ABSTRACT

Forestry takes up a major part in the economy of Northern Europe countries. The aim of this work is to evaluate the economic and production consequences in Scots pine (*Pinus sylvestris*) stands in Lithuania based on the data of the National Forest Inventory (NFI). Scots pine stands cover the biggest area of Lithuanian forests. It this thesis, it was decided to evaluate only the thinnings of the IV forest group (commercial forests) where the economical profit is the major aim.

One of the tasks was to summarize and critically evaluate the intensity of thinnings carried in Lithuanian Scots pine stands. The results were achieved after collecting the necessary data and creating a database. After analysing the NFI data, it was noticed that thinnings in Scots pine are of the same intensity in all the stands of heights between 13 to 30 metres and more. The stocking level after the thinning meets the recommendations. One important detail was that many light and very light thinnings are carried out in Lithuania, which may be unprofitable. It was also noted that thinnings were often done in stands of 25 metres and higher which can increase the risk of windthrow.

The second task was to find alternative rotation lengths that would be economically beneficial and compare them to current ones. In order to find out the alternative forest management models, stand modelling software "Heureka" and economic analysis was used. It was estimated that current rotation ages of Lithuanian Scots pine stands are longer than the ones that would be most profitable. There was no significant extension of the most profitable felling age when the thinning regimes are of different intensity. The results of this thesis can be helpful analysing the problems of effectiveness and economical profit in the forestry sector of Lithuania.

Key words: National Forest Inventory (NFI), Scots pine, *Pinus sylvestris*, thinning, rotation lenght, alternatives, economical consequences.

SANTRAUKA

Šiaurės Europos šalyse miškininkystė užima svarbią dalį šalių ekonomikoje. Šio darbo tikslas yra, remiantis Nacionalinės miškų inventorizacijos (NMI) duomenimis, įvertinti ekonomines ir produktyvumo pasekmes grynuose paprastosios pušies (*Pinus sylvestris*) medynuose. Paprastosios pušies medynai užima didžiausią Lietuvos miškų dalį. Šiame darbe nuspręsta įvertinti tik IV miškų grupėje (ūkiniuose miškuose) vykdomus kirtimus, kuriuose ekonominė miškininkavimo nauda turėtų būti viena svarbiausių.

Vienas iš darbo uždavinių buvo apibendrinti ir kritiškai įvertinti ugdomųjų kirtimų intensyvumus, taikomus paprastosios pušies (*Pinus sylvestris*) medynams. Rezultatai pasiekti sistemingai atrinkus reikiamus duomenis ir suformavus duomenų bazę. Išanalizavus NMI duomenis, nustatyta, jog ugdymo kirtimai paprastosios pušies medynuose vykdomi vienodai intensyviai visuose vidutinio aukštumo medynuose nuo 13 iki 30 ir daugiau metrų aukščio. Medyno skalsumas po ugdymo atitinka ugdymo rekomendacijas. Atkreiptinas dėmesys, jog Lietuvos pušynuose vykdoma ypatingai daug mažo ar labai mažo intensyvumo ugdymų, kas ekonomiškai nėra efektyvu. Taip pat pastebėta, kad ugdymas taikomas 25 m ir aukštesniuose medynuose, kas gali sukelti vėjo pažeidimų riziką.

Antrasis darbo uždavinys buvo surasti ekonomiškai naudingas alternatyvias kirtimo apyvartas ir palyginti su dabartinėmis. Siekiant išsiaiškinti alternatyvius miškininkavimo modelius, naudota medyno modeliavimo programa „Heureka“ ir plačiai pasaulyje taikomos ekonominės formulės. Nustatyta, jog dabartiniai pagrindinių kirtimų amžiai Lietuvos pušynuose yra 30–40 metų ilgesni už ekonomiškai naudingiausius. Skirtingo intensyvumo ugdomųjų kirtimų režimai tik neženkliai prailgina ekonomiškai naudingiausią kirtimo amžių. Magistrinio darbo rezultatai gali būti panaudojami sprendžiant efektyvumo ir ekonominės naudos padidinimo uždavinius Lietuvos miškų sektoriuje.

Raktiniai žodžiai: Nacionalinė miškų inventorizacija (NMI), paprastoji pušis, *Pinus sylvestris*, ugdymo režimas, minimalus kirtimo amžius, alternatyvos, ekonominės pasekmės.

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1. INTRODUCTION

1.1. Project background

Forests contribute greatly to the economy of Lithuania. Forestry and logging make 1 % of country's GDP. In order to exploit these natural resources and increase the profit, regular analysis of production is essential (Mizaras, 2012). Forest management and its models are relevant for both, state forest and private forest owners. Because of long forest rotation period a lot of factors must be considered when economic indicators are calculated.

Foresters use many criteria for selecting the age to cut forest stands, some of them do not take into consideration any of the economic factors involved. Some good examples of criteria are the age at which the trees reach a best size for making some products, the age at which the volume in stands is maximized, and the age at which the rate of growth in volume is maximized. These technical criteria have widely divergent rotation ages with major implications on the costs and benefits generated. Forest management decisions are not only driven by wood volume considerations, but also by economy and other factors (Roberge et al., 2016). Therefore, this thesis focuses on analysing current forest management in Lithuania from the perspective of economy.

All forests in Lithuania are divided into four groups: I – strict reserves (1 %); II – special purpose forest with primary function of either environmental conservation or recreation (12 %); III – protective forest for protection of soil, water etc. (15 %); IV – commercial forest (72 %). In this thesis, the attention is focused on the IV group, of which only pure Scots pine (*Pinus sylvestris*) stands were analysed. In Lithuania, pine forests is the most common forest type – 35 % of area (SFS, 2017), and it is the most important tree species from an economical point of view.

A lot of useful information has been collected during the National Forest Inventory (NFI) which commenced in 1998. Until the 2017, four full five-year cycles have been implemented. The data of this process is very essential to evaluate forest management in Lithuania. That is the reason why the NFI-data from the period 1998–2017 was chosen as data for this thesis.

1.2. Objectives

The aim of this work is to provide an overview of current forest management in pure Scots pine forests in Lithuania, emphasizing the criteria of profitability and productivity using NFI-data.

To meet the aim of the thesis, the analysis was divided into two stages:

1. Description of current management models in pure Scots pine stands in Lithuania.
2. Studies of alternative forest management models and how they would influence forest production and economy.

Based on previously mentioned information, the following hypothesis can be stated: current forest management in Lithuania does not fulfill the economic potential. To be more economically effective alternative rotation lengths should considered.

2. SCOTS PINE FOREST MANAGEMENT IN LITHUANIA

2.1. Scots pine and its comparison to other tree species

Scots pine was chosen as the research subject of this thesis for two reasons. Firstly, it is the most commercially important tree species in Lithuania and neighbour countries. It has the biggest share of harvested volume of tree species. Secondly, Scots pine grows in different soil conditions in Lithuania, but rotation age is the same everywhere. This tree can tolerate the worst growing conditions, from dry sandy soils to wetlands (Juodvalkis, 2009).

Scots pine is one of the most important species economically not only in Lithuania, but the whole north of Europe. It is significantly relevant commercially, because the wood is strong and easy to work with, making it excellent for constructions, furniture-making and the pulp and paper industry. It is also used for stabilising sandy soils (EUFORGEN, 2019).

The ability of this species to adapt and resist enormously different natural conditions is clearly visible from its distribution (figure 1). The areal of Scots pine spreads in the Central Europe, Scandinavia, and reaches Manchuria and Okhotsk Sea. Its distribution also depends on the height above the sea level. In the south of the areal it is more common up in the mountains. For example, in the North of Scandinavia it grows only up to 220 m above the sea level; however, in the Balkans it can be found as high as 2200 m (Navasaitis et al., 2003). In Lithuania, the average of the site index of Scots pine is I, which indicates the height of 28 m at an age of 100 years (SFS, 2017).

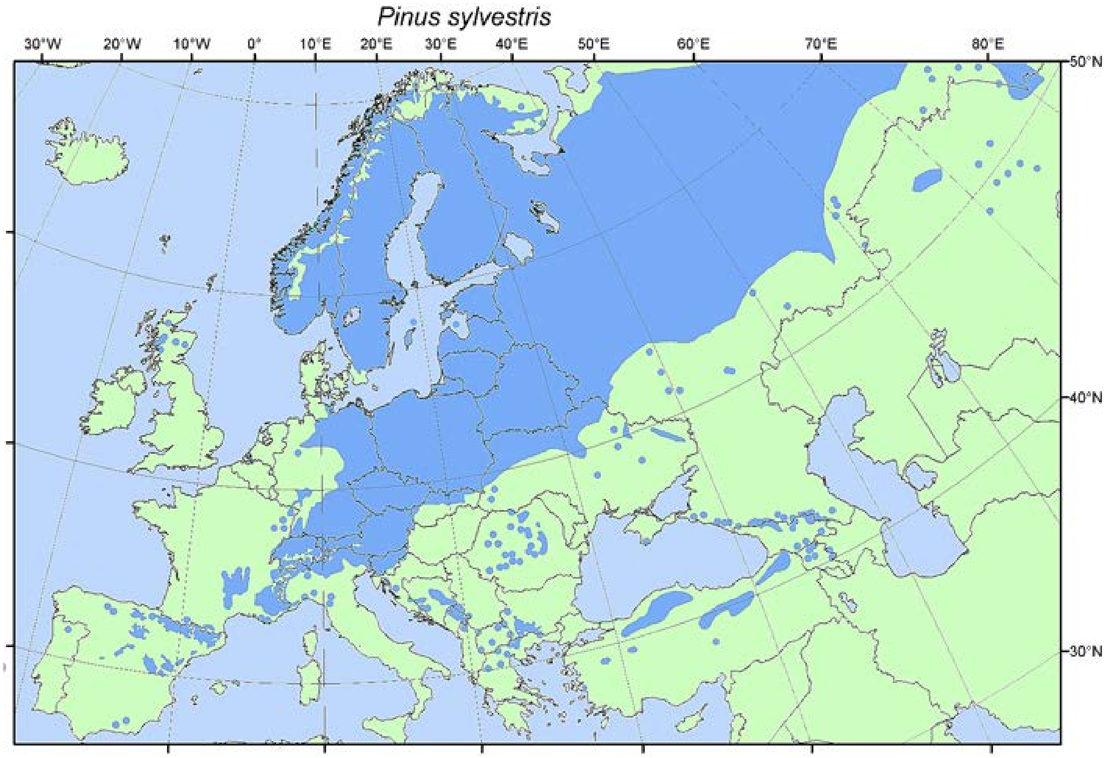

Figure 1. Natural distribution area of *Pinus sylvestris* in Europe (source: EUFORGEN, 2019)

Scots pine (*Pinus sylvestris*) is the most dominant tree species in Lithuania (figure 2) and covers 34,6 % of all forest land (SFS, 2017). By the percentage of dominance, it vastly surpasses other species, as birch and spruce only take a bit more than 20 % each. In Lithuania, the biggest areas of Scots pine stands are in south and south-eastern parts. The majority of the of Scots pine stands are pure (83 %), but 10 % are mixed with Norway spruce and 5 % with birch (EUFORGEN, 2019). The threshold when stand is pure is 80% and more volume of one species in the stand.

