Effects of different thinning regimes on growth of Silver birch (*Betula pendula* Roth.) planted on agricultural lands in Latvia

Edžus Romāns

Master's thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
EUROFORESTER
Alnarp, 2022

Effect of different thinning regimes on growth of Silver birch (*Betula pendula* Roth) planted on agricultural lands in Latvia

Edžus Romāns

Supervisor: **Andis Zvirgzdiņš, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre**

Assistant supervisor: Urban Nilsson, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre

Examiner: Giulia Attocchi, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre

Credits:	30 credits
Level:	A2E
Course title:	Master's thesis in Forest Science
Course code:	EX0984
Programme/education:	Euroforester – Master's Programme
Course coordinating dept:	Southern Swedish Forest Research Centre
Place of publication:	Alnarp
Year of publication:	2022

Keywords: *Betula pendula*, thinning, plantations, growth, production, abandoned agricultural land

Swedish University of Agricultural Sciences
Faculty of Forest Sciences
Southern Swedish Forest Research Centre

Abstract

This study a is continuation of the long-term experiment established by Šaicāne (2019). The main aim of the study was to examine the initial effect of different thinning regimes on growth of Silver birch (*Betula pendula* Roth) planted on abandoned farmlands in Latvia. The experimental design consisted of 6 different thinning treatments, varying in thinning intensity from 33.3% (800 trees ha^{-1} being left after first thinning) to 66.7% (400 trees ha^{-1} left after the first thinning). The long-term experiment as initially planned by Šaicāne (2019) will require a continuous implementation of the different thinning regimes intended for each treatment, including a different rotation length across the treatments – from 30 to 45 years. However, in this study, only the initial effect of the first thinning was evaluated and presented.

The two main objectives derived from the main aim of this study was to evaluate both growth of individual Silver birch trees as well as and the production as a whole. The collected data was used to estimate and evaluate different stand describing variables such as basal area, volume, basal area weighted height and diameter. Various functions were applied to estimate height, basal area, and volume. Ultimately, a statistical model was constructed to test effect of different thinning treatments on growth of Silver birch.

Positive corelation was found between thinning intensity and diameter growth, with most heavy thinning showing the highest growth and the untinned Control the lowest. Moreover, it was shown, that the largest trees in each treatment also exhibited the highest diameter growth. Differences between 1st quartile (smallest) and 4th quartile (largest) were 14 – 25% for thinned plots and 148% for the untinned Control. Height growth had no statistically significant deviation across the treatments and sites. Basal area growth negatively corelated with thinning intensity, i.e., best growth was achieved by the light intensity thinning and the poorest growth by the high intensity thinning. Volume production was highest in lowest intensity treatment – 15 m^3, followed closely by Control with 14 m^3. Lowest volume production was in most intensive thinning 9.6 m^3.

Keywords: Betula pendula, plantations, thinning, growth, production, abandoned agricultural lands

Table of contents

List of tables

List of figures

Abbreviations

BA	Basal area
DBH	Diameter at breast-height
Dq	Quadratic mean diameter
Hbaw	Basal area weighted height
HDF	High density fireboard
H	Height
MAI	Mean annual increment
MDF	Medium density fireboard
OSB	Oriented strand board
PCT	Pre-commercial thinning
RCB	Randomized complete block

1. Introduction

1.1 Birch in Latvia: Habitat and geographic distribution

Silver birch (*Betula pendula* Roth) is remarkable for its wide native range. It covers most of Europe with exception of the very north parts of Norway and southern parts of Greece and Iberian Peninsula. In longitude, it spreads from United Kingdom up until the very East of China and Russia (Figure 1a) (Beck et al., 2016). In comparison, downy birch (*Betula pubescens* Ehrh) is also a naturally occurring birch species in Europe. It exhibits similar native range; however, it covers Europe's north and even parts of Iceland, but does not reach as far as to the south as Silver birch (Figure 1b). Both of the species are also commonly found in Latvia (Figure 1a, b). However, in this study, we are only assessing the growth of silver birch.

a) b)

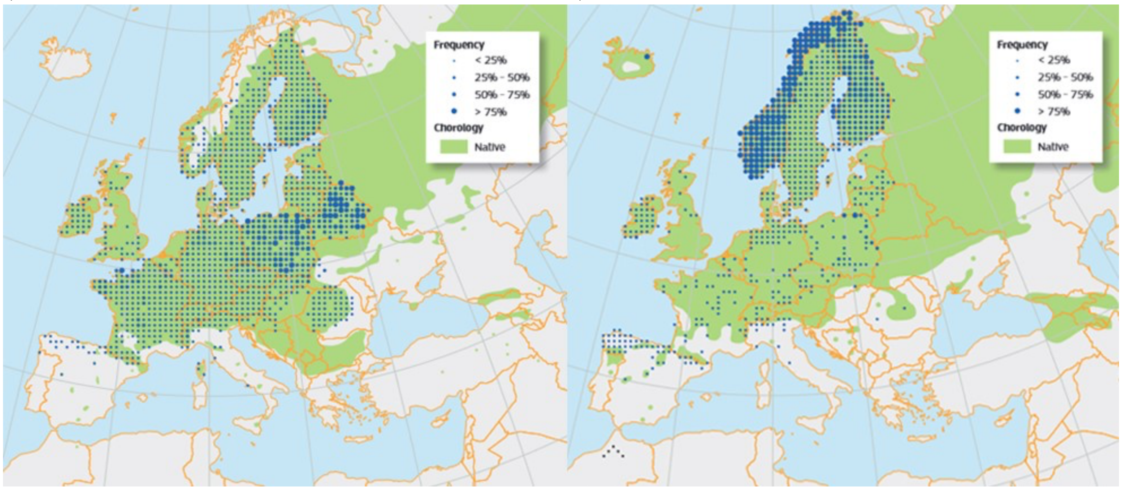

Figure 1. Map showing distribution and frequency of occurrence of Silver birch (a) and Downy birch (b) (Beck et al., 2016)

Latvia could be called a birch-forest capital and Figure 2. is great example of that. There are patches of high proportion birch forests in all parts of the country. According to National Forest Monitoring, there were 770.5 thousand hectares of forests, where birch is the dominant species. Moreover, birch often naturally creates mixtures with various species. One of the most interesting mixture dynamics is created with Norway spruce (*Picea abies* (L.) Karst.). Significant part of birch dominated forests have Norway spruce in second layer – 16% (Vuguls et al., 2019). It is an interesting dynamic, of early successional birch and shade tolerant, late successional Norway spruce. Naturally, birch makes mixtures also with other hardwood species, such as Gray alder (*Alnus incana* (L.) Moench) and European aspen (*Populus tremula* L.).

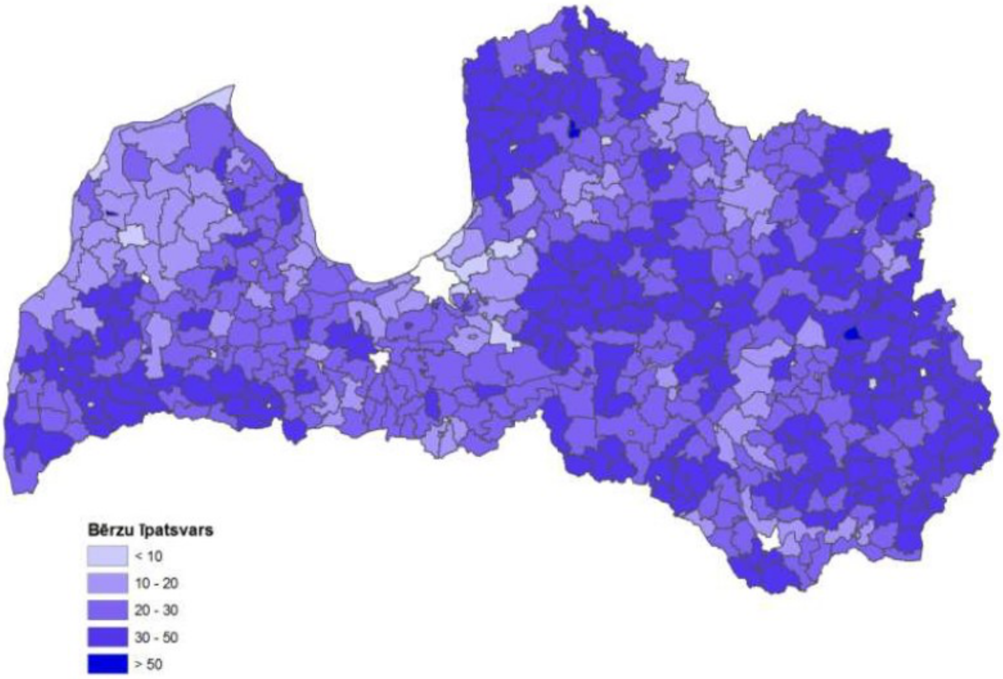

Figure 2. Map with proportion of birch spp. in Latvian municipalities (Pilvere, 2014)

1.2 Growth of Silver birch

Silver birch is a pioneer species that is light demanding and is known for its fast initial growth. In early stages, birch can have rapid growth that matches the growth pace of Sycamore maple (*Acer pseudoplatanus*) and European ash (*Fraxinus excelsior*) (Duboi et al., 2020). Compared to Downy birch, Silver birch shows significantly higher growth and better quality (Viherä-Aarnio & Velling, 1999). When it comes to height growth, Silver birch can reach a height of 12 – 13.6 m within its first 15 years (Liepiņš et al., 2013), followed by a slightly slower growth, reaching 17 -25 m during the next 15 years (Hynynen et al., 2010; Dubois et al., 2021). Height growth of Silver birch peaks at around 20 years. After the culmination, Silver birch still maintains a relatively fast growth pace, that drops sharply after age of 40 years (Hynynen et al., 2010; Dubois et al., 2021). Naturally regenerated Silver birch exhibits shorter period of vigorous growth, and height growth curve flattens faster than in planted Silver birch stands (Hynynen et al., 2010). However, growth of Silver birch can vary greatly depending on site properties, i.e., on poor sites growth most often is considerably lower compared to nutrient rich sites.

