A comparison of thinning programmes in European beech (*Fagus sylvatica* L.) based on permanent plots in Southern Sweden

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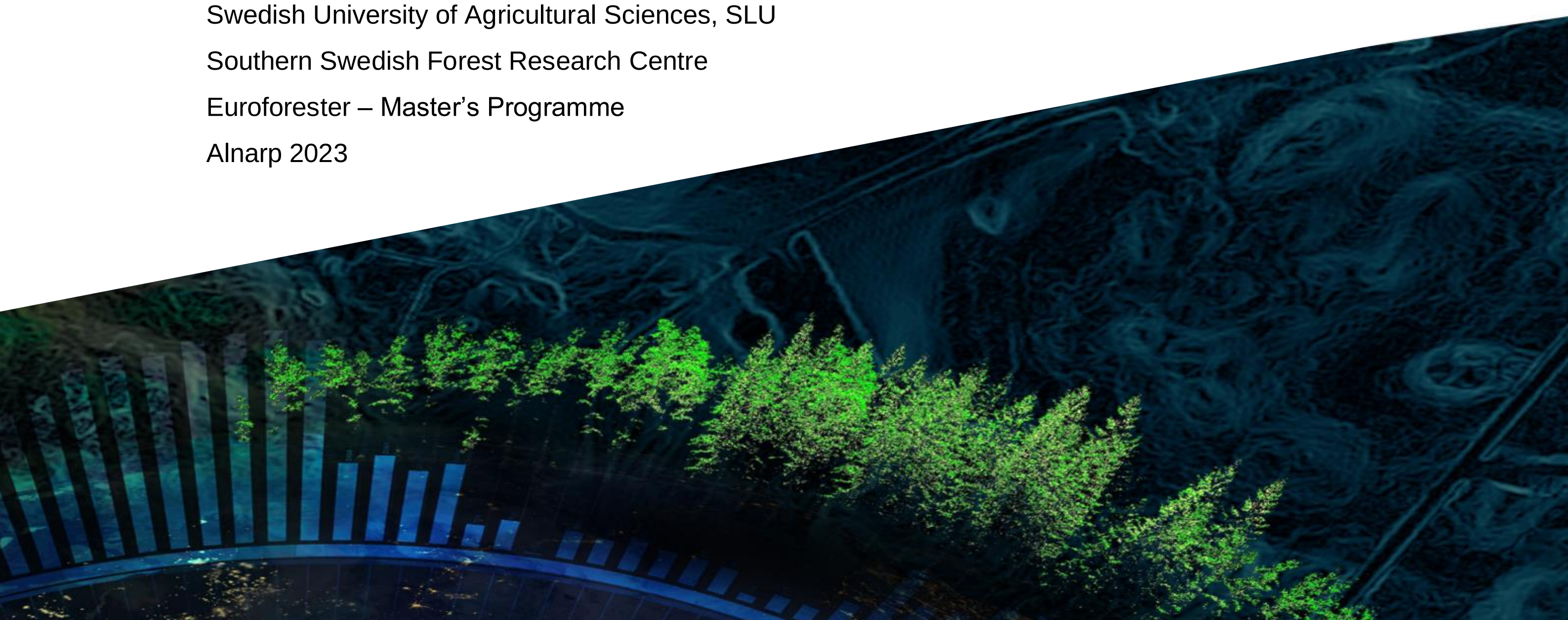

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Abstract

The present study investigated 7 thinning experiments in beech which were established in 1971. The purpose was to compare two thinning programmes with different thinning intervals. The programmes (A and B) were designed according to yield tables by Carbonnier (1971). The experimental plots have been measured regularly in 5 to 10 years intervals. More so, wood quality, the occurrence of epicormic branches, scars and other quality traits were investigated. In this study, data from five experiments in Tönnersjöheden experimental forest were used and analysed alongside data from regular inventories. A field study was made to collect data on epicormic branches, scars, tree vitality, stem damage and other variables that have a negative impact on wood quality. The results indicate that there are no major differences between the two thinning programmes A and B in volume production and diameter development as well as in the quality traits.

Keywords*:* beech, volume growth, diameter development, thinning programme , quality traits

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Abbreviations

MAI   Mean Annual Increment
PCT   Pre-commercial thinning
SFA   Swedish Forest Agency
SEPA   Swedish Environmental Protection Agency
NFI   National Forest Inventory

1. Introduction

1.1 The distribution of European beech (*Fagus sylvatica*)

European beech (*Fagus sylvatica*) is a deciduous tree widely distributed in central and western Europe. The range extends from the western coast of Norway at 60°, north to Sicily in the south, and from the northwest corner of Spain to eastern Romania in the west with the greatest area in France, central and southern Germany (Durrant et al., 2016) (Figure 1). It's the main species of one sixth of all broadleaved in the UK woodland (Evans, 1982). According to (SoEF, 2020) it is known to be one out of five economically most important tree species in Europe, mainly due to its high-quality wood. It thrives well in temperate, mild, and humid climate, low winter temperature and a late spring frost that has limited its distribution towards north and eastern Europe (Jahn, 1991; Peters, 1997; Bolte et al., 2007). It needs a growing season of at least 140 days (Magri, 2008). For this reason, it cannot survive too far north in Scandinavia (Peter, 1997). Climate change may affect the tree's distribution, potentially reducing its competitiveness in the south and east due to drought, while also expanding its range into Scandinavia and the Baltic Region (Kramer et al., 2010).

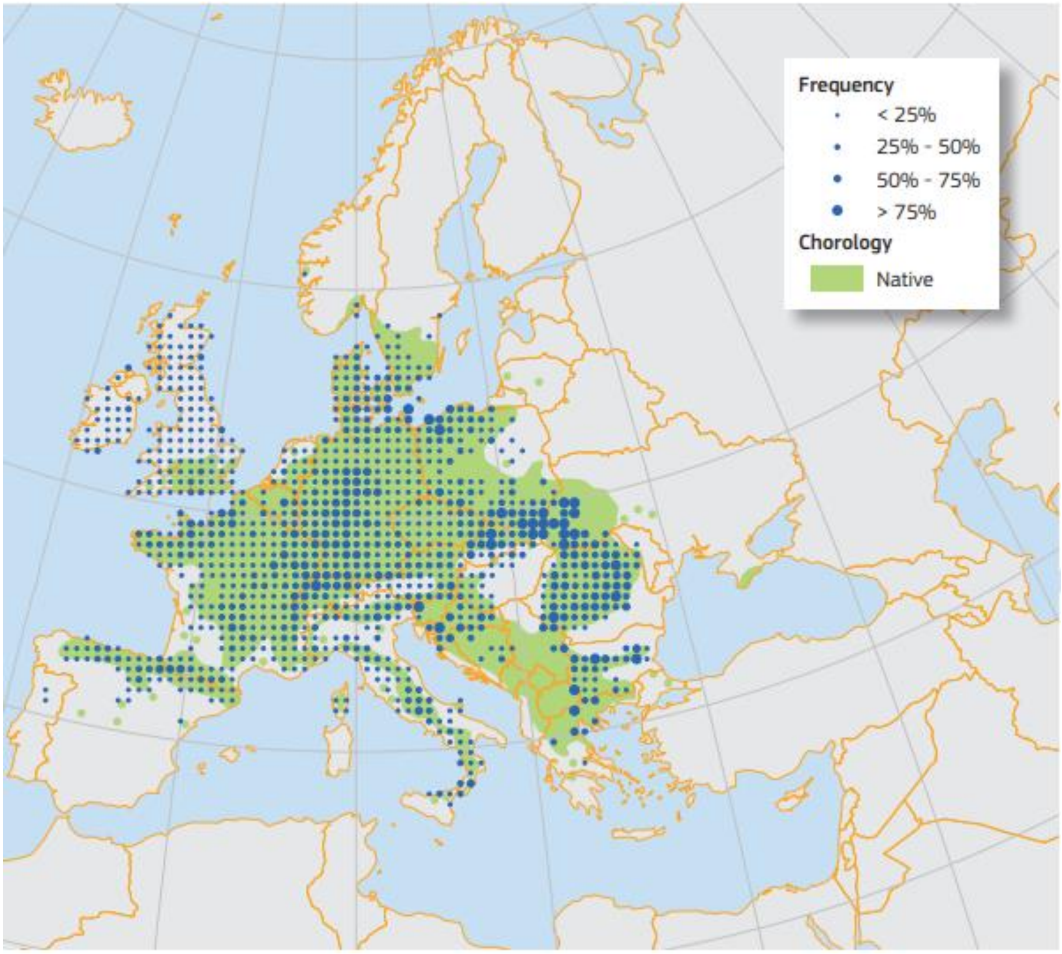


Figure 1. The distribution and occurrence of European beech in Europe (Durrant et al., 2016).

The history of beech in southern Sweden indicates that European beech was the most dominant tree species alongside oak in the 17th century (Berglund, 1991; Bjorkman , 1996; Lindbladh et al., 2008; 2011). More so, it shows that beech forests covered large areas in the parts of southwestern Sweden until the early eighteenth century (Brunet, 2005; Lindbladh et al., 2011). However, the demand for agricultural land by the swift growing population in the eighteen-century led to a drastic fall in beech, about three folds. (Brunet, 2005; Lindbladh et al., 2011; Svenningsson, 1992). What is left of the remaining beech forest witnessed ubiquitous changes because of the introduction of an organized forest management system (Emanuelsson et al., 2002). Most forests are located in the continental vegetation zone in the counties of Skåne, Blekinge, Götaland, Halland and Bohuslän (Liziniewicz, 2009; Övergaard, 2010). This distribution is due to the occurrence of spring frosts during flowering, which damage flowers in a way that very limited viable seedlings are formed to produce a substantial new regeneration (Lindquist, 1931; Matthews, 1955). However, broadleaved tree species would probably constitute a large proportion of the forests in the southern part of Sweden if they had been left unmanaged (Björse and Bradshaw, 1998). (Figure 2) below shows it distribution in southern Sweden.

According to Nationl Forest Inventory (2020), the total standing stock for beech in the whole country is 22.6 million m^3 corresponding to 0.7 % of the total standing stock and distributed as follows; Skåne 14.2%, Blekinge 7.1%, Halland 5.3% and Götaland 2.4% NFI (2020).