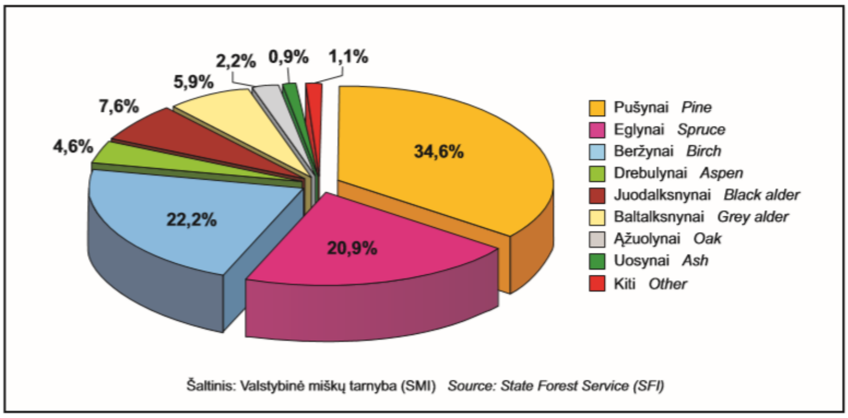

Figure 2. Dominant tree species in forest stands on 01/01/2017 (source: SFS, 2017)

The characteristics of the three most common tree species in Lithuania (Scots pine, Norway spruce and birch) are compared in the table 1. The table only provides the information from the IV forest group which includes commercial forests. The stands of Scots pine are older and denser than the ones of Norway spruce and birch. The age differs by approximately twenty years and stocking level (ratio of stand volume or basal area compared to normal stand volume or basal area (a stand is considered to be normal when the crowns are fully merged)) is bigger by 0,04–0,12 (LRS, 2010). What is more, growing stock volume is considerably bigger. Surprisingly, the gross annual increment of Scots pine is only slightly lower than Norway spruce, which naturally grows on more fertile soils (Nilsson et al., 2010). However, it noticeably surpasses the birch. All the other rates are similar.

Table 1. Characteristics of exploitable forest stands in the IV forest group (SFS, 2017)

Forest type (IV group)	Area (SFI)		Average characteristics of forest stands (NFI)				
	1000 ha	%	Age	Site index HAB, m	Stocking level	Growing stock volume, m^3/ha	Gross annual increment, m^3/ha
Scots pine	466,3	31,4	69	29	0,8	322	9,7
Norway spruce	345,9	23,3	47	30	0,68	229	9,9
Birch	357,0	24,1	45	27	0,76	207	8,1

2.2. Short history of thinnings in Lithuania

The history of thinnings in Lithuania is divided into two periods. According to Juodvalkis, there is no exact information about the very first thinnings (Juodvalkis, 2003). However, it is stated that this process began in the second half on the 19th century. This first stage lasted until the middle of the 20th century. This period is related to increased need of firewood and possibilities to fulfil it by thinning young forests. At that time areas of thinnings were small. Mostly tiny woods were thinned in highly inhabitant zones. Bad quality trees were often cut only in small areas and not in the whole stand. The situation changed when the demand of domestic tools increased. In 1934, the new regulations were established. Three ways of thinning were mentioned there: plucking, thinning, and gap-cutting. Plucking referred to pruning nowadays; thinning meant eliminating single trees out of a stand; gap-cutting was meant to create open areas by cutting gaps out of a stand. Theoretically, it was recommended combining all the three methods. Nevertheless, practically, forests were abandoned; therefore, the thinnings were implemented in a hurry by cutting the trees that were damaged and interrupted the growth of dominant trees (Juodvalkis and Kairiūkštis, 2009).

The second stage began in 1950 and was dedicated to classical thinnings according to the Soviet Union school. It was very important to follow all the requirements and instructions because Lithuania was restricted by the Soviet regime. In the forest management plans, attention was paid to the development of four thinning ways: lighting, clearing, and two steps of commercial thinning. After the WWII, only after a while the right intensity of thinnings was chosen. Different researches were carried out and the most appropriate thinning ways were applied following species composition and stand conditions. In 1961 the two-storey stand thinning method was formed. The thinnings were used not only for the purpose of quickening the growth of dominant tree species, but also to increase the volume in the area of thinned stand. In Lithuania, the general idea behind thinnings is to maximize the increment in order to produce the biggest amounts of large sawn timber. After huge amount of experiments and research, the new model for stand forming system was created. This led to the further development of thinning methods and is used until these days (Juodvalkis, 2003).

It can be stated that the new, third, stage of thinning stands has begun since the 1st of March, 2010. From this day, the Republic of Lithuania has legitimized the "Regulations for Forest Felling" in which the thinnings are divided into three groups (table 2) and are differentiated among tree species. Nowadays, the thinnings are done for various aims:

- To form tree species composition;
- To regulate the structure and density of the stand;
- To increase the productivity;
- To improve the structure of sortiments;
- To increase the resistance of negative abiotic factor;
- To extract the wood which would rot due to natural thinning;
- To strengthen recreational and aesthetic functions;
- To create suitable conditions for different ecosystems to survive;
- To protect genetic reserves sustainability.

Table 2. Types of thinnings and age (source: LRS, 2010)

Type of thinnings	**Forest age, years**	
	Coniferous and hard deciduous	Soft deciduous
Pre-commercial	8–21	6–21
First commercial	21–41	21–31
Second commercial	≥ 41	≥ 41

Even though the word “commercial” is used in the titles of the thinning types, there is nothing related to commerce. This translation was chosen to be used in this thesis according to Swedish tradition. The purpose of the 1st commercial thinning in Lithuania is to reduce competition between trees and create optimal growing conditions for the best trees. The 2nd commercial thinning is oriented in increasing the increment of separate trees and the whole stand (Juodvalkis and Kuliešis, 2009). Both thinning types do not have objectives for timber extraction during the thinnings, the main goal is the condition of the stand in the future. On the other hand, there is some commerce present here, as the thinnings in fact are also aimed for getting some assortments, even though the regulations emphasize forestry professionalism of thinking about the next generations.

2.3. Management of pine forest

2.3.1. Thinnings

Silvicultural treatments in Lithuania are based on optimal light conditions in the stand. The main goal is to achieve maximum possible volume at the age of final felling. According to Juodvalkis and Kairiūkštis (2009), light is a natural factor that can be efficiently regulated in the forest stand. Consistently, stand treatments are supposed to be based on the light regime, in order to achieve maximal productivity (Kairiūkštis et al., 1979). However, economic factors were not considered when designing this management program. The attention is only paid to final volume (Mizaras et al., 2013). This kind of recommendations and management is based on the theories introduced several decades ago and does not match the needs of nowadays. The economical interim results should also be taken into consideration.

Over the last years, thinnings in pure Scots pine stands in Lithuania are projected following the restrictions described in the “Regulations of Forest Felling” (table 3). The most important factors that need to be considered when making the decision are the dominant tree species, soil, mean height of stand, stocking level, mean diameter of trees (LRS, 2010). If the dominant tree species in the site is the Scots pine, the table of this tree (table 3) is the main tool that helps creating the cutting plan. The specifications are provided for two types of soil: slope and infertile, and others. Here is the example of how this table works: if the mean height of the stand is 11 m and the mean diameter is less than 12 cm, the stocking level after thinnings could be reduced to 0,7.

Table 3. Standards of thinning projection in pure Scots pine stands (source: LRS, 2010)

Mean height of first storey, m	Stocking level after thinnings of the first storey by mean diameter of dominant species, cm			
	0,6	0,7	0,8	0,9
Scots pine– *myrtillosum, vaccinio–myrtillosum, oxalidosum, myrtillo–oxalidosum* et al.				
5		<8	8	>8
6		<8	8	>8
7		<10	10	>10
8		<10	10	>10
9		<12	12	>12
10		<12	12	>12
11		<12	12	>12
12		<14	14	>14
13		<14	14	>14
14		<14	14	>14
15		<16	16	>16
16		<16	16	>16
17		<18	18	>18
18		<18	18	>18
19		<18	18	>18
20		<20	20	>20
21		<20	22	>22
22		<22	22	>22
23		<22	22	>22
24		<24	24	>24
25		<26	26	>26
26		<26	26	>26
27		<28	28	>28

The intensity of thinnings in pure stands is evaluated according to the requirements for the number of trees in the stand. The requirements for the Scots pine stands are provided in the table 4. The number of trees cannot be lower than it is legitimated in the regulations. The maximum error of 20 % is allowed. According to Pretzsch, this type of evaluation is mostly useful then the stand is of young age or in pre-commercial thinning phase when all the trees are of small dimensions and similar size; however, it is inaccurate when the stand develops and reaches relevant parameters. Basal area of stand could be more suitable tool for evaluation of real stand density (Pretzsch, 2009).

