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Thinning strategies of birch in Latvia, with application in a newly established field experiment

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Abstract

Birch (*Betula pendula* Roth) is an early successional species which, if grown in suitable soils with wise management, can have high and valuable production. Large-dimension birch-wood is used for saw logs and plywood production, but smaller ones for pulpwood and energy wood.

During the last decades in Latvia, the area occupied by silver birch have been increasing. One of the reasons for that is that forest owners let clearcuts regenerate naturally, as a result, pioneer-species come first and another reason is abandoned agricultural land afforestation.

The purpose of this long-term experiment is to find suitable thinning intensity programs for birch stands with the aim to obtain veneer quality assortment in shorter rotation time. A second aim is to study if manual pruning can be an effective additional treatment to reach the aim of high-quality timber.

The experiment was implemented in south-east Latvia, in 14-years-old birch stands, which have been artificially regenerated by planting on former agriculture lands.

The chosen experimental design was randomized complete block (RCB) with split plots and 5 m wide buffer zone around. Each experiment consisted of six plots and six different thinning treatments that were randomly assigned to plots. The plots were split in half and in one half of the plots branches were pruned while trees were unpruned on the other half.

After first thinning quadratic mean diameter and quadratic mean height for remaining trees did not show statistically significant differences between treatments. However, basal area and volume differences between treatments were significant. Removed volumes varied considerably between various treatments; removed basal area and volume varied between 16% – 65% of initial basal area and volume dependent on treatment.

Key words: silver birch, abandoned agriculture land, thinning, pruning, design.

Contents

1. Introduction

A few decades ago it was considered that birch is a "forest weed" with low economic value. The main reason was that the application was not found and therefore the demand for the birch-wood was low (Araminiene, Varnagirytė-Kabašinskiene, 2014). However, today the situation is completely different. Currently, in the boreal zone birch is economically the most important deciduous tree (Hynynen et al., 2009). Smaller dimension trees are used for cellulose needs and larger dimensions are used for plywood production (Liepiņš et al., 2013).

In Latvia, the area occupied by birch is increasing. In 1966, the birch area was 24% (Tauriņš, 1969), whereas in 2014, birch occupied 30.8% of total forest area according to the State Forest Service. One of the explanations of this increase is that, especially in private forest owned forests, after clearcuts naturally regeneration dominates as a result early succession species taking over the stands (Beķeris, 2015). Another reason is that abandoned agricultural lands areas increase. One part of these lands are overgrown naturally by pioneer species, especially, by birch and alder but other part of abandoned agricultural land is afforested artificially with birch seedlings. In particular, forest companies are practicing afforestation. For example, in 1996 Join Stock Company Latvijas Finieris started an afforestation program with the aim to afforested abandoned agricultural land with birch seedlings and later taking appropriate silvicultural treatment for high quality timber production (Liepiņš et al., 2013).

Swedish company Skogsällskapet is one of the largest private land-management company in Latvia and manage around 7 500 ha forest stands. On this land, birch as dominant species occupies not only the largest part of land approximately 3 500 ha (47%), but also gives the greatest total volume 471 000 m^3 (54%) (Skogssällskapet.com). Because of this significant volume of wood and promising potential of birch in Latvia, it is important find out appropriate silviculture program so that birch stands with as high quality as possible can be created.

1.1. Birch, general characteristics and site requirements

The genus *Betula* L. consists of approximately 120 species. The area of distribution is the Northern Hemisphere's temperate and boreal zones (Mauriņš, Zvirgzds, 2009). In Latvia, four birch species are growing naturally: dwarf (*B. nana* L.), low (*B. humilis* Schrank), silver (*B. pendula* Roth) and downy (*B. pubescens* Ehrh.) birch. But only the last two species are used in economic forestry (Zviedre, Mangalis, 2003). Over the years, Finnish researchers have confirmed that downy birch shows 30% lower productivity than silver birch. Therefore, more is invested in silver birch research and the development of genetically improved planting material than for downy birch (Hynynen et al., 2009).

Silver birch (*B. pendula* Roth (syn. *B. verrucosa* Ehrh.)) is a medium size deciduous tree with straight and slim trunk. For the first six years of development the bark is brown with many lenticels. For up to 15 – 20 years, bark is smooth and silver-white. Later on, dark vertical fissures appear in the lower part of the trunk up to 1.2 – 1.5 metres.

The crown shape is oblong or narrowly egg-shaped. The branches are thin, loony and hanging (Mauriņš, Zvirgzds, 2009). The new shoots are brown, shiny and covered by bright dwarts (glands) (Liepiņš et al., 2013; Atkinson, 1992). The shape of leaf can be triangular or egg-shaped rhombic with long, peaked tip and double, serrated edge.

The root system is plastic and in the first years a taproot is formed with wide network of lateral roots. The roots are characterised by a strong mycorrhiza association (Mauriņš, Zvirgzds, 2009).

Birch is monoecious. Winged fruits are small, light and ripen at the end of July and early August. In Northern Europe, abundant mast-years occur each second- or third-year. Birch regenerate also vegetative by coppice (Hynynen et al., 2009).

High volume and quality timber can be reached under certain growing conditions that are suitable for a specific tree species, because then it can efficiently satisfy physiological requirements and be able to keep vitality and competitiveness, thus doing appropriate management is possible to get high productivity. For silver birch, sandy loam, light and medium mechanical composition loamy soils are described as one of the most suitable (Zviedre, Mangalis, 2003), where humidity level is even whole year, because silver birch is very sensitive to ground water fluctuation (Mauriņš, Zvirgzds, 2009). Clay and clay loam soils are too dense for successful development (Sutinen et al., 2002). Silver birch productivity also depend on the amount of minerals in the soil, mainly nitrogen, phosphorus, calcium, potassium and magnesium. Podolytic sandy soils are characterized by poor mineral content, which means that birch growth will be low (Daugaviete et al., 2013).

Like most deciduous trees, birch also is a soil enhancer. In spruce stands, litter decompose slowly, creating mor humus with acid reaction and characteristic podzolification process. But if birch is introduced after the felling of spruce, then over the time mor humus changes to the mull humus. This can be explained by the fact that birch litter decompose faster and it is richer with calcium, nitrogen, magnesium, potassium and cellulose (Kāposts, 2005).

1.2. Silviculture programmes for birch in Latvia

The silviculture program for birch stand should be planned to promote growth of target trees but at the same time obtain high quality timbers.

1.2.1. Goal for the production – timber quality requirements

The most valuable assortment of birch round logs is veneer. The veneer quality requirements may vary depending on the end product. According to the internal and external birch log quality requirements standarts, the veneer is divided into A or extra class veneer, for which requirements are stricter and class B veneer, which is lower quality, but also the price per cubic meter is lower compared to extra class.

When calssifying birch logs the following traits are taken into account: branches, cracks, buttress, crookedness, double top, double pith, bark pocket, rot and decay, mechanical damage, inclusion of metals, burnt wood.

Sound knots up to 4 cm may be present for both the A and B class veneer logs. Rotted knots, dead knots and spike knots are not allowed for the A class, but are acceptable for class B with requirement that the diameter and / or height of the branch does not exceed 4 cm.

Heart and drying cracks, what start at the heart pith and move to sapwood, length can not exceed 7 cm in order to be included in extra class. But for class B it is important that these cracks do not split logs lateral side. Ring cracks along the annual rings are acceptable, but can not exceed more than 180 degrees.

For both A and B felling and crosscutting cracks are allowed with requirement that those are not affecting peeling cylinder, but cracks that are formed from frost and lightning are not allowed at all.

The buttress is permitted outside the peeling cylinder and / or if the angle between the grooves is greater than 90 degrees. If the angle is smaller, the groove depth can be up to 5 cm.

Such defects as stem crookedness, partially or completely grown bark in wood, mechanical damages are only allowed outside peeling cylinder.

Double top, double pith, rot and decay, inclusion of metals, burnt wood are not allowable neither for class A class B veneer.

Sapwood discoloration or heartwood is allowed for both classes of veneer, however only the diameter of heartwood may not exceed 1/3 of the tree diameter (AS Latvijas Finieris).

Based on the obtained results about the quality of veneer logs in Latvia the main conclusions were that 75% of the veneer logs meet the requirements of quality class A, while 20% meet the requirements for class B, and only 5% have been rejected. The main reasons why the veneer log does not fit into class A or B is, firstly, crookedness (48%), rotted knots (15%) and diameter or length outside the requirements (Līpiņš, 2002).

It is good to remember that stand quality is related and/or depended from genetical, ecological factors and silviculture measures (Zālītis, 2006).

1.2.2. Stand establishment

The Latvian State Forest Service statistics for 2016 show that 92.6% (10549.71 ha) from the total area occupied by birch is naturally regenerate, and only 7.4% - by planting (VMD, 2018). This tendency can be explained by the fact that the establishment of birch stands require necessary agrotechnical tending and protective measures, which means large investments, while natural regeneration does not require any initial costs.