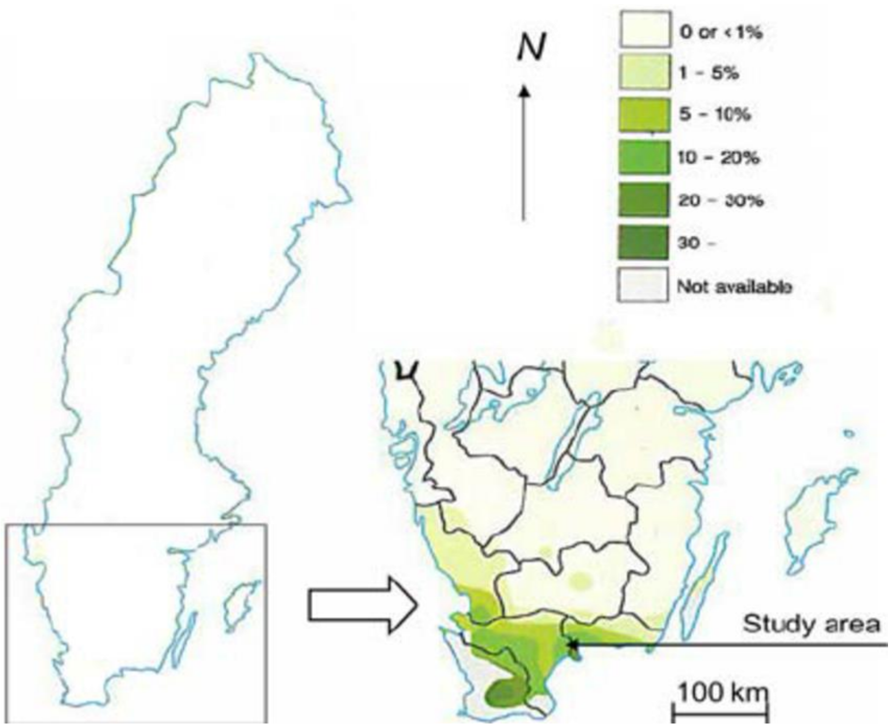


Figure 2. *The study area in southern Sweden and the percentage of beech of all tree species. Adapted from (Kempe and von Segebaden, 1990).*

1.2 Some characteristics of European beech

Beech is a hardwood species, and it is the most shade-tolerant broadleaved tree in its range (Savill, 2019). Therefore, natural regeneration is possible in silvicultural systems with continuous crown coverage as the seedlings can survive and grow below the canopy of the old trees (Patrick et al., 2013). The main reason why beech predominates is because of a reduction of light level in the understorey vegetation and in that beech, seedlings survive better than those of other tree species. In densely populated stands, beech trees self-prune, while open-grown trees often have large crowns and lower branches near to the ground. Other species are sometimes planted or seeded into beech stands to boost stand density and serve as "trainers" to promote straight stems and early self-pruning of lower branches. An example is hornbeam.

1.3 The importance of European beech for industrial and domestic use

Beech is an important European wood. The timber wood is hard, and it has a pale cream colour with a good workability. It is known to have more than 200 usages and is one of the most diversely used tree species in Europe. Its wear-resistance, strong, and have excellent bending capabilities. This makes this species ideal for boat construction, flooring, staircases, furniture, musical instruments, plywood, veneering, cooking utensils among others. It is because of these attributes that the timber of beech is known to be one of the most valuable wood species in Europe (Zell, 2004). However, it should be noted that beech more than a 100 years old frequently develop red heartwood, which is a discoloration that limits the use of its wood. (Knot, 2003; Zell, 2004; Georg, 2008).

European beech is the only tree species that can regenerate under very limited light conditions (Bolte et al., 2007; Ellenberg, 1988). They grow well in areas with good drainage and nutrient-rich soil, particularly moist moraines sites that contain some limestone (Peters, 1997). Beech trees prefer a temperate marine environment with mild winters, high humidity, and abundant rainfall. They are commonly seen growing with pine and spruce in managed or natural stands, especially in the northern part of it range. Oak, ash, and hornbeam are some of the most frequently observed broadleaf species growing alongside beech (Agestam et al., 2006; Övergaard, 2010). It however hinder long winters with extreme dryness which limits its distribution to the east (Dengler, 1944; Röhrig and Tarasiuk, 1999; Bartsch, 1992).

1.4 An overview of silviculture on beech with focus on volume growth, diameter development and on quality traits

The main goal for beech production in Sweden is to produce high quality timber with large diameters of 50 cm or more. Nevertheless, the market has during periods been quite low. The pulp market on the other hand has been very good and it is important for the economy in the early part of the rotation. Generally, in much of continental Europe natural regeneration of beech is common and the species- is managed under a variety of silvicultural systems. It grows, well in the uniform shelter wood system, but because of its tolerance to shade it can be managed in a selection cutting systems (Savill, 2013).

1.4.1 Regeneration

Natural regeneration is the most common method used to regenerate beech in Sweden. (Evans, 1984; Övergaard, 2010). Most often large quantities of seedlings are established, and as long as the population of ungulates in the area are not too large, fencing is not necessary, and it is even seldomly done. The reason being that the area of regeneration is often quite large due to the vast number of seedlings. As a result of this, the regeneration can withstand some browsing without jeopardizing the quality of the regeneration. Hence, there is the possibility to benefit from a high number of seedlings establishment (Madsen and Larsen, 1997; Agestam et al., 2003).

1.4.2 Seed production of beech

Usually, the forest manager awaits a mast year. A binocular or using the eyes directly can be used to detect the beech nuts in late summer. The mast years on average occurs between 5-7 years in southern Sweden. Naturally, the number of seeds needed to establish a good regeneration varies between sites and the weather conditions during the establishment period. The occurrence of mast years, the size of the seed production and the site index are important factors when preparing for seed production from beech regeneration (Övergaard et al., 2007; Drobyshev et al., 2010). In a mast year a huge number of beechnuts fall to the ground often 500 per m^2 or more.

1.4.3 Site preparation

In Sweden, it is customary to do some kind of site preparation before the beech nuts fall to the ground (Agestam et al., 2003; Övergaard, 2010) This is especially important if the organic layer is thick or there is a lot of field vegetation. The scarification should be done at the end of summer or better still at the beginning of autumn before the seeds start to fall. In many ways, bare mineral soil or a combination of bare mineral soil and humus creates a good seedbed (Agestam et al., 2003; Madsen, 1995). Utilizing machinery initially created for the regeneration of conifers, such as a patch-scarifier or a disc-trencher, is the most popular approach to create areas with bare mineral soil surfaces (Övergaard et al., 2009). But preparing the site in this way may make it easier for birds, rodents, and ungulates, which eat seeds, to find them. Soil or humus should be used as a barrier to protect seedlings that are out in the open. When the majority of the seeds have already dropped and the soil is yet not frozen, then this should be done (Övergaard, 2010). To cover the seeds with soil is a good measure, but it’s seldom done in practice.

1.4.4 Removal of seed trees and shelter, PCT

In the first winter a cutting is made among the seed trees to create a 2shelter for the seed trees, leaving about 80 trees per ha. The shelter protects the regeneration from frost and hampers the growth of more light demanding weeds. The shelter is removed in several steps during a 15 - 20-year period, in paste with the growing light demand of the seedlings. Pre-commercial thinning (PCT) begins when the regeneration has reached a height of about two meters and involves the removal of undesirable and fast-growing beech species, known as “wolf trees” (that is trees of low quality such as spike-knots, forks, thick branches with some dominating and suppressed trees) and undesired species (Övergaard et al., 2009; Reventlow et al., 2019) ,This is often done when the trees are between 10-15 years. PCT is usually made on two to three occasions. At this period nothing is harvested, and the measure is seen as an investment for the future. Its main purpose is to create a good base for the future stand development. The disadvantage is that it is labour intensive and thus costly but according to the Swedish Forestry Act (1994) one can get a subsidy corresponding to 60% of the cost (SFA, 2023). Even so, Ekö et al., 1995) have studied alternative methods that include fewer and less intensive operations which have yielded promising results.

1.4.5 Commercial thinning

The main objective of commercial thinning is to take out pulpwood and timber to get revenue earlier than the final harvest and to promote the future stand development**.** In beech the focus on which trees to promote must be on a higher number than what is the target for the final stand, which should contain between 150-200 trees per ha. The reason being that it is difficult to forecast the development of the individual tree.

The traditional thinning programme denoted as A by Carbonnier (1971) is intensive and includes often more than 10 thinning with rather small removals in the individual thinnings. (Figure 3). The programme is based on principles outlined by Schädelin (1934). Crown thinning is used in the first part of the rotation to give selected dominant trees with good timber quality freedom to grow rapidly, by gradually removing competing trees. Thus, the selection of trees to cut is done among all tree classes. The reason for the intensive programme is that beech does not have a strong apical dominance. Therefore, once a gap is created it becomes easier for sunlight to penetrate in the stand thereby giving opportunity for large branches to develop into forks. Furthermore, the increased light enables the development of epicormic branches, by stimulating dominant buds in the bark to burst. In the later part of the rotation, when the timber quality is set, the thinning form later changes to thinning from below.

Programme B was designed by Carbonnier (1971) to develop a more modern programme adapted to new economic circumstances, which demanded more rational operations. The programme B was designed by approximately doubling both the interval and the removal in thinnings, compared to programme A. The average basal area over time is the same in both thinning programmes, as is the total removal during the thinning period. (Figure 3). At the time when Carbonnier proposed the programme B, there was no empirical data to evaluate and there was some fear that the few but heavy thinnings would lead to low timber quality, due to fewer occasions of selection and by letting in more light into the stand.

A series of thinning experiments in beech were established some 50 years ago by SLU. The experiments have been followed by regularly according to the principles applied for permanent plots at SLU. However, the data has yet not been evaluated. Thus, there is now an opportunity to compare the two programmes A and B.

1.5 Study objectives

The main objective of this study was to evaluate the differences between two thinning programmes A and B in beech Carbonnier (1971) concerning volume production and diameter development. In addition, the research was to focus on wood quality with the emphasis on forks and epicormic branches, a comparison of the quality traits in the two programmes will be examined based on data collected in this study. Also, the study aims at analysing data from two thinning experiments contain thinning programmes other than A and B. These experiments contain no thinning, programme A, thinning from above and very heavy thinning.

2. Materials and Methods

The 7 studied experiments are in Halland and Skåne Table 1. Ordinary inventories have been made on all sites according to the routines for long term experiments at SLU (Karlsson et al., 2012). The current inventory includes only the experiments located in Tönnersjöhedens experimental forest. Site index varies between 23 and 26 m indicating medium to good site conditions for beech.

Table 1 Overview of the experiments. Stand data refers to the latest inventory. Experiment 826 and 8054 contains one replication of the treatments, where the data refers to the average. A and B thinning programmes outlined by Carbonnier (1971).