Table 4. Requirements for number of trees in pure Scots pine stand (source: LRS, 2010)

Mean height tree, m	Forest type	
	cl, v	*m, v–m, ox, m–ox*
	Number of trees, ha	
6	3510	3670
7	3110	3250
8	2760	2890
9	2460	2580
10	2200	2320
11	1980	2090
12	1780	1890
13	1610	1720
14	1460	1570
15	1330	1430
16	1210	1310
17	1100	1200
18	1000	1110
19	910	1020
20	830	940
21	760	870
22	700	800
23	650	740
24	600	680
25	550	630
26		580
27		530
28		490

In Lithuania, the trees can be classified according to their quality. As it is shown in the figure 3, the healthiest trees with the biggest volume are in the group A or even A^1 if their condition is extremely well. The trees with worse features are labelled B, and the weakest and smallest ones are in the group C.

Peculiarities of thinnings in Scots pine stands determine ecological properties of this species and, primarily, its demand of sunlight. Thinnings of this species in Lithuania are projected in all kinds of site conditions, except bogs and wetlands where pine grows very slowly because of poor soil. The first commercial thinning is done in the stands with 0,8 and / or bigger stocking level (table 2). The main purpose of the first thinning is to create optimal growing conditions for the A-class (figure 3) healthy trees with straight stem, well developed crown. All non productive trees of B and C classes are removed as well as damaged or crocked stem. What is more, the trees of the A^1-class are also eliminated as they are too dominant and worsen the growing conditions of other trees. The stocking level after the first commercial thinning is usually reduced to 0,7 (Juodvalkis et al. 2011).

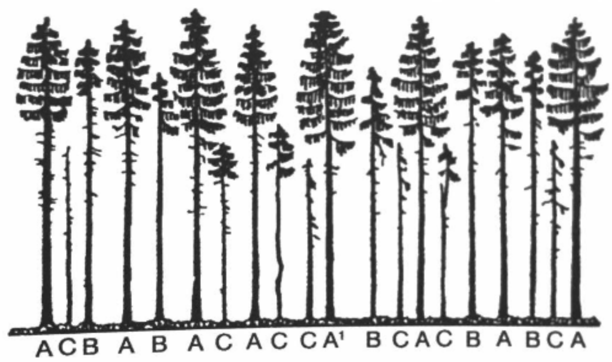

Figure 3. Classes of trees in Lithuania (source: Juodvalkis and Kairiūkštis, 2009)

Following recommendations, irrespective of the forest type, the second commercial thinning is done in Scots pine stands with 0,9 and bigger stocking level. This thinning should be less intensive than the first one. After all the thinnings, only the A-class trees with stand stocking level around 0,8 should be left. Combined thinnings from below and above are done almost all over Lithuania (Juodvalkis and Kairiūkštis, 2009). Even though this practice is applied in Lithuania, several studies show that the thinning type does not have a statistically significant effect on total stem volume production for Scots pine (Nilsson et al., 2010). According to some critics, there is no big difference in the final result whether the thinning was done from above, below or combined.

According to the records of stand-wise forest inventory, during the period from 2006 to 2015, the first commercial thinning was done on 41 % of the area covered by stands of the first commercial thinning age in state forests. The figure for private forests was 5 %. The second commercial thinning was recorded on 8 % of the second commercial thinning stand area in state forests and on 10 % in private forests. The recommendations for 2016–2025 are of bigger percentage than it was reached during 2006–2015. The proposed commercial thinning sizes are the following: in state forests the first commercial thinning is suggested on the area making 52 % of the first commercial thinning age stand area (in private forests, 52 %). The second commercial thinning is suggested on the area making 21 % of the second commercial thinning age stand area (in private forests, 24 %) (Mozgeris et al., 2018).

2.3.2. Final felling

Based on legal acts, rotation period for Scots pine in Lithuania is 101 year for the IV group forest and even longer for other groups (LRS, 2010). The rotation period for Scots pine is defined by legal acts and is considered to be too long by forestry experts. There were several studies conducted suggesting differentiation of maturity age based on soil and site productivity properties (Brukas et al., 2001; Deltuvas et al., 2008). Practically, the rotation period in state forests is even longer due to the principles of estimating the annual cutting norm. These principles are not applied for private forests, yielding in relatively large areas of over-mature and high average age forests. Annual five-year cutting norm is calculated by the State Forest Service and must be accepted and validated by the Government. From 2019 to 2023 the norm is 11850 ha and it is bigger by 6 % than it was over the last five years (lrv.lt, 2018). In principle, the main issue is not with who calculates, but with the age class method "Optina" and the requirement to harvest resources of mature stands just in 15 years (Mozgeris et al., 2017). Therefore, not all stands which are older than 101 year can be felled. This leads to accumulation of mature forest stands, reduced timber quality and necessitating harvesting priorities on over-maturing forest. Private forests are usually cut after having reached the minimum rotation age. There are more than 20 % Scots pine stands that are over the minimum allowable rotation age (figure 4), especially in the forest owned by the state. Also, the huge amount of prematuring Scots pine forests planted after the WWII is reaching the final felling age (age class from 6 to 8 in figure 4) and it needs to be managed. The management application could lead to even bigger accumulation of mature stands what would increase economic loss.

Figure 4. Age class distribution of Scots pine stands in the IV forest group by different owners (source: SFS, 2017)

2.4. National Forest Inventory

The National Forest Inventory (NFI) started in 1998 in Lithuania. It is based on permanent sample plots. A strictly systematic distribution pattern of permanent plots was applied in order to distribute those plots more evenly on the whole territory as well as regularly control transformation of other land categories and forest growth there. The location of the first permanent tract was determined randomly. The sample plots were grouped by four plots each (figure 5). Combining to Lithuanian coordination net, every group of permanent sample-plots was placed in every 4 km row and 4 km column by the principle of chess-board. One group of permanent sample plots represents 16 km^2 of territory or 400 ha for one permanent plot. Measurements of permanent sample plots are done every five years (VMT, 2015).

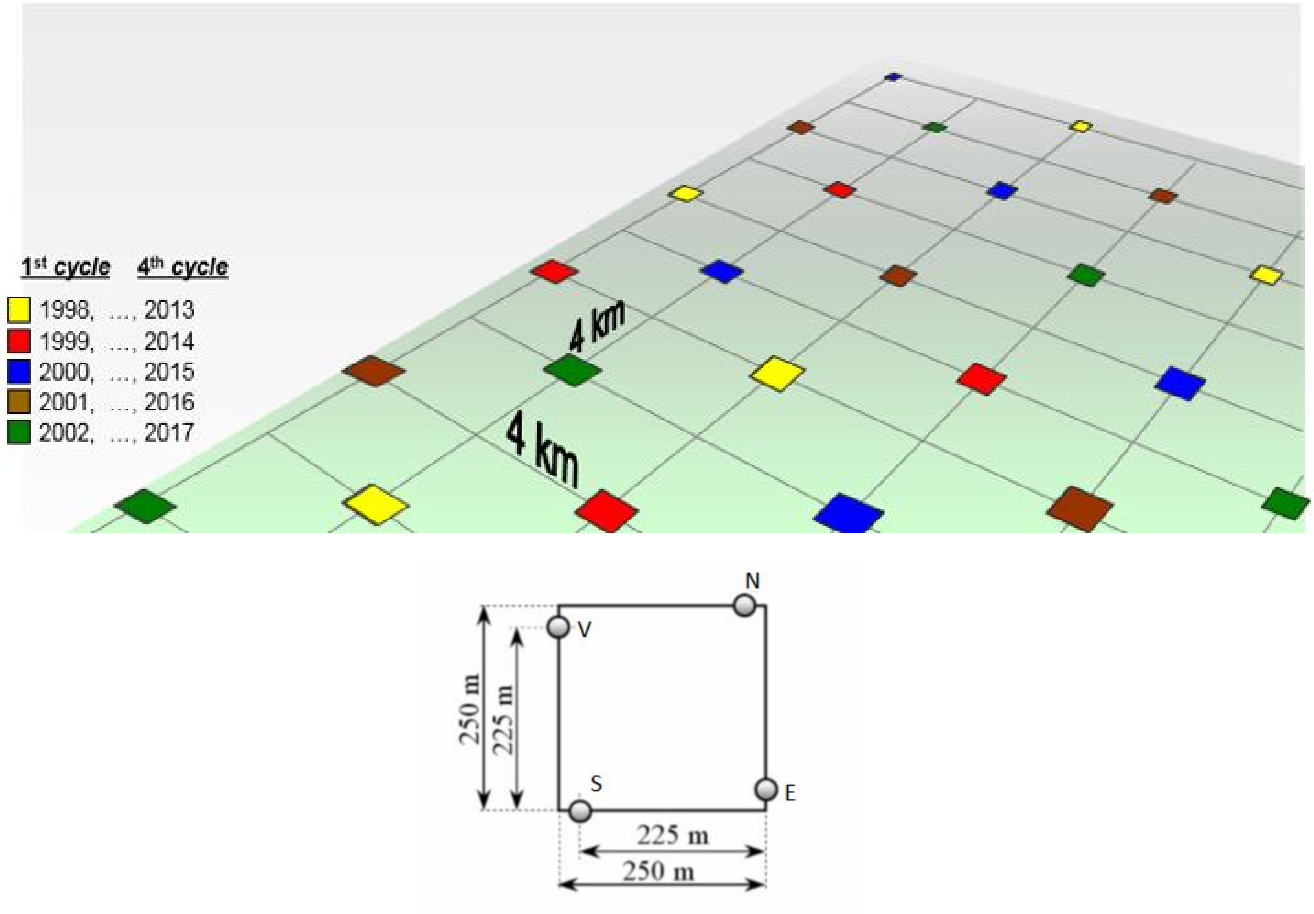

Figure 5. Scheme of NFI measurement tracks and plots (source: SFSS, 2002)

For each tree in a sample plot, tree species, competitive position, condition are registered and diameters at 1,3 m height are measured (figure 6). For sample trees, i. e. on average for 3–5 trees of dominant species and not less than 1–2 trees of any trees, heights and diameter at their butts are measured. Data from sample-trees is used to construct regression-functions of tree heights dependence on diameter. With these functions, heights of all callipered trees are calculated. Each permanent first year sample plot represents 2000 ha, second year – 1000 ha, third year – 666 ha, fourth year – 500, and fifth year – 400 (Kuliešis et al., 2008). Succession of trees in permanent sample plot never ends: some of trees are cut, die or degrade naturally. When other trees reach proper parameters, it is started to be measure them. This process assures uninterrupted observation of trees. Measurements are done when the tree is felled down or fully disappears in litter.