Naturally, birch is able to regenerate by seeds or by producing stump sprouts. According to Forest Law the minimum required amount of naturally regenerated seedlings after clearcut is 2000 seedlings per hectare, but for plantations it is lower, only 800 seedlings per hectare (Meža likums, 2000).

1.2.3. Early tending

Latvian legislation does not regulate to do agro – technical tending, what is removal of competing vegetation around the new seedling. Usually grass is removed in a 50 cm radius around the plant using a brushcutter. Thereby promoting the survival and growth of the seedlings. It is recommended on fertile soils in the first year after planting to carry out agro - tending at least 3 - 4 times during the vegetation season. In the second and third year 2 - 3 times, but in the fourth and fifth year 1 time (Liepiņš et al., 2013).

1.2.3.1. Pre commercial thinning

Latvian legislation defines as mandatory requirement that pre commercial thinning should be done when the average tree height is from 2 to 10 meters. But when stand reaches ages 10 years, pre commercial thinning is already overdue. After pre commercial thinning, the number of trees per hectare should not exceed 3200 - 3000 trees, but should not be less than 1500 - 1200 trees per hectare (Meža likums, 2000).

1.2.3.2. Pruning

In Latvia pruning is not a common practice and is not regulated by Forest Law, it is more a forest owner's initiative. For the planted birch stand, tree pruning is recommended to be done at the same time as the first commercial thinning. It is when the trees have reach a height of 12 m and the DBH is 8 - 10 cm. Pruning should be carried out only for 400 - 500 selected target trees which will be retained until the final felling. Latvian studies report that 6 m is optimal height for birch to be pruned. Because higher trees are technologically complicated and expensive to prune (Liepiņš et al., 2013).

1.2.4. Thinning programme

Latvian legislation does not impose a mandatory requirement on the forest owners to carry out commercial thinning. The choice of performing and frequency of thinning is depending on the vision of the forest owner. It should only be taken into account that the amount of retained basal area in the stand after thinning must not be less than the minimum basal area specified in the Forest Law.

According to Join Stock Company Latvia State Forest thinning models for forest land recommend to do first thinnings when birch stands reach about 11 m height (AS Latvijas valsts meži, 2008)

According to research in Latvia on fertile agriculture soils for planted birch stands the first commercial thinning should be done when birch reaches approximately 12 m dominant height, at age of 10-12 years, leaving 1000 to 800 trees per hectare. The second commercial thinning is recommended at a stand age of 22-24 years. Stem number at final felling is 400 – 600 trees per hectare, with an approximate rotation age of 40 years (Liepiņš et al., 2013). Also *Zālītis 2006* confirm that thinning should be done at age 9 – 13 reducing the number of trees to 1000 trees per hectare thus providing greater growth increase later.

1.2.5. Rotation and production

It is allowed to cut clear cut birch stands, if the stand has reached the appropriate age or a certain target diameter at breast height. Under good growing conditions stand have to be at least 71 years old, but on the poor sites 51 years. Depending on the growing conditions, the required target diameter ranges from 31 cm to 27 cm.

In Latvia, the total volume yield of birch widely varies from 224 $m^3\ ha^{-1}$ to 301 $m^3\ ha^{-1}$. On the mineral soils, the yield is considerably larger than in drained and non-drained stands. Artificially regenerate birch stands at age 60-70 is expected to reach 10-15% larger yield than if the stand is naturally regenerated (Zviedre, Mangalis, 2005).

2. Objectives

The research subjects are silver birch (Betula pendula Roth) stands on agriculture lands. The aim of this study is, firstly, to discuss how well management of birch is underpinned by research. Secondly, to analyse how well a newly established long term thinning experiment is designed to give novel insights on how to manage birch in Latvia. Some forerunning result from the experiment will also be shown.

3. Materials and methods

3.1. A literature review

The analysis of literature was based on the current studies of birch management, thinnings and prunings, which would be useful and relevant for evaluating the Latvian management of birch on agricultural land. Literature was mainly searched in Latvia and in neighbouring countries with similar growing conditions.

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3.2. A long term thinning experiment

The newly design of the experiment in field was established between 24th of February to 10th of March, 2018 in forest management company Skogsällskapet properties. Six different thinning intensity programs for birch stands were applied. As well manual pruning was carried out as an additional treatment. Thinning was done between 10th to 19th of March, 2018. Pruning was carried out on 6th of October in 2018 and done using pruning shears (scissors) for the bottom part of stem and with a pruning saw with telescopic pole for upper part. Pruning was made up to 4 m. The company Skogsällskapet will take care of the future development of the experiment.

3.2.1. Sites selection criteria

Stands used in the experiment were selected, firstly, based on current inventory data and then inspection in the field. The selection criteria were:

-birch stands that are growing on abandoned agricultural land;
-stand regenerated artificially;
- no previous commercial thinning;
-without serious frost, snow, wind or animals damages;
-relatively homogeneous;
- at least 1 ha.

3.2.2. Description of the selected experiment sites

The experiment was established on three sites located in south-east Latvia, in Ludza regional community (Figure 1). All three selected birch stands were 14 years old, and artificially regenerated by planting on former agriculture land.

The first site was in property Skaistuli, located in Istra rural municipality (x=242118.858, y=748012.311) Soil is described as dried peat soil. Drainage ditch is located approximately 10 meters from the experimental plots.

The second site was choosen in property Mallepes, Rundenu rural municipality (x=238943.852, y=735312.286). Stand was on dry mineral soil.

The third experiment site was in property Vilki, Istra rural municipality (coord. x=29615.110, y=741134.911). In property Vilki soil was also described as dry mineral.

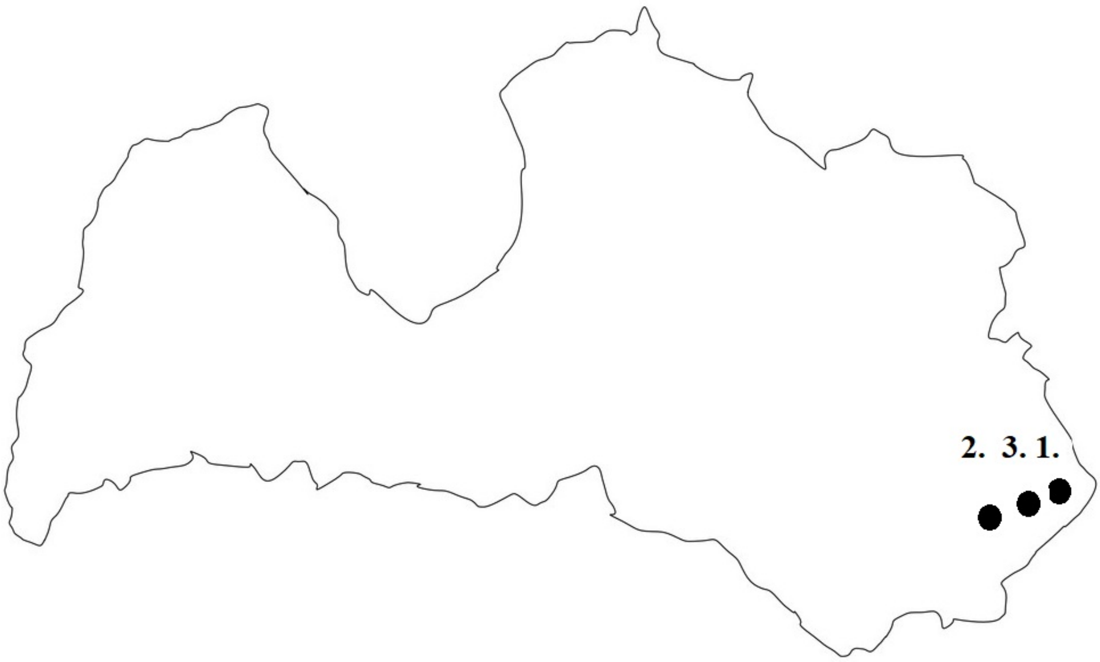

Figure 1. Location of experimental sites:
1. - Skaistuli; 2.- Mallepes; 3. –Vilki

3.2.3. Measurements of stands parameters

All measurements were performed before thinning. Diameters at breast height were measured by calliper in one direction for all trees in each plot. After calipering all trees, trees to be retained after thinning were chosen. These trees were marked, permanently numbered and diameter at breast height were measured in two perpendicular directions.

Four sample-trees among retained trees were selected, one from smaller, two from middle and one from larger diameter class for each plot. For these four trees, total height, height of the first green branch, height of first dead branch and diameter of the five branches closest to breast height were measured.

Among trees that have been selected to be retained, one half were selected and marked for pruning.

3.2.4. Description of the main parameters before first commercial thinning

On the first site in property Skaistuli the basal area weighted height (Hgv, m) of trees ranged between 12.3-13.3 meters and the quadratic mean diameter (Dq, cm) at breast height varied between 10.3- 12.9 cm. Mean basal area (Ba, m^2h^{-1}) was 11.9 m^2ha^{-1} and varied between 9.9-13.2 m^2ha^{-1}. Stem volume (Vol, m^3ha^{-1}) varied between 59.2-81.1 m^3ha^{-1}.

