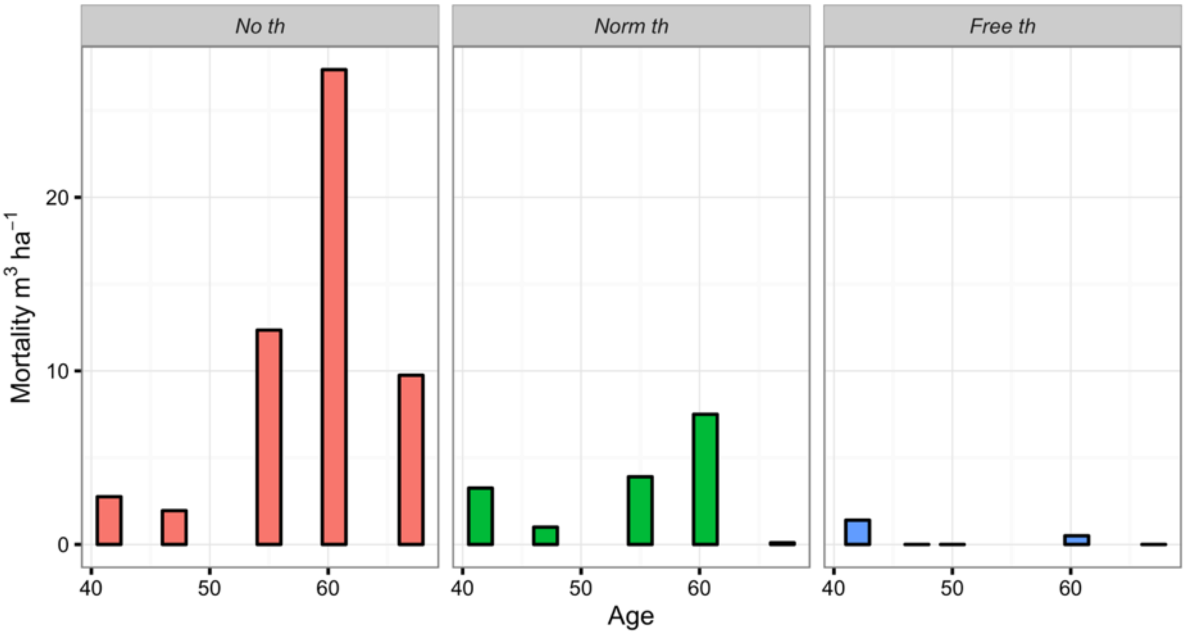


Figure 5. Mortality distributed over age and treatments.

The volume increment varies among plots and over different time periods (Figure 6). The mean annual increment during the whole observation period was for *No th* 10.0 m^{3}ha^{-1}, which was 1.7 m^{3}ha^{-1} more compared to in *Norm th* and 3.5 m^{3}ha^{-1} more compared to in *Free th* (Figure 6). The pre-planned contrasts between *No th* and the other two treatments and between *Norm th* and *Free th* were not statistically significant (p= 0,0586, p = 0,1390).

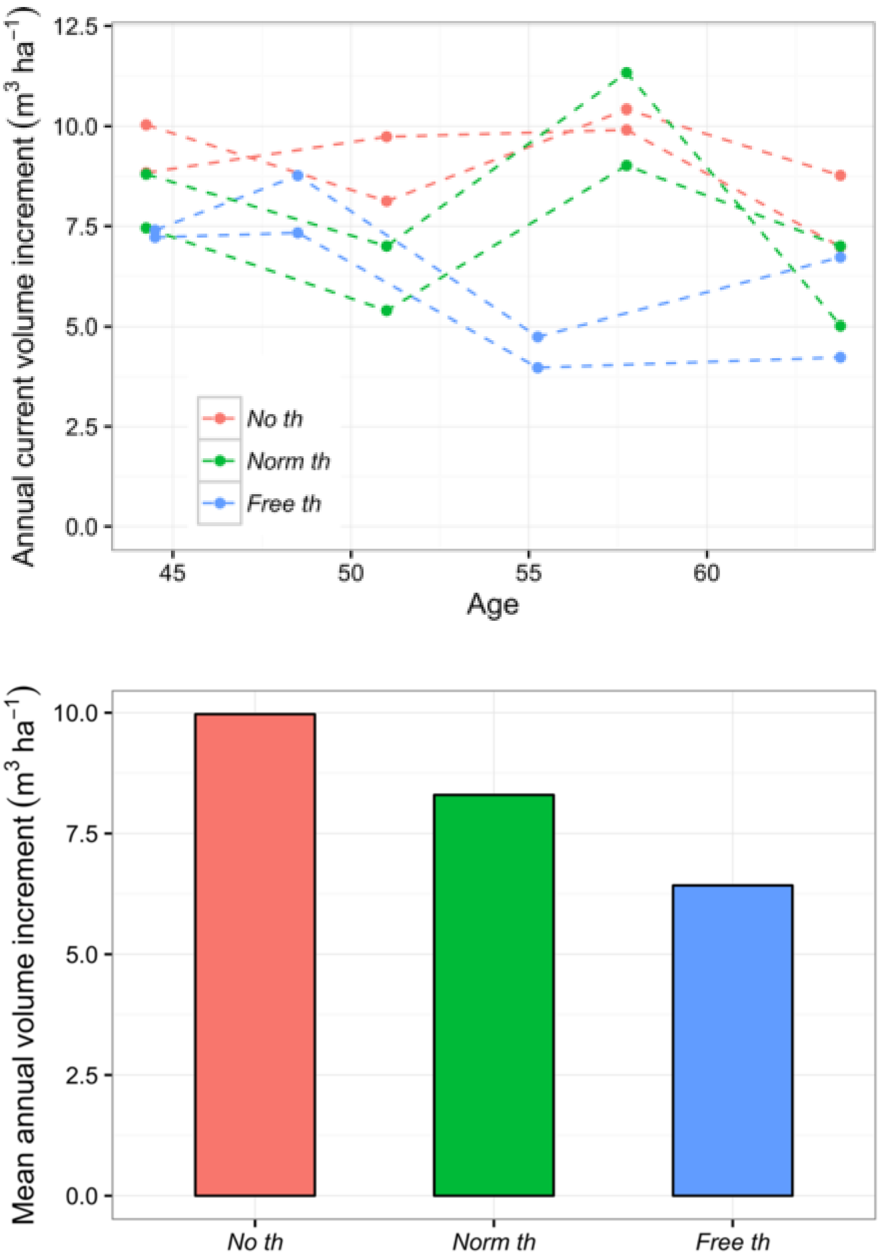


Figure 6. Annual current increment in different age periods (above) and mean annual increment during the observation period (below).