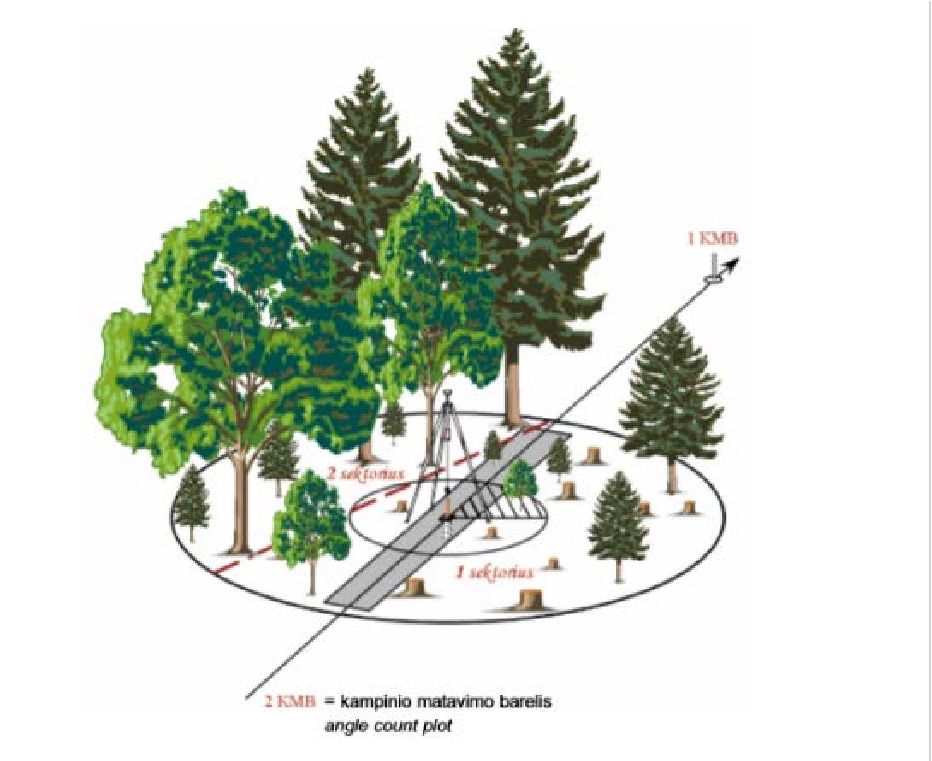

Figure 6. Inventory of trees and stumps in a permanent sample plot (source: SFSS, 2002)

3. MATERIAL AND METHODS

Figure 7 illustrates the methodology of this thesis. Four main steps were taken in order to make the conclusions. Firstly, the data was collected from the NFI. Then it was systemized to a database that would be possible to work with. Furthermore, calculations were made according to distinguished objectives. The intensity of thinnings was calculated with the programme "R Studio". The alternative management models were simulated with the programme "Heureka". Finally, Net Present Value (NPV) and Land Expectation Value (LEV) were calculated. Each of these steps are described in detail in this section.

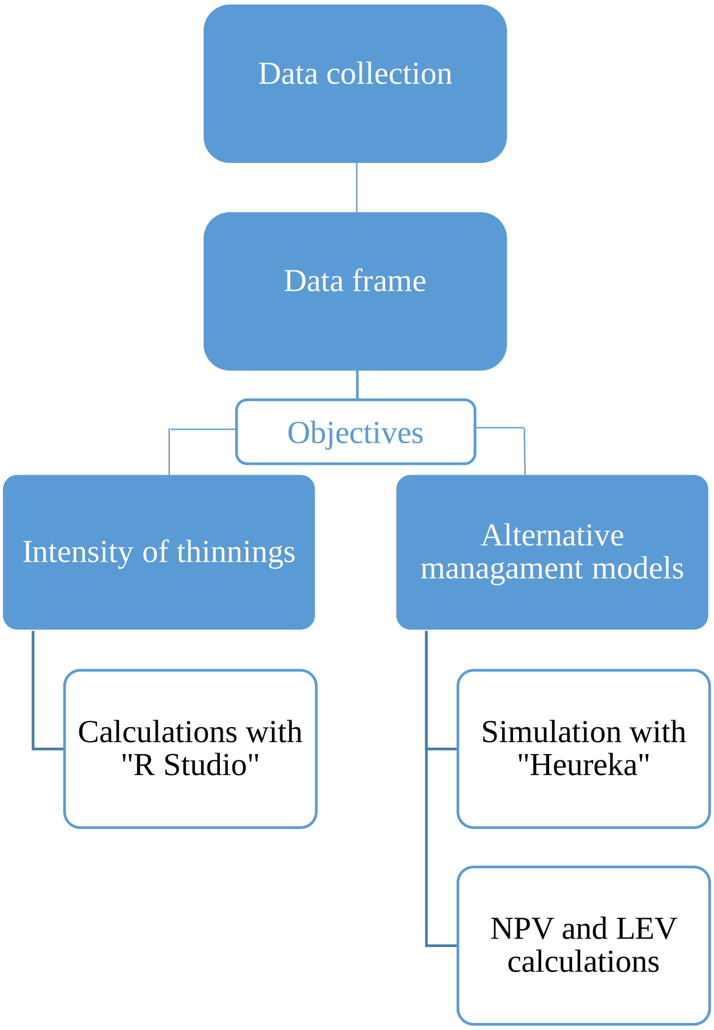

Figure 7. Scheme of methodology part with the sequence of work done

3.1. Data collection

The data used in this thesis was collected from the NFI. The figures were taken from the period from 1998, when the NFI began in Lithuania, until 2017. This means, that the data includes the information from five fully completed 5-year periods. In total, the data consisted of 35 687 lines of records with information about permanent NFI sample plots.

In NFI database, the information on more than 100 different forest parameters within a sample plot are saved (table 5; annex 1). All of it may be analysed in various ways to get different information about Lithuanian forest, i. e. the height structure of different tree species, distribution of age, cutting volume etc.

Table 5. Stand parameters in NFI data (source: SFSS, 2002)

Dimensions of plants	*State of plants*	*Area characteristics*
		Ownership
Trees	Species	Land use category
Diameter 1,3 m	Storey	Protective status (forest group, subgroup)
Height	Growing	Administrative region
Length of crown	Dead	Site type
Age	Removed	Forest type
Volume $V=f(D,H,F_{DH})$	Quality class	Age class
Increment $Z_V=f(V_A,V_{A-n})$	Damages	Site index
Understorey	Type	H_{AB}
Height	Cause	D_{AB}
Age	Position	Stocking level
Underbrush	Intensity	Species composition
Height	Defoliation	

3.2. Data frame

To reach the objectives of examining the intensity of thinnings in Scots pine stands and alternative management models in Lithuania, a subset of plots were selected. Criteria for plots to be included were:

1. Pure Scots pine plots (80 % or more of Scots pine);
2. Group IV (commercial forest);
3. The plot area larger than 400 m^2;
4. Some cuttings must be done.

From the total data, 576 permanent sample plots were chosen following the four criteria mentioned above. 237 of those sample plots were from the period 1998–2002, 68 sample plots from 2003–2007, 123 sample plots from 2008–2012, and 148 sample plots from 2013–2017 period. Four groups of data from four different five-year periods were prepared for further calculations.

3.3. Intensity of thinnings

To assess the intensity of thinnings in Lithuanian pine forests calculations with the collected data were done using the programme “R Studio”. It is a software designed for statistical computing using R programming language. The most important parameters for the calculations were the following:

1. Identification number;
2. Mean height of dominant species;
3. Volume of the 1st and the 2nd storeys;
4. Harvested volume (the 1st storey; the 2nd storey; living trees; dead trees).

To calculate the value of interest, the following formulas have been used:

Volume after harvesting:

$$V_{ah} = V_1 + V_2;$$

where: V_1 – volume of 1st storey (m^3/ha);
V_2 – volume of 2nd storey (m^3/ha).

Harvested volume of living and dead trees:

$$V_h = V_{h1} + V_{h2} + V_{dh1} + V_{dh2};$$

where: $V_{h1}; V_{h2}$ – harvested volume of living trees 1st and 2nd storey (m^3/ha);
$V_{dh1}; V_{dh2}$ – harvested volume of dead trees 1st and 2nd storey (m^3/ha).

Volume before harvesting:

$$V_{bh} = V_{ah} + V_h.$$

The calculated data was used to draw a graph illustrating the intensity of thinnings in Scots pine forest (figure 8). The thinnings were differentiated depending on the forest owner (either state or private) which allowed to compare the thinning models by ownership.

3.4. Alternative management models

The alternative management models were simulated with the "Heureka" software. For continuous simulation five representative plots were chosen from the NFI data including common heights and volumes. The economic analysis was meant to calculate the optimal rotation length for different representative stands in Scots pine stands in Lithuania. The calculation of rotation length was based on pure economic calculations of the Net Present Value (NPV) and the Land Expectation Value (LEV).