In optimal conditions, the diameter can reach close to 11 cm in 15 years (Liepiņš et al., 2013). However, diameter growth largely depends on crown diameter (Dubois et al., 2020). Therefore, it is crucial to have optimal stand density and timely performed management activities. Hynynen et al. (2010) states that in optimal growing conditions, annual ring width is ca 3-4 mm. Diameter growth of birch in plantations, similarly to height growth, peaks approximately before the age of 20 years. Interestingly, in stands naturally regenerated by sowing, diameter growth peaks already at the age of 5-7 years (Dubois et al., 2020). Overall yield of birch plantations also largely depends on site properties. In Latvia, mean annual increment (MAI) can fluctuate from 3.8 m^3 ha^{-1} (cumulative volume of 227 m^3 ha^{-1} in 60 years) on overly wet sites, up to 8.8 m^3 ha^{-1} (439 m^3 ha^{-1} in 50 years) on sod calcareous soils. On podzolic soils, MAI is approximately 7.1 – 7.5 m^3 ha^{-1} (328 m^3 ha^{-1} in 45 years) (Liepiņš et al., 2013). In Finland, MAI in naturally regenerated and unmanaged stands varies between 4 – 6.75 m^3 ha^{-1} (320 – 540 m^3 ha^{-1} in 80 years). However, in managed plantations it is ca 6 – 9.3 m^3 ha^{-1} (360 – 560 m^3 ha^{-1} in 60 years). In Sweden MAI can reach up to 10 m^3 ha^{-1} with rotation length being between 30 – 60 years. (Dahlberg et al., 2006 as cited in Hynynen et al., 2010). In Central Europe, on most appropriate sites, MAI only reaches 4.9 m^3 ha^{-1} (389 m^3 ha^{-1} in 80 years) (Hynynen et al., 2010). However, with largely varying rotation lengths it is hard to compare these results. With most rapid growth occurring within the first 40 years, longer rotations can be more productive than they seem. However, too long rotations may subject the stands to increased risks. According to Dubois et al. (2021), rotation beyond 60 years already has an increased risk of discoloration of heart and stem rot, with 80 years of age already being a high-risk zone (Hynynen et al., 2010).

1.3 Establishment and management of Silver birch in Latvia

In order to grow economically valuable birch plantations, intensive forest management has to be applied. Starting with soil scarification, proper place for planting, early tending (vegetation control), pre-commercial thinning (PCT) and thinning. When establishing plantations of Silver birch, it is important to remember, that birch is extremely light demanding, especially at young age. Therefore, vegetation can undermine growth of new trees, thus early tending is required. Planting density varies between countries. For instance, in Latvia, legislation expects a minimum of 2000 trees per ha, however, in other countries of Baltic sea region, requirements vary from 1600 to 2500 trees ha-1 (Law on Forests, 2000).

Perhaps the most challenging part of managing birch plantation is the first two years after planting. In a birch experiment in Latvia Liepiņš, et al. (2017) showed that up to 2/3 of all plantations failed due to lack of well-timed and regular early tending, which resulted in either vigorous natural regeneration or suppression from vegetation, for example, shrubs, such as raspberry (*Rubus idaeus* L.). It was noted, that in certain plantations, height of raspberry was above average human height (170-175 cm). In such conditions competition for resources in stand is very high and the growth of birches is severely inhibited or even stopped. After escaping threat of being suppressed by vegetation, there is threat of competition from naturally regenerated birch and other pioneer species. Growth and quality of naturally regenerated birch is inferior to planted seedlings of genetically improved material, therefore it is crucial to preserve as many as possible, given the investment.

1.3.1 PCT

Pre-commercial thinning (PCT) is an important silvicultural treatment for reducing overall stand density. Lowering density accelerates diameter growth as a result of crown release. With more space, trees can expand their crowns and increase LAI (leaf area index), that increases their photosynthetic activity. Moreover, slim trees are more vulnerable to wind and snow damage. Performing PCT is especially important in naturally regenerated stands, with up to 5000 seedlings ha^{-1} (Niemistö et al., 2008). However, it is also crucial in artificially regenerated stands, where density is much lower, but where natural regeneration is also part of an equation. As a general rule of thumb, desired crown length for Silver birch should be ½ of overall height (Hynynen et al., 2010; Liepiņš et al., 2013; Zālītis and Zālītis, 2007). This general rule can be used for decision making on whether go on with PCT or wait. Zālītis and Zālītis (2007) concluded, that in PCT it is mandatory to reduce number of trees down to 1500 – 2000 trees ha^{-1}, regardless of initial stand density, it ensures formation of productive stands. According to them, PCT should be done, when stand height is between 3 – 12 m. However, it is a vague approximation, as according to the Latvian model, the first commercial thinning should be carried out already at a height of 12 m. However, soil properties dictate pace of growth and thus influence when PCT will be necessary. Another issue that presents a certain threat is damage by ungulates. In a study in Latvia, Liepiņš et al. (2017) addressed this issue. On 45 ha of surveyed birch plantations, almost half of them had some degree of damage, but only 4 plantations had over 10% of damaged trees. Most common type of damage was browsed top bud, broken top and stem abrasion, likely done by roe deer males in early summer.

1.3.2 Thinning

Timely done thinnings decreases competition, thus remaining trees have access to more water, nutrients, light, and space for crown extension, that is crucial for diameter growth. There are differences between countries of Baltic sea region in terms of thinning practices. However, most commonly the thinning programmes in birch consist of two thinnings throughout the rotation. In Finland, a common practice is a heavy first thinning. The first thinning is carried out when the average stand height is between 13-15 m. As a result, the number of remaining trees after the first thinning is about 700 – 800 trees ha^{-1} (Hynynen et al., 2010). The period between thinnings is 15 years and during second thinning, the density is reduced down to 350 – 400 trees ha^{-1}. In his report, Liepiņš et al. (2017) described another Finnish model that is very similar to previously described by Hynynen et al. (2010). The experiment was established in 1990, near Padasjoki. Initial density of the stand was 1500 trees ha^{-1}, and the first thinning was performed, when stand had reached height of 14 m, with the remaining stem density being 750 trees ha^{-1}. The second thinning was done partly from above, when the dominant trees had reached veneer log quality and dimension requirements. In this model it is important to make sure that remaining stand has vital crowns and sufficient quality. Remaining density after the second intervention was 400 stems. Liepiņš et al. (2013) presents most common birch thinning practises in Latvia. The first thinning is done at an average height of 12 m with the remaining density being 800 – 1200 trees ha^{-1}. Period between first and second thinning is around 12 years and final density is ca 400 – 600 trees ha^{-1}. Intensity of first thinning depends on site productivity – in less productive sites, the intensity is lower. One of the differences between Latvian and Finnish practices is the density of the stand. In Latvia initial establishment starts with 2000 trees ha^{-1}, while in Finland it is usually lower – 1600 trees ha^{-1}. Higher stand density remains in Latvian birch management strategy throughout the rotation, including number of crop trees.

1.3.3 Rotation length

When it comes to rotation length, in general, Silver birch plantations are managed for 40 - 50 years. However, in less fertile sites, rotation can be extended up to 60 years. In most birch management practices the aim is to produce high quality and large dimension timber. If aim of the management is to produce biomass for energy use, rotation is significantly shorter. However, such practices are more common, when stand has regenerated naturally, or it is a Downy birch stand.

From the economical point of view optimal, rotation length in Silver birch plantations has been found to be 34 - 45 years (Tullus et al., 2012). In a study conducted in Sweden, Liziniewicz et al., (2022) via simulation determined 31 years as the optimal rotation age for Silver birch on high fertility sites. Latvian legislation has set a minimal age for harvesting at 71 years in high and medium productivity sites, and 51 years at low productivity sites (Law on Forests, 2000). Increasing rotation length beyond that is not recommended, keeping in mind involved risks, that were touched upon before in paragraph 1.2. In Latvia, there is also a target diameter method for harvesting timber, that allows to harvest a stand prior reaching minimal felling age. Target diameter in most productive sites is 31 cm, in medium productivity 25-27 cm and in lower productivity – 22 cm (Rules on felling trees in forest, 2013).

1.4 Breeding of Silver birch in Latvia

In Latvia, small-scale plus tree selection of birch started in 1960’s and 1970’s, with no significant results. During the soviet occupation, birch was regarded as a weed, similarly, like in Scandinavia. After regaining of independence in 1991, there were plenty of old and mature birch stands, but close to none in young age forest structure. Approximately 0.5 million hectares of old agricultural land was left without use. The largest birch timber processing company “Latvijas Finieris” had to completely restructure and find local supply of timber. Quality of seedlings in nurseries were quite low. As a result, in 1996, a birch program was developed by forest science, legislation, education and industry members. It aimed at developing birch breeding program, growing high quality seedlings in nurseries, support for private forest owners, improvement of legislation, support from science, that research all of the above. In more than 20 years the program has led to the following results:

- genetic improvement of planted birch led to 20 – 30% increase in growth and quality, compared with naturally regenerated birch;
- high quality planting material (container-grown and bare-root), that is able to satisfy local demand;
- information provided to forest owners as well as financial support from EU and “Latvijas Finieris” for establishing birch plantations;
- improved legislation, that supports afforestation of abandoned agriculture lands (20 years of Birch Program, 2016).

One of the great things about birch selection is its rapid growth that allows to assess the growth and quality of new generations already within 7-8 years (Liepiņš et al., 2013). As a result of that, breeding of birch is less time consuming, in comparison to conifers or other broadleaves. To compare, Finnish Silver birch breeding program has also shown great results, for example genetic gains of 29% in terms of volume, reduced tapering by 13% and smaller branch diameter by 10% (Pöykkö, 2013). This can result in largely increased financial gain for forest owners deciding to plant birch for high quality timber production.

In Latvia, birch program is still active and among futures challenges and objectives are:

- increased proportion of artificial birch regeneration using nursery seedlings, as currently natural regeneration is still most dominant regeneration method due to low costs, however, quality and production suffers from it;
- continuous work to raise quality of nursery planting material, to increase their competitiveness in forest against vegetation and natural regeneration;
- continue to develop management technologies in established plantations, one of the most significant directions is thinning intensity, regime and stem quality;
- preservation and establishing of new long-term studies;

1.5 Importance of birch in Latvia and other countries around the Baltic sea region

In Latvia, approximately 30% of forest area has birch as a dominant species, which constitutes for 23.8% of overall growing stock – approximately 160 million m^3 (Forest industry in numbers and facts, 2022). In Finland, birch species makes up a total of 16% of total growing stock, including both species (Hynynen et al., 2010), while in Sweden, birch makes up for around 12.7% of the total growing stock (Forest statistics, 2021). Birch is economically, ecologically, and socially significant species. Paper and pulp industry is one of the largest birch timber consumers in Northern Europe, with Sweden and Finland being top pulp producers. In 2020, Sweden produced 9.3 million tons of paper and board (Swedish Forest Industries, 2020). In Latvia, birch firewood is one of the most popular use. Although it is not so highly regarded in Central Europe, its qualities are well suited for food preparation. When it comes to industrial and construction application, birch is used to produce such products as oriented strand boards (OSB), medium-density fiberboards (MDF), high-density fiberboards (HDF), glued veneer boards and other products, that are used for construction (Duboi et al., 2020). Similar products can also be used as design elements if outer surface is specifically processed. Some companies in Latvia worth mentioning are “Latvijas Finieris” that are producing all types of processed and unprocessed veneer board and “Kronospan” that are producing many types of OSB, MDF, and HDF. Birch timber is aesthetically pleasing with its light, splinter-free, simple, but elegant appearance of timber.