For the second site the mean diameter ranged between 9.3-11.9 cm and the height between 12.0-12.9 m. Mean basal area was 10.0 m^2h^{-1} and varied between 7.9-11.5 m^2h^{-1}. Stem-volume ranged between 45.6-68.6 m^3ha^{-1} with an average value 58.3 m^3ha^{-1}.

On the third site in property Vilki the diameter at breast height ranges between 10.4-11.3 cm and height varied between 12.4-12.7 m. Mean basal area was 11.0 m^2h^{-1} with a variation between 8.9-12.6 m^2h^{-1}. Stem-volume ranged between 52.4-76.0 m^3ha^{-1} with an average value of 65.6 m^3ha^{-1}.

Table 1. Sites mean parameters before commercial thinning in 2018

Site	Plot	Tree number ha^{-1}	Dq, cm	Hgv, m	Ba, m^2h^{-1}	Vol, m^3ha^{-1}
1	3	1067	12,4	13,0	12,9	79,1
1	1	1033	12,2	13,0	12,1	73,4
1	2	1000	12,9	13,2	13,2	81,1
1	6	1083	10,8	12,5	9,9	59,2
1	5	1267	11,4	12,7	12,9	77,6
1	4	1283	10,3	12,3	10,7	63,4
2	5	1483	9,5	12,1	10,5	60,5
2	3	1333	10,5	12,4	11,5	68,2
2	4	1267	9,6	12,1	9,3	53,8
2	1	1167	9,3	12,0	7,9	45,6
2	2	1267	9,6	12,2	9,2	53,0
2	6	1017	11,9	12,9	11,3	68,6
3	6	1133	11,1	12,6	10,9	65,0
3	3	1050	10,4	12,4	8,9	52,4
3	5	1167	11,2	12,7	11,4	68,1
3	2	1150	10,6	12,4	10,2	61,3
3	1	1317	10,7	12,5	11,8	70,2
3	4	1267	11,3	12,7	12,6	76,0

3.2.5. Tree selection criteria for first commercial thinning

In all treatments the same tree selection criteria for removal of trees were applied:
-to try to evenly distribute trees, i.e., to make uniform distances between trees;
-to remove damaged, diseased trees (IV and V Kraft classes trees);
-to remove the largest trees from Kraft class I, with inferior stem quality and heavily competing with adjacent trees from Kraft classes I, II.

Thus, the idea is to combine thinning from below, promoting the dimension development, with selective thinning to enhance the the timber quality.
 (Hynynen et al., 2009; Prindulis et al., 2013). Thinning from above essential reduces production (Fujimori, 2001) and is not included in the study.

4. Results and discussion

4.1. Is the the management programme for birch relevant?

4.1.1. Stand establishment

Latvian research suggests for birch plantations a number of seedlings between 1600 to 2500 trees per hectare, lower density is not recommended, because some trees in the plantation may not survive. Although lower density of seedlings is associated with lower establishment costs, however the competition between trees in such density is low, which contributes not only the development of larger dimensions but also formation of thicker branches and poorer self-pruning (Liepiņš et al., 2013).

When establishing birch plantations on abandoned agriculture land it should be taken into account the high density of grass, shrubs and compacted, poorly aerated soils. In such circumstances it is recommended to do soil scarification and choose birch seedlings that is larger in size (Liepiņš et al., 2013). Compared to other types of plant material, plug+1 (combination of containerized-seedling and bareroot growing technologies) seedlings have shown the highest growth rate when planted on abandoned agricultural lands (Liepiņš, K., Liepiņš J., 2009). Also Finnish literature says, that planting seedlings is the most effective method of regeneration on agriculture land, because seedlings are able to compete with high a vegetation density, of course, tending is needed in the next years (Hynynen et al., 2009).

4.1.2. Early tending

4.1.2.1. Pre commercial thinning

Potential future target trees are selected already in pre-commercial thinnings, when good trees are retained in a uniform (regular) spatial position, providing good growing conditions. In very dense young birch stands (in the interval from 1 500 to 5 000 stems ha^{-1}) volume of Kraft classes I, II (dominant, codominant trees) do not increase but instead volume move on Kraft classes IV and V. Therefore, early pre-commercial thinnings are important in order to obtain good dimensions and a high yield as well it can reduce the risk of snow break. When over-densed stands reach and exceeds an average height of about 10 m pre-commercial thinning could be already too late, because reaction of selected future trees will be insignificant at least in the next 12 years (Zālītis, 2006). Other literature says that pre-commercial thinning should be done before birch trees reach 5 or 7 m in order to decrease initial density and competition, leaving from 1 600 to 2 500 stems per hectare (Hynynen et al., 2009; Rytter, Werner, 2007).

4.1.2.2. Pruning

In birch stands with a low tree density, slower and longer self-pruning as well as lack of mechanical stresses on the lower branches will promote thicker and more frequent branches (Schatz et al., 2008), also a greater tapering have been observed (Stener et al., 2017). But more important than living branches, one of the main wood-quality indicator is knottiness. In many cases logs with healthy knots are acceptable, but not spike, decayed and dry knots, because they reduce mechanical strength of the wood (Luostarinen, Verkasalo, 2000). One of the solutions of knottiness is manual (artificial) pruning.

One disadvantage with pruning is that height and diameter growth may be reduced for a couple of years after the treatment, but the reduction intensity depends on how big part of green crown that is pruned (Schatz et al., 2008, Stener et al., 2017). It is important to remember that faster growth is ensured if the proportion of living tree crown is at least 50 percentage of tree height (Hynynen et al., 2009).

Because of self-pruning, the butt log can be free of living branches up to 5-7 m, if the stand density is around 1500 trees ha^{-1}. Thus, artificial pruning is not necessary until first commercial thinning. In another Finnish study, the first pruning was done in a 20 years old birch planation with average height 9.7 m and average diameter at breast height - 10 cm (Vartiamäki et al., 2009). In Sweden planted birch monoculture was pruned at age 9 and 10 years (Stener et al., 2017). Latvian research show that it is not profitable to prune birch stands on fertile soils with DBH more than 11 and 13 cm. In addition, in a study where 60% of the length of the trunk was pruned (average height of tree 9 – 12 metres), neither diameter growth or height growth decreased significantly. Although the diameter increase was slightly lower during the first year after pruning, it was similar to less heavily pruned trees the following years (Liepiņš et al., 2013).

Various studies show that the most appropriate time for pruning is from early mid-summer until late winter, because then sap transportation is inactive and wounds healing is fast (Vartiamäki et al., 2009). In autumn, the bark is stronger than in spring, which means that there is a lower risk to get bark injuries (Bobik, 2008).

In addition, it is important to avoid pruning large diameter branches, because thicker branches heal up more slowly thereby increasing the infection risk. Recommended maximum diameter of the branches varies between 1.5-3 cm (Vartiamäki et al., 2009; Schatz et al., 2008).

According to the general recommendations branches should be pruned as close to the bud collar as possible without damaging it and without leaving any residual stub (Hynynen et al., 2010; Stener et al., 2017). A saw can be the first choice used for pruning, because it shows higher productivity than pruning scissors or secateurs (Liepiņš et al., 2013). However, it is also advocated that a pruning secateur is better than a saw, because a saw may create a wider and rougher cross section surface, which makes it easier for bacteria and microbes to penetrate into wood tissue (Schatz et al., 2008).

One of the risks, what affect birch internal stem quality, is discolouration, which has been observed more frequently for pruned trees than for unpruned trees. The discolouration mostly affects the wood inside the knot, but not knot-free wood. Although, if the diameter of the pruned branch is small and pruning is done correctly, then the risk of defect is reduced. But occurrrence of stem-rot and ingrowth bark does not differ between pruned and unpruned trees (Stener et al., 2017; Vartiamäki et al., 2009).

4.1.5. Thinning programme

The main aims of thinning are, firstly, to remove low quality stems, which will improve growing conditions (reduce competition) and quality of the remaining stand, secondly, to cut merchantable trees for an income.

First thinning should be carried out while the living crown ratio of the dominant trees is at least 50% or more. Initial thinning should be strong, promoting long green crowns and increased diameter growth. Fast diameter increment will not reduce wood quality (Hynynen et al., 2009; Heräjärvi, 2001). If the stand is too dense and thinning is delayed, the trees become slender and unstable (gangling), because diameter growth decreases before height growth. Slender trees are more susceptible to strong wind freezing rain and snow, which can damage them permanently (Liepiņš et al., 2013; Hynynen et al., 2009).