Tree classes, and change of tree classes over the observation period

The relative distribution of tree classes differs between treatments both at the first and at the latest inventory (Table1). It should be noted that the assessment was made on trees that remained during the whole observation, and therefore classification at the first inventory concerned only trees after thinning. In *Free th* tree class were just assessed on main trees. In general, most of the trees in dominating classes have kept their status during the observation period. The greatest transition from higher to lower classes was found in *No th* (Table 1).

Table 1. Relative distribution (%) of tree classes in 1991 and 2017 (bold) and relative changes within tree classes during the period. Calculations based on trees present both at the first and latest inventory. Note that only main trees were classified in *Free th*

		No th 1991					*Norm th* 1991					*Free th* 1991 (Main trees)			
		Dominant	Co-dominant	Dominated	Supressed		Dominant	Co-dominant	Dominated	Supressed		Dominant	Co-dominant	Dominated	Supressed
	2017	**73**	**18**	**6**	**3**		**88**	**7**	**1**	**4**		**100**	**0**	**0**	**0**
	1991	**85**	**11**	**2**	**2**		**91**	**4**	**4**	**1**		**100**	**0**	**0**	**0**
2016	Dominant	*81*	30	0	0	2016	*96*	30	0	0	2016	*100*	0	0	0
	Co-dominated	17	*36*	0	0		4	*60*	13	0		0	*0*	0	0
	Dominated	2	34	*14*	0		0	10	*25*	0		0	0	*0*	0
	Supressed	0	0	86	*100*		0	0	62	*100*		0	0	0	*0*

Main trees

The number of main trees at the establishment was on average 50 per ha, with small differences between plots and treatments (Table 2). During the 26 years observation period a few main trees have been lost due to natural mortality and on average 48 main trees per ha remained at the end of the period. Main trees in the *Free th*, where tree coordinates were collected, were chosen with the goal that the trees should not be closer than 15 m. However, this requirement could not be fulfilled (Figure 7).

Table 2. Number of main stems per treatment and block at establishment of the experiment and at the latest inventory. Numbers per ha in brackets.

	Block 1		Block 2	
	1991	2017	1991	2017
No th	24 *(49)*	24 (*49)*	19 (*53)*	18 *(50)*
Norm th	27 (*55)*	25 (*51)*	21 (*49)*	19 *(44)*
Free th	23 (*49)*	22 (*47)*	22 (*44)*	22 (*44)*

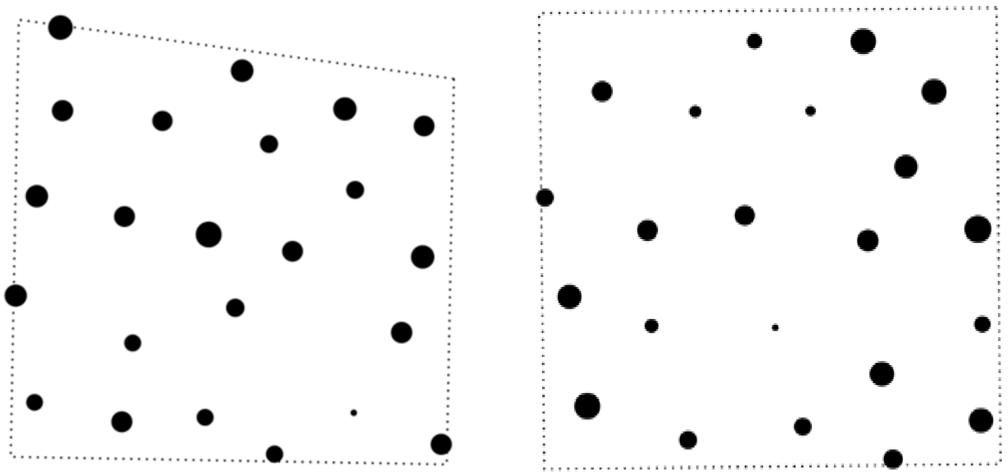


Figure 7. Distribution of main trees at the time of establishment of the experiment, on the two plots with *Free th*. The dot size relates to crown diamter. The mean and minimum distances between main trees were in Block 1: 13.4 and 12.5 (left), and in Block 2: 14.2 and 12.3 m (right)

Diameter and volume distributions

The diameter distribution at the latest inventory has been affected by the treatments. The distributions of trees with a *dbh* greater than 100 mm on the *No th* plots have approximatively a normal shape, while the distributions in the other treatments are bimodal (Figure 8).

At the end of the observation period the average diameter of main trees in the *Free th* was 34 and 44 mm bigger than in *No th* and in *Norm th*. In *No th* and *Norm th* the average diameters were quite similar for main trees, as well as for trees in different parts of the diameter distribution (Table 3). In all treatments the average diameter of main trees was smaller compared to the diameter of the biggest trees (Table 3). Already at the start of the experiment the main trees was smaller than the biggest trees. Averaged over all treatments the differences were 24 and 37 mm compared to the 100 and 50 biggest trees per ha.

Table 3. Average diameter (mm) at the latest inventory (67 years) among main trees and trees in different fractions of the diameter distribution

	Trees with *dbh* > 100 mm	Main trees	100 thickest trees per ha	50 thickest trees per ha
No th	256	336	365	377
Norm th	255	326	362	386
Free th	248	370	362	390