Ecologically birch is considered to be a great soil improver. Its fine roots and leaves have good decomposition rate, thus improving water infiltration and soil structure. Often birch forms symbiotic relationship with mycorrhiza, therefore enhancing growth and survival (Perala and Alm, 1990). Growing birch on forest land previously occupied by conifers can improve soil fertility (De Schrijver et al., 2004) and reverse process of podzolization (Emmer et al., 1998). Birch has great positive influence on biodiversity. For example, in a study done in Sweden, Felton et al. (2011) found an increase in biodiversity of birds associated with broadleaves, when comparing spruce and spruce-birch stands. Moreover, biodiversity of conifer-related bird species mostly did not fluctuate. Abundance of light under birch canopy promotes light-demanding flowering species, it attracts nectar feeders and pollinators (Dubois et al., 2020). Improved soil structure benefits soil fauna, such as earthworms, springtails, and other insects, which, in turn, creates conditions for moles, shrews, badgers etc. (Dubois et al., 2020). Birch is crucial for preserving biodiversity of invertebrates in a landscape (Woodcock et al., 2007).

Socially, birch stands out among other species with their black and white bark, creating light, eye-pleasing stands, that are great for recreation. As for the other use, birch offers wide range of non-timber forest products. Bark of birch could be one of the most valuable substances for medicine, as it provides variety of medicine – birch bark extract for improved wound healing (Ebeling et al., 2014), betulinic acid is effective against melanoma cells (Patočka, 2003), betulin and other triterpenes extracted from bark has antifungal, antimicrobial, anti-inflammatory, antiviral (even anti-HIV) effects (Innocente et al., 2013; Aiken and Chen, 2005; Šiman et al., 2016). Birch is also a host for valuable mushrooms, such as chaga (*Inonotus obliquus*), whose extracts shows anti-tumour effect, antioxidant, antimicrobial, and anti-quorum sensing activity (Glamočlija et al., 2015). *Ganoderma lucidum* called reishi is quite rare mushroom that grows on birch deadwood, it possesses hepatoprotective, anti-hypertensive, anti-tumour and many other effects that are significant for medicine (Boh et al., 2007). Another non-timber product that birch offers in spring is its sap. Collection of sap is fairly popular in Baltic sea region countries. Practice of renting birch stands to sap tapping companies in Finland has been reported by Dubois et al., (2020). Apparently, income of such practice is higher than of final felling. Unfortunately, large-scale sap collection cannot be combined with stand management for high-quality timber, due to discoloration that happens after sap collection. Nevalainen (2005) isolated 486 microbial pure cultures 5 years after sap collection. While discoloration does not necessarily mean wood decaying fungi being present, it does, however, dramatically reduce the value of such timber.

1.6 Aims of the study

This study is a first assessment of initial growth response in this long-term experiment that was established by Šaicāne (2019) on a land previously used for agriculture. There is a large amount of abandoned agricultural areas that could be potentially used for afforestation, however, there is a lack of knowledge on the growth and production of different tree species. Different growth trends might require adjusted management interactions. Therefore, it is of crucial importance to evaluate the effect of different thinning regimes on growth and production of birch – primarily to avoid suboptimal management choices. Accordingly, three experimental sites were selected and re-measured to assess the different tree and stand growth characteristics. From the overall aim, two main objectives emerged:

1. Compare diameter growth of individual trees between the different thinning regimes.
2. Evaluate the effect of different thinning regimes on growth variables of Silver birch.

2 Materials and Methods

2.1 Study sites

The original thinning experiment was established in early 2018 by Šaicāne (2019), in south eastern part of Latvia (Figure 3.) - in an area managed by Skogsallskapet. As a first step, a thorough stand selection was done. As it is described in Šaicāne (2019), main criteria for site selection were:

- artificially planted birch plantation on abandoned farmland, where commercial thinning has not been done yet;
- stand had to be without serious damage from various factors, including wind, snow and animals;
- area of a stand had to exceed 1 ha. Size of a stand was important, as thereafter it was planned to install six plots representing six different thinning treatments.

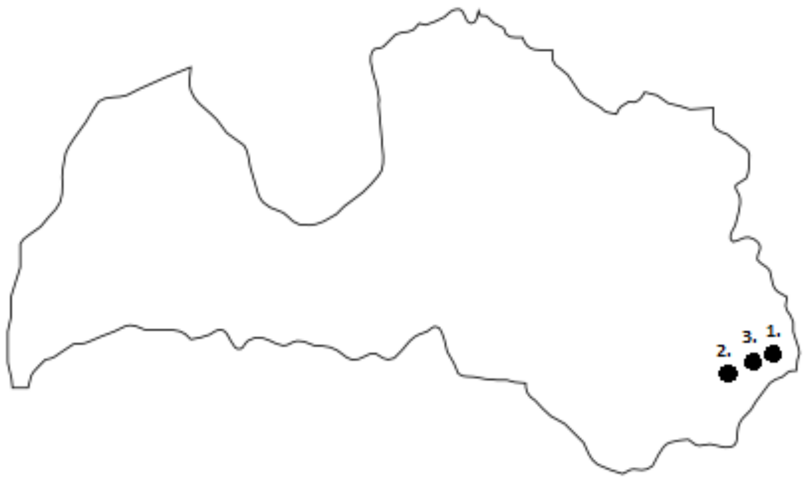

Figure 3. Location of the study sites in Latvia: 1 - Skaistuļi, 2 – Māllēpes & 3 – Vilki.

The selection resulted in three sites being chosen for the thinning study located on three different properties (Table 1). Area of experiment, is located in distance from Baltic sea, however, relatively flat relief of Latvia provides virtualy unobstructed movement of air mass into the region from Atlantic ocean. Average yearly air temperature in study area was 5.5 °C during meteorological observations from 1981 – 2010. Precipitation in the area during same period was between 650 - 700 mm^{-1}, which is only slightly below average for the whole country (Briede, 2021).

Table 1. Basic information and main metrics of study sites before start of experiment

Site	**Name of property**	**Coord. (LKS92)**	**Soil**	**Plot**	**Number of trees, N ha^{-1}**	**Dq, cm**	**Hbaw, m**	**Ba, m^2ha^{-1}**	**Vol, m^3ha^{-1}**
1	Skaistuļi	746201, 236779	DPS	1	1033	12.2	13	12.1	73.4
				2	1000	12.9	13.2	13.2	81.1
				3	1067	12.4	13	12.9	79.1
				4	1283	10.3	12.3	10.7	63.4
				5	1267	11.4	12.7	12.9	77.6
				6	1083	10.8	12.5	9.9	59.2
2	Māllēpes	735452, 235999	DMS	1	1167	9.3	12	7.9	45.6
				2	1267	9.6	12.2	9.2	53
				3	1333	10.5	12.4	11.5	68.2
				4	1267	9.6	12.1	9.3	53.8
				5	1483	9.5	12.1	10.5	60.5
				6	1017	11.9	12.9	11.3	68.6
3	Vilki	741040, 239244	DMS	1	1317	10.7	12.5	11.8	70.2
				2	1150	10.6	12.4	10.2	61.3
				3	1050	10.4	12.4	8.9	52.4
				4	1267	11.3	12.7	12.6	76
				5	1167	11.2	12.7	11.4	68.1
				6	1133	11.1	12.6	10.9	65

Note: DPS is drained mineral soil and DMS is dry mineral soil.

2.2 Experimental design

The experiment consists of three sites (blocks) and within each block there are 6 plots where 6 thinning treatments were replicated once in each site. The allocation of each treatment within the bloch was installed using a randomized complete block design. All plots (except Control) were split in half and one half had manual pruning done. Size of each block is 30 by 20 m (600 m^2) and additional buffer around each block, to mitigate the edge effect. Main stand parameters before thinning are summarized in Table 1. Positioning of plots within study site can be seen in Figures 4 - 6.