In Finland the first commercial thinning of silver birch plantations is planned when dominant height is around 13-15 m, then tree density is reduced from 1600 (initially density) to 800 or 700 trees per hectare. The second thinning is planned roughly 15 years later. After two thinnings, approximately 350 – 400 trees per hectare are retained until final felling. If initial density is considerably more than 1600, a third thinning may be required. And, in this case all thinnings should be lighter, but the number of target trees is the same. In general, recommended thinning for birch plantation is two high intensity thinnings removing around 30 to 40 percent of the basal area (Hynynen et al., 2009).

4.1.6. Rotation and production

In Finland, depending on the growing conditions and stand-productivity, rotation age can vary between 40 and 60 years. A naturally regenerated, unmanaged 80-year-old birch stand can reach a volume between 320 m^3 ha^{-1} and 540 m^3 ha^{-1} and the mean annual increment fluctuates between 4 and 6.75 m^3 ha^{-1}. But in 60 years old managed birch plantation total volume in the final stand varies between 360 - 560 m^3 ha^{-1} with a mean annual increment of 6 m^3 ha^{-1} and 9.3 m^3 ha^{-1} (Oikarinen, 1983, Hynynen et al., 2009).

4.2. The thinning experiment

4.2.1. Experimental design

The experimental design is a randomized complete block (RCB) with split plots. On each site, one full block (six plots) were established. Each RCB unit (plot) size was 20 m × 30 m (0.06 ha), and the plots were split in half into 0.03 ha areas. In each RCB-plot, thinning was done according to one of the 6 thinning regimes and in one half of the plot pruning was made while trees were unpruned in the other half. Around each plot, a 5 m wide buffer zone was established. For each site, between plots, one or more 4 m wide strip roads were marked. Plots edges lengths were measured using measuring tape and plots corners were marked with wooden poles. It should be noted that arrangement of plots is different on each site, because of site conditions and tree distribution (Figures 2, 3, 4)

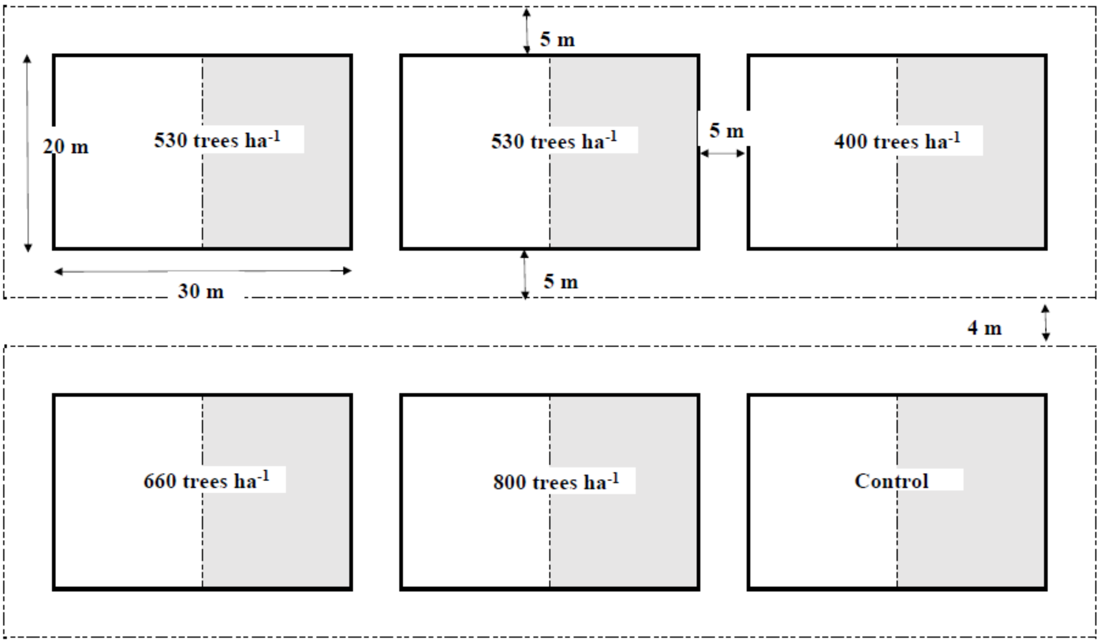

Figure 2. Schematic location of plots in Skaistuli

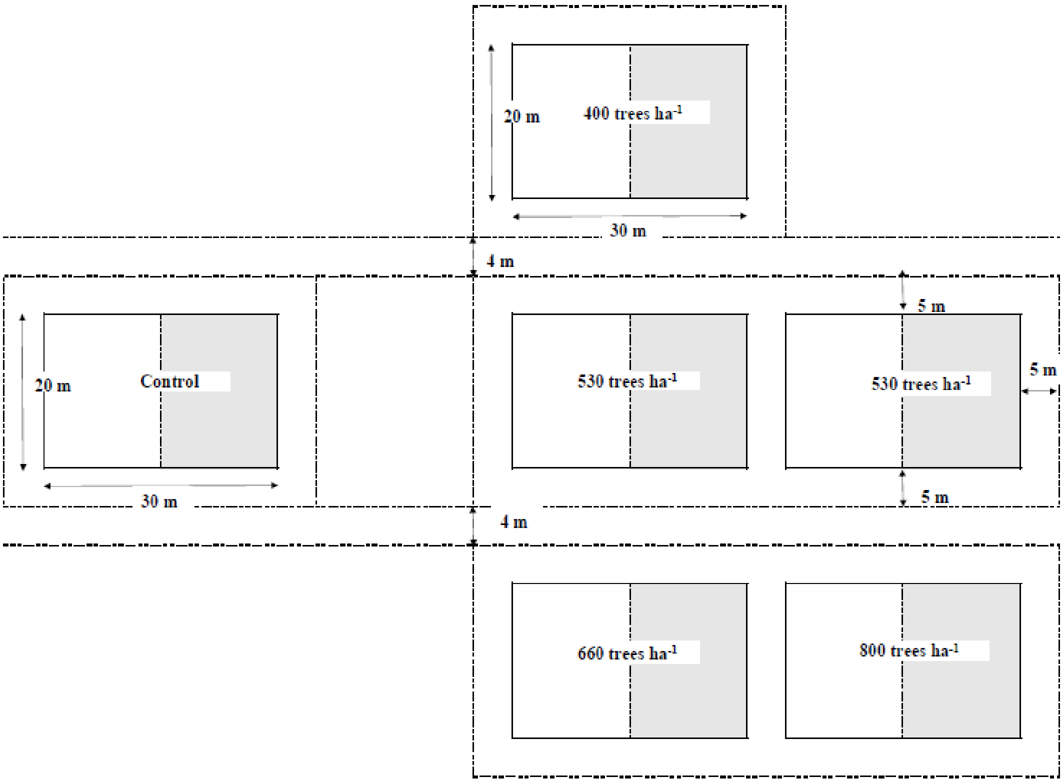

Figure 3. Schematic location of plots in Mallepes

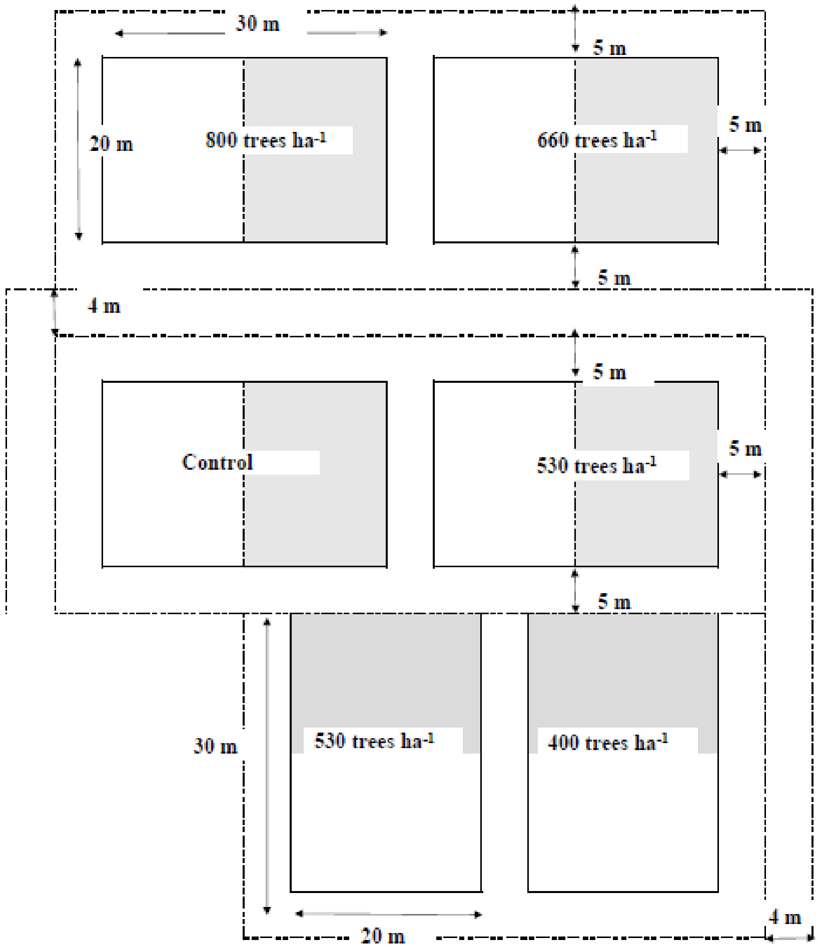

Figure 4. Schematic location of plots in Vilki

Randomized complete blocks (RCB) combined with split plots was chosen as the most appropriate desing. One of the main arguments was that although the selected stands had similar growing condition and productivity, differences between the stands normally occur, for example, different weather conditions, topography, drainage, stem density, previously silvicultural treatments etc. This inequality may increase the experimental error with a risk of biased conclusions (Oehlert, 2010). In this case simple random sampling may be less efficient to minimize the consequences of heterogeneity.