	Location	Treat-ments	Site index (m)	Last inventory	Age	Obs. period (years)	Height (m)	Diam-eter (cm)	No of stems per ha	Basal area (m3/ha)	Volume (m^2/ha)
826	Borrestad	A	32	2013	91	55	30.0	29.3	375	25.2	334
		B	32		90		29.5	32.0	304	24.5	320
831	Skäralid	A	29	2017	99	58	29.1	36.4	318	33.1	434
		B	32		99		31.5	35.4	300	29.5	416
835	Frode-parken	A	27	2016	100	584	26.2	41.1	204	27.0	315
		B	28		100		28.2	30.9	347	26.0	314
8054	Tönnersjö-heden	A	27	2016	89	49	25.1	37.3	187	20.4	224
		B	27		89		24.7	33.5	256	22.6	241
8071	Tönnersjö-heden	A	28	2016	83	44	25.5	31.4	251	19.4	215
		B	26		83		23.5	29.7	278	19.2	192
8070	Tönnersjö-heden	No th	31	2016	62	16	22.4	16.3	1483	31.0	301
		A	30		62		21.9	19.8	622	19.1	182
		Above	27		62		19.9	14.6	1207	20.2	165
		Hard	29		62		21.0	27.0	273	15.6	144
8260	Tönnersjö-heden	No th	28	2021	51	5	17.2	13.5	1443	20.6	145
		A	27		51		16.8	11.8	1323	14.5	99
		Hard	28		51		17.3	20.8	253	8.6	63

2.1 Treatments

The focus in the study is on thinning treatment A and B as they are defined by Carbonnier (1971) (Figure 3.) Programme A should refer to traditional, "normal" programme. In programme B the average basal area over time is the same as in A, but the intervals between thinning are doubled. (Figure 3) see also introduction. In two of the experiments thinning from above, that is removal of the biggest trees, and hard thinning is also included. Hard thinning means in this case that the number of trees is reduced to a number that is expected in the final stand, when managed in accordance with programme A.

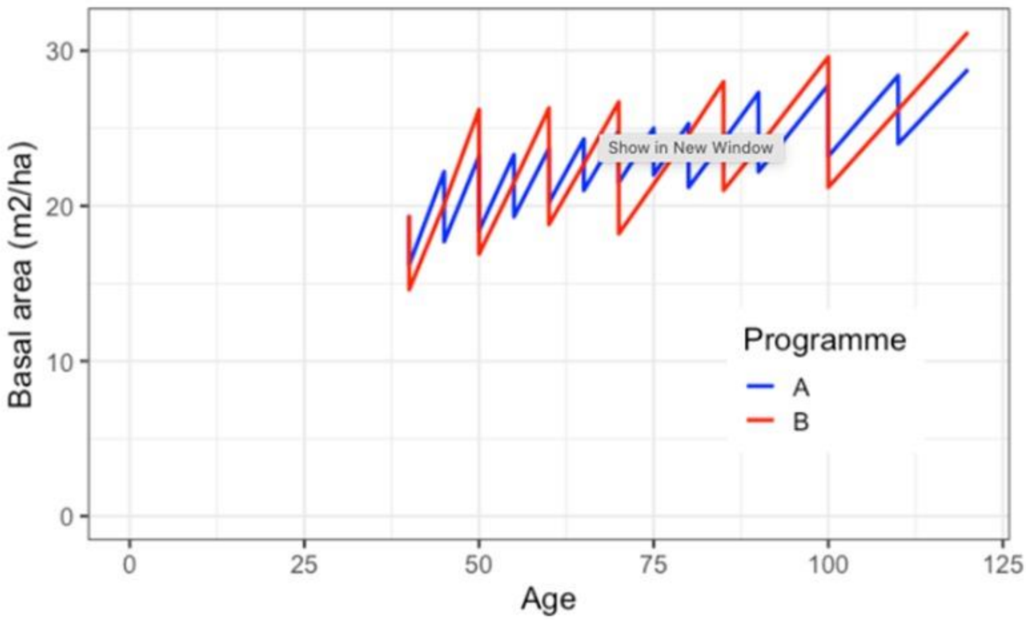


Figure 3. Basal area development over dominant height for program A and B. From Carbonnier (1971) yield tables for site index Beech 32.

2.2 The ordinary data collection

The ordinary inventories applied for SLU's permanent plots are carried out at an interval of 5-10 years. All trees are measured for diameter. Furthermore, the tree class is judged with three different tree properties. In this study forks and spike knots (Figure 4) are of special interest since they have effect on the wood quality. It is noted where they are placed on the stem in relation to the tree height: below 1/3, between 1/3 and 2/3, or above 2/3 of the height. Several sample trees are measured for height and other traits. Secondary functions for estimation of height can be calculated from the sample tree data and then applied for all trees. Thus, tree volume can be estimated based on diameter and height relationships. The data collection in this study

The purpose of this inventory was to measure, describe and assess the vitality and different quality traits within the plots: T8070, T8071, T8054, and T8260 (Table 1), all located at Tönnersjöheden experimental forest. On each plot approximately 20 trees were measured . These trees were chosen as a quota of the numbered trees and therefore represent the diameter distribution. The variables taken into considerations are listed below.

2.3.1 Epicormic branches

Epicormic branches emerge from “sleeping” buds in the bark and have a negative impact on the wood quality. The occurrence is stimulated by a reduction of the crown, light on the stem and by genetic factors. (Evans,1982) highlights that epicormic branches are more severe to oak as compared to beech, but it could also be more in beech because of genetic factor. (Figure 4) Both living and dead epicormic branches were considered in this study. A classification was made in the following categories: 1 which represents 1 - 5 epicormic branches, category 2, 5-10 epicormic branches and category 3 more than 10 epicormic branches. An assessment was separated depending on if they were located below or above 2.5 m.

Figure 4. *Epicormic branches (topleft), scars (topright), vitality(centreleft), and stem damange (centreright), forks (bottomleft) and spike knots(bottomright). Photos by Delphine*

2.3.2 Scars

Scars are marks from branches that have died and has been shredded, and eventually been overgrown by new wood (Figure 4). An assessment was made on each tree that contained scars below 2.5 m. The scars were measured in two ways, diameter and angle. The biggest diameter of the "eye" was measured using a measuring tape. The previous branch angle is indicated by the "Chines moustaches" emanating from the "eye". (Figure 4a)The angel was measured as the angle between a horizonal line through the "eye" of the scar and the "mustaches". Measurement was made with a special gadget and registered in the following classes: 1 represents angels less than 30°, 2 angles between 30° to 50° and 3 angles more than 50°. A steep angel means that it could affect a rather big section of the stem. Scars play a very decisive role when estimating the quality of wood.

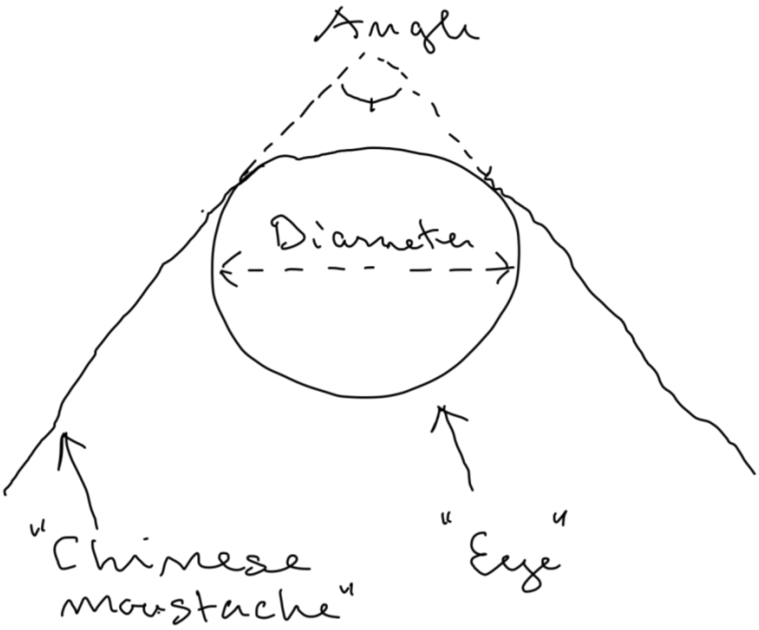


Figure 4a. *Measurement of scars, the "eye" and the "Chinese moustache"*

2.3.3 Vitality

Vitality refers to the present state of a tree. If a tree suffers from some kind of stress caused as a result of a disease such as fungi, drought, competition or from mechanical damages it will affects the tree vitality. Typical signs of low vitality are reduced crown size, dry branches in the crown or that the tree is not fully leaved. For this data collection, three classes of vitality were used: vital, somewhat impaired vitality and impaired vitality (Figure 4).

2.3.4 Stem damage

Stem damage could be caused for example by mechanical damages due to harvesting operations, resulting in open or overgrown wounds. Trees were assessed below 2.5m. (Figure 4).

2.3.5 Calculations

Volume growth and diameter development were analysed in absolute values. While relative frequencies were used for quality traits, vitality and stem damages. Calculations of statistical significance was made by ANOVA, comparing programmes within experiments.

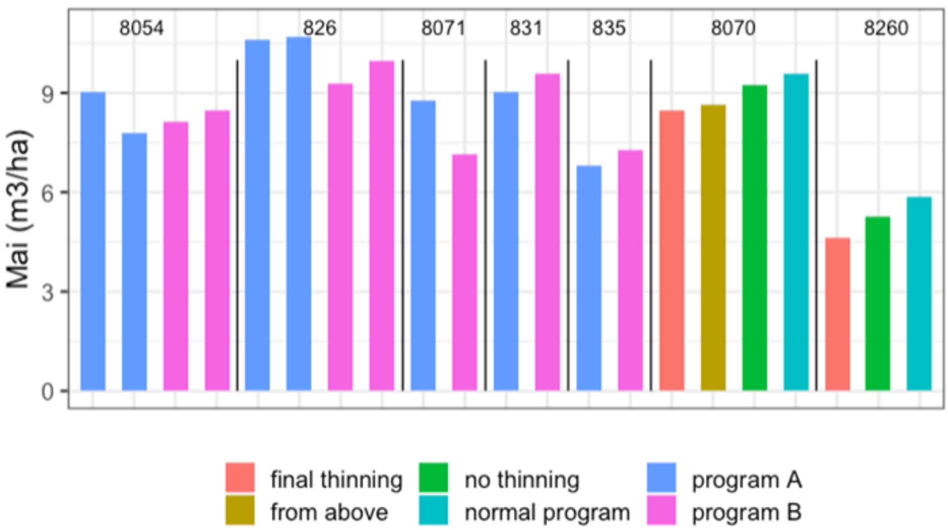
The two thinning experiments included in the study have only been observed for 5 and 16 years since the establishments. The results and conclusions could therefore be different in the future.