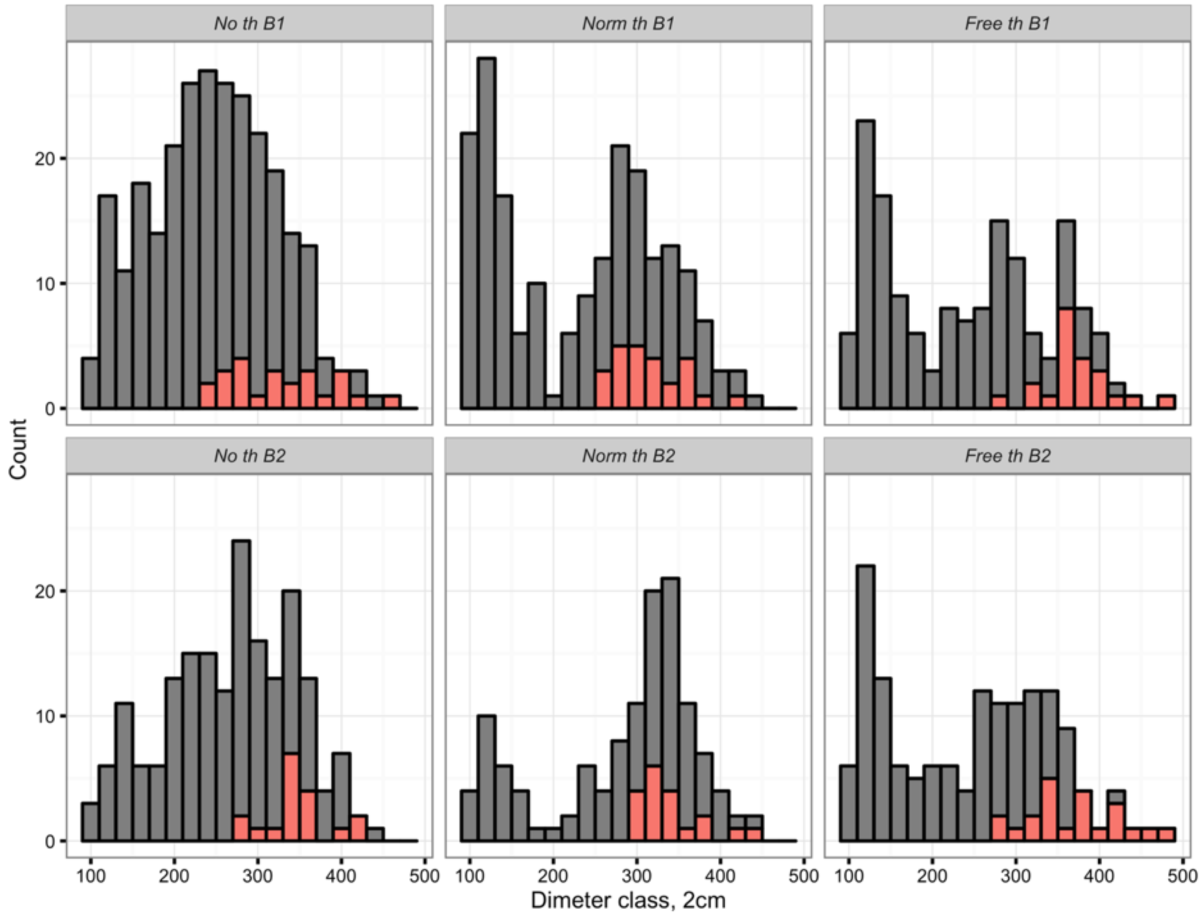


Figure 8. Diameter distributions of trees with a *dbh* greater than 100 mm at the latest inventory (67 years). Grey: all trees, Red; main trees. (Stacked bars)

At the end of the observation period the volume distribution over diameter differed between treatments especially at lower diameters. (Figure 9.). In *No th* 25% of the volume consisted of trees with a smaller diameter than 256 mm. The corresponding diameter in *Norm th* was 287 dm and in *Free th* 279 mm. The share of the total stand volume consisting of main trees were in *No th* 15%, in *Norm th* 20% and in *Free th* 28%.

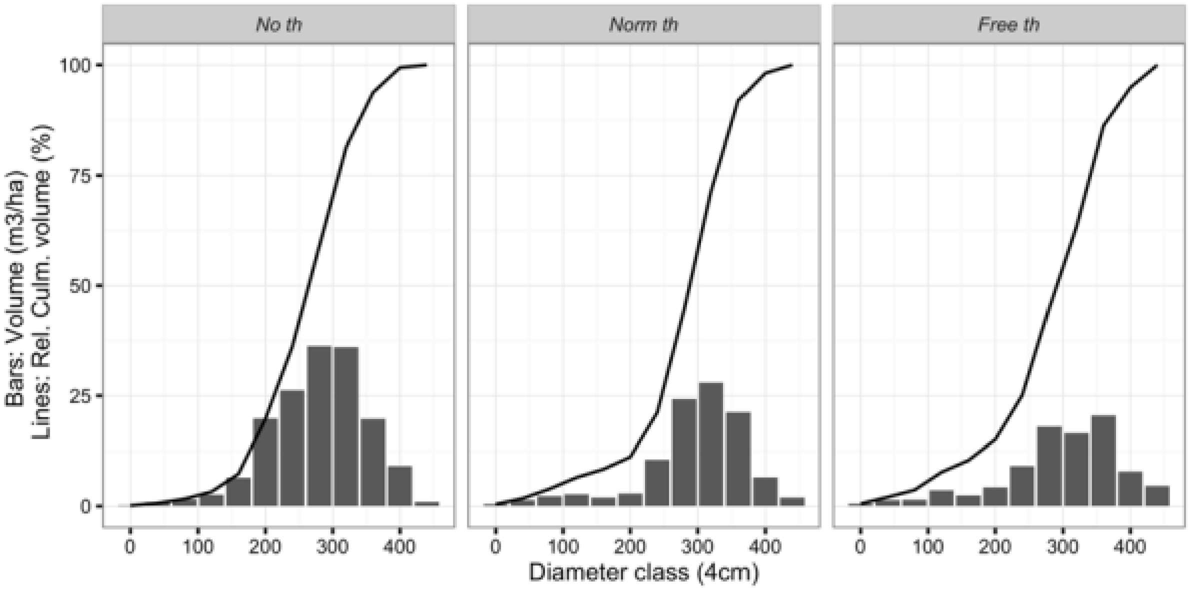


Figure 9. Volume in diameter classes at the latest inventory (67 years) (bars) and relative cumulative volume distribution over diameter (lines)

Diameter increment

In all observations periods the average diameter increment of main stems was bigger in *Free th* compared to in the other two treatments (Figure 10, Table 4). The difference between *No th* and *Norm th* averaged over the whole period was 0.1 mm and not significant. However, there was a significant difference of 1.7 mm (p = 0.0044) between *Norm th* and *No th*. The variation among trees within plots was considerable, standard deviation between 1.1 and 1.9 mm (Figure 10).