In randomized complete blocks design experiment, units (plots) are sorted into similar groups (blocks) using values of extraneous factor as sorting criteria. In each block, a group of plots with similar background conditions is selected, thus providing homogeneity and also similar response in each block (Quinn, Keough 2002; Oehlert, 2010). In the case of this experiment blocking variable (extraneous variable/nuisance factor) is heterogeneous conditions between stands that may introduce additional variation in data of thinning response. Therefore, site was chosen as block-factor in order to reduce the effect of differences between sites.

Beside the thinning treatment, a pruning treatment was included as a split-plot design. Thinning was the whole plot treatment (factor) and each plot was split up in two smaller plots (sub-plots or split-plots), thus creating a nested desing. In one of the split-plots pruning was performed. Thus, pruning was split-plot treatment (factor) (Oehlert, 2010; Altman et al., 2015).

In general, when establishing experiments, certain resources are often of limited availability, for example, forest-area, labour or number of measurements. When setting up an experiment, we should think of the best way how to get statistically qualitative data with as little resource consumption as possible (Oehlert, 2010). Statistical analysis of experiment is based on comparing variation between treatment groups. To evaluate this variability replications are necessary (Quinn, Keough, 2002). Therefore, the final experimental design will always be a compromise between number of treatments and number of replications.

4.2.2. Replications

Initially the experiment was planned to include four or five replications. However, in the end only three replications were established. The main reason for the reduction of replicates was lack of suitable birch stands as well limited time for establishment of the experiment.

In other thinnings experiments, the selected number of replications have varied. Three replications were used in a thinning and pruning experiment in western white pine (Roger et al., 1981) and in a commercial thinning study in the spruce-fir forest (Gauthier et al., 2015); seven replications were used in a mixed spruce-birch thinning experiment (Repola et al., 2006); ten replications were installed in a long term birch thinning trials (Liepiņš et al., 2013); eight-twelve replications were used in studies of Norway spruce (Picea abies (L.) Karst.) growing on abandoned farmland (Johansson, 1991); 35 replications were used in a thinning experiment in Scots pine (Nilsson et al., 2010). From this we can conclude, that number of replications is closely dependent on available resources but at the same time the obtained results (feature values) must be such that it is possible to estimate the variation in these values, in other words, the results must be statistically reliable**.**

4.2.3. Buffer zone and plot size

Buffer zones are needed in order to avoid border effects, that means, avoid treatments in one plot to have an effect on growth of trees in neighbouring plots. To avoid this effect, the buffer-zone should have the same treatment as the net-plot (where measurements are made). In addition, buffer-zones may reduce the risk of snow damages etc (Ahtikoski et al. 2004; Johansson 1999). Looking at the other thinning experiments in literature the common plot-area is 1000–1600 m^2 (range 500 – 2500 m^2) with 4 to 5 m wide buffer zones for spruce- and birch-experiments (Repola et al., 2006). In Finland for thinning experiments in silver birch stands date were collected from plots with area 700 to 1250 m^2 with 5 m wide buffer zone around (Ahtikoski et al., 2004). But thinning experiment in pine stand employed plots with 1200 m^2 large area and 10 m wide buffer zone (Peltola et al., 2007). Also in spruce thinning experiment around each 1000 m^2 plot was established 10 m wide buffer zone (Johansson, 1999).

In the experiment the pot size 30 m × 20 m (0,06 ha) and split-plots 15 m × 20 m (0,03 ha).

4.2.4. Strip roads

Strip roads potential location was planned and marked **i**n order to avoid damages when extracting wood. It should be taken into consideration that trees that are in 3 m wide zone along strip road are the most exposed to the edge effect, it means, that for those trees growth will increase significantly after strip-roads creation compared with trees further in stand (Eriksson, 1994). At the same time there is a risk that border trees along strip road will be injured during the logging operation. According with Latvian legislation maximum width of strip road in commercial thinning is 4 m and distance between two strip roads is not less than 16 m (AS Latvijas valsts meži, 2008). Therefore, the striproad width was set to 4m.

4.2.5. Thinning treatments

In each block six treatments were randomly assigned to plots (Table 2):

1. Control – unthinned.

2. Retaining 800 trees per hectare after the first thinning. According to Finnish and Latvian studies (Hynynen et al., 2009; Liepiņš et al., 2013) 800 trees per hectare is the number of remaining trees that is normally recommended. Two additional thinnings are planned. Planned rotation length about 45 years.

3. Retaining 660 trees per hectare after first thinning. *Hynynen 1993* created a self-thinning model of even-aged birch stands which shows that 600 trees per hectare is the maximum number of trees in order to reach 25 cm diameter. For this treatment, no additional thinning is planned. Rotation length could be around 40 years.

4. Retaining 530 trees per hectare after first thinning. After 10 years, a second thinning is planned leaving 300 trees ha^{-1}, and after the next 10 years a third thinning will be done - leaving 200 trees per hectare. The idea is to do heavy thinning at the beginning, because the response to thinning is reduced with age. The most significant diameter growth is up to 25 years. The two light thinnings are done in order to increase the stability of the stand. Planned rotation length around 40 years.

5. In the fifth treatment, 530 trees ha^{-1} were retained after first thinning. After 15 years a second thinning will be done leaving 250 trees ha^{-1}. The aim of this treatment is to find out if it is possible to reach the same or better effect as in treatment 4 but with only one additional thinning. Rotation around 40 years.

6. One heavy thinning retaining 400 trees ha^{-1} in order to promote rapid diameter-development on retained trees. But could be a risk for reduced total volume and stability of the stand (increased risk for snow-break and wind-felling) Predictable rotation length around 30 - 35 years.

Table 2. Planned treatments and timeframe for their performance

	1.thinning		2.thinning			3.thinning		
	Remaining trees, (trees ha^{-1})	Pruning yes/no	Interval between 1st and 2nd thinning, (years)	Stem number after thinning, (trees ha^{-1})	Pruning yes/no	Interval between 2nd and 3rd thinning, (years)	Stem number after thinning, (trees ha^{-1})	Rotation length, (years)
1. Trust our Mother Nature. Control	-	-	-	-	-	-	-	-
2. Close to recommendation (T800)*	800	yes	After 10 - 15 years	400	-	After 10 years	300 - 250	45
3. Easy and fast (T660)	660	yes	-	-	-	-	-	40
4. Compromise between volume and quality? (T530a)	530	yes	After 10 years	300	-	After 10 years	200	40
5. Reach large diameters + stand stability (T530b)	530	yes	After 10 - 15 years	250	-	-	-	40
6. Open growth (T400)	400	yes		-	-	-	-	30-35

*T800 – *T* means *Treatment*, *800* – remaining trees ha^{-1} after first thinning

The control had after the first thinning a basal area and volume that was higher compared to other treatments (Table 2). In a longer perspective the un-thinned stand has a higher productivity than different thinning treatments (Repola et al., 2006).

In T800 approximately 800 trees per ha were retained after first thinning. It is the average number of trees found in Finnish and Latvian thinning recommendations (Hynynen et al., 2009; Liepiņš et al., 2013). According to studies in Finland, the mean diameter at breast height increased from 12.2 cm to 18.5 cm, and the volume from 59 m^3 ha^{-1} to 190 m^3 ha^{-1} during the period from the first to the second thinning (Hynynen et al., 2009). In this study, the mean diameter after first thinning was 11.6 cm, but volume – 51.0 m^3 ha^{-1}.

Only one thinning is currently planned for the T660 leaving 660 trees ha^{-1}. Based on current veneer timber market prices, the highest price is for veneer logs with a diameter of 25 cm up to 40 cm and even larger (Meža avīze, 2018). As the tree diameter rises, the price per cubic meter also increases (Dunham, 1989). According to the self-thinning models for even-aged birch stands, maximum stem number per hectare at diameter 25 cm is ca 600 trees per hectare (Hynynen, 1993). Therefore, the thinning treatments should aim less than 600 trees per ha in the final stand. However, this may be achieved by many light thinnings or with fewer heavier thinnings. This treatment with one thinning will improve diameter development but there is a risk for reduced total production. Another advantage is that one thinning and one pruning will not require much effort from the forest owner.