Table 6. Stands selected for economic analysis

Number of the plot	*Name*	*Age*	*Basal Area*	*Diameter*	*Height*	*Site Index*	*Number of stems*	*Volume*
1	A	30	29	16,3	16	32	1500	192
2	B	40	28	17,9	19,4	32	1188	253
3	C	60	28	18,5	20,7	28	1100	268,6
4	D	75	45	23	23	25	1100	463
5	E	75	35	30	31	35	500	477

3.4.1. Simulation with "Heureka"

To create the simulations (the examples of work can be found in annexes 2–11), programme "Heureka" has been chosen. It is a free-accessible software developed by Swedish University of Agricultural Sciences (SLU). The system is designed to process the information related to forestry – from forest inventory data processing to choosing alternatives through multi-criteria decision support methods. It is for both, tasks related to timber management and other ecosystem service's problem solving (Heureka, 2019). Heureka has various modules, such as "PlanWise", "StandWise", "RegWise", "PlanEval". The "StandWise" module was chosen for this thesis, because it makes stand level analysis. The aim of this module is to evaluate specific management options and study growth, revenues, costs, and forest development for single stands.

Despite the differences in forestry of Lithuania and Sweden, a variety of "Heureka" tools can be applied in Lithuania. While creating the simulations for this project, the settings of forest management model of a region in Sweden that matches the conditions of Lithuania in a maximum level were chosen.

For creating the simulations with the "Heureka" software, default values for cost of harvesting and income at thinnings and final felling were used. Prices for different diameter and quality saw logs and proportion in various quality classes were set as default values in "Heureka" (table 7). For all plots, three different thinning models were tested: 15 % removal, 35 % removal and no thinning. In addition, Lithuanian thinning recommendations were used to mimic thinning model for one stand (annex 5).

Table 7. Prices of timber in "Heureka" software (source: Heureka)

DIAMETER CLASS	*PRICE EUR/M³*			
	Quality 1	*Quality 2*	*Quality 3*	*Quality 4*
13	30	30	30	30
14	41,5	41,5	36,5	32,5
16	44	44	39	32,5
18	47,5	47,5	42,5	34
20	57,5	48,5	46	34
22	62,5	48,5	48,5	34
24	67,5	50	50	34
26	70	52,5	52,5	34
28	72,5	54,5	54,5	36,5
30	75	56,5	56,5	36,5
32	75	57	57	36,5
34	75	57,5	57,5	36,5
36	70	47,5	47,5	30

3.4.2. Net Present Value and Land Expectation Value calculations

For the economic calculations, an interest rate (IR) of 2% was used, following Brukas et al. (2001) studies related to Lithuanian economy. An IR-sensitivity analysis was done in one stand where interest rates of 1 %, 2 %, 3 %, 4 %, and 5 % were tested.

The Net Present Value is outlined as the sum of present value of the revenues minus the sum of the present value of the costs (Lawrence, 2001).

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

where R_t = revenue in period t

C_t = cost in period t

t = period length

i = interest rate

n = number of planning periods.

In 1849, a German forester Martin Faustmann created the formula to count what is the maximum an investor could pay for bare land and still earn the minimum acceptable rate of return. The Faustmann formula is a stand-level economic decision model that was originally conceived for pure even aged stands (Heshmatol Vaezin, 2009). Calculations using this formula help us estimate economically optimal rotation age, because the most profitable choice is assumed to correspond to the highest Land Expectation Value (Lawrence, 2001).

Land Expectation Value is a net present value designed for bare forestland – the present value of future revenues minus the present value of future costs, calculating just before the appearance of a new forest (Klemperer, 1996).

$$LEV = \frac{NPV_1(1+i)^t}{(1+i)^t - 1}$$

where NPV_1 = net present value of 1 full rotation

t = period length

i = interest rate.

Since the costs of regeneration and net income in previous thinnings were unknown, it was assumed that the NPV from thinnings was equal to the costs of regeneration and the sum NPV at the beginning of the calculation was zero.

4. RESULTS

4.1. Thinning intensity

Thinning intensity increases with height of the trees (Fig 8). The majority of thinnings were done between 19 and 25 meters of height. The volume of the stand before thinning was around 200 m^3/ha in the stands lower than 20 m. The mean volume before thinning the stands of 20–25 m height was 300 m^3/ha and stands higher than 25 m contained about 400 m^3/ha. Surprisingly, the volume of some of the stands was even more than 600 m^3/ha. The illustrated thinning intensity by different heights meets the legal thinning recommendations of Lithuania. The green line of the graph shows the upper limit where the stock level is 1,0. All the stands above this line need to be thinned. The blue line shows the lower limit of stocking level which could be reached after thinning. There are some stands that are out of the range.

A large proportion of thinnings in Scots pine stands in Lithuania were light or very light intensity thinnings in different height classes (Fig. 8). The removal grade was less than 10 % of 60 % of the stands. In more than 40 % of the thinnings, average height was above 25 meters (figure 9). The average tree height for thinnings was 23 meters. 60 % of the thinnings were done when the trees were between 21 and 27 meters in mean height. Thinnings in stands higher than 25 meters had the variation of volume from 150 to 600 cubic meters before and after cutting (Fig 8).

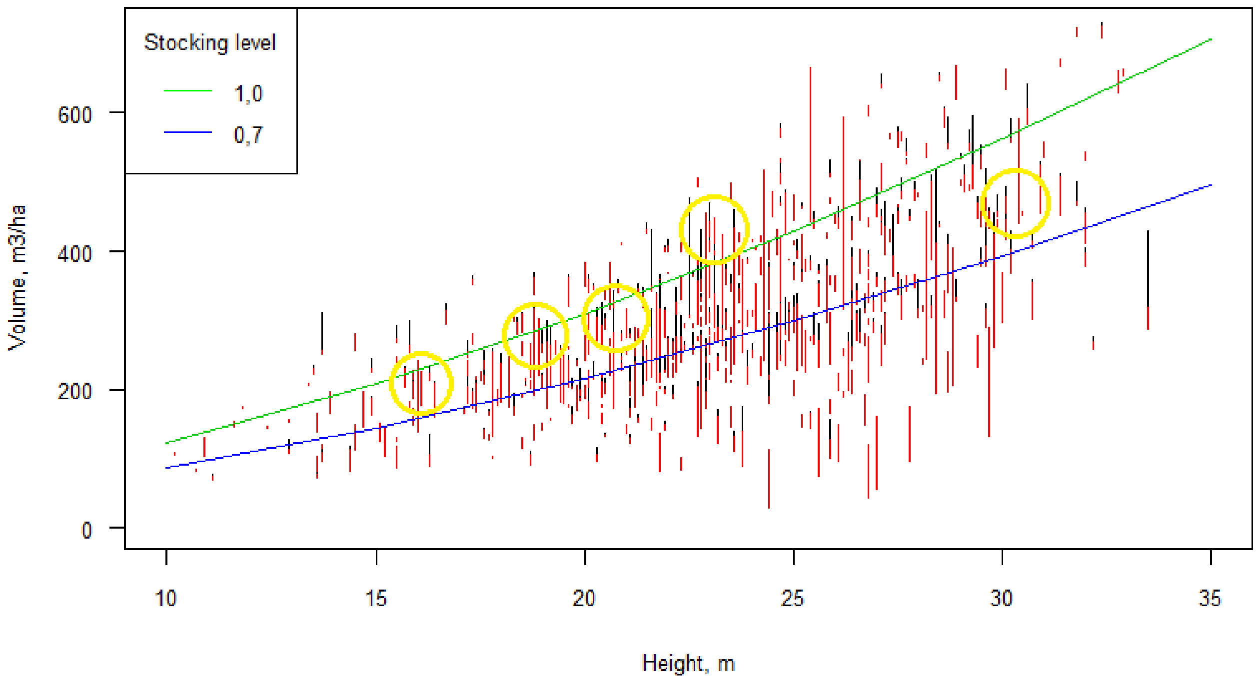

Figure 8. Thinnings in Scots pine stands in Lithuania. Each red and black lines represent the removal of volume (m^3/ha) from stand, respectively, of living and dead trees. Green and blue lines represent stocking level of stands. Yellow circles show the area that has been chosen as a representative stand for the economic analysis

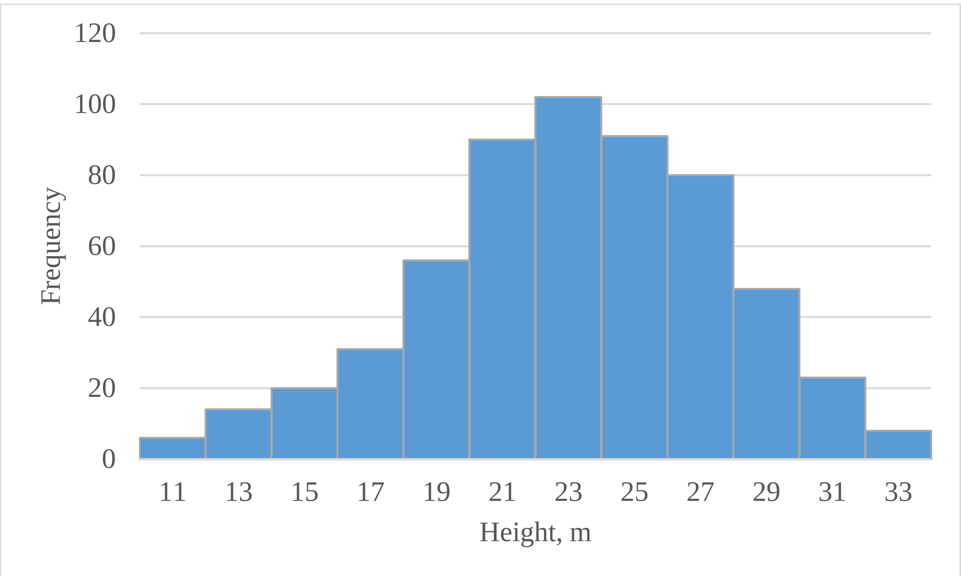

Figure 9. Number of thinnings in different height classes

The most common thinning grade was 3 %. The frequency of thinnings constantly decreased as the thinning grade increased. When the thinning grade was 27 %, the frequency became stable – around 10 for each ownership. Only a few plots were thinned with thinning grade above 33 %. The maximum thinning grade was 63 %. The proportion of light thinnings was higher in state forests than in private forests ((Fig 10)