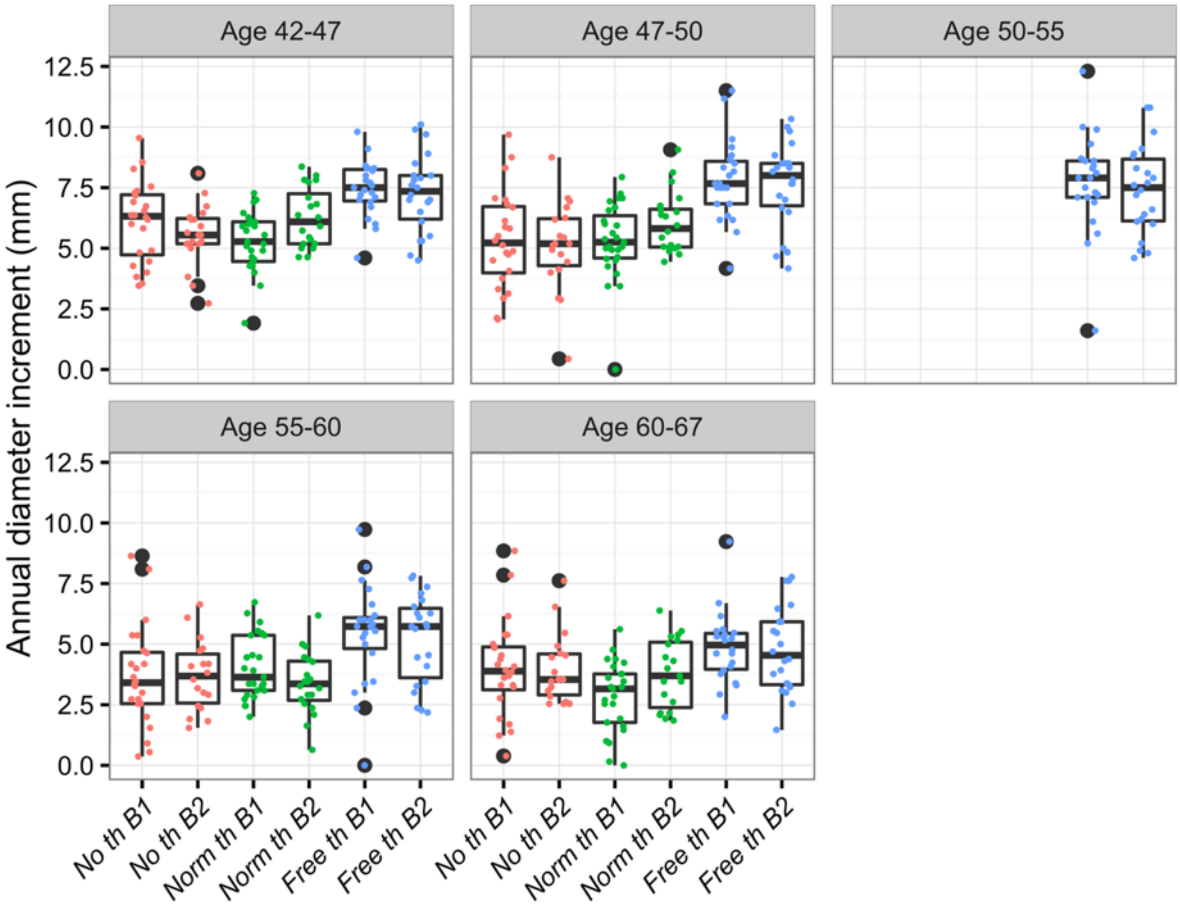


Figure 10. Annual diameter increment among main trees during the observation period. The coloured dots represent individual trees (jittered for visibility). Vertical thick line: median, Hinges: 25% and 75% quantile, Whisker: largest observation less than or equal to upper hinge + 1.5 * IQR (inter-quartile range), Lower whisker: smallest observation greater than or equal to upper hinge - 1.5 * IQR, Black dots: observations greater than 1.58 * IQR * $n^{-0.5}$

Table 4. Mean annual diameter increment (mm) for main trees in the different treatments and for different age intervals.

Age	*No th*		*Norm th*		*Free th*	
	B1	B2	B1	B2	B1	B2
42 - 47	6.1	5.6	5.3	6.3	7.4	7.3
47 - 50	5.3	5.1	5.3	6	7.8	7.6
50 - 55	3.7	3.5	3.7	3.4	5.4	5.2
55 - 60					7.7	7.4
60 - 67	4.0	4.0	2.8	3.8	4.8	4.8
42 - 65	**4.8**	**4.7**	**4.5**	**5.0**	**6.6**	**6.2**

A positive correlation exists between *dbh* and diameter increment calculated for main trees (Figure 11). The correlation increased over time and was on average for all plots 0.32, 0.52, 0.54, 0.68 and 0.73 for the age intervals as specified in Figure 11.