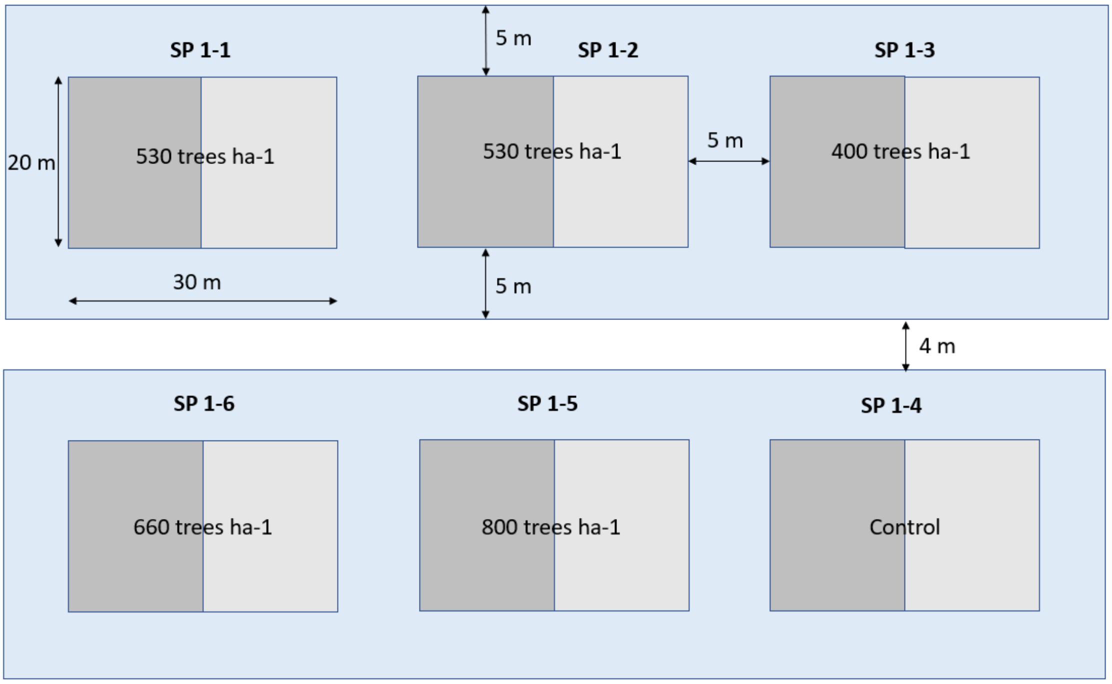

Figure 4. Study site Skaistuļi, Istra municipality

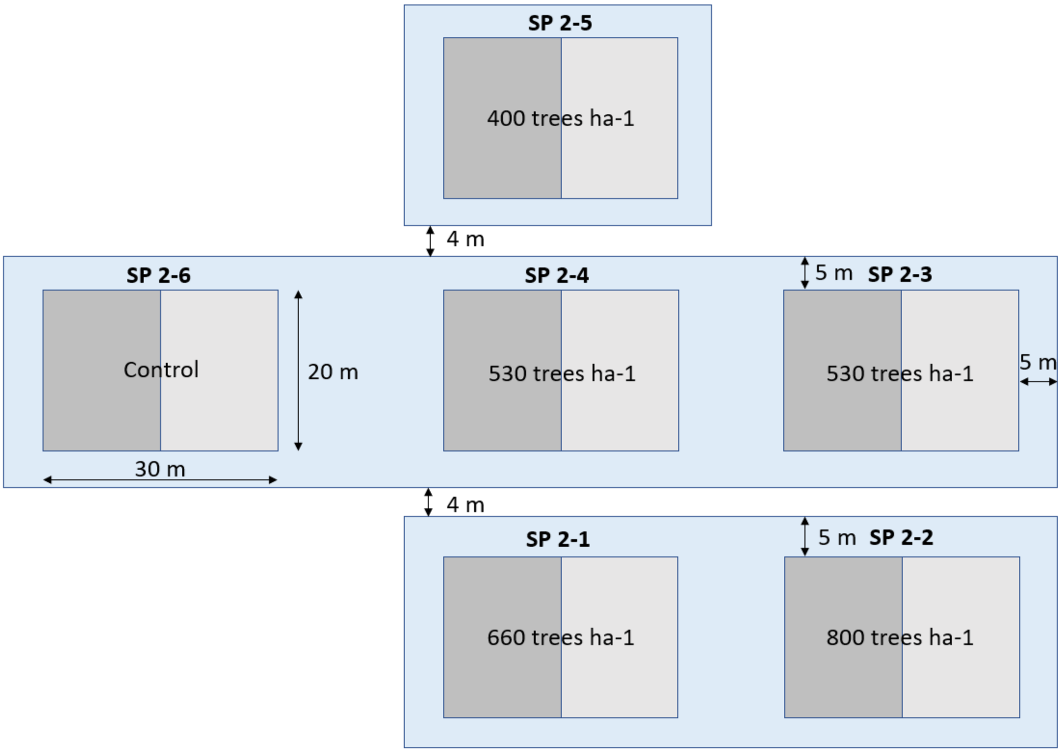

Figure 5. Study site Māllēpes, Rundēnu municipality

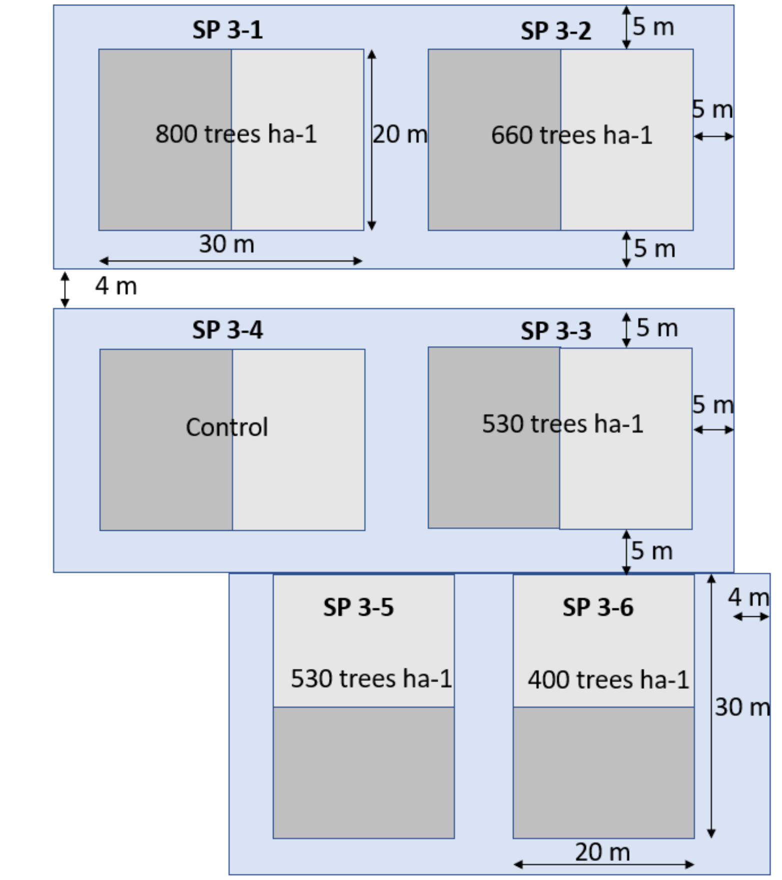

Figure 6. Study site Vilki, Istra municipality

The six thinning treatments were defined in Table 2, as follows.

Table 2. Descriptions of applied treatments in experiment

Treatment	Density after first thinning, trees ha^{-1}	Overall number of thinnings	Interval between treatments	Final density, trees ha^{-1}	Rotation length, years	Comments
S800	800	3	10 -15	250 - 300	45	Compromise between most common practices
S660	660	1	-	660	40	More intensive initial treatment, but no further activietes
S530a	530	3	10	200	40	Very intensive management plan
S530b	530	2	10 -15	250	40	Slightly less intensive as alternative to S530a
S400	400	1	-	400	30-35	Intensive initial treatment
Control	-	-	-	-	-	

As can be seen in Table 2, there are two similar thinning regimes S530a and S530b, treatment a includes 3 thinnings, instead of 2. Therefore, in this study we will treat both regimes the same, given, that changes will only occur in later stages of stand development.

2.3. Data collection

The data for this study was collected at the end of summer of 2021. Measurements took place between 23rd – 27th of August. In the experimental plots, cross-sectional diameter measurements were taken of all trees - in two directions: N-S and E-W. Height was measured using Haglöf Vertex IV hypsometer. Height was measured only for the sample trees due to the time-consuming procedure of measuring height. Selection of sample trees was done before the start of the field work using the previously measured data set (Šaicāne, 2019), all diameters to be specific. The selection of sample trees was done on a stand-plot level, by first, sorting trees into ascending order, then selecting systematically across all actual diameters based on sum of squared diameters, e.g., roughly every 4th tree. Measured heights were later used to estimate the height of all trees.

2.4 Calculations

2.4.1 Estimation of height of all calipered trees

As mentioned before, height was measured only for sample trees, therefore, it was necessary to calculate height for rest of the trees, that had diameter measurements recorded. To do so, height-diameter model, developed by Näslund (1936) was used. Model uses measured diameters and height from sample trees.

$$H = \frac{D^2}{(a + b * D)^2} + 1.3 \tag{1}$$

where H – height of the tree (m), D – diameter of a sample tree at breast height (cm), a and b – model coefficients. Two forms of the Näslund function were tested, i.e., a form with the exponent (or power) of 2 and a form using the exponent of 3. In this case, the power of two was used in the function, as it was found to provide a better fit via the residual analysis.

Coefficients were estimated on every stand and plot separately using a non-linear regression. Consequently, Näslund function with the newly estimated coefficients was used to estimate height of all calipered trees. Further analysis on height, height growth is based on the tree heights estimated by the function.

2.4.2 Estimation of basal area and volume

Basal area or in other words, cross-section area of all trees is important stand variable in forestry, it is typically recorded in square meters for hectare. To calculate basal area in study sites, simple formula was applied, using calipered diameters at breast height.

$$BA = \frac{\pi \times DBH^2}{40000} \tag{2}$$

In this formula BA stands for Basal area and DBH – diameter at breast height.

For calculation of individual tree volume, Latvian formula, developed by Liepa (1996) was used.

$$v = \Psi H^{\alpha} d_{1.3}^{\beta \lg H + \phi} \tag{3}$$

where v – volume; H – height of tree; $d_{1.3}$ – diameter at breast height; and coefficients – Ψ ($0.9090*10^{-4}$), α (0.71677), β (0.16692), ϕ (1.75701) estimated specifically for birch.

2.5 Statistical analysis

For statistical analysis, a linear mixed-effect model was used, to discover statistical differences between plot growth characteristics (specified below) as a result of thinning treatments.

$$y_{ij} = \mu + b_i + c_j + \varepsilon_{ij} \tag{4}$$

where y_{ij} is the response variable, μ – mean value, b_i – fixed effect of thinning treatment, c_j – random effect of site, ε_{ij} – random error term for observation ij. A set of response variables were tested: diameter growth, height, volume growth and basal area growth. The predictors consisted of fixed and random effects, with fixed being the variables treatment (the different thinning treatments: S400, S530, S660, 800, S1200) and site (sites: 1,2,3). Variable site was also included as the only random effect in the model. Consequently, a post hoc analysis was performed. Estimated marginal means and compact letter displays of pairwise comparisons were obtained using the emmeans and cld functions of emmeans and multcomp packages respectively. The model was constructed and tested using R (R core Team 2022), nlme package (Pinheiro et al., 2021). All data processing in this study was done using R (R core Team 2022).