3. Results

3.1 Volume production and diameter development

The development of the beech stands in the individual plots and experiments are presented graphically in Appendix 1 and include the number of trees, basal area, volume, and volume growth. The graphs show that the different treatments are well represented in the data.
The volume growth during the observation period is calculated based on the data from the ordinary data collection. The calculations were made according to routines for permanent plots at SLU. (Karlsson et al., 2012) (Figure 5)

Figure 5 Mean annual volume increment (MAI) during the observation periods. Table 2. Comparison between programme A and B. Mean annual increment (MAI) during the observation period (m3/ha and year). In 8054 and 826 the MAI is averaged over plots containing the same thinning programme.



The difference in MAI during the observation periods between programme A and B varies between plots. In three experiments the production is higher in A and in the other two it is higher in B. The average difference is 0.3 (m^3/ha and year) and not significant (p 0.4113) (Table 2). On average the volume production in program B is 97 % of the production in programme A.

Table 2 Mean annual increment (Mai) during the observation period (m3/ha and year) in the two experiments with different thinning grades and thinning forms. The normal programme is the same as programme A. Final thinning means a heavy thinning down to the number of trees suggested for a mature stand.

Experiment	Program A	Program B	A - B	B / A *100
8054	8.4	8.3	0.09	99
8071	8.8	7.2	1.60	82
826	10.6	9.6	1.01	91
831	9.0	9.6	-0.55	106
835	6.8	7.3	-0.47	107

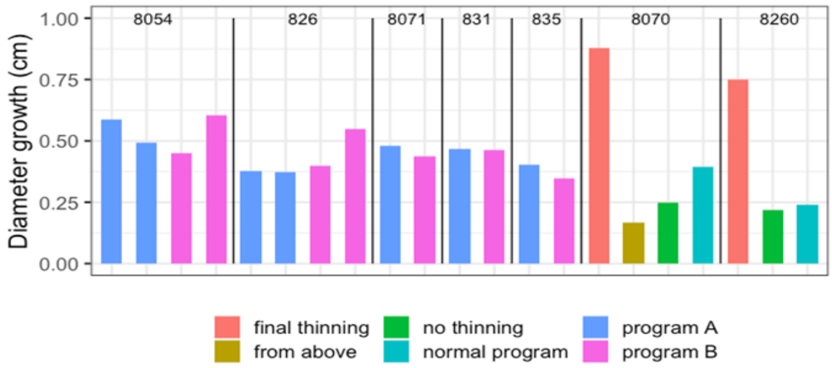
Heavy thinning down to the final stem number has a lower MAI compared to the other treatments (Table 3). It should be noted that observation periods are quite short 16 years in experiment 8070 and 5 years in 8260

Table 3. Mean annual increment (MAI) during the observation period (m3/ha and year) in the two experiments with different thinning grades and thinning forms. The normal programme is the same as A. Final thinning means a heavy thinning down to the number of trees suggested for a mature stand.

Experiment	Program	Mai	p -norm	P / norm
8070	normal program (A)	9.6	0.0	100
	no treatment	9.2	-0.3	96
	from above	8.7	-0.9	90
	final thinning	8.5	-1.1	89
8260	normal program (A)	5.9 (A)	0.0	100
	no thinning	5.3	-0.6	90
	final thinning	4.6	-1.2	79

Figure 6 Annual development of the average quadratic diameter during the observation periods. The differences between program A and B in diameter development are small and inconsistent.

However, in the two experiments with different thinning grades the diameter development after the heavy thinning treatment is significantly higher compared to the other treatments



3.2 Quality traits

3.2.1 Epicormic branches

Trees with epicormic branches exclusively below 2.5 m were found in one plot only (Figure 4) In general, the frequency of trees with epicormic was high and occurred mainly above 2.5 m. In program A on average 12 % of the trees were found to be free of epicormic branches. The corresponding figure for programme B was somewhat higher, 19 %. Of the trees with epicormic branches 67 % had between 1 to 5 branches, 16 % between 6 to 10 and 17 % more than 10 epicormic branches.

Table 4 The frequency (%) of trees with epicormic branches below and above 2.5 m.

Experiment	Plot	Treatment	None	Only below 2.5 m	Only above 2.5 m	Both below and above 2.5 m
8054	1	A	18	0	76	6
8054	2	B	17	0	78	6
8054	3	B	28	0	72	0
8054	4	A	0	0	84	16
8071	1	A	18	0	71	12
8071	2	B	11	0	83	6
Average programme A			12	0	77	11
Average programme B			19	0	78	4
8070	1	no thinning	16	0	74	11
8070	2	normal program	28	0	56	17
8070	3	from above	19	0	75	6
8070	4	final thinning	16	0	58	26
8260	1	no thinning	19	0	46	35
8260	2	normal program	5	5	27	64
8260	3	final thinning	0	0	45	55

3.2.2 Scars

Only four trees were found without visible scars. The average scar diameter in the total data is 61 mm, the difference between programme A and B is small (Table 5). The frequency of scars with an angle below 30° is 31 %, between 30° and 50° 51 % and above 50° 18%. There are no obvious differences between treatments.

Table 5 Scar diameter (diameter of the "eye") below 2.5m stem height.

			Scar diameter (mm)			
Experiment	**plot**	**Treatment**	**mean**	**s.dev**	**min**	**max**
8054	1	program A	46	25	20	100
8054	2	program B	49	29	1	115
8054	3	program B	50	49	15	190
8054	4	program A	62	34	15	130
8071	1	program A	51	38	13	140
8071	2	program B	50	28	6	110
	Average program A		53			
	Average program B		50			
8070	1	no thinning	41	22	10	90
8070	2	normal program	46	37	1	140
8070	3	from above	57	25	20	100
8070	4	final thinning	76	41	10	190
8260	1	no thinning	103	53	20	240
8260	2	normal program	75	42	20	180
8260	3	final thinning	55	35	20	165

3.2.3 Vitality

It is the total data of 86 % of the trees that were judged to be vital. The share of trees with impaired vitality is varying between plots. There is no obvious difference between programme A and B.

Table 6 Frequency (%) of trees in three classes of judged vitality.

Experiment	plot	treatment	Vital	Somewhat impaired vitality	Impaired vitality
8054	1	program A	94	6	0
8054	2	program B	100	0	0
8054	3	program B	78	17	6
8054	4	program A	79	21	0
8071	1	program A	71	29	0
8071	2	program B	89	11	0
	Average programme A		81	19	0
	Average programme B		89	9	2
8070	1	no treatment	68	21	11
8070	2	normal program	100	0	0
8070	3	from above	81	19	0
8070	4	final thinning	89	11	0
8260	1	no thinning	73	19	8
8260	2	normal program	95	0	5
8260	3	final thinning	100	0	0

3.2.4 Forks

The frequency of forks is low in the base-section of the tree (Table 7). Trees with forks in this section have likely been removed in early thinnings. In the mid-section the frequency varies between 4.1 % and 12 % at the first inventory in the observation period. The frequency in the latest inventory is about the same as in the first. A minor decrease is noted in the B programme. Even if the frequency of trees with a fork in the mid-section remains almost the same in both inventories, a great share of the trees with fork at the time of the first inventory have been removed in thinnings during the observation period. The share of removed trees is greatest in B programme. Trees with forks in the mid-section of the tree at the first period in the observation period and share of these trees that has been removed until the latest inventory.

Table 7 Frequency (%) of forks in different parts of the stem in experiments with comparison of the thinning programmes A and B. Statistics from the first and last ordinary inventory in the observation period. Base: < 1/3 of the tree height, Mid: between 1/3 and 2/3, Top: > 2/3 of the top height.

			First inventory			Latest inventory			Latest - First
Experiment	**Plot**	**Treatment**	**Base**	**Mid**	**Top**	**Base**	**Mid**	**Top***	**Mid**
8054	1, 4	A		9.2	0		13.2		4
8054	2, 3	B		4.1	0		5.7		1.6
8071	1	A		6.6	4.4		8		1.4
8071	2	B		5	4.3		1.7		-3.3
826	2, 3	A	0.5	4.4	3.3		3.8		-0.6
826	1, 4	B		2.3	5.4		0.7		-1.6
831	1	A		11	6	0.8	7.5		-3.5
831	2	B	0.9	8.4	5.6		2.4		-6
835	2	A	0.9	11.6			11.8		0.2
835	1	B		7.3			1.1		-6.2
Mean A			0.28	8.56	2.74	0.16	8.86		0.3
Mean B			0.18	5.42	3.06		2.32		-3.1

* Probably not observed in the latest inventory

Experiment	Plot	Treatment	Trees per ha with forks in the mid-section at the first inventory	Share (%) removed until the latest inventory
8054	1, 4	A	99	79
8054	2, 3	B	51	95
8071	1	A	119	89
8071	2	B	86	100
826	2, 3	A	45	95
826	1, 4	B	21	100
831	1	A	125	91
831	2	B	90	100
835	2	A	53	69
835	1	B	61	93
Mean A				85
Mean B				98

3.2.5 Spike knots

The frequency of trees with spike knots is highest in the mid-section of the stem, approximately 10%. (Table 8). The frequency has been reduced considerably between the first and the latest ordinary inventory in the observation period. The frequencies in programme A and B are similar. At minimum 97% of the trees with spike knots in the base- and mid-section at the time of the first inventory have been removed until the latest inventory, regardless of thinning programme.

Table 8 Frequency (%) of spike knots in different sections of the stem in experiments with comparison of the thinning programmes A and B. Statistics from the first and latest ordinary inventory in the observation period. Base: < 1/3 of the tree height, Mid: between 1/3 and 2/3, Top: > 2/3 of the top height.

	First inventory			**Latest inventory**			**Latet - First**
	Base	**Mid**	**Top**	**Base**	**Mid**	**Top***	**Mid**
8054 A	**3.8**	**15.5**	**0.1**				**-15.5**
8054 B	7.1	.1.3					-11.3
8071 A	4	7.8	0.9				-7.8
8071 B	5.4	14.4	0.3	1.7			-14.4
826 A	3.3	5.9	0.8	0.5	0.5		-5.4
826 B	2.2	4.8	0.7				-4.8
831 A	1.9	15.1	2.2				-15.1
831 B		12.1	0.9				-12.1
835 A	12.6	6.3	0.4	2	2		-4.3
835 B	2.9	9.4					-9.4
Mean A	5.1	10.1	0.9	1.3	0.6		-9.6
Mean B	4.4	10.4	0.6	1.7	0.0		-10.4

Probably not noted in the latest inventory

4. Discussion

4.1 Are there any significant differences between thinning programmes A and B?

The focus of this study is the comparison between the two thinning programmes A and B, as suggested by Carbonnier 1971. In total the comparison includes seven experiments (14 plots) which includes these programmes, (A and B) of which two were inventoried for quality traits in this study.