For T530a and T530b the remaining number of trees after the first thinning is 530 trees per ha. According to *Hynynen (1993)* this is the approximately maximum number of trees to reach 26 – 27 cm diameter before severe self-thinning. After 10 to 15 years, a second thinning is planned. In T530a350 trees ha^{-1} will be retained after the second thinning, and 10 years after that, a third thinning will be carried out retaining 250 trees ha^{-1}. The idea behind this treatment is to do one heavy thinning at the beginning, because the response to thinning is greater in young stands than in older stands. By carrying out two light thinning later in the rotation, the stability of the stand is maintained. In T530b, 300 – 250 trees ha^{-1} will be retained already after the second thinning. The aim of this treatment is to investigate if it is possible to reach the same or better effect as in T530a, only here skipping one light thinning.

In T400 only one heavy thinning is planned leaving 400 trees ha^{-1} that will provide larger tree dimensions, but there is a risk of reduced stability of the stand (increased risk by snow, wind etc.) (Kerr, Haufe, 2011). On one hand, wide spacing provides faster growth thus reducing the traditional rotational length, but on the other hand branch diameter increases in the lower part of the stems, because tree competition and mechanical stress on the lower part of the stem are reduced. In addition, total volume per hectare decreases (Niemestö, 1995; Fujimori, 2001) and there is a risk that fast growing trees may be more tapered with reduced wood technical quality compared to light thinning (Dunham, 1989; Niemestö, 1995). Although in a study about effects of heavy thinning (average 390 trees ha^{-1}) in silver birch stands, it is claimed that the impact on wood basic density, grain angle and shrinkage are not significant compared with light thinning or unthinned stand (Cameron et al., 1995). It is also estimated that in heavy thinning, diameter increment is about 25% larger than for light thinning (average 895 trees ha^{-1}), but when converted to volume, the difference is 58%, on tree level. Plantation birches have shown lower wood density than trees that have grown on forest land (Möttönen, Luostarinen, 2006; Liepiņš, Rieksts – Riekstiņš, 2013), since naturally regenerated birches had thicker walls of vessels and fibres than artificially planted trees. In turn, this will reduces the strength of the wood (Luostarinen, Möttönen, 2010).

In all treatments, the planned rotation-length is about 40 years. According to *Hynynen et al. (2009)* silver birch keeps its vigorousness until it reaches 40 – 50 years and then it declines. But culmination of height and volume growth is achieved at the ages of 10-25 years. However Latvian study says that culmination of height growth is observed when stand reach 15 to 20 years (Zālītis, 2006).

4.2.6. Pruning treatment

In this study, stem density fluctuated between 1017-1280 stems ha^{-1} in the control plots. In young stands with higher stem density, the diameter of branches is smaller and with canopy closing, the branches at the bottom of trunk get dry which results in self-pruning (Makinen et al., 2003). However, at the later stage of development, high density may reduce the intensity of self-pruning, because diameter-growth decreases (Niemistö, 1995).

Branch characteristics are similar in unthinned stand and in stand where light thinning has been carried our (Cameron et al., 1995). Although larger diameters of green and dead branches have been observed in thinned stand. But on the other hand, trees in unthinned stand have smaller branch scars, which is explained by tree competition and early self-pruning.

As one of the main disadvantage of heavy thinnings, in this study treatments with 530 and 400 trees per ha^{-1}, is that with the rapid diameter increase diameter of branches also increase and self-pruning is reduced (Cameron et al., 1995; Niemistö, 1995).

In this study after first thinning, the mean diameter ranged from 10.3-14.0 cm. According to the literature, trees of these dimensions for the first pruning are too large to produce completely knot-free wood. This is based on the fact that in plywood production, the diameter of the core, what is left after timber peeling is around 6 - 8 cm (Walker et al., 1993). This size of diameter is reached at height of 7 - 8 metres under good growth conditions (Liepiņš et al., 2013). It has also been found that pruning should be carried out before trees reach 10 cm diameter at DBH (Skovsgaard et al., 2018). The average height at pruning ranged from 12.3-13.5 m, which, based on other experience, is too high for pruning. In Finland, first pruning is carried out when birch reach 6–7 m height and are pruned up to 2.5–3 m height. The second pruning is done when the tree height is about 10 m, and pruning is done up to 5-6 m (Hynynen et al., 2009). The first 4 metres were pruned, which considering the average height of the trees, is approximately 1/4 from the trunk. There is a view that pruning has an economic effect if the proportion of pruned and unpruned trunk is at least 2,5:1 (Liepiņš et al., 2013).

4.3. Some forerunning results

4.3.1. Mathematical processing of collected data

For each plot particular stands parameters have been calculated:

- Stand basal area (Ba), m^2 ha^{-1}
- quadratic mean diameter, cm

$$D_{ba} = \sqrt{\frac{4 \cdot Ba}{\pi \cdot N}} = \sqrt{\frac{\sum di^2}{N}}$$

where N – number of trees per hectare.

- Basal area weighted mean height (Lorey's mean height), m

$$Hgv = \frac{\sum ba \cdot h}{Ba},$$

where h – sum of tree height for each tree, using a Näslund height function that was constructed from all sample-trees in all sites. The height function was:

$$h = \frac{dbh^2}{(0.500655 + 0.250249 \cdot dbh)^2} + 1.3$$

A secondary volume function was calculated using estimated volume of sample-trees. The secondary volume-function was:

$$V = \exp(-8.22011 + 2.22532 \cdot \ln(dbh)).$$

4.3.2. Quadratic mean diameter, quadratic mean height, basal area and volume

The results were summarized from all three sites and mean values were calculated. Before first thinning, the initial quadratic mean diameter (Figure 5) was larger for T530a 11.3 cm and control 11.2 cm, but the smallest for T660 10.2 cm and T800 10.6 cm treatments.

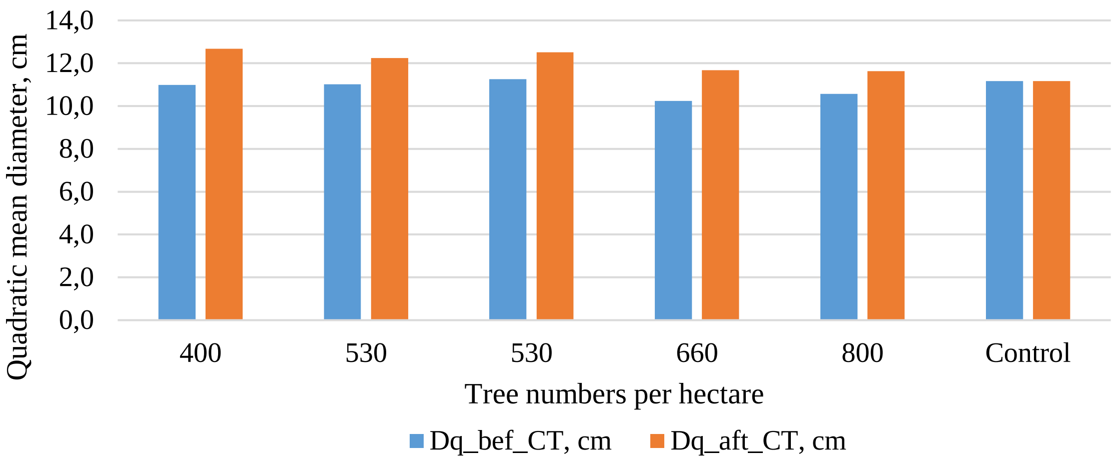

Figure 5. Comparison of **quadratic mean diameter** before and after first commercial thinning under different thinning intensities

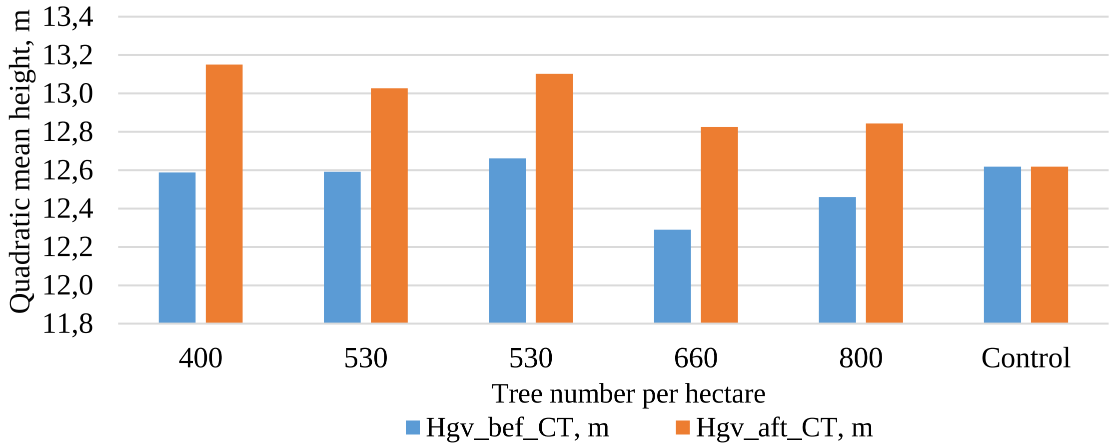

Figure 6. Comparision of **mean quadratic height** before and after first commercial thinning under different thinning intensities

After first commercial thinning both quadratic mean diameter and quadratic mean height increased for all active treatments. In T400 the quadratic mean diameter showed the greatest increase by 1.7 cm (15.3 %). But for T800 and T530a treatment diameter increase was the smallest 1.1 cm (10%) and 1.2 cm (11.1%), respectively.