3 Results

3.1 Diameter growth and distribution

Figure 7, shows that thinning activities, directly stimulate diameter growth in all thinned plots, but especially growth of dominant trees. Those trees, that had largest diameters before thinning, also exhibited largest diameter growth during 4 vegetation seasons. Data displayed in Figure 7 shows annual diameter growth. It was calculated using old data from before thinning treatment (collected in 2017), and new data from 2021. Trees of corresponding treatments were divided in 4 quartiles, according to their diameter growth. To compare diameter growth between each treatment, 1st quartile (lowest growth) and 4th quartile (highest growth) were compared. Initially idea was that increasing thinning intensity decreases growth difference between largest and smallest trees, due to more open space, light and resources. At first it did looks so, with treatments S400, S530 and S660 showing low deviations between mean values of quartiles – 14.1%, 20.8%, 24.0% or 0.13, 0.17, 0.18 cm year^{-1} accordingly. However, S800 showed only 18% or 0.13 cm year^{-1} difference and put a dent into this theory. Absolutely extreme variation was between Control values – 148.1% or 0.33 cm year^{-1}, that can be explained by large number of small trees, that will eventually die off in self-thinning.

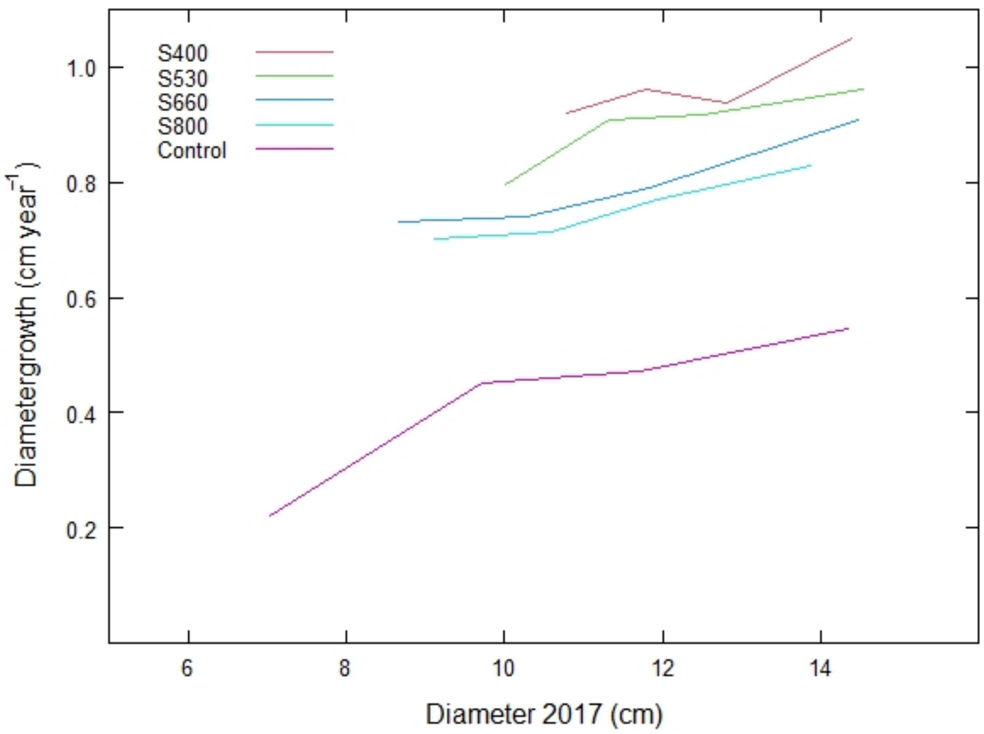

Figure 7. Comparison of diameter in 2017 and diameter growth until 2021

Figure 7 clearly supports general theory, that thinning intensity directly correlates with diameter growth. In Control plots, most dominant trees reached diameter growth just below 0.6 cm $year^{-1}$, while smallest trees had growth just above 0.2 cm $year^{-1}$. There is a considerable gap between Control and rest of the thinning regimes. For example, even in S800 treatment, smallest trees have more than 0.1 cm year-1 of growth advantage over the largest Control plot trees. Highest diameter growth was recorded in most intensive treatment S400. Comparison between largest tree growth in S400 and Control, shows difference of approximately 0.6 cm $year^{-1}$.

Impact of thinning treatments was statistically significant as it can be seen in Table 3. Statistical analysis showed p values lower than 0.0001. Treatments are placed in ascending order based on their estimated mean value. Letter display shows grouping of treatments indicating statistical differences between them. In this case, treatments were divided into three groups (a, b, c). The statistical analysis revealed that there are statistically significant differences between the treatments. Here, Control was separate from other treatments (a), lower intensity treatments were grouped together (b), and high intensity treatments were also grouped separately (c).

Table 3. Response of diameter growth in statistical tests

Response variable	**Treatment**	**α**	**Estimated mean value**	**p-value**	**Letter display**	**SE**
Diameter growth	Control	0.05	1.76	<.0001	a	0.163
	S800		3.04		b	0.163
	S660		3.18		b	0.163
	S530		3.6		c	0.163
	S400		3.91		c	0.163

Comparing Control with the rest of the plots in Figure 8, gives apparent evidence of thinning. As it can be seen, there is lack of small trees (1 – 10 DBH cm) in thinned plots, but plenty of them in the Control plots. While the fact that there is lack of small trees in the S400 is quite self-explanatory, the graph also shows that all of the remaining trees have grown extremely well, including the relatively smaller diameter trees, once again confirming the findings presented in Figure 7.

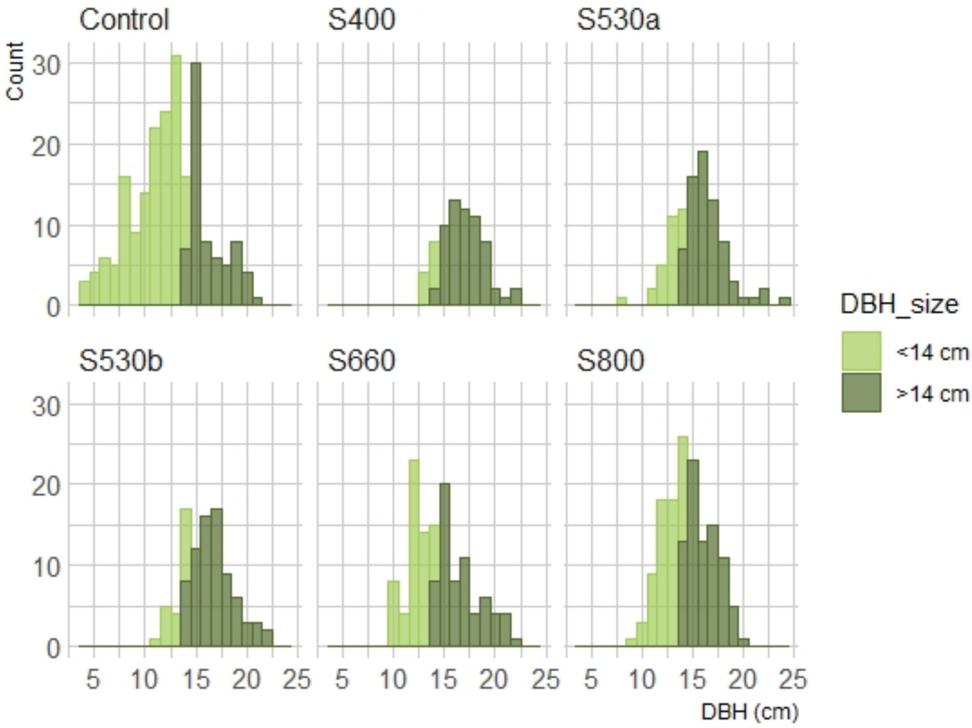

Figure 8. Diameter distribution within thinning treatments

3.2 Height growth

Even though there was no statistical difference between sites, overall height is noticeably lower on Site 2 (Figure 9). However, when it comes to height growth, since the start of experiment, all sites perform rather similarly. Height growth was calculated using original data from 2017 and 2021. There are no clear indications of treatment effect on height growth, it is rather quite random. For example, Control treatment has 4th best growth on Site 1, lowest growth on Site 2 and best growth on Site 3. Most consistent result was showed by S800 and S530, where amplitude between site average height growth values was only 0.34 m and 0.38 m respectively. Lowest height growth since the beginning of experiment was recorded on Site 1, S660 treatment - 3.79 m, but highest growth on Site 3, in Control plot – 5.44 m, which is a substantial difference.

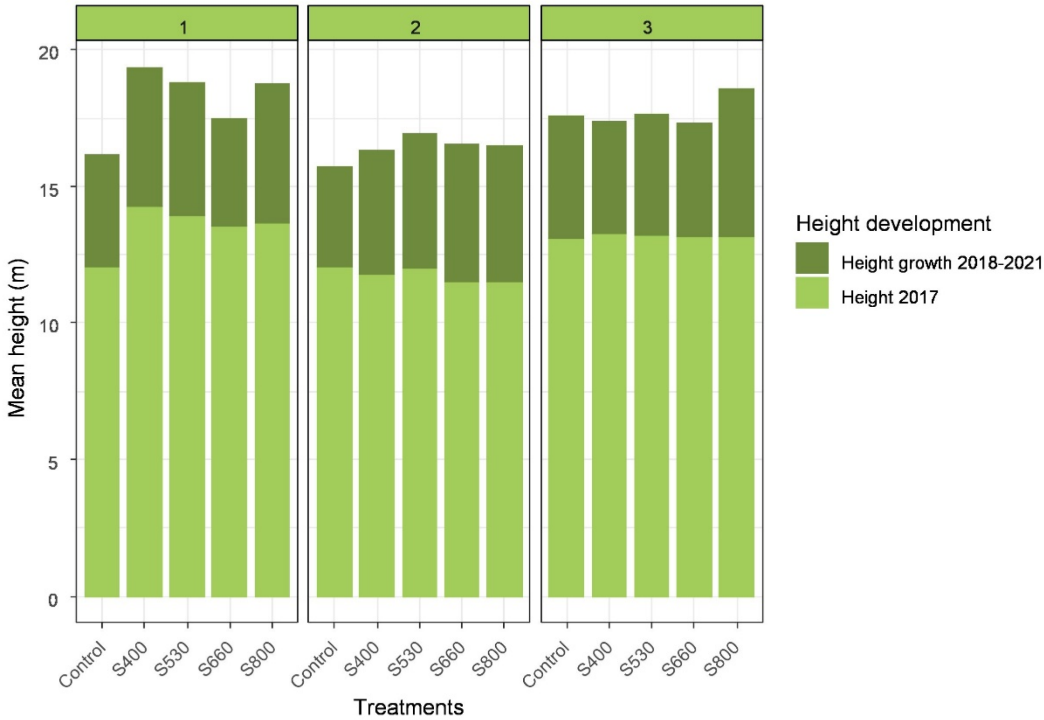

Figure 9. Mean height and height growth in different thinning regimes and sites

Nevertheless, no statistically significant difference in height growth between the different treatments was found (Table 4). Since there was no statistical difference between treatments, all treatments were sorted into the same group (a), when analysed.