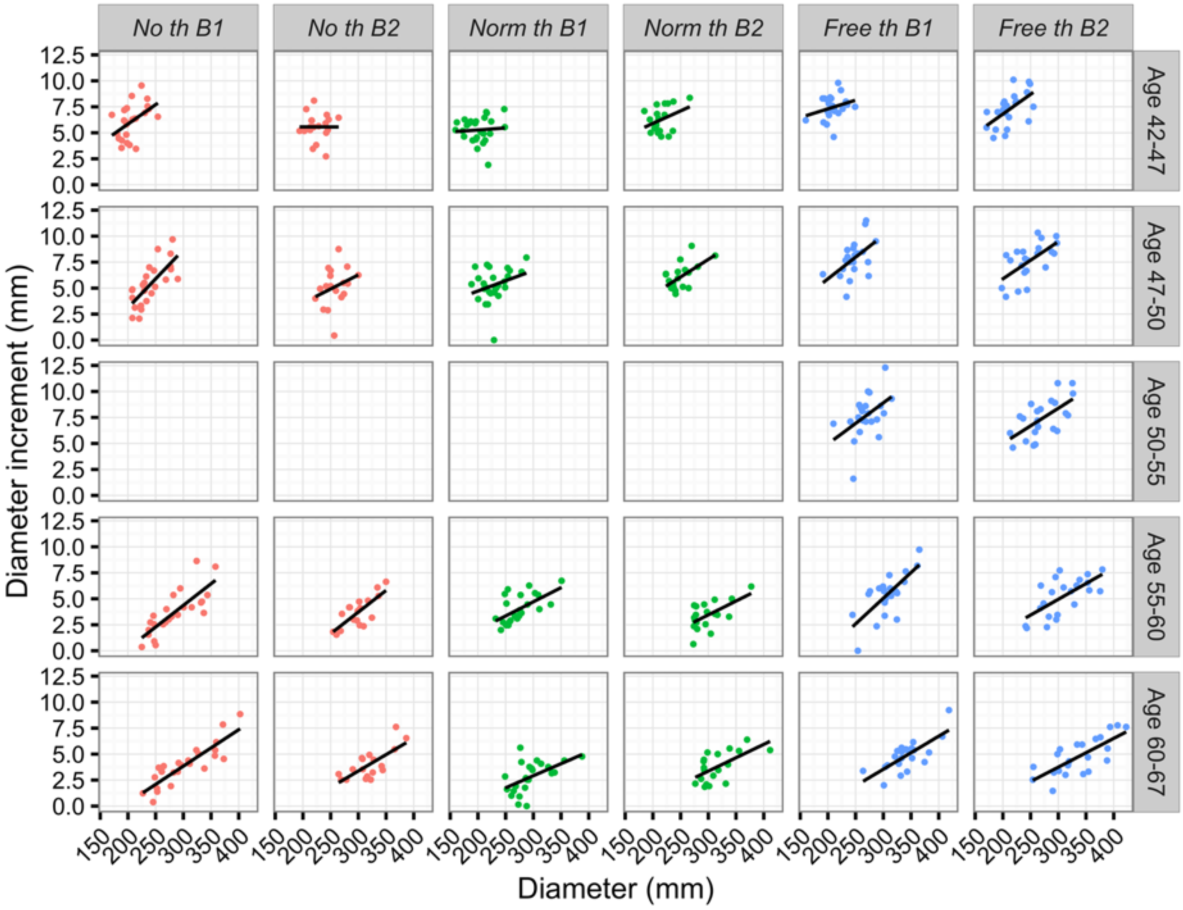


Figure 11. Relation between *dbh* and diameter growth for main trees, divided for plots and age intervals in which dimeter growth was assessed.

Crown size

Measurements of crown height (height to the first living branch) was made only on sample trees selected according to standard procedures (Institutionen för skogsproduktion, 1992). Average crown height was calculated for trees having reached a *dbh* of at least 200 mm at the end of the observation period.

At the start of the observation period the average crown height was 66 dm, with small differences between treatments (Figure 12, Table 5). At the end of the period the average was 108 dm, but with a difference between treatments (p= 0.069). Thus, the crown height was 1.7 m higher in *No th* compared to in *Norm th* and 2.8 m higher compared to in *Free th*.

The mean annual increment of crown height during the observation period was 2.0, 1.5, 1.2 dm in *No th*, *Norm th* and *Free th*. (Calculations including only trees that were measure both at the first and latest inventory.)

The average crown ratio (crown length / tree height) at the latest inventory was 54% with differences between treatments in accordance with the differences in crown height (Table 5). The minimum crown ratio among main trees was 42%.

No difference in crown height or crown ratio could be found comparing pruned and not pruned main stems.

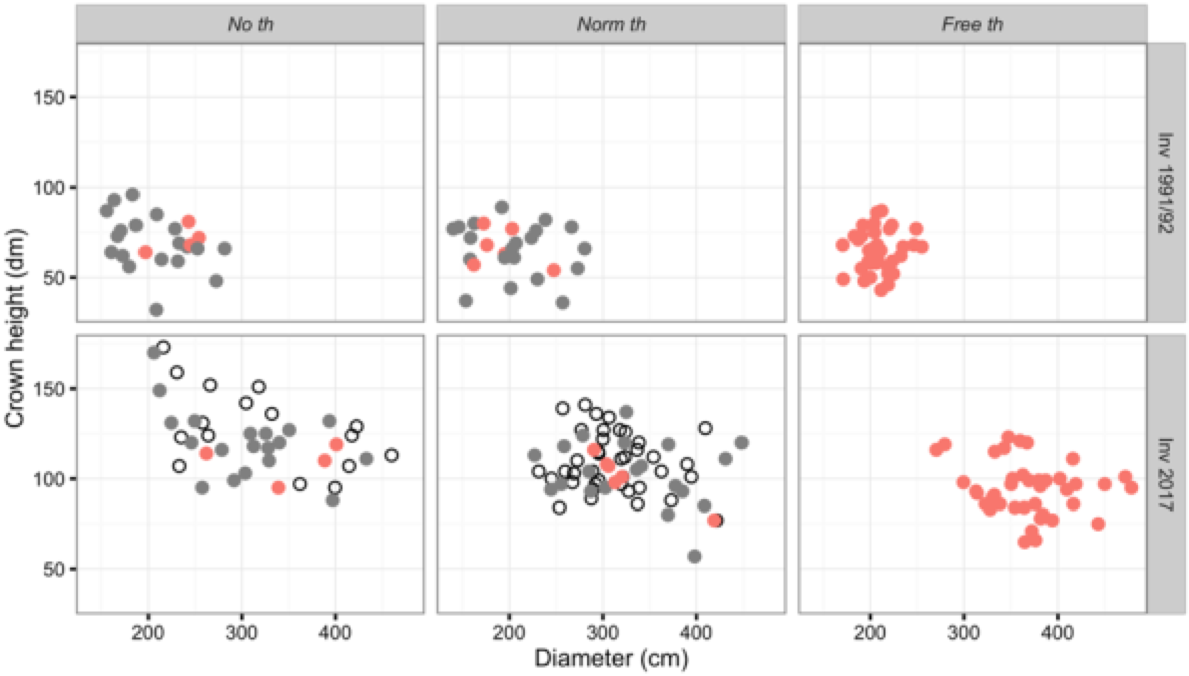


Fig 12. Crown height (height to first living branch) for trees at the beginning and end of the observation period. Only trees considered with a *dbh* greater than 200 mm at the latest inventory. - Red: main trees, Grey: Other trees measured both at the first and at the latest inventory, Open circles: trees only measured at the latest inventory. (Crown heights were only measured on sample trees selected according to standard routines.)

Table 5. Average crown height (height to first living branch) and crown ratio for trees at the beginning and at end of the observation period. Calculations include only trees bigger than 200 mm at the end of the observation period.

	Crown height (dm)		
Inventory	*No th*	*Norm th*	*Free th*
1991/92	70	66	65
2017	123	106	95
	Correlation between crown height and dbh		
1991/92	-0.32	-0.17	0.13
2017	-0.47	-0.24	-0.22
	Crown ratio (%)		
1991/92	56	58	59
2017	46	51	57

The green crown diameter at the end of the observation period varied in the *Free th* between 8.4 and 11.4 m in Block 1, and between 7.7 and 13.5 m in Block 2, means 9.7 and 10.2 m (Fig 13). The annual crown diameter increment during the observation period was 0.17 and 0.18 m respectively.