Initial quadratic mean height (Figure 6) fluctuated from 12.3 m to 12.7 m. After the first commercial thinning the largest increase were 0.6 m (4.5 %) in T400 and 0.5 m for T530b. For the other treatments 0.4 m.

Basal area and volume showed were negativel correlated with the removal of stems per ha (Figure 7, 8).

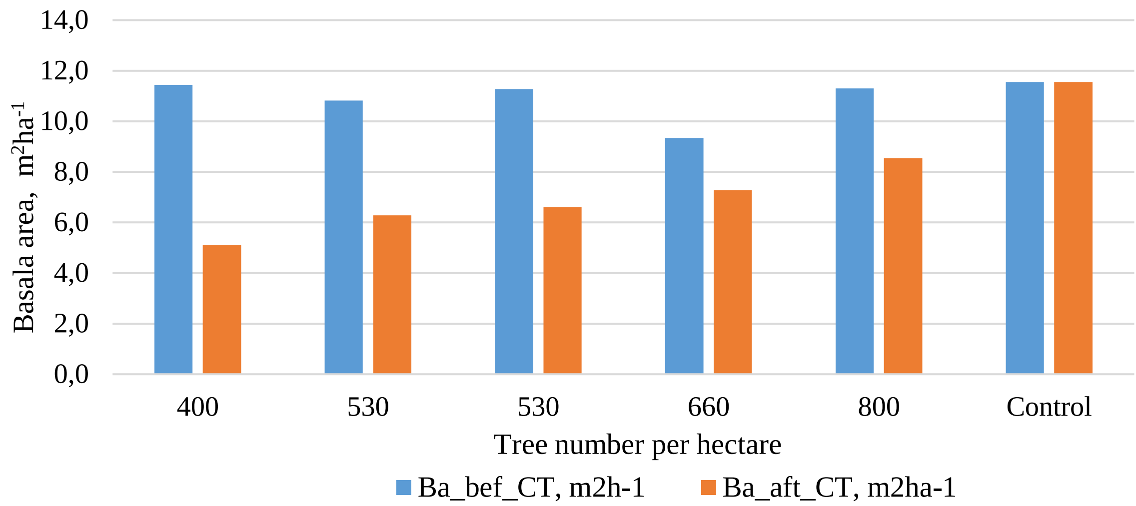

Figure 7. Comparision of **basal area** before and after first commercial thinning under different thinning intensities

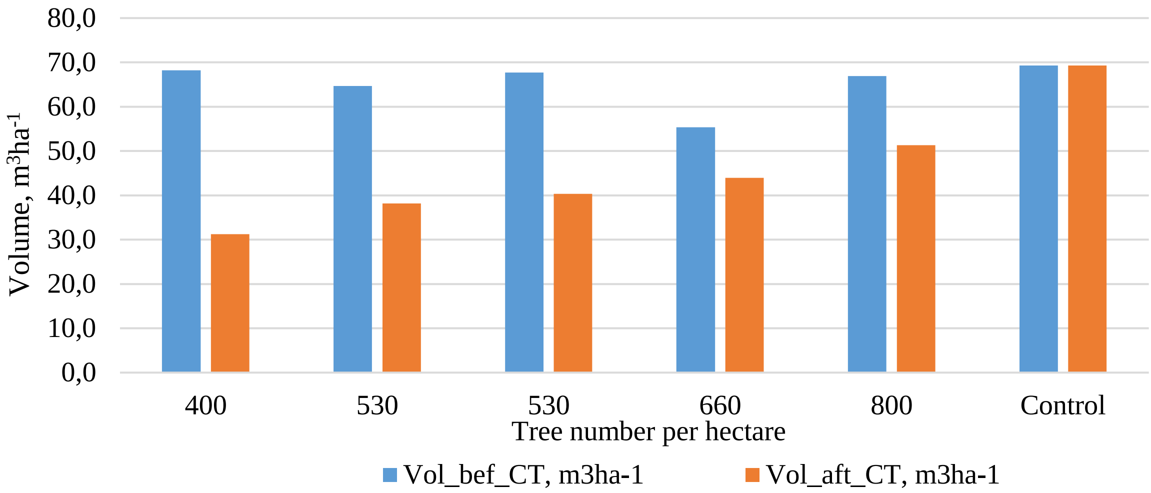

Figure 8. Comparision of **volume** before and after first commercial thinning under different thinning intensities

Before first thinning was carried out the lowest mean basal area and volume was found in T660 (9.3 m^2ha^{-1} and 55.4 m^3ha^{-1}, respectively), but larger - for control (11.6 m^2ha^{-1} and 69.3 $m^3ha^{-1)}$. The highest proportion of removed basal area (6.3 m^2ha^{-1} or 55.4%) and volume (37.0 m^3ha^{-1} or 54.3%) was in T400. In T600 the removed basal area (2.1 m^2 ha^{-1}, 22.0 %) and volume (11.4 m^3ha^{-1} or 2.1 %) was the lowest.

4.3.3. Branch characteristics

The largest and average branch diameters after thinning (Figure 9, 10) increase with increasing tree diameter at breast height. The largest proportion of branches with larger and average diameters vary between 6 and 10 mm. The largest branch diameter 21.5 mm were found at DBH 10.2 and 18.8 cm. It is noticeable that the thickest branche diameters show quite big distribution over DBH. This indicates that high quality trees, with small brances can also be found among the biggest trees.

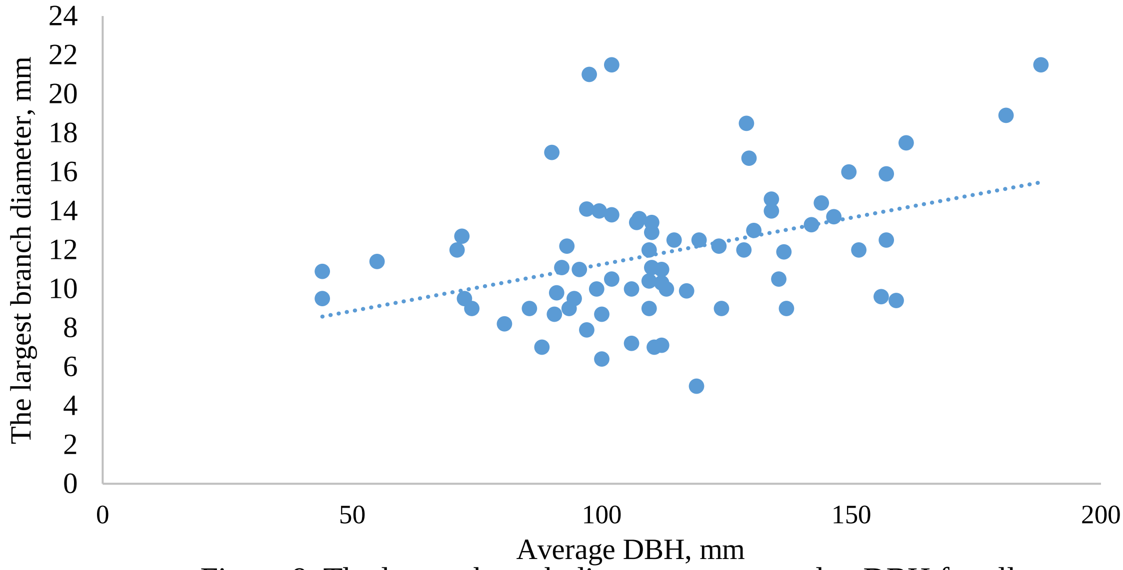

Figure 9. The largest branch diameters measured at DBH for all treatments and control, after thinning