4.2 Volume growth and diameter development

The difference in volume production between programme A and B was on average 3 % lower in A compared to in B. In two of the experiments the production was higher in two experiments and lower in the other three. (Table 2, Figure 10). It can be concluded that this study cannot find any significant difference between the programmes.

The annual diameter growth, referring to the quadratic mean diameter, averaged over all plots, was 4.6 mm/year. The difference between the two thinning programmes was small. On average, the diameter growth in programme B was 0.5 % higher than in A and varying between experiments. As in the case of volume growth, number statistically significant differences could be detected. It should be noted that diameter growth refers to the quadratic mean diameter, which means that thinning during the observation immediately will influence the diameter development if the thinning quotient differs from 1.

4.3 Quality traits

4.3.1 Epicormic branches and scars

The frequency of trees without epicormic branches was somewhat higher in programme B compared to programme A, 19% and 12% respectively. The difference is small, but in contradiction to the hypothesis that open up the stand more heavily would cause more sleeping buds in the bark to burst.

Scars on the bottom log (below 2.5 m) from fallen off branches were present on almost all trees. The size of the scar and the angel of the chinse moustache indicates the degree to which branch stumps in the wood influences the timber quality. No difference between programmes A and B could be noted. This could be due to that the treatment before the start of the experiments was the same for all plots, and that quality of the lower part of the stem was already set at the establishment of the experiment.

4.3.2 Damages and vitality

The frequency of damages and trees with impaired vitality was low, and it is likely that these kinds of trees have a high priority to be removed in thinnings. In programme A the frequency of thinning is twice as high as in programme B, and thus the opportunity for selection is higher, but no differences between the programmes could be detected.

4.3.3 Forks and spike knots

As is the cases of volume and diameter growth, calculations concerning forks and spike knots could be based on all experiments since these variables were collected in the ordinary data collection inventories.

Forking is regarded as a severe problem in beech forestry since it directly affects the yield and it could also cause cracks in harvesting operations. It's a common phenomenon due to the weak apical dominance in beech and to some extent induced by thinning. Thinning open up the canopy layer, making room for big branches to grow and could eventually create forks. In the data the frequency of forks in the lower part of the stem is very low. This is likely due to that such trees have been removed earlier in the rotation in pre-commercial and other thinning prior to the observation period.

At first thinning about 9 % of the trees in programme A had forks in the mid-section of the stem. In programme B the corresponding figure was 5%. The frequency at the latest inventory remained the same in A, while in B it was reduced to 2%. However, there was a great variation between plots. It can be concluded from (Table 4) that forks are considered an important factor for selecting trees in thinnings, since a great share of trees with forks in the first inventory have been removed in subsequent thinnings.

A priority could be assumed that programme B would induce more forks than A, due to that the stand is opened up more by the heavy thinnings. Furthermore, there are fewer occasions to remove forked trees in programme B. However, it cannot be confirmed in the data that the frequency is higher in programme B. In fact, there is small, but insignificant, tendency of the opposite.

At the first thinning, the frequency of trees with spike knots in the lower section of the tree was about 5 % and in the mid-section about 10%, regardless of thinning programme.

The frequency of spike knots in the latest thinning has been heavily reduced, to about the same level in both thinning programmes.

4.4 Volume and diameter growth in the two thinning grade experiments

In both experiments the production is not the highest in the untreated plots. This result is inconsistence with the finding in most thinning experiments, including also other species than beech, where in most cases the highest production is found if no thinning has been conducted. Again, it must be noted that the observations in the current study only comprise a short part of the rotation. However, the differences between all programmes are rather small, which is in accordance with a comprehensive Danish thinning experiment (Bryndum, 1980, 1988).

More so, in both experiments, the average diameter is much higher where very heavy thinning has been applied, compared to the other treatments. This is likely due a decreased competition, but also due to selection, since trees with small diameters have been removed in the heavy thinning treatment.

4.5 How does the result in the current study comply with previous studies?

There are few thinning experiments in beech in Sweden and in Europe as a whole. However, there is a well-known experiment in Denmark (Totterup), mentioned above, where a great variety of thinning programmes have been applied (Bryndum, 1980, 1988). The results show that thinning have a significant influence on the diameter development, that is frequent and heavy thinning will result in a great average diameter. On the other hand, if the thinnings are not extremely heavy, the results will show that the volume production is rather unaffected by the thinning grade and by the frequency of thinning. These results agree well with the findings in the current study.

4.6 Uncertainties due to the experimental design and data.

The study does not include many experiments and plots, which makes it difficult to obtain statistical significance. The experiments comparing the A and B programmes will in short be in the stage of regeneration and the reported results should be stable. The beech in the two thinning programmes is middle-aged and needs to be followed for a long period before a conclusion can be made.

4.7 Factors outside this study that could have impact on the results

There are some factors outside this study that could have impact the results such as the way individual selection of trees have been chosen in the thinning, for example, how much attention that has been paid on quality traits compared to tree classes. Another factor could be how successful the regeneration has been (also the genetic origin), affecting the quality formation and variation in stand structure.

4.8 Future research

To get more reliable results comparing the thinning programmes would require establishment of more experiments with permanent plots to be evaluated after decades. That this will be realised is unlikely and perhaps is the results from this study and previous studies sufficient to guide practical forestry.

5. Conclusion and recommendations for practical forestry

It can be concluded that in the results there are no statistical differences between programme A and B in either volume growth or quality traits. Thus, the apprehension by Carbonnier of extending the thinning interval and make heavier thinning seems not to be an issue. Thinning in beech is flexible and the thinning programme could be outlined based on other criteria, such as economic circumstance.

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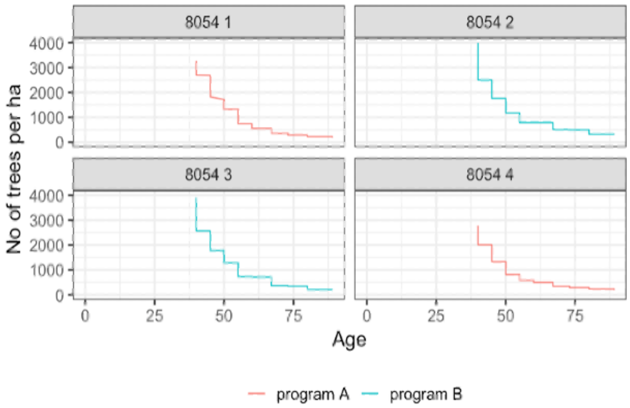
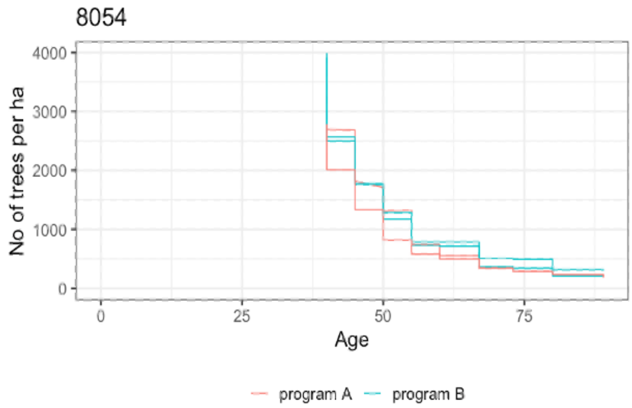
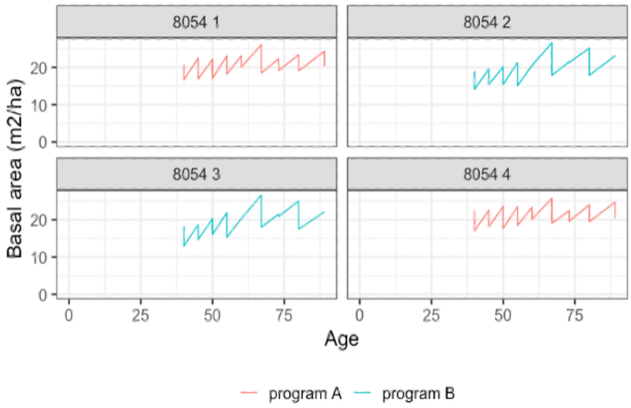
Appendix

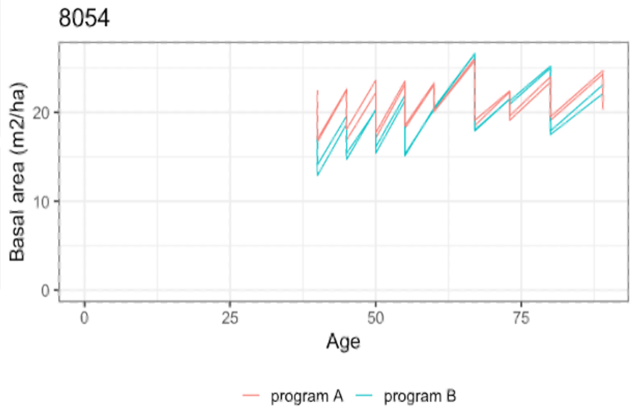
The figures in the appendix show the development of trees, basal area, volume and volume increment. All the experiments and plots in this study are represented. The data are from the collections during the observation periods.