Table 4. Response of height growth in statistical test

Response variable	Treatment	α	emmean	p-value	Letter display	SE
Height growth	Control	0.05	4.06	0.118	a	0.256
	S660		4.33		a	0.256
	S400		4.55		a	0.256
	S530		4.72		a	0.256
	S800		5.15		a	0.256

3.3 Basal area growth

Interesting results were obtained for basal area growth (Figure 10). Absolutely logical performance of treatments from S400 up to S800, however, low placement of Control plot was slightly surprising. Figure shows annual basal area growth for hectare. Control plot still holds largest overall basal area in Sites 2 and 3 with basal area of 15.2 and 17.0 m^2 ha^{-1}, with S800 standing at 11.7 and 14.2 m^2 ha^{-1}

respectively. However, on Site 1, S800 already has larger total net basal area (14.5 against 14.4 m^2 ha^{-1}) and higher annual growth (1.17 against 0.92 m^2 ha^{-1}).

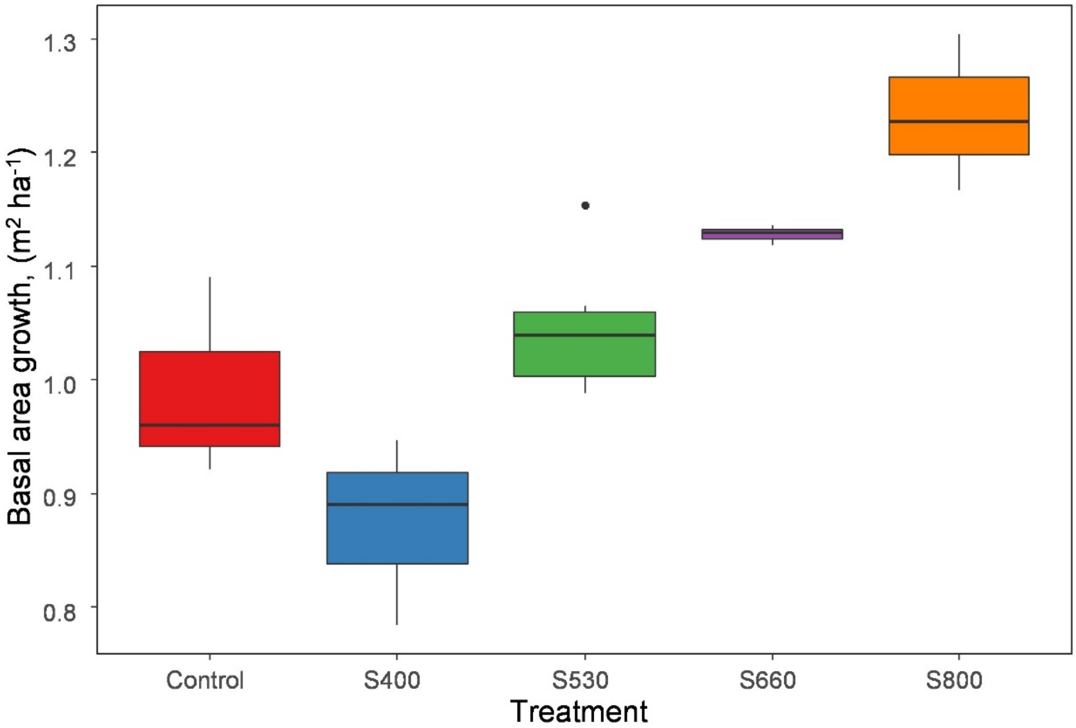

Figure 10. Annual basal area growth in different thinning treatments

Statistically, there were differences between certain treatments. Each treatment was grouped and separated with individual letter display, however, means sharing a letter were found not to be statistically different. According to the post hoc analysis, significant differences were found between S400, S530 and S800 treatments (Table 5).

Table 5. Response of Basal area growth in statistical test

Response variable	**Treatment**	**α**	**emmeans**	**p-value**	**Letter display**	**SE**
Basal area growth	S400	0.05	0.874	0.0002	a	0.0389
	Control		0.991		ab	0.0389
	S530		1.046		b	0.0299
	S660		1.127		bc	0.0389
	S800		1.233		c	0.0389

3.4 Volume growth

Similarly like with height growth, also volume growth is slightly worse on Site 2 (Figure 11). Volume growth was calculated using volume estimations from 2017 and 2021. Data showed in Figure 11, represents annual volume growth in each plot ha^{-1}. Decrease in volume growth is to be expected with heavy thinnings, such as S400, S530. Unexpected is relatively low volume growth in Control plots on Site 1 and Site 2. On Site 1 it is much lower than in S800 (12.5 m^3 ha^{-1} and 15.5 m^3 ha^{-1}) and almost identical to S530 and S660 (12.7 m^3 ha^{-1} and 12.4 m^3 ha^{-1}). While on Site 2 it is slightly lower than S800 and only a little higher than in S660. Overall, S800 has best volume growth (Site 1 – 15.5 m^3 ha^{-1}, Site 2 – 13.25 m^3 ha^{-1}, Site 3 – 16.15 m^3 ha^{-1}). On Site 3 more intensive thinning treatment resulted in lower volume growth, which is to be expected, as remaining trees cannot produce as much as larger number of trees in Control, for example. However, on Site 1 volume growth did not follow the same tendency. S530 had better growth than S660 (12.7 m^3 ha^{-1} and 12.4 m^3 ha^{-1} respectively). The lowest volume growth was recorded on Site 2, in S400 treatment, with 7.8 m^3 ha^{-1}. Therefore, it is possible, that volume growth could be even higher with less intensive thinning.

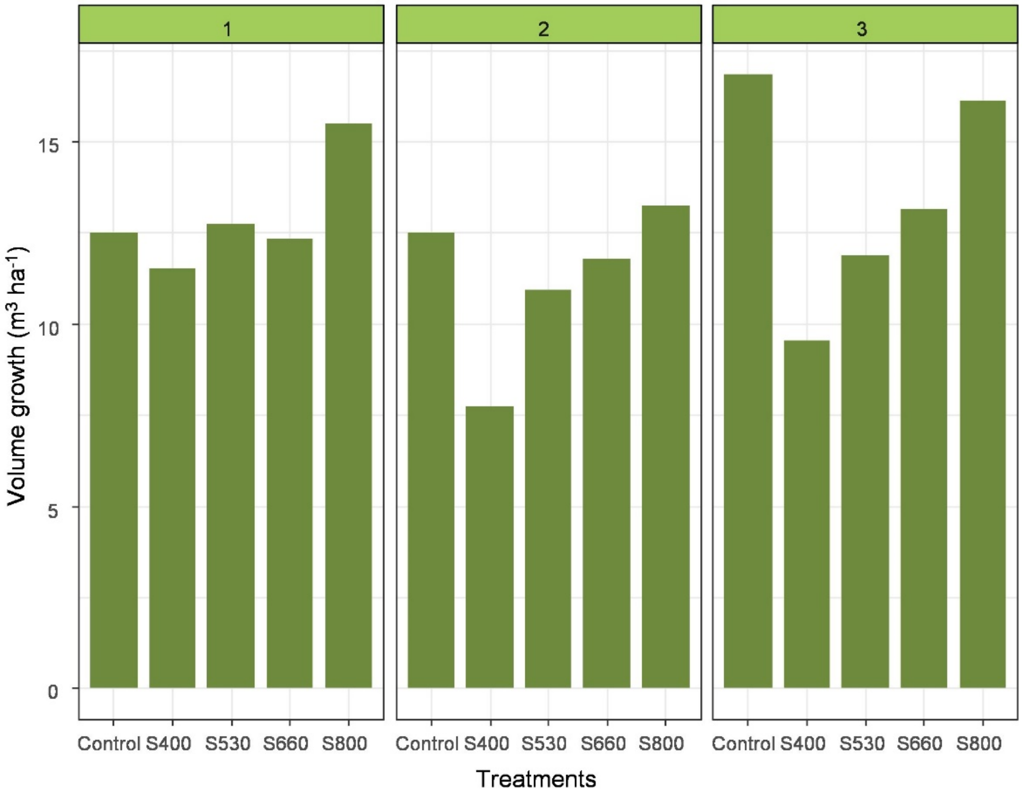

Figure 11. Annual volume growth across treatments per hectare

Volume growth response to statistical test was significant (Table 6). In terms of mean values, statistically different were only most extreme treatments. For example, significant difference between S400 and S800/Control, or S800 and S400/S530, because they do not share any displayed letters.

Table 6. Response of volume growth in statistical test

Response variable	Treatment	α	emmeans	p-value	Letter display	SE
Volume growth	S400	0.05	9.61	0.0029	a	1.108
	S530		11.85		ab	0.977

	S660		12.45		abc	1.108
	Control		13.97		bc	1.108
	S800		14.97		c	1.108

4 Discussion

4.1 Diameter growth and distribution

Results of this study, as expected, showed clear indications that thinning intensity has positive influence on diameter growth ($p < .0001$, $\alpha = 0.05$). All thinning treatments had marginally better diameter growth than unthinned Control, since the establishment of the experiment. Statistical test grouped treatments into 3 groups (Control, lower intensity thinnings, higher intensity thinnings). Thinning treatments clearly benefited to the growth of already dominant trees considerably more compared to the growth of medium and small trees. Trees of all treatments were divided into 4 quartiles based on diameter growth and their mean values were extracted. There were substantial differences between 1st and 4th quartile in every treatment. In Control, difference between quartiles was 148,1%, S800 – 18.0%, S660 – 24.0%, S530 – 20.8%, S400 – 14.1%. As it can be seen, the most extreme difference is in Control plots, where average of 1st quartile was 0.2205 cm year^{-1}, and 4th quartile – 0.5469 cm year^{-1}.

One of the aims of thinning is to reduce self-thinning of a stand, it is especially important if large investments have been made to establish a stand. Removing trees that are lagging behind in growth, can give at least some financial return compared to self-thinning. On the other hand, there is no such pronounced difference between treatments, when it comes to the largest trees within plots. There are large dimension trees in every plot, and their quantity does not differ that much. Results of this study agree with the findings of Juodvalkis et al., 2005, where DBH increment was positively correlated with thinning degree. Study tested 6 different tree species, including Silver birch, and all six had the same response, but in varying degrees. Birch responded worse than English oak and European aspen. Maximum effect of treatment was observed 2-3 years after thinning, after which it evens out with the growth pace of unthinned plots - within 7-8 years (Juodvalkis et al., 2005). Rapid diameter increase might be concerning for certain tree species, but not Silver birch, due to its diffuse porous structure.