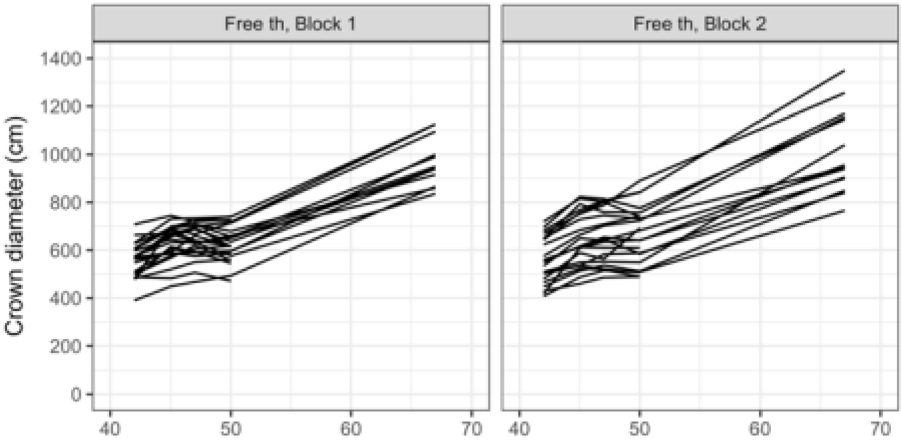


Fig 13. Crown diameter development on mains stems in the *Free th* plots

The correlation between dbh and crown diameter was at the beginning of the observation period 0.65 and at the end of the observation period 0.80. (Figure 14). A liner regression was made with stem diameter growth as dependent variable and stem diameter and crown diameter as independent variables. The result showed that crown diameter did not significantly reduce the residual variation.

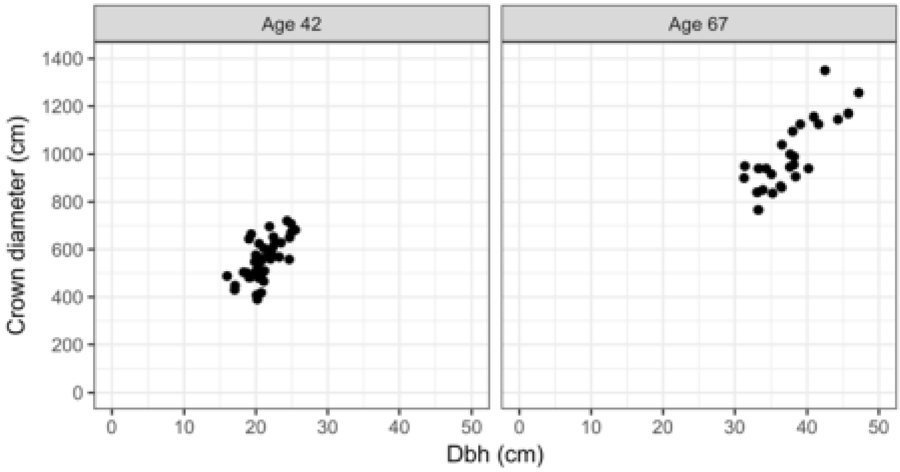
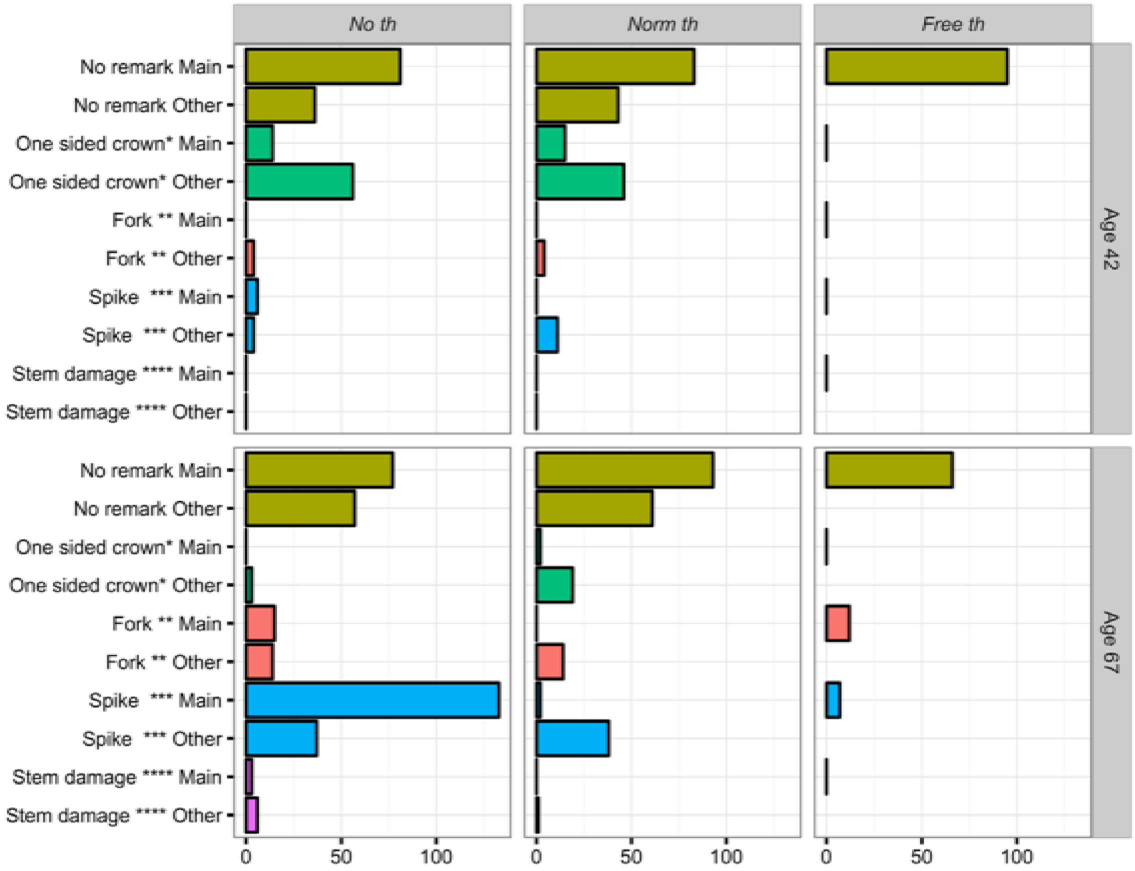


Fig 14. Relation between dbh and crown diameter at the beginning and at end of the observation period, main trees in *Free th*.

Defects and damages

Trees with no defects and damages was most common among main trees, at the latest inventory on average 80% of the tress were without remarks (Figure 15). The lowest frequency was found in *free th,* 67%. However, in this case only few of the more severe defects were observed, fork and spike knots. Other defects of minor importance are not included in Figure 15.