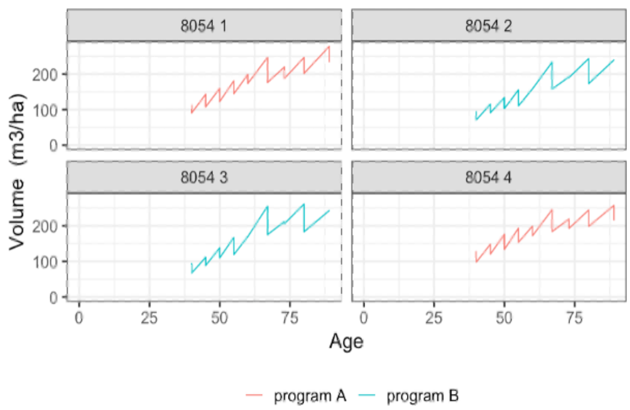
8054 Tönnersjöheden, programmes A and B

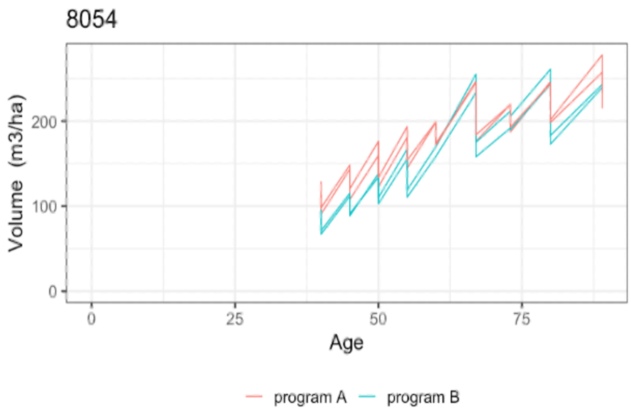


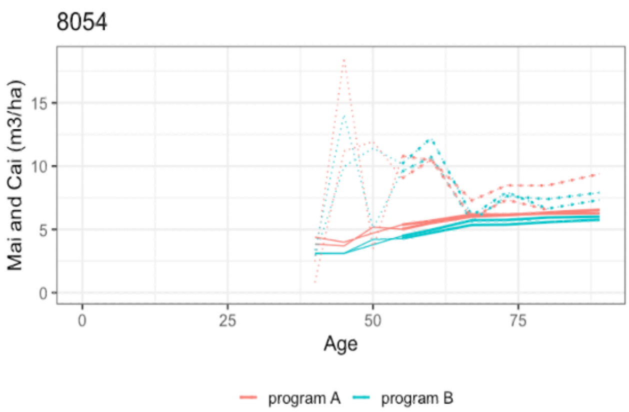




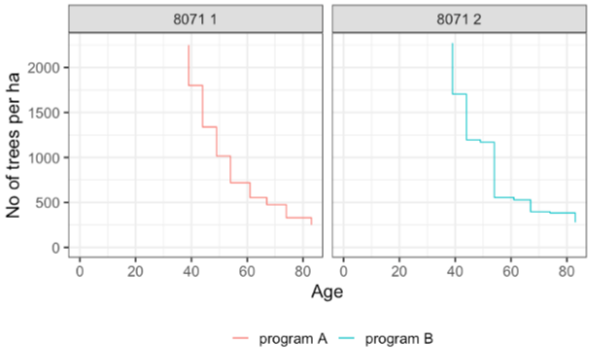


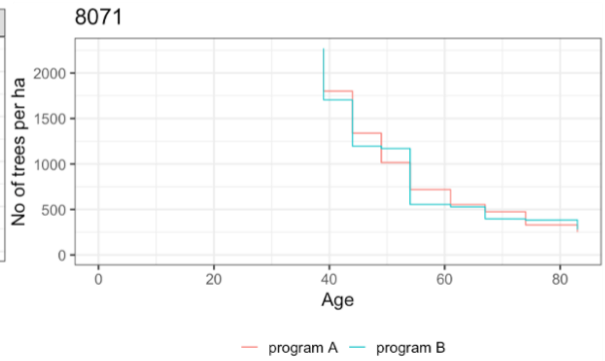


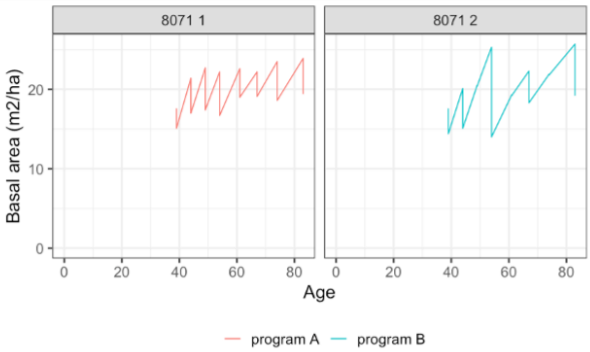


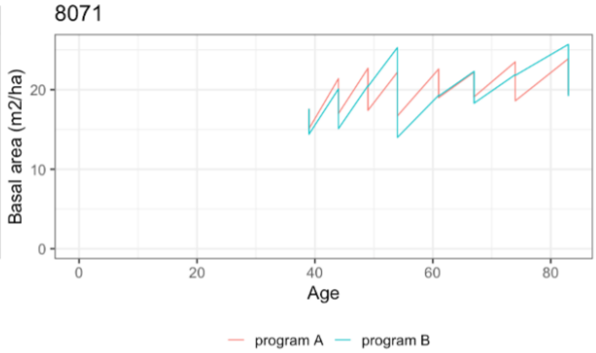


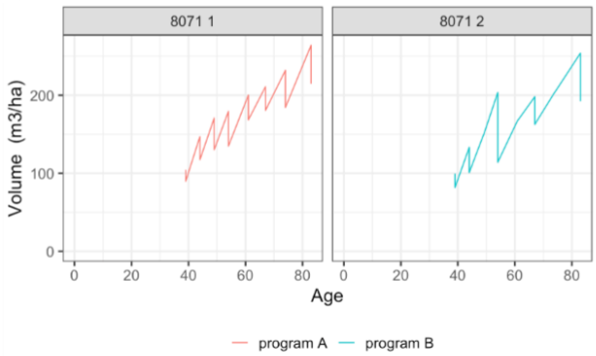
8071 Tönnersjöheden, programmes A and B

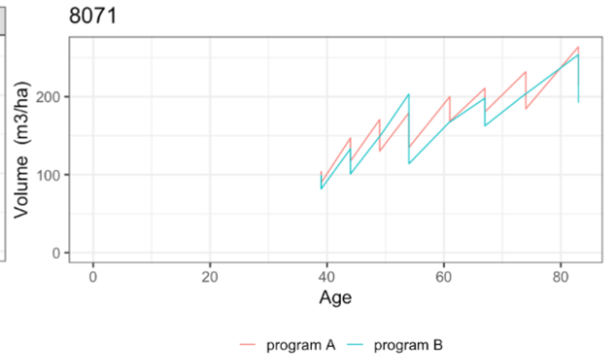


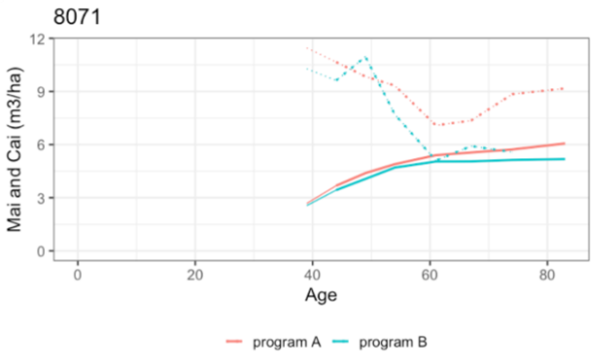




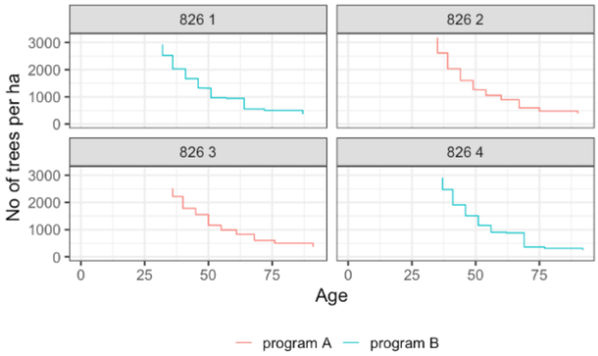


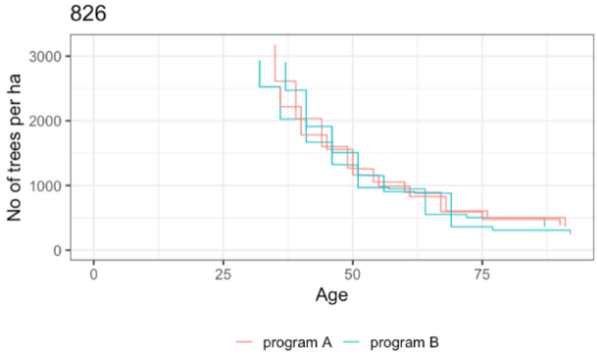


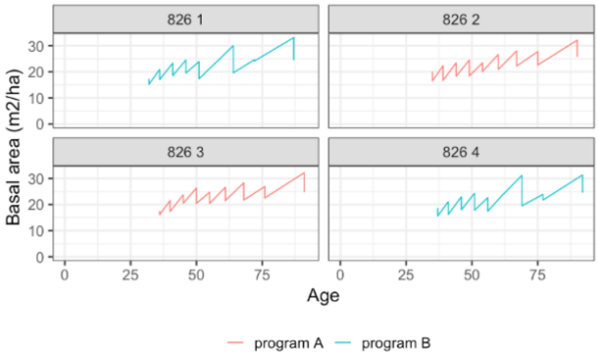


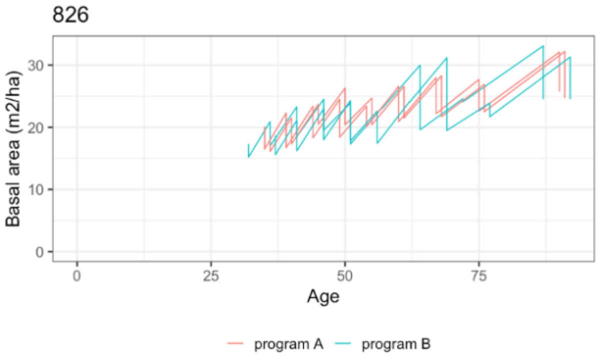


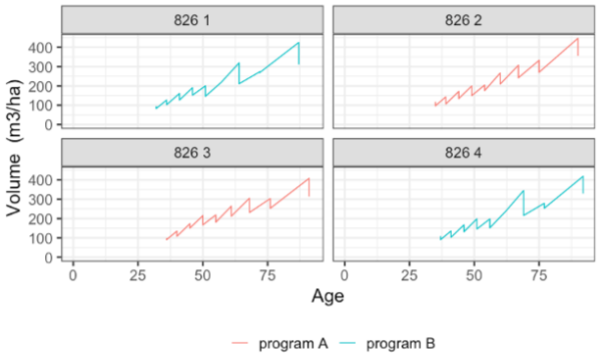
826 Borrestad, programmes A and B