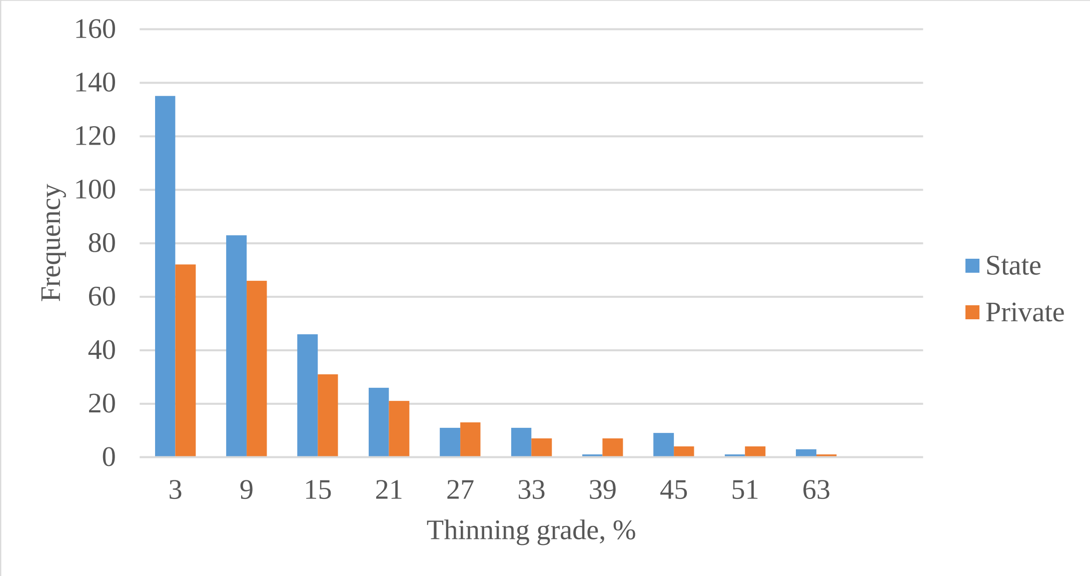

Figure 10. Thinning intensity by frequency of different owners from NFI data period 1998–2017

4.2. Economic analysis

All the simulations show that unthinned stands reach maximum NPV + LEV earlier than the thinned ones. With increasing thinning grade, the rotation age also gets longer. In young stands (A; B), there is no noticeable difference for the best rotation age between light thinning (15 %) and unthinned control; 35 % thinning grade increases the rotation length by 5 years. Thinning in young stands increases the NPV only slightly. For the stand of 21 m height and 270 m^3 volume (C), the best rotation age without thinnings is 80 years. Light thinnings extend the rotation length to 85 years, heavy thinning extends it to 90 years. Older stands with big volume (D; E) have already passed the best rotation age for unthinned stand. Light and heavy thinnings increase the rotation length, respectively, by 5 and 15 years. Earlier commercial thinning allows to achieve the biggest NPV value for rotation at a younger age.

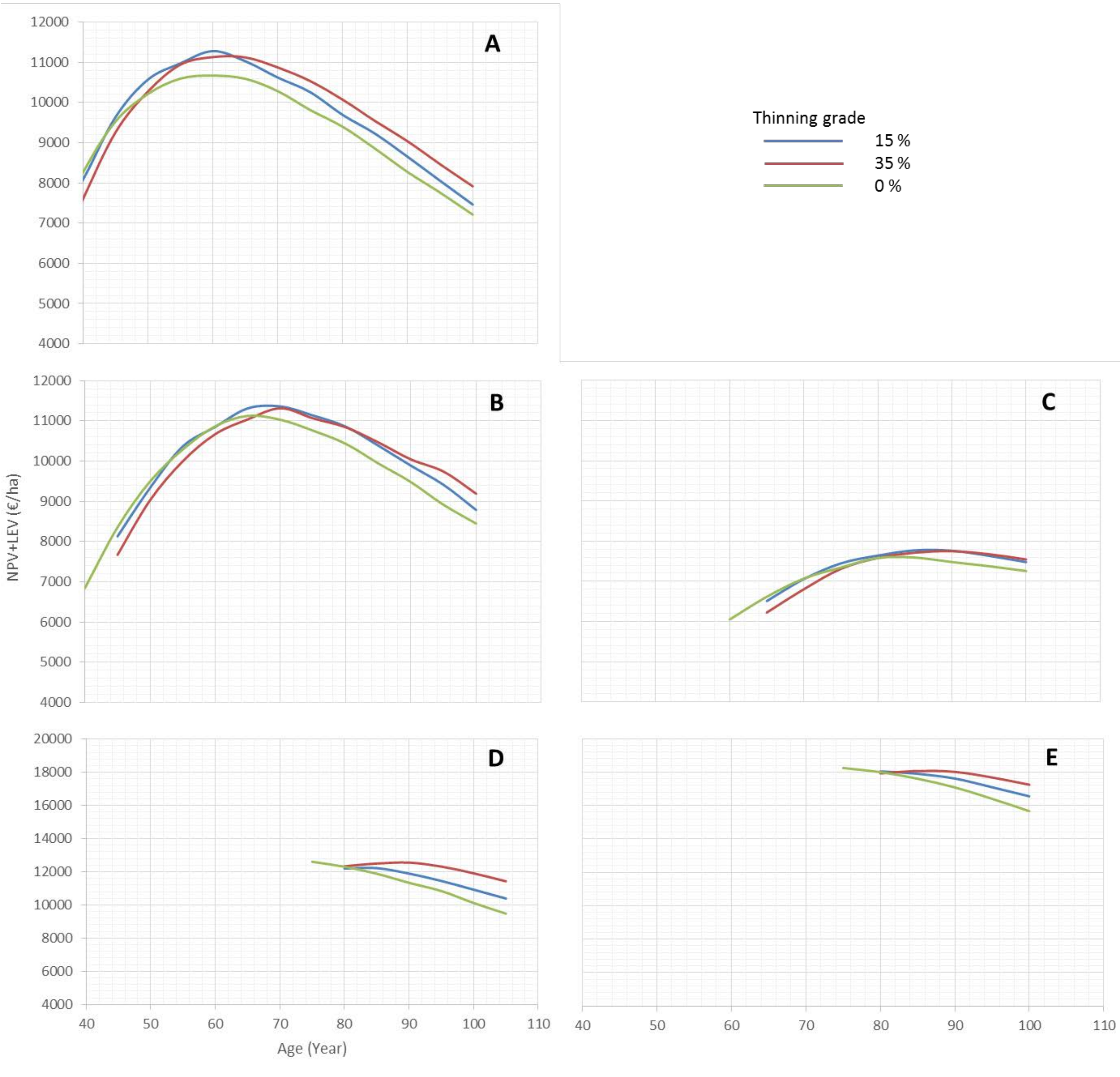

Figure 11. Value of NPV (€/ha) of different thinning intensity in different age for representative stands

When using the Faustmann formula to calculate the LEV, the interest rate must be chosen. Differences between NPV and optimal rotation age are significant if the interest rate varies (Table 8). The NPV is inversely proportional to the interest rate – when the first one increases, the second one decreases. The best optimal rotation age also increases when interest rate decreases (Table 8).

Unthinned stands have the biggest NPV among all the thinning models with 2 %, 4 % and 5 % interest rate. Light thinnings (15%) have the biggest NPV when the interest rate is 1 % and 3 %. The MIMIC thinnings have the lowest NPV. It is lower by 3,5 %, 8 %, 15 %, 24 %, and 31 %, when the interest rate is, respectively, 1–5 % compared to heavy thinnings. Despite that, the rotation length for MIMIC is from 30 to 55 years longer than the best economical rotation age.

The best optimal rotation age is the same for three different thinning models with the interest rate of 2 %, 3 % and 4 %. With interest rate of 1 %, an unthinned stand has 5-year lower rotation age, and with the interest rate of 5 %, a light thinning has a rotation age longer by 5 years.

Table 8. NPV and best optimal rotation age using different interest rates. All calculations have been done with stand A. MIMIC* – thinnings that have been made when stocking reached 1,0 following the thinning recommendations (30 % of the thinnings at the age of 30, 40, 55, 75 years)

Thinning model	*Interest rate*									
	1%		*2%*		*3%*		*4%*		*5%*	
	NPV	*Rot. Age*	*NPV*	*Rot. Age*	*NPV*	*Rot. Age*	*NPV*	*Rot. Age*	*NPV*	*Rot. Age*
0%	23 558	65	11 280	60	7 135	55	5 288	50	4 187	45
15%	23 656	70	11 130	60	7 206	55	5 269	50	4 184	50
35%	22 792	70	10 669	60	6 857	55	5 065	50	4 092	45
*MIMIC**	21 990	101	9 802	101	5 775	101	3 856	101	2 794	101

5. DISCUSSION

5.1. Thinnings

Intermediate cuttings are as important as final-fellings, managing them is essential for future development of stands. It is announced more and more frequently about the damage in the forests done by the climate change. Snow and especially storm damage appear to have increased in Europe during recent decades. Climate change leads to a higher frequency of heavy storms, so more widespread damage in forest systems can be expected if stands are not managed to reduce their vulnerability (Schelhaas et al., 2003; Gardiner et al., 2012). Even though Scots pine is resistant to natural disturbances, it is constantly damaged because pine forests have a large proportion of all stands. To avoid or at least reduce this in the future, it is important to carry out the initial thinning at a young stand age or apply pre-commercial thinning to improve tree stability right from the early development stages.