Cameron et al., 1995 did not find any significant differences in technical quality of birch timber, when comparing heavy, light and no thinning treatments. This includes density, shrinkage, and grain angle. There were some indications, that logs from heavy thinning had more and larger living and dead branches. However, when considering only most valuable part of the stem (lower half), there were 0.6 dead and 0.1 living branches more per meter of log. On the contrary, Jones (2022) reports possible decrease of density and acoustic velocity, with higher growth rates.

4.2 Height growth

S800 treatment showed great height increment and consistency, when compared to other treatments. Height growth was rather random as it showed no clear indications of thinning effect, except for S800. Control had highest mean height growth on Site 3, but lowest on Site 2. S660 had lowest height growth on Site 1 but had strong growth on the two other sites. S400 had strong growth on Site 1 but had 0.84 m fluctuation in mean height between Site 1 and Site 3. S530 also had good consistency with its growth across sites. There is lack of evidence, that thinning treatments has effect on height growth, that is supported by statistical results, that showed p value = 0.118; $\alpha = 0.05$). For other species, for example, Scots pine, Mäkinen and Isomäki, (2004) reports decrease of dominant height increment, when thinning intensity was increased. However, in this study, at least in first 4 seasons after treatment, there is no evidence to support such correlation in Silver birch stands. It is interesting, that Site 2, despite having lowest overall height, did not exhibit lower height growth since the start of the study. Estimated mean height growth values for each treatment are as follows: S400 – 4.55 m, S530 – 4.72 m, S660 – 4.33 m, S800 – 5.15 m, Control – 4.06 m, thus it is clear, at current stage of the stand, there are no clear effect of treatment on height growth. Given, that thinning effect is most pronounced in first 5-7 years after treatment, there might not be significant difference even in later studies.

4.3 Basal area growth

Basal area is an important metric, used to characterize forest stand. It represents sum of tree cross section area per hectare. It is widely used as indication, whether it is time for thinning. In Latvian forestry, basal area tables are used to calculate, legal amount of basal area, that can be removed in commercial thinning. Influence of treatments on basal area growth was statistically significant ($p = 0.0002$, $\alpha = 0.05$). Average basal area growth for each treatment was S400 – 0.87 m^2 ha^{-1}, S530 – 1.05 m^2 ha^{-1}, S660 – 1.13 m^2 ha^{-1}, S800 – 1.23 m^2 ha^{-1}, Control – 0.99 m^2 ha^{-1}. Growth of basal area correlates positively with lower thinning intensity, however, Control plots on average had second worst growth. This was slightly surprising, but perhaps it could be explained by high density of trees in Control plots, that will later result in heavy self-thinning within plots.

4.4 Volume growth

Growth of volume was strongly impacted by thinning treatments ($p = 0.0029$, $\alpha = 0.05$). Volume growth was relatively high and consistent in S800 plots, with average growth on Site 1 – 15.5 m^3 ha^{-1}, Site 2 – 13.3 m^3 ha^{-1} and Site 3 – 16.2 m^3 ha^{-1}. Despite having highest overall growth on Site 3, Control plots had much lower growth on the two other sites. Especially on Site 1, having similar growth as S530 and S660. This leads to a question, whether having another treatment with low intensity thinning, such as S950 – S1000) would not result in highest volume growth? In the literature, there are indications, that certain species, respond positively to light thinnings in terms of volume growth. For example, Juodvalkis et al., 2005 reports 13% volume increment in Norway spruce using a light thinning (12-14% of volume). Moreover, it is noted, that significant volume increment can be achieved if light thinning is performed between the age of 10 and 20 for several species including Silver birch. Perhaps such treatment – S1000 with light first thinning, to promote volume growth, basal area growth and even diameter growth (relatively to Control) would allow to increase financial outcome of the second, more intensive thinning. Second thinning would be more intensive, leaving approximately 400 trees ha^{-1} for diameter increase as potential high quality crop trees, aimed for plywood logs. However, Skovsgaard et al., (2021) reports the opposite, even with low intensity thinning (16-25%) of standing volume, there were reduction in volume growth by 12%. It must be noted, that both studies likely used different stocking densities and thinning practices, thus it is impossible to conclusively say, whether such experiment would be successful. However, it leaves the door open for further studies.

4.5 Limitations of the study and future research

One of the flaws of this study is the limitation of size and type of the chosen stands. In case of more and/or larger available stands, it would have been possible to create more replicates of the presented treatments, resulting in larger quantity of data. However, plot size in thinning trials such as this one tends to be relatively large, and placement of large plots can often be problematic due to logistical reasons. This study had a total of 3 replicates of each treatment installed over three different sites - on fairly similar soil conditions. Due to different reasons, the study was focused on abandoned farmlands, thus, not much of room was given to diversify soil conditions in this experiment.

Another limitation that should be mentioned is the absence of data containing pruning and unpruned trees. Initially, pruning was included in the experimental design as in practical forestry, pruning is occasionally performed to increase merchantable value of first log, by creating branch-free timber. The full effect of pruning could be seen only at the end of rotation, but it would have been interesting to see, if there is any early effect on diameter or height growth after 4 vegetation seasons since the first treatment (pruning) was applied.

For future research, it would be interesting to diversify the thinning treatments. For example, instead of two treatments with 530 trees ha^{-1} after first thinning, having an additional treatment retaining 1000 trees after the first thinning (S1000), with 3 light intensity thinnings in total, with an overall aim of maximizing potential volume growth without allowing self-thinning to happen. Another, treatment, could be with early crop-tree marking and thinning for crop-tree crown release, while rest of stand is unthinned or thinned very lightly.

5. Conclusion

In this study various thinning intensities in Silver birch stands in Latvia were compared. This study gives first indications of thinning effect in this long-term experiment designed and established by Šaicāne (2019). Only four years have passed since establishment of experiment. However, this study shows, that, at least in initial phase, S800 provides the best volume growth and basal area growth, while S400 shows strong diameter growth. In later stages of this experiment, treatments will vary from one another even more and will give possibly more distinct results.

The effect of thinning on diameter and volume growth was observed already after the first four years after the establishment of the trial. Especially important was the observation showing the continuous growth of the largest trees in each stand. Difference between largest and smallest tree growth across treatments was from 14 – 24%, but in Control, difference was 148%, presumably on the account suppressed trees. Diameter growth had positive response to increasing thinning intensity. Therefore, S400 had best diameter growth, and Control – worst.

Volume growth in 2 out of 3 sites was highest in S800 with average of 15 $m^3\ ha^{-1}$. S400 had lowest growth with average of 9.6 $m^3\ ha^{-1}$.

There was no statistically significant effect of treatments on height growth, only small deviations. It has to be pointed out, that S800 did have strong and consistent height growth in all 3 sites.

Growth of basal area negatively correlated with increasing thinning intensity within plots, where thinning was performed. S400 exhibited lowest growth and S800 the strongest. However, Control plot showed relatively low basal area growth, which was slightly surprising.

Given, that this is a long-term experiment, there will be more studies, with same design. In the future studies, thinning treatments will differ to a larger degree, including second and third thinnings for some treatments. Also, future work will include focus on pruning effect on quality.

References

1. Aiken, C., Ho Chen, C. (2005). Betulinic acid derivatives as HIV-1 antivirals. *Trends in Molecular Medicine,* 11(1): 31-36. https://doi.org/10.1016/j.molmed.2004.11.001
2. Beck, P., Caudullo, G., de Rigo, D., Tinner, W. (2016). *Betula pendula*, *Betula pubescens* and other birches in Europe: distribution, habitat, usage, and threats. In: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. (Eds)., European Atlas of Forest Tree species. Publ. Off. EU, Luxembourg, pp. e010226+
3. Bērzu programmai 20 (20 years of birch program). (2016). Report. "Latvijas Finieris". [In Latvian]
4. Boh., B., Berovic, M., Zhang, J., Zhi-Bin, L. (2007). *Ganoderma lucidum* and its pharmaceutically active compounds. *Biotechnology Annual Review,* 13: 265-301. https://doi.org/10.1016/S1387-2656(07)13010-6
5. Briede, A. (2021). Klimats Latvijā (Climate in Latvia). *Nacionālā enciklopēdija (National encyclopedia)* [Viewed 11.05.2022]. Available: https://enciklopedija.lv/skirklis/26052-klimats-Latvij%C4%81 (In Latvian)
6. Cameron, A.D., Dunham, R.A., Petty, J.A. (1995). The effects of heavy thinning on stem quality and timber properties of silver birch (*Betula pendula* Roth). *Forestry,* 68(3): 275-286. https://doi.org/10.1093/forestry/68.3.275
7. De Schrijver, A., Nachtergale, L., Staelens, J., Luyssaert, S., De Keersmaeker, L. (2004). Comparison of throughfall and soil solution chemistry between a high-density Corsican pine stand and a naturally regenerated Silver birch stand. *Environmental Pollution,* 131(1): 93-105. https://doi.org/10.1016/j.envpol.2004.01.019
8. Dubois, H., Claessens, H., Ligot, G. (2021). Towards Silviculture Guidelines to Produce Large-Sized Silver Birch (*Betula pendula* Roth) Logs in Western Europe. *Forests,* 12(5):599. https://doi.org/10.3390/f12050599
9. Dubois, H., Verkasalo, E., Claessens, H. (2020). Potential of Birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) for Forestry and Forest-Based Industry Sector within the Changing Climatic and Socio-Economic Context of Western Europe. *Forests,* 11(3):336. https://doi.org/10.3390/f11030336
10. Ebeling, S., Naumann, K., Pollok, S., Wardecki, T., Vidal-y-Sy, S., Nascimento, J.M., Boerries, M., Schmidt, G., Brandner, J.M., Merfort, I. (2014). From a Traditional Medicinal Plant to a Rational Drug: Understanding the Clinically Proven Wound Healing Efficacy of Birch Bark Extract. *PLoS ONE,* 9(1): e86147. https://doi.org/10.1371/journal.pone.0086147
11. Emmer, I.M., Fanta, J., Kobus, A.Th., Kooijman, A., Sevink, J. (1998). Reversing borealization as a means to restore biodiversity in Central-European