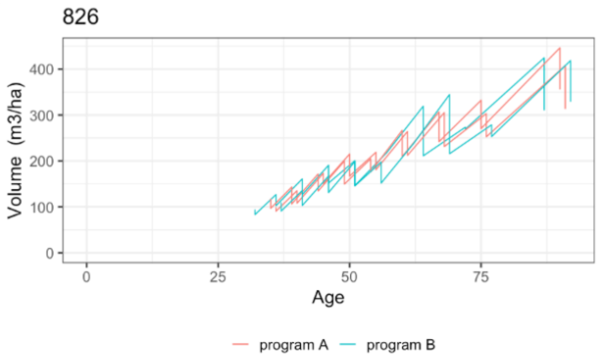


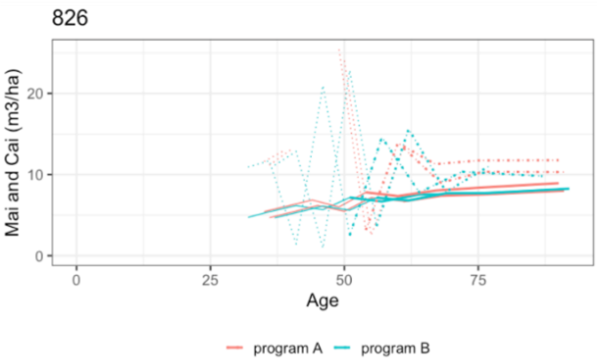




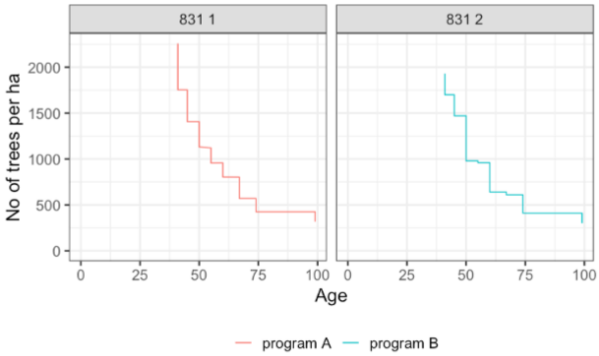


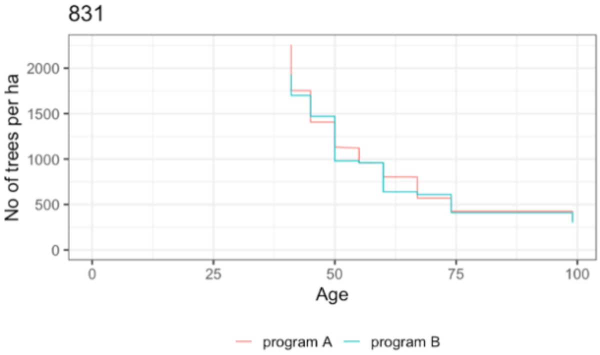


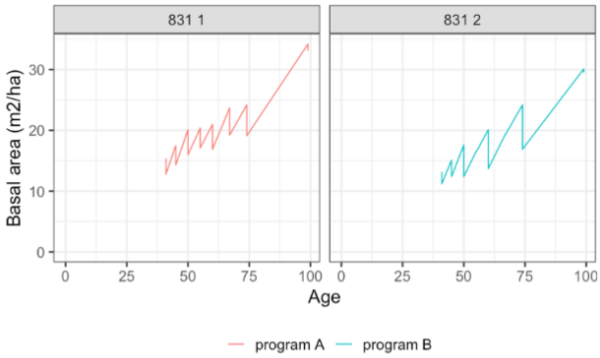


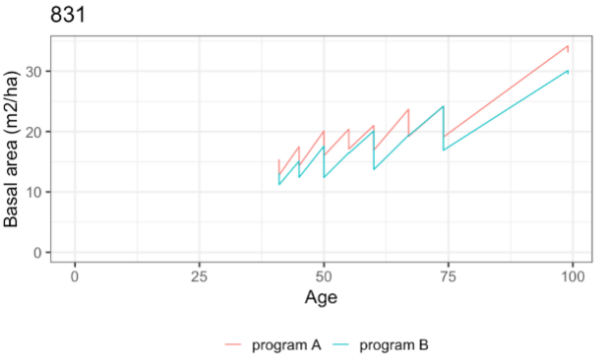


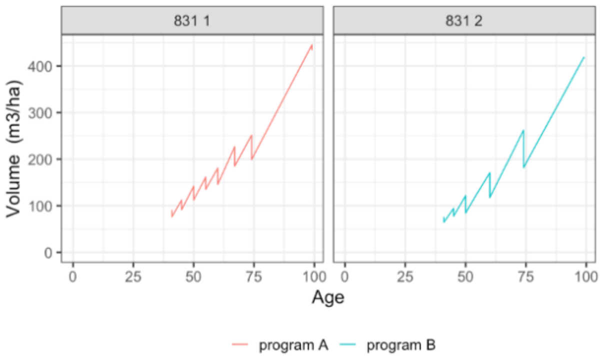
831 Skäralid programmes A and B

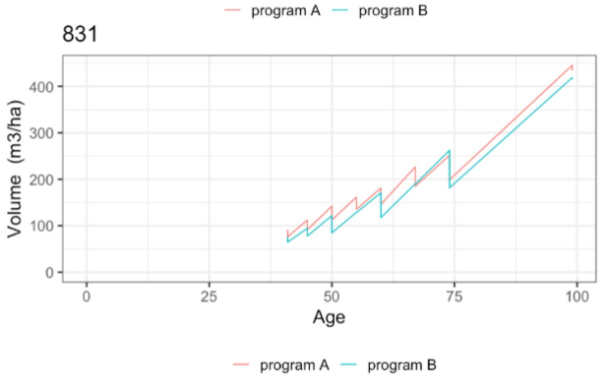


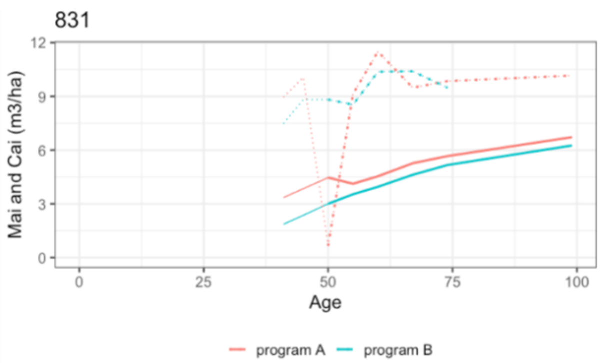




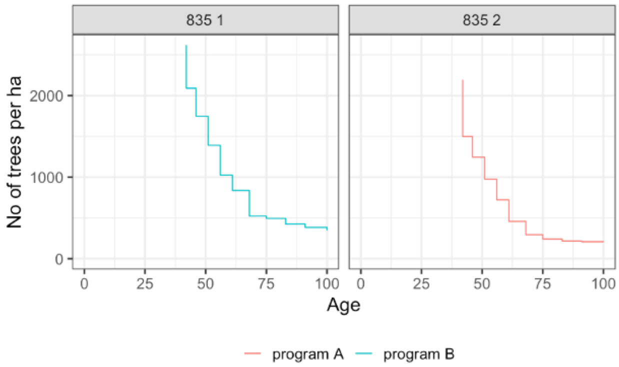


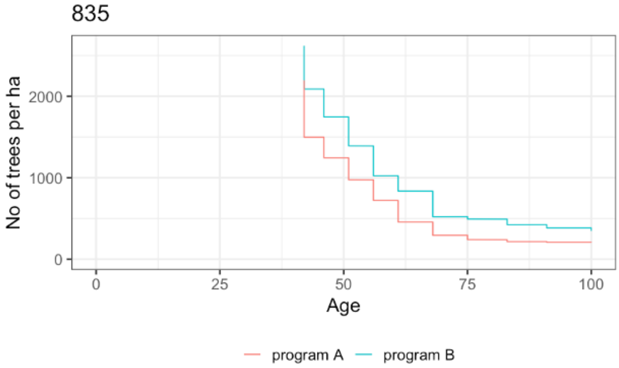


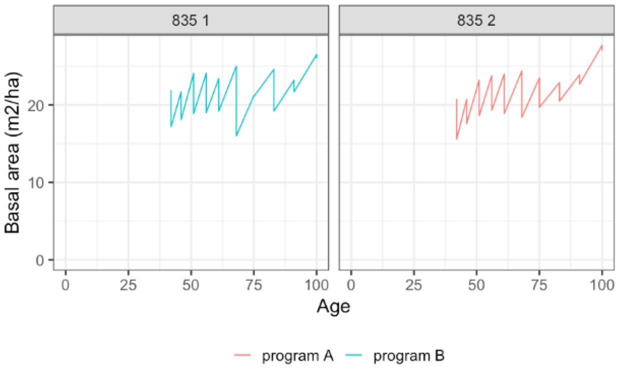


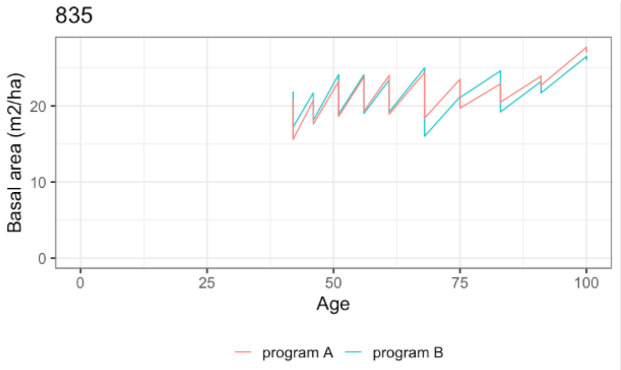


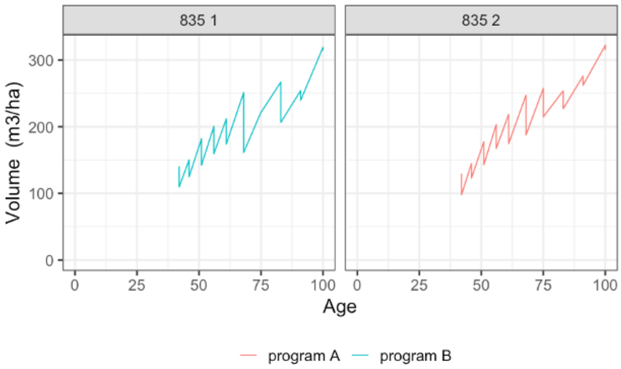
835 Frodeparken, programmes A and B

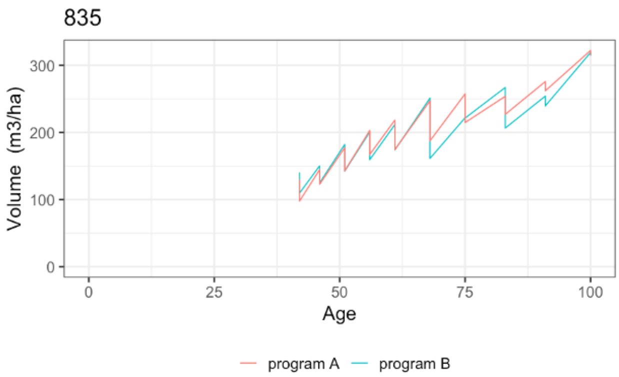


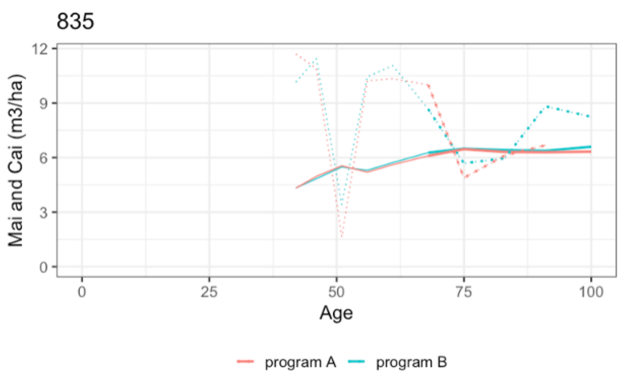




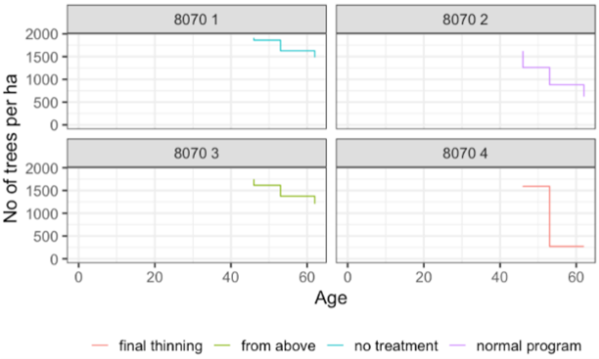