One of the most important tree attributes for stability is tree height (del Rio et al., 2017). Therefore, thinnings in old and high stands increase vulnerability. In Lithuania, the most common are light thinnings which reduce the risk of windthrow and snow damage. However, as these thinnings are of lower intensity they need to be done more often. This leads to a bigger probability of mechanical tree injuries made by heavy harvest-machines. Also, frequent movement of machinery puts a lot of pressure on the soil and ground vegetation. In addition, light thinnings are unbeneficial economically as the price of the cutting is rather high compared to the income gained. Thus, it would be useful to avoid light thinnings and carry out the intensive ones that would be done in an earlier age.

The average diameter of the final Scots pine stand is increased by thinning. There have been several studies carried out that show similar results (Mäkinen and Isomäki, 2004; Nilsson et al., 2011). One of the aims of the “Regulations of forest felling” in Lithuania is to increase the dimensions and sortiments structure of timber. This purpose is fulfilled by thinning. Firstly, the average diameter increases when the smallest trees from the stands are removed. Secondly, diameter annual increment is increased by thinnings. The net income from a tree depends on its size. The economically optimal rotations are shorter if the price premium for large-diameter saw logs is low (Roberge, 2016). Moreover, nowadays sawmills do not want big diameter logs for their production. Pricelist of one of the sawmills called “Storaenso” shows that Scots pine saw logs with diameter 20–25 cm on the bottom part have the same price as 26–40 cm saw logs (Storaenso, 2019). Naturally, modern wood industry always looks for better alternatives than solid wood. I. e. builders more and more often use glued wood constructions which are firmer by 50–70 % than the structures made from whole trees (Raftery and Harte, 2011). To produce this product large dimension saw logs are not needed.

5.2. Rotation age

Rotation age has an impact on various ecosystem services. These services are essential for humanity as they lead to production of oxygen, water detoxification and soil formation (Mizaras et al., 2013). One of those services is cultural ecosystem service as forest management directly affects aesthetical and recreational values. Even though people often have different preferences, the tendency in Lithuania is clear a forest stand's attractiveness for recreational activities generally increases with the size of the trees, and consequently old forests are usually preferred to young stands (Juodvalkis and Kairiūkštis, 2009). This means, shortened rotations would impact aesthetic and recreational values negatively due to larger landscape-scale proportions of clear-cuts and dense young stands at the expense of old forest, while extended rotations should have positive effects (Curtis, 1997). From increased activeness in the social media and civil movements to protect the trees from cutting, it becomes clear that society sees the bigger changes in the forest as a threat. This distinguishes the positive aspects of current thinning intensity, because Scots pines are grown for a long period. On the other hand, high levels of green-tree retention may alleviate to some extent the negative aesthetic impacts of more frequent clearcutting under shortened rotations (Ribe, 2005). In this case, clear-cuts would still have many big and old trees for retention. The other solution is to carry out the clear-cuts in the areas that are rarely visited by people.

Other ecosystem services could also be affected by rotation age. Carbon sequestration is a very important process for combating climate change. Climate change mitigation becomes an additional concern to be considered in silvicultural decisions. Current Scots pine forest management is inducing carbon sequestration. Carbon stock level is very high in Scots pine stands which grow up to 101 year and even longer. On the other hand, by reducing rotation length we would not have major losses on carbon sequestration because the effect would only be felt during the transitory period. According to Lundmark et al. (2018), the climate benefit would only be temporary as it is restricted to the first new rotation with the increased rotation length (above 85 for Scots pine) due to the increased standing forest carbon stock being conjugated to a permanently lowered yield.

The rotation length can also influence the biodiversity. Even though Scots pine forests are not very rich in variety of different species compared to broadleaves, they still maintain a unique fauna and flora (Kuliešis, 2008). Scientists have different opinions about biodiversity conservation's dependence on different rotation lengths. Some state that only old forest supports microhabitats that are rare or absent in younger forest and critical to large numbers of red-listed forest species (Bernes, 2011). In addition to that, shorter rotations imply more frequent clear felling and soil scarification events, which typically result in the destruction of a large proportion of the dead wood (Hautala et al., 2004). According to others, shorter rotation would not violate biodiversity. Shortened rotation lengths increase the frequency at which lost retention trees are replaced. As such, retention practices can reduce the impact of shortening rotation lengths on the availability of some types of habitat (Felton et al., 2017). From the economical point of view, the main purpose of the IV forest group is to grow as much quality timber as possible. Evaluating only this, forest with red-listed species be set aside for protection and the rest of commercial forest should be economically productive.

5.3. Critical approach

When only economic factors are taken into consideration, other relevant ecosystem services are often neglected. Because of long forest rotation period a lot of factors must be considered when economic indicators are calculated. Various circumstances, such as disturbances or market fluctuations, are difficult to foresee; this means, that the calculations can mismatch in the future. Economic calculations are very sensitive to the change of the interest rate. It is important to take this into account, thus very difficult to anticipate because of the rotation length. As it was noted in the this thesis, the economic rotation age can vary as much as 25 years. Similar tendency was also noticed in the research of V. Brukas et al. (2001).

After evaluating the results (figure 8), it would be incorrect to state that the NFI data can precisely describe the features of forest management in Lithuania. The area of permanent sample plots is 500 m^2, so the parameters of each measured tree can make a huge impact on the final results. The fact that there have been no records of the type of implemented cuttings in the NFI data leads to assumption that very heavy thinnings (figure 8) at high trees could represent the shelter wood management system. More studies need to be carried out to figure out whether it is proper to rely on the NFI data to make the conclusions about forest management.

6. CONCLUSIONS

After analysing the intensity of thinnings in Scots pine stands in Lithuania according to the NFI data, it was concluded that too many light and very light thinnings are done. Cuttings of this kind are less profitable than optimal thinning regimes and increase the risk of mechanical damage.

In Lithuania, thinnings are carried out in Scots pine stands of large heights. More than half of all the thinnings are done in stands of 23 m and higher. Thinnings in stands of this height increase the risk of windthrow and this can cause economic and forest sustainability losses.

Heavy thinnings in Scots pine stands increases the rotation length in which the biggest profit is gained. Light thinnings carried out in young stands have no impact on the rotation age. To maximize the economic profitability, older stands should rather be final felled than thinned.

With the rotation length, which is set now in Lithuania, the forestry sector loses additional income. It would be more profitable to grow the Scots pine stands of shorter rotation age. However, the current rotation length is probably positive for other ecosystem services such as recreational values and for biodiversity conservation.

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9. ANNEXES

Annex 1. Formulas of height and volume in NFI data

The height of each tree is calculated by formula (SFSS, 2002):

$$h_{ij} = \overline{H}_i \cdot R_{ij}; \qquad (1.1)$$

where $\overline{H}_i$ – mean height of trees of *i* species on the analysed storey of a sample plot,

$$\overline{H}_i = \frac{\overline{H}_{ai}}{R_{ij}}; \qquad (1.2)$$

where $\overline{H}_{ai}$ – mean height of sample trees of *i* species,

R_{ij} – reductional height value obtained from the dependence model of relative tree height on relative diameter (Kuliešis, 1993),

$$\overline{H}_{ai} = \frac{\sum_{j=1}^{k_{ai}} h_{ai} \cdot {d_{aij}}^2}{\sum_{j=1}^{k_{ai}} {d_{aij}}^2}; \qquad (1.3)$$

where h_{ai}, d_{ai} – height (m) and diameter (cm) of sample tress respectively,

k_{ai} – number of sample trees of i spieces in a plot,

$$R_{ij} = f\left(d_{ij,} \overline{D}_i\right); \qquad (1.4)$$

where d_{ij} - diameter of *j* tree at 1.3m height, cm for *i* tree species,

$\overline{D}_i$ – mean diameter of *i* species trees in a plot,

$$\overline{D}_i = \sqrt{\frac{\sum_{j=1}^{k_i} {d_{ij}}^2}{k_i}}; \qquad (1.5)$$

where k_i – number of *i* species trees in a plot.

Then tree volume in a plot is:

$$V_{ij} = \frac{\pi {d_{ij}}^2}{4 \cdot 10000} \cdot h_{ij} \cdot F_{h_{ij} d_{ij}}; \qquad (1.6)$$

where d_{ij} – measured diameter of j tree of i species at 1.3m height, cm,

h_{ij} – height of the same tree estimated by 1.1 formula, m,

$F_{h_{ij} d_{ij}}$ – form factor of a tree derived from its dependence on tree height and diameter (Kuliešis, 1993).