* One sided or heavily competed crown
** Fork in the middle section or the bottom section of the stem
*** Spike knot in the middle section or the bottom section of the stem
**** Stem damage affecting more than 25% of the stem circumference

Figure 15. Frequency (%) of damages and defects, divided for treatments, age at observations and for tree categories (Main trees, Other trees). No assessments were made in *free thinning* at the first inventory (age 42)

Epicormic branches

The share of trees with no epicormics shoots was in *No th* 48%, in *Norm th* 50% and *in Free th* 27%. The general pattern indicates less and smaller epicormics in *No th* compared to in the two other treatments (Figure 16). The share of trees with epicormics with a diameter more than 10 mm was lowest in *No th* 8%, followed by *Norm th* 21% and *Free th* 31%.

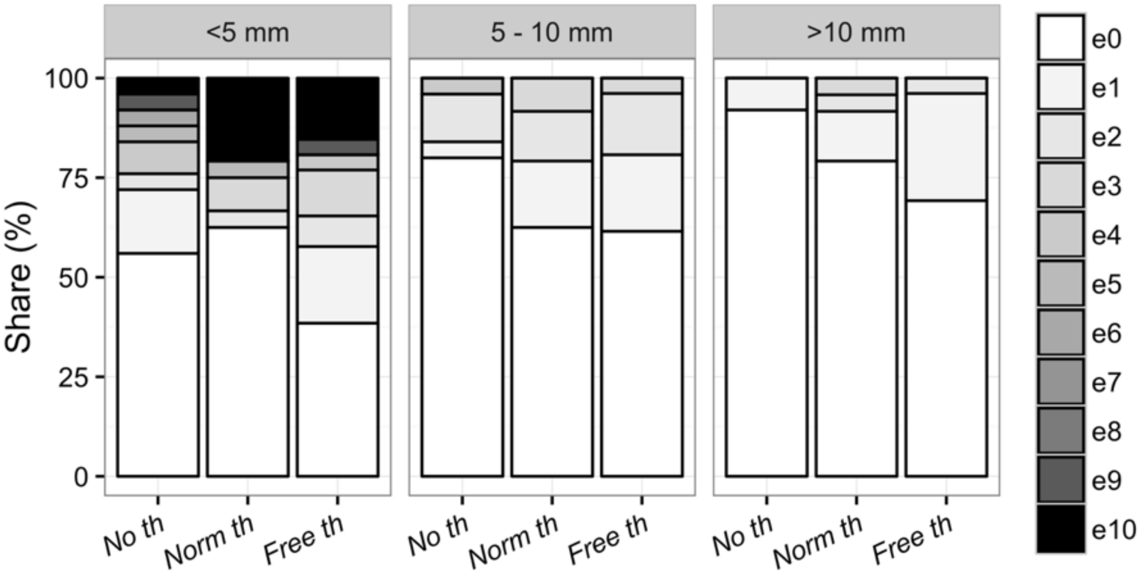


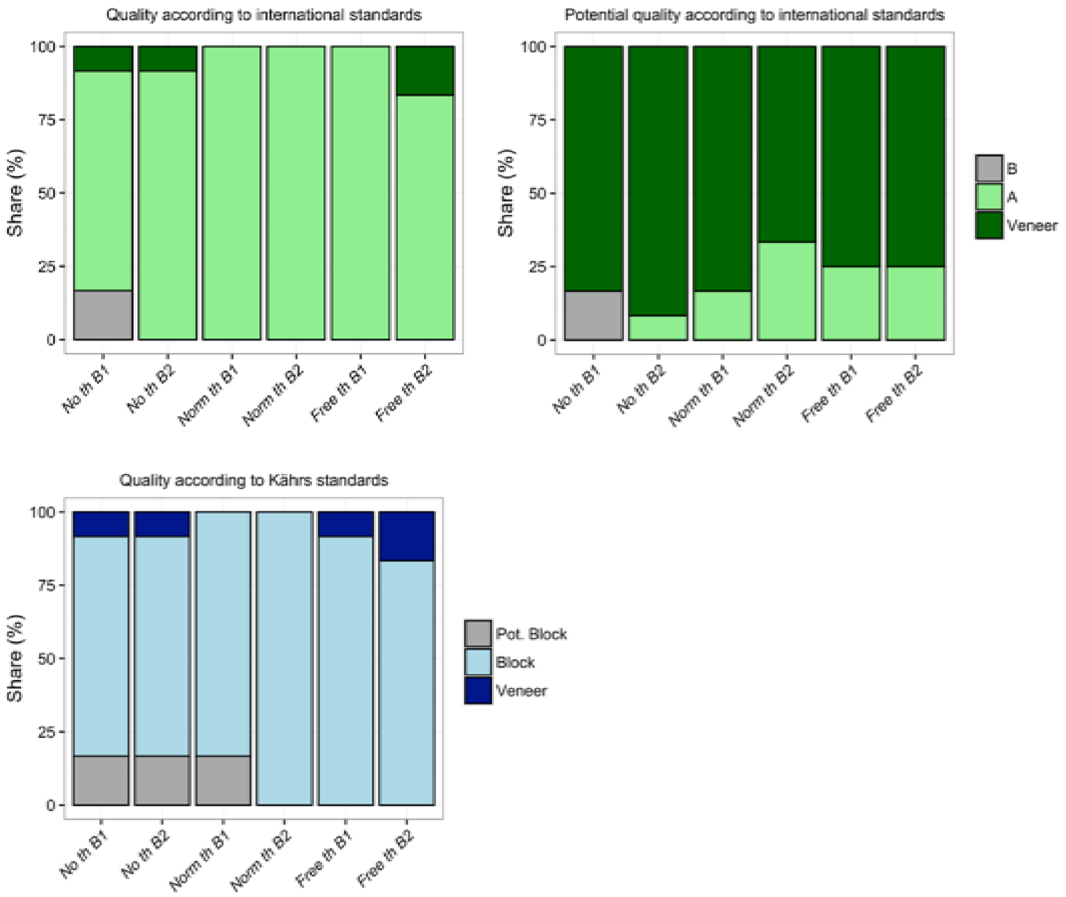
Figure 16. Epicormic shoots of different diameter up to a height of 3m on the main stems. e0: no epicormics, e1: 1 epicormic, …, e10: 10 or more epicormics.

Commercial timber quality

The assessment of timber quality of the bottom logs of the main trees indicates in general a good timber quality, with small differences between treatments (Figure 17). B quality was only found in *No th*, Block 1 (17% of the graded logs). Among all logs graded as A quality 12% had cracks at the stem base. Therefore, the lower end of the log had to be moved 2 to 5 dm up along the stem. The downgrading from A to B quality were due to spike knots and dry branch stumps.