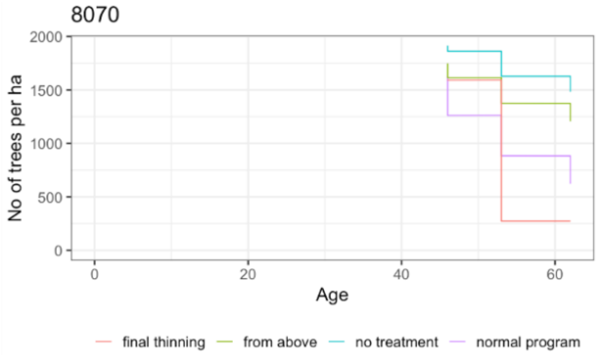


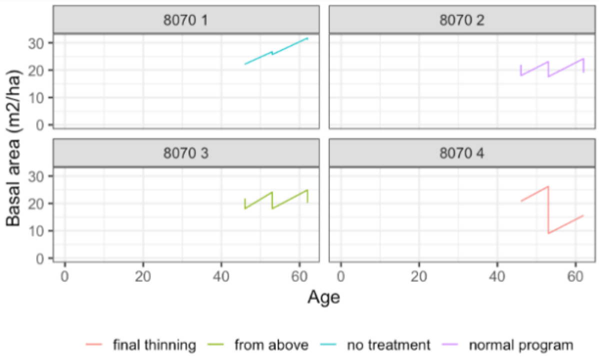


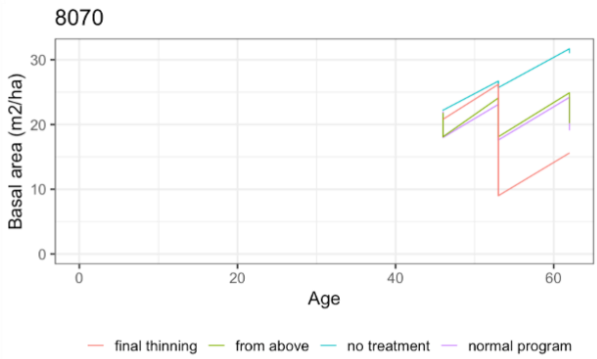


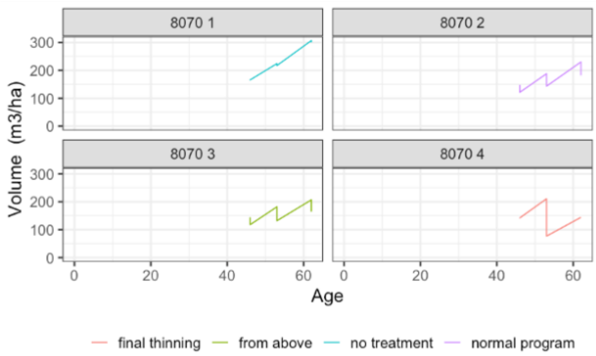
8070 Tönnersjöheden, No thinning, Programme A, From above, One heavy thinning

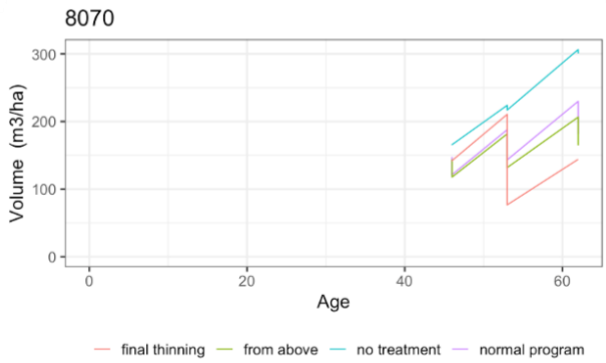


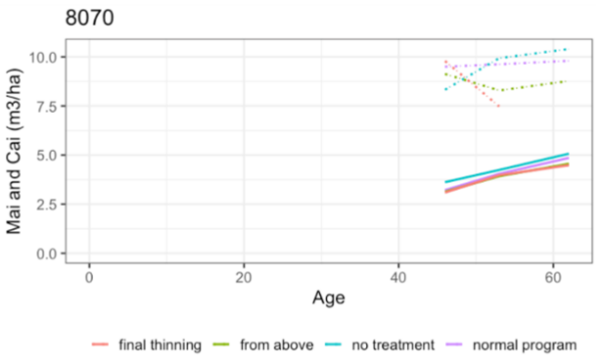




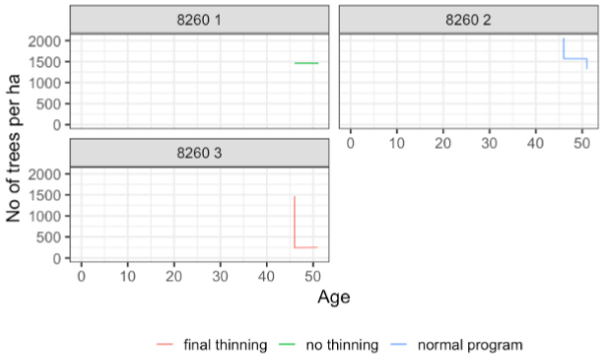


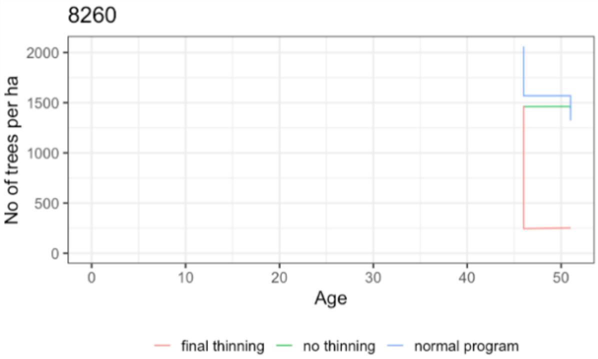


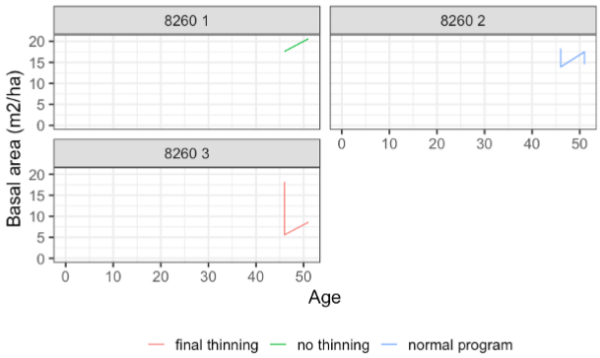


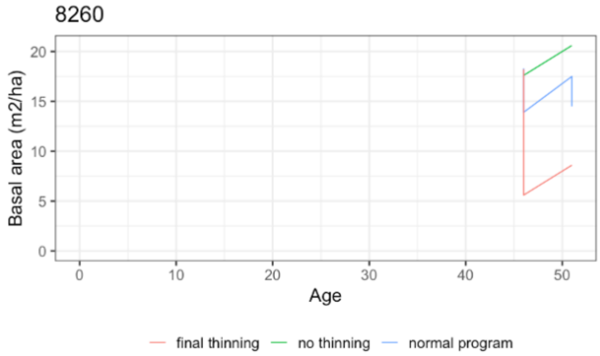


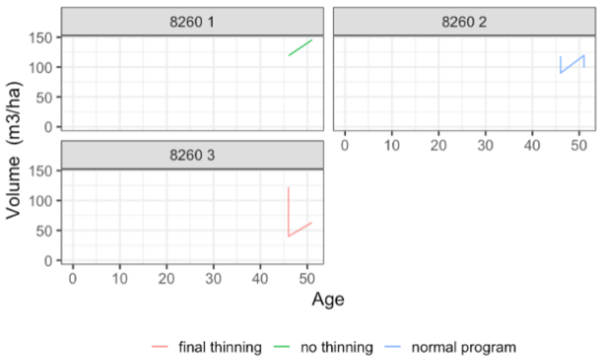
8260 Tönnersjöheden, No thinning, Programme A, One heavy thinning

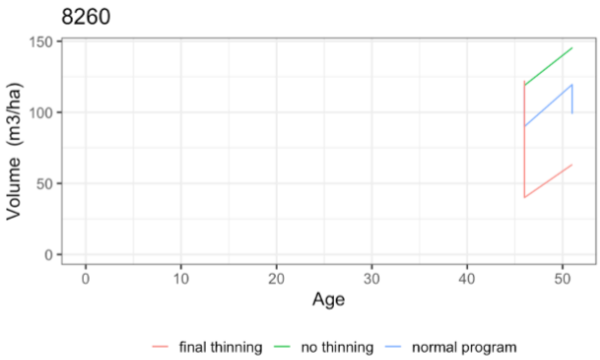


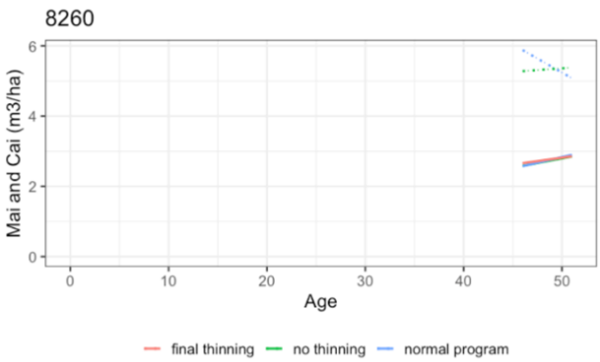












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