mountainforests – an example from the Krkonoše Mountains, Czech Republic. *Biodiversity & Conservation,* 7: 229-247. https://doi.org/10.1023/A:1008840603549
12. Felton, A., Andersson, E., Ventorp, D., Lindbladh, M. (2011). A comparison of avian diversity in spruce monocultures and spruce-birch polycultures in southern Sweden. *Silva Fennica,* 45(5). https://doi.org/10.14214/sf.92
13. Forest statistics (Skogsdata 2021). Official Statistics of Sweden. Swedish University of Agricultural Sciences. Umeå 2021. (In Swedish)
14. Glamočlija, J., Ćirić, A., Nikolić, M., Fernandes, Â., Barros, L., Calhelha, R.C., Ferreira, I.C.F.R., Soković, M., van Griensven, L.J.L.D. (2015). Chemical characterization and biological activity of Chaga (*Inonotus obliquus*), a medicinal "mushroom". *Journal of Ethnopharmacology,* 162: 323-332. https://doi.org/10.1016/j.jep.2014.12.069
15. Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A., Hein, S., Velling, P. (2010). Silviculture of birch (Betula pendula Roth and Betula pubescen*s Ehrh.) in n*orthern Eu*rope. Forestry:* An International Journal of *Forest Research, 83(1): 103-119.* https://doi.org/10.1093/forestry/cpp035
16. Innocente, A., Casanova, B.B., Klein, F., Lana, A.D., Pereira, D., Muniz, M.N., Sonnet, P., Gosmann, G., Fuentefria, A.M., Gnoatto, S.C.B. (2013). Synthesis of Isosteric Triterpenoid Derivatives and Antifungal Activity. *Chemical Biology & Drug Design.* https://doi.org/10.1111/cbdd.12251
17. Jones, G. (2022). Birch Stem and Wood Traits in Genetic and Silviculture Trials in Southern Sweden. Linnaeus University Dissertations No 446/2022, ISBN: 978-91-89460-86-7
18. Juodvalkis, A., Kairiukstis, L., Vasiliauskas, R. (2005). Effects of thinning on growth of six tree species in north-temperate forests of Lithuania. *European Journal of Forest Research*, 124: 187-192. https://doi.org/10.1007/s10342-005-0070-x
19. Law on Forests (2000). (Meža likums): [viewed 15.05.2022]. Available at: https://likumi.lv/ta/id/2825-meza-likums (In Latvian)
20. Liepa, I. (1996). Pieauguma mācība (Growth science). Jelgava: LLU – 123p. [In Latvian]
21. Liepiņš, K., Brūna, L., Šmits, A. (2017). Investigations on establishment of birch plantations and production of birch planting stock. Project report. Salaspils, Latvian State Forest Research Institute "Silava". 55 pp. (In Latvian)
22. Liepiņš, K., Daugaviete, M., Zālītis, P. (2013). Bērza plantācijas lauksaimniecības zemēs "Birch plantations on agricultural lands". Salaspils: Latvian State Forest Research Institute "Silava", p. 93. (In Latvian)
23. Liziniewicz, M., Barbeito, I., Zvirgzdiņš, A., Stener, L-G., Niemistö, P., Fahlvik, N., Johansson, U., Karlsson, B., Nilsson, U. (2022). Production of genetically improved Silver birch plantations in southern and central Sweden. *Silva Fennica,* 56(1). https://doi.org/10.14214/sf.10512

24. Mäkinen, H., Isomäki, A. (2004). Thinning intensity and growth of Scots pine stands in Finland. *Forest Ecology and Management*, 201(2-3): 311-325. https://doi.org/10.1016/j.foreco.2004.07.016.
25. Meža nozare skaitļos un faktos 20220 (Forest industry in numbers and facts 2022). Annual report. Ministry of Agriculture, Republic of Latvia. (In Latvian)
26. Nacionālā enciklopēdija – Klimats Latvijā (National Encyclopedia – Climate in Latvia) (In Latvian)
27. Nevalainen, S. (2005). Discolouration of birch after sapping. Aktuelt fra skogforskningen
28. Näslund M. (1936): Skogsforsö ksastaltens gallringsforsök i tallskog.
29. Niemistö, P., Viherä-Aarnio, A., Velling, P., Heräjärvi, H., Verkasalo, E. (2008). Koivun kasvatus ja käyttö. From Finnish translated to Latvian by Lāce, L. Bērzu Audzēšana un Izmantošana (In Latvian)
30. Patočka, J. (2003). Biologically active pentacyclic triterpenes and their current medicine signification. *Journal of Applied Biomedicine,* 1, 7-12.
31. Perala, D., Alm, A.A. (1990). Reproductive ecology of birch: A review. *Forest Ecology and Management,* 32(1): 1-38. https://doi.org/10.1016/0378-1127(90)90104-J
32. Pinheiro, J., Bates., Debroy, S., Sarkar, D. R Core Team (2021). Nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-153, URL: https://CRAN.R-project.org/package=nlme
33. Pöykkö. S. (2013). Finnish birch seed production 1970-2012. [presentation] – Seed orchard conference, Riga 05.04.2013
34. R core Team (2022). R: A language environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/
35. Rules of felling trees in forest (2013). Noteikumi par koku ciršanu mežā: [viewed 15.05.2022]. Available at: https://likumi.lv/ta/id/253760-noteikumi-par-koku-cirsanu-meza (In Latvian)
36. Skovsgaard, J.P., Johansson, U., Holmstrom, E., McCarthy-Tune, R., Ols, C., Attocchi, G. (2021). Effects of Thinning Practice, High Pruning and Slash Management on Crop Tree and Stand Growth in Young Even-Aged Stands of Planted Silver Birch (*Betula pendula* Roth). *Forests*, 12(2): 225. https://doi.org/10.3390/f12020225
37. Swedish Forest Industries (2020). [Viewed 04.05.2022]. Available at: https://www.forestindustries.se/forest-industry/statistics/pulp-industry/
38. Šaicāne, D. (2019). Thinning strategies of birch in Latvia, with application in a newly established field experiment. Swedish University of Agricultural Sciences. Master Thesis No. 320.
39. Šiman, P., Filipova, A., Ticha, A., Niang, M., Bezrouk, A., Havelek, R. (2016). Effective Method of Purification of Betulin from Birch Bark: The Importance of

Its Purity for Scientific and Medicinal Use. *PLoS ONE,* 11(5): e0154933. https://doi.org/10.1371/journal.pone.0154933
40. Tullus, A., Lukason, O., Vares, A., Padari, A., Lutter, R., Tullus, T., Karoles, K., Tullus, H. (2012). Economics of Hybrid Aspen (*Populus tremula* L. x *P. tremuloides* Michx.) and Silver Birch (*Betula pendula* Roth.) Plantations on Abandoned Agricultural Lands in Estonia. *Baltic Forestry*, 18(2): 288-298.
41. Viherä-Aarnio, A., Velling, P. (1999(. Growth and stem quality of mature birches in a combined species and progeny trial. *Silva Fennica,* 33(3):225-234.
42. Vuguls, J., Šņepsts, G., Lībiete, Z., Zālītis, P. (2019). Forests management challenges and opportunities of two-layered birch and spruce stands in Latvia. *Research for Rural Development,* 1: 65-70. DOI: 10.22616/rrd.25.2019.010
43. Woodcock, B., Leather, S., Watt, A. (2003). Changing management in Scottish birch woodlands: A potential threat to local invertebrate biodiversity. *Bulletin of Entomological Research,* 93(2): 159-167. doi:10.1079/BER2003227
44. Zālītis, T., Zālītis, P. (2007). Growth of Young Stands of Silver Birch (*Betula pendula* Roth.) Depending on Pre-Commercial Thinning Intensity. *Baltic Forest*, 13(1): 61-67.

Popular science summary

This study is aimed at exploring effects of different commercial thinning intensities and regimes on Silver birch (*Betula pendula* Roth). Commercial thinning is part of an active forest management, that is most commonly used for removing small and suppressed trees as well as to improve growth conditions for remaining trees (more space, light, and resources). Silver birch is among most common broadleaved species in northern Europe and has crucial social, environmental, and economic role. This study is based on study design established by Šaicāne (2019) in Latvia. This is long-term experiment that contains 6 different thinning practices. At this point of the experiment only one thinning has been done and treatments are named after number of remaining trees per hectare (1 ha = 10000 m^2). Treatments are S400, S530, S660, S800 and Control. Control treatment did not have thinning. Thus, it will be possible to compare it to thinned treatments. In later stages of this long-term project, some stands will have second and third thinnings.

Since establishment of the experiment, four growing seasons have passed. In order to obtain data on how trees respond to different treatments, data collection was done. The collected data primarily consists of tree diameters (of all trees within scientific plots were measured using calliper) and tree height. Height was measured for chosen sample trees using hypsometer (tool that measures distance to the tree and angle from person with tool to the top of the tree). Given, that height was measured only for sample trees, a height-diameter function was applied to estimate height of all trees. In addition, other mathematical formulas were used to estimate important metrics such as volume, basal area (sum of all trees cross sections). To find out, whether collected data is statistically significant, statistical model was constructed. It is believed, that thinning has large impact on diameter growth and this study confirms it, with increasing intensity of thinning (intensity depends on number of trees removed) also increased diameter growth of individual trees. In other words, S400 had highest growth, because thinning intensity was bigger. Moreover, it was proven, that largest trees in each treatment had largest growth since the beginning of the experiment. Similarly, like rich get richer – large get larger. There was a huge difference between growth of smallest and largest trees in unthinned Control plot – 148%, this can be explained by large number of suppressed trees. In thinning small and suppressed trees are removed, but in Control this practice was not done. Volume growth is one of the most important metrics in forestry, because it allows to quantify forest into m^3 that can be converted into monetary value. However, despite having largest diameter growth S400 had the worst volume growth, seems unfair, but that is how it is. S800 had the best volume growth despite having low diameter growth. That is because there are twice as many trees left in plot, if compared with S400 and even with slower diameter growth, they still can produce more volume than treatments with higher intensity of thinning.

Acknowledgements

I would like to express gratitude to Latvian State Forest Research Institute “Silava” for helping with data collection.

Moreover, I would like to thank my supervisor MSc Andis Zvirgzdiņš and assistant supervisor Prof. Urban Nilsson who were supporting and helping throughout the whole process of this study.

Appendix 1 – Photos taken during data collection

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. Read about SLU's publishing agreement here:

- https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.