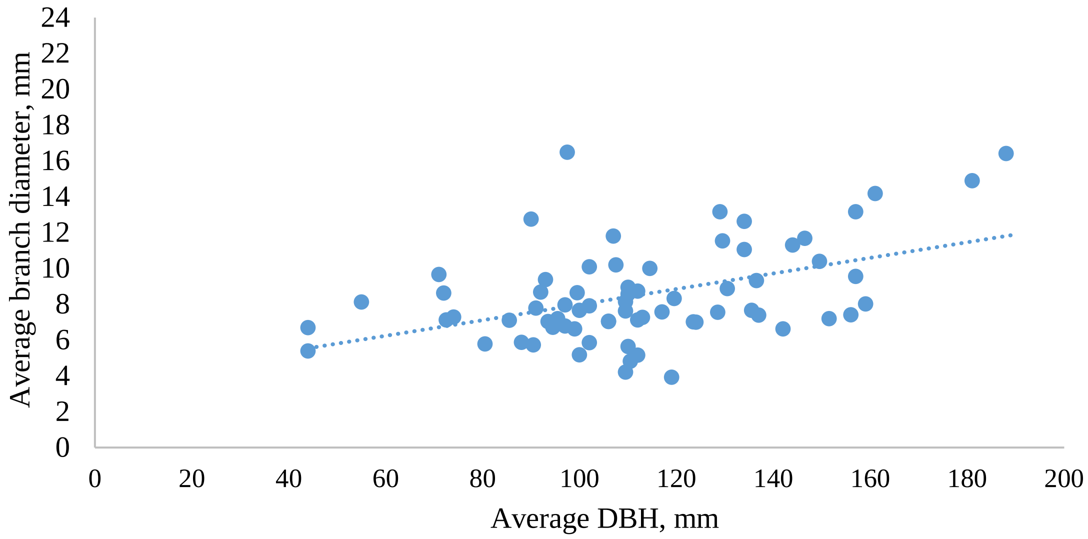

Figure 10. Average branch diameters measured at DBH for all treatments and control

Average of the largest branch diameter (Figure 11) were found for T400, but the lowest for T800, 12.7 mm and 9.8 mm respectively. What could be explained by the fact that after heavy thinning larger diameter trees are left, but for larger trees are typical thicker branches.

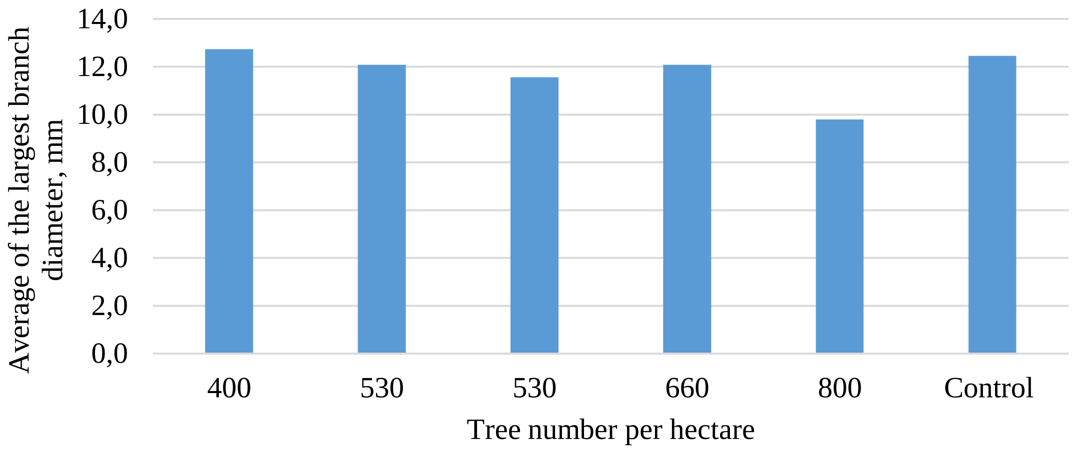

Figure 11. Average of the largest branch diameters under different thinning intensities

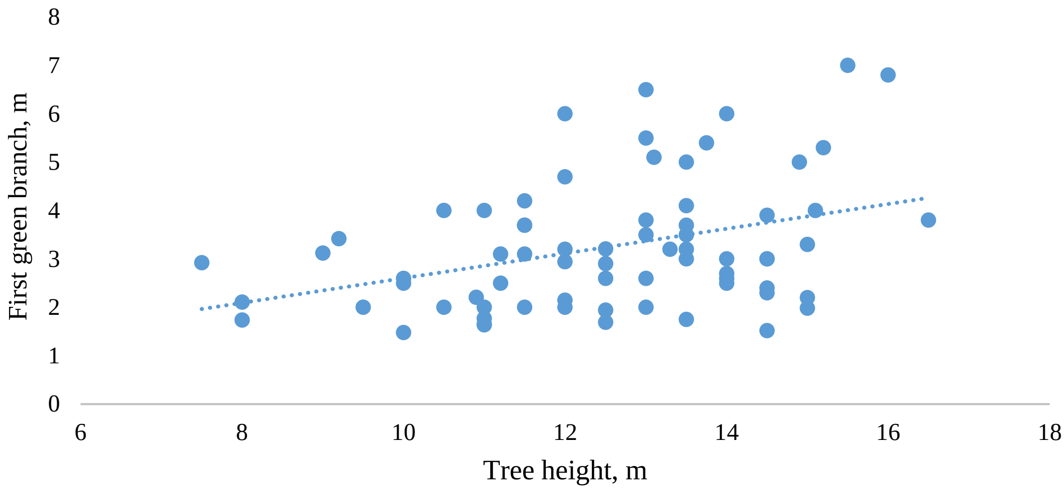

Figure 12. Relationship between tree height and first green branch

The relation between the tree height and the first green branch shows that the height of the first green branch increases with increasing height of trees (Figure 12). On average the green crown was 74% of the tree's height. There was one sample tree, whose first green branch was at 1.52 m height, thus green crown ratio was 90%. There were a few trees whose green crown length was 50% of tree height. Some large diameter trees have quite thick green branches which should be taken into account selecting remaining trees before thinning. It is not enough if the choice is based only on the tree dimensions. Each tree should be assessed individually, as large diameter trees can be of poor or good quality.

5. Conclusions

The interest in the use of birch wood has increased in recent decades, consequently the interest to carry out research in the field of birch management has also increased. Comparing birch management and growth of birch in Latvia with other countries in the region show great similarities, despite different climatic and other growth conditions.

The newly established long-term thinning experiment in birch contains new commercial thinning regimes that is outside the traditional and currently practiced management. Hopefully in the future this study will give relevant results on how to obtain high quality birch timber under a short rotation. However, it has to be admitted that the proposed heavy thinnings regimes are in contradiction with the current Latvian Forest Law. So, if in the future these thinning regimes will show remarkable results there is a need to change the current legislation, before introduction in practical forestry.

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Appendix

Table 1. Summary of sites parameters before and after first thinning

		Stem number, ha^{-1}		Quadratic mean diameter (Dq), cm		Quadratic mean height (Hgv), m		Basal area, m^2ha^{-1}		Removed basal area		Volume, $m^3\ ha^{-1}$		Removed volume	
Site	**Plot**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**m^2ha^{-1}**	**%**	**before**	**after**	**m^3ha^{-1}**	**%**
1	3	1067	400	12,4	14,0	13,0	13,5	12,9	6,2	6,7	52	79,1	38,4	40,8	52
1	1	1033	530	12,2	12,7	13,0	13,2	12,1	6,7	5,3	44	73,4	41,2	32,3	44
1	2	1000	530	12,9	13,8	13,2	13,4	13,2	8,0	5,2	39	81,1	49,8	31,4	39
1	6	1083	660	10,8	12,5	12,5	13,1	9,9	8,2	1,7	17	59,2	50,1	9,2	15
1	5	1267	800	11,4	12,5	12,7	13,1	12,9	9,8	3,1	24	77,6	60,0	17,6	23
1	4	1283	Control	10,3	10,3	12,3	12,3	10,7	10,7	0,0	0	63,4	63,4	0,0	0
2	5	1483	400	9,5	10,9	12,1	12,7	10,5	3,7	6,8	64	60,5	22,1	38,5	64
2	3	1333	530	10,5	11,9	12,4	12,9	11,5	5,9	5,6	49	68,2	35,6	32,7	48
2	4	1267	530	9,6	11,1	12,1	12,7	9,3	5,1	4,1	45	53,8	30,4	23,4	44
2	1	1167	660	9,3	10,5	12,0	12,5	7,9	6,0	1,9	24	45,6	35,2	10,4	23
2	2	1267	800	9,6	10,4	12,2	12,5	9,2	6,8	2,4	26	53,0	39,8	13,2	25
2	6	1017	Control	11,9	11,9	12,9	12,9	11,3	11,3	0,0	0	68,6	68,6	0,0	0
3	6	1133	400	11,1	13,1	12,6	13,3	10,9	5,4	5,5	50	65,0	33,2	31,8	49
3	3	1050	530	10,4	12,2	12,4	13,0	8,9	6,2	2,6	30	52,4	37,7	14,7	28
3	5	1167	530	11,2	12,6	12,7	13,2	11,4	6,7	4,7	41	68,1	40,8	27,3	40
3	2	1150	660	10,6	12,1	12,4	12,9	10,2	7,6	2,6	25	61,3	46,5	14,7	24
3	1	1317	800	10,7	11,9	12,5	12,9	11,8	9,0	2,9	24	70,2	54,1	16,1	23
3	4	1267	Control	11,3	11,3	12,7	12,7	12,6	12,6	0,0	0	76,0	76,0	0,0	0