The judgement of potential quality showed a high proportion of veneer quality, 88, 75 and 75% in *No th*, *Norm th* and *Free th* (Figure 17).

The assessment according to Kährs standards gave in general results consisting with the assessment according to the international standards (Figure 17).



Quality according to international standards

Potential quality according to international standards

Quality according to Kährs standards

Figure 17. Quality assessment of bottom logs (length 3.1m) according to two grading system. The potential quality of the bottom logs according to the international standard is based on the judgement that small epicormic shoots will disappear and that the size of the logs will meet the minimum requirements on diameters for the assortments. In case of the Kährs standards only diameter requirements were considered. (Pot. Block: Potential block log)

Discussion

Stand development

The height development pattern agrees rather well with the site index curves (Johansson *et a*l 2013), indicating an average site index of 27 m at the end of the observation period (Figure 3). Thus, the site should be judged suitable for production of oak timber. Bryndum (1957, 1965) found that the top height development was positively influenced by an increasing stand density. This tendency is also present in the current experiment where the top height during the observation period increased by 1.0 m more in *Free th* compared to in the other two treatments. The strange deviation in the general height development pattern at age 61 (Figure 3) is difficult to explain and could possibly be due to systematic erroneous measurements on this occasion.

The stand density in *No th* is far beyond recommendations in Sweden (Figure 4). The volume and basal area levels in *Norm th* follow well the development in Carbonnier´s (1975) yield tables, but the number of stems are somewhat higher than in the tables. The current difference in stand density between *Norm th* and *Free th* is expected to decrease in the future since the main stems in *Free th* have less competitors of the same size or greater (Figure 8). Consequently, the need of heavy cuttings to keep the main trees fully exposed will be smaller.

The mortality during the observation period was mainly classified as storm damage and sudden oak death (results not shown). The declining process in case of sudden oak death is rapid. From the time that the first symptoms have emerged trees often dies in just a few years, typically retaining a more or less intact crown structure. Several causes of this disease have been suggested, *e.g. Phytophthora sp.*, climatic damages and defoliation (*cf.* Witzell & Michelle Cleary, 2017, Barklund 2002). Mortality has occurred during the whole observation period, and trees belonging to all tree classes have died (Figure 5) (Agestam *et al*, 1993). It is of course serious if main trees are afflicted, especially in *Free th* since there are hardly any trees that can be used as replacements. Fortunately, only a few main stems have been lost during the observation period (Table 2).

The volume increment in *Norm th* averaged over the observation period, 8.3 m^3ha^{-1}, is slightly higher compared to the levels in Carbonnier's (1975) yield tables, where it is 7.8 m^3ha^{-1} for the same age interval. (Table: Oak Si 28, Fine earth (<0.06 mm) per cent = 50, Thinning programme A). Comparing with the yield tables the current level indicates that the mean annual increment during the rotation will reach more than the 5.9 m^3ha^{-1} estimated for a site index of 28m. There is a clear tendency in the experiment that the thinning grade influence the volume increment (Figure 6). However, the difference between *Norm th* and *Free th* in removal during the observation period is small, on average 118 and 107 m^3ha^{-1} were harvested. It should be noted that the strategy in stem selection differ between the two treatments. *Free th* should create a more unevenly distributed stand after thinning than *Norm th*.

The changes in tree class during the period is small (Table 1). The difference between *No th* and *Norm th* is likely due to differences in stand density. In both treatments, more than 90% of the trees were classified as belonging to the dominating classes at end of the observation period.

Main trees

Based on the observations by StååI (1986), the originally idea was to choose main trees at a distance of 15 m. However, due to the requirement that the selected trees should also have potentially good timber quality and belong to the dominating tree classes the minimum distance had to be considerably reduced (Figure 7). In the current stand a thinning had been conducted before the establishment of the experiment. But, it is not likely that this intervention has influenced the possibility of selecting main trees, since it can be assumed that dominating potential high quality trees were favoured in the operation. The results suggest that if free thinning is to be applied, selection of main trees should start from an earlier point in time compared to in the experiment and be combined with measures to foster the timber quality.

In the experiment the diameters of main trees in *Norm th* and *Free th* were smaller compared to the 50 and 100 biggest trees per ha (Table 2). This finding could also be used as an argument for early selection and promotion of main trees.

The diameter distributions at the end of the observation period differ between *No th* and *Norm th* (Figure 8), but average diameters are similar (Tabel 3). This is a quite unexpected result since thinnings have aimed at favouring trees in the dominating tree classes and since the stand density have been kept considerably lower in *Norm th* than in *No th* (Figure 4).

The average dimeter increment was significantly higher In *Free th* compared to in *Norm th* (Figure 10, Table 4). This implies a shorter rotation. (If the difference in growth rate would be consistent over the next for 60 years the average diameter would be 10 cm bigger in *Free th*.) However, the growth rates in the two treatments will likely equalize in the late part of the rotation, since the stand densities and number of stems gradually will become more similar. The small difference in diameter increment between *No th* and *Norm th* is in accordance with the finding above that the influence of thinning conducted according to Carbonnier's (1975) have only a small impact on the diameter development.

The difference between treatments in crown height and crown ratio at the end of the observation period are logical considering differences in stand density and strategy in thinnings. The crown ratio among bigger trees indicates well-proportioned trees, also in *No th*.

The annual crown diameter dimeter growth during the observation period was on average 0.17 m. If the same growth rate is to be expected during the rest of the rotation the crowns of several trees will overlap.

The grading of bottom logs show a very good timber quality, with insignificant differences between treatments. More than 75% of the logs were judged to potentially be of veneer quality, assuming that small epicormic braches will die and disappear. This could be questioned since the understory is sparse and thus will not help much to shade away the epicormics. On the other hand epicormics could be removed manually.

Conclusions

- There is a strong indication that thinning will lower the stand volume increment
- The diameter development among main trees is considerably increased by free thinning compared to no thinning and the normal thinning programme
- The difference between no thinning and the normal thinning programme regarding development of main trees and trees in the upper part of the diameter distribution is small, as is the differences in timber quality
- The results indicate that if free thinning is considered it should be applied from earlier age than in the current experiment

It should be noted that the small difference found between main stems after no thinning and in the normal thinning programme could be due to that a thinning was already conducted before the start of the experiment, bringing the stem number down to less than 1000 per ha. The thinning was likely focused on promoting trees of good quality and on removing highly competitive trees of bad quality. If this assumption is correct the intensive management during the thinning period is perhaps not as crucial as often advocated in text books, on condition that stem reduction in the early phase has been made with careful stem selection.

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