Annex 2. Heureka simulation and calculation results of stand A thinned by 35 %

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Period 13	Period 14
Financial Value	Gross Revenue	SEK/ha	Thinning intensity 35 %	13438	0	0	0	0	0	0	0	0	0	0	0	0	0	287333
Financial Value	Net Revenue	SEK/ha		4652	26739	44961	67193	89011	111461	131741	151721	169771	187294	202933	216939	231242	243002	254326
Financial Value	Total Cost	SEK/ha		8786	0	0	0	0	0	0	0	0	0	0	0	0	0	33007
Forest Data	Basal area (incl overstorey) After	m2/ha		18,85	24,3515	29,9763	34,945	39,3653	43,2831	46,6788	49,521	52,0066	54,1477	55,9681	57,5073	58,8023	59,8923	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		29	24,3515	29,9763	34,945	39,3653	43,2831	46,6788	49,521	52,0066	54,1477	55,9681	57,5073	58,8023	59,8923	60,8118
Forest Data	Dgv After	cm		16,6	19	21,2	23,1	24,8	26,3	27,7	28,9	30,1	31,2	32,3	33,4	34,4	35,4	0
Forest Data	Dgv Before	cm		16,3	19	21,2	23,1	24,8	26,3	27,7	28,9	30,1	31,2	32,3	33,4	34,4	35,4	36,3
Forest Data	DominantHeight Before	m		14,1	16,49	18,54	20,35	21,93	23,32	24,52	25,56	26,47	27,25	27,94	28,54	29,07	29,53	29,94
Forest Data	Hgv After	m		13,1	15,4	17,4	19,2	20,8	22,1	23,3	24,3	25,2	26	26,7	27,3	27,8	28,3	0
Forest Data	Hgv Before	m		13	15,4	17,4	19,2	20,8	22,1	23,3	24,3	25,2	26	26,7	27,3	27,8	28,3	28,7
Forest Data	Mean Age (excl overstorey) Before	yrs		30	35,1	40,1	45,2	50,2	55,2	60,2	65,1	70,1	75,1	80,1	85,1	90	95	99,9
Forest Data	SIH (estimated) Before	m		29,08	29,13	29,17	29,2	29,23	29,25	29,26	29,27	29,28	29,29	29,29	29,3	29,3	29,3	29,31
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		925,4	914,3	904,5	888,3	870,6	872,4	868,7	860,1	847,6	831,7	813,2	797	779,2	760,6	6146,3
Forest Data	Stems Before	Trees/ha		1500	914,3	904,5	888,3	870,6	872,4	868,7	860,1	847,6	831,7	813,2	797	779,2	760,6	741,6
Forest Data	Volume (incl overstorey) After	m3sk/ha		125,5	185,4	253,1	320,3	385,4	446,8	503,2	553,4	598,8	639,4	675,1	706,3	733,4	756,9	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		192	185,4	253,1	320,3	385,4	446,8	503,2	553,4	598,8	639,4	675,1	706,3	733,4	756,9	777,2
Treatments	Volume Harvested All Species	m³sk/ha		66,5111	0	0	0	0	0	0	0	0	0	0	0	0	0	776,1892
	NPV	EUR/ha		465	2422	3688	4993	5990	6794	7273	7586	7689	7683	7540	7300	7048	6708	6359
	SUMNPV	EUR/ha			2887	4154	5458	6455	7259	7738	8052	8154	8148	8005	7765	7513	7173	6824
	KOEF			2,23	2,00	1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		257	1594	2293	3013	3564	4008	4272	4445	4502	4498	4419	4287	4148	3960	3767
	LEV	EUR/ha			3188	4191	5109	5671	6040	6145	6140	6002	5815	5559	5265	4987	4672	4371
	NPV+LEV	EUR/ha			5774	7592	9253	10272	10941	**11131**	11122	10872	10533	10070	9537	9033	8463	7917

Annex 3. Heureka simulation and calculation results of stand A thinned by 15 %

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Period 13	Period 14
Financial Value	Gross Revenue	SEK/ha	Thinning intensity 15 %	5574	0	0	0	0	0	0	0	0	0	0	0	0	0	286150
Financial Value	Net Revenue	SEK/ha		1235	35852	52349	74805	96864	117414	139811	157194	173162	190428	204008	219463	231939	242746	252333
Financial Value	Total Cost	SEK/ha		4340	0	0	0	0	0	0	0	0	0	0	0	0	0	33817
Forest Data	Basal area (incl overstorey) After	m2/ha		24,65	30,3115	35,9561	40,7539	44,872	48,3542	51,2242	53,4049	55,2388	56,7817	58,0828	59,1893	60,1356	60,9478	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		29	30,3115	35,9561	40,7539	44,872	48,3542	51,2242	53,4049	55,2388	56,7817	58,0828	59,1893	60,1356	60,9478	61,6503
Forest Data	Dgv After	cm		16,5	18,5	20,3	22	23,5	24,9	26,2	27,4	28,6	29,7	30,7	31,8	32,8	33,8	0
Forest Data	Dgv Before	cm		16,3	18,5	20,3	22	23,5	24,9	26,2	27,4	28,6	29,7	30,7	31,8	32,8	33,8	34,7
Forest Data	DominantHeight Before	m		14,1	16,54	18,63	20,46	22,06	23,45	24,65	25,7	26,61	27,4	28,09	28,69	29,22	29,68	30,08
Forest Data	Hgv After	m		13,1	15,4	17,4	19,2	20,7	22,1	23,3	24,3	25,2	26	26,7	27,3	27,9	28,4	0
Forest Data	Hgv Before	m		13	15,4	17,4	19,2	20,7	22,1	23,3	24,3	25,2	26	26,7	27,3	27,9	28,4	28,8
Forest Data	Mean Age (excl overstorey) Before	yrs		30	35,1	40,1	45,2	50,2	55,2	60,2	65,2	70,2	75,2	80,2	85,2	90,2	95,1	100,1
Forest Data	SIH (estimated) Before	m		29,08	29,14	29,19	29,22	29,24	29,26	29,28	29,29	29,29	29,3	29,3	29,31	29,31	29,31	29,31
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		1225,4	1209,2	1190,2	1157,7	1119,8	1095,2	1063,7	1028	991,1	954,2	918	887,2	857,6	829,4	6146,3
Forest Data	Stems Before	Trees/ha		1500	1209,2	1190,2	1157,7	1119,8	1095,2	1063,7	1028	991,1	954,2	918	887,2	857,6	829,4	802,7
Forest Data	Volume (incl overstorey) After	m3sk/ha		163,9	230,9	304,2	374,5	440,6	500,9	554,3	599,3	639	673,8	704,3	730,9	754,2	774,6	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		192	230,9	304,2	374,5	440,6	500,9	554,3	599,3	639	673,8	704,3	730,9	754,2	774,6	792,5
Treatments	Volume Harvested All Species	m^{3}sk/ha		28,1034	0	0	0	0	0	0	0	0	0	0	0	0	0	791,5316
	NPV	EUR/ha		124	3247	4294	5558	6519	7157	7719	7860	7842	7811	7579	7385	7069	6701	6309
	SUMNPV	EUR/ha			3371	4418	5682	6642	7280	7842	7984	7966	7935	7703	7509	7193	6825	6433
	KOEF			2,23	2,00	1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		68	1861	2439	3137	3667	4019	4329	4408	4398	4381	4253	4145	3971	3768	3551
	LEV	EUR/ha			3722	4458	5318	5835	6058	6227	6088	5864	5663	5350	5091	4774	4445	4120
	NPV+LEV	EUR/ha			6742	8075	9633	10569	10973	**11280**	11028	10622	10258	9691	9222	8648	8052	7463

Annex 4. Heureka simulation and calculation results of an unthinned stand A

Result type	Variable	Unit	Not thinned	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Period 13	Period 14
Financial Value	Gross Revenue	SEK/ha		0	0	0	0	0	0	0	0	0	0	0	0	0	0	282942
Financial Value	Net Revenue	SEK/ha		20413	36291	55067	75607	95367	115329	134355	153332	170249	185056	201032	214127	225648	238213	248645
Financial Value	Total Cost	SEK/ha		0	0	0	0	0	0	0	0	0	0	0	0	0	0	34297
Forest Data	Basal area (incl overstorey) After	m2/ha		29	34,4726	39,1963	43,2313	46,6484	49,5552	52,0026	54,0607	55,7923	57,2521	58,4864	59,5344	60,4332	61,2069	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		29	34,4726	39,1963	43,2313	46,6484	49,5552	52,0026	54,0607	55,7923	57,2521	58,4864	59,5344	60,4332	61,2069	61,8781
Forest Data	Dgv After	cm		16,3	18	19,6	21,1	22,4	23,7	24,9	26,1	27,2	28,3	29,3	30,4	31,3	32,3	0
Forest Data	Dgv Before	cm		16,3	18	19,6	21,1	22,4	23,7	24,9	26,1	27,2	28,3	29,3	30,4	31,3	32,3	33,3
Forest Data	DominantHeight Before	m		14,1	16,51	18,65	20,51	22,12	23,53	24,75	25,8	26,71	27,5	28,19	28,79	29,32	29,79	30,19
Forest Data	Hgv After	m		13	15,3	17,3	19,1	20,7	22	23,2	24,3	25,2	26	26,7	27,3	27,9	28,4	0
Forest Data	Hgv Before	m		13	15,3	17,3	19,1	20,7	22	23,2	24,3	25,2	26	26,7	27,3	27,9	28,4	28,8
Forest Data	Mean Age (excl overstorey) Before	yrs		30	35	40,1	45,1	50,1	55,1	60,2	65,2	70,2	75,2	80,2	85,2	90,1	95,1	100,1
Forest Data	SIH (estimated) Before	m		29,08	29,15	29,2	29,24	29,27	29,29	29,3	29,32	29,32	29,33	29,34	29,34	29,34	29,34	29,35
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		1500	1455,8	1404,8	1348,2	1287,9	1243,7	1196,5	1148,3	1100,5	1054,1	1009,7	967,5	931,6	897,9	6146,3
Forest Data	Stems Before	Trees/ha		1500	1455,8	1404,8	1348,2	1287,9	1243,7	1196,5	1148,3	1100,5	1054,1	1009,7	967,5	931,6	897,9	866,3
Forest Data	Volume (incl overstorey) After	m3sk/ha		192	261,9	331,1	397,2	458,3	514	563,8	608	647,1	681,3	711,3	737,6	760,6	780,8	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		192	261,9	331,1	397,2	458,3	514	563,8	608	647,1	681,3	711,3	737,6	760,6	780,8	798,5
Treatments	Volume Harvested All Species	m³sk/ha		0	0	0	0	0	0	0	0	0	0	0	0	0	0	797,6093
	NPV	EUR/ha		2041	3287	4517	5618	6418	7030	7417	7667	7710	7591	7469	7205	6877	6576	6217
	SUMNPV	EUR/ha		2041	3287	4517	5618	6418	7030	7417	7667	7710	7591	7469	7205	6877	6576	6217
	KOEF			2,23	2,00	1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		1127	1815	2494	3101	3543	3881	4095	4233	4257	4191	4123	3978	3797	3630	3432
	LEV	EUR/ha		2516	3630	4558	5258	5638	5849	5890	5847	5676	5418	5187	4886	4565	4283	3982
	NPV+LEV	EUR/ha		4557	6574	8257	9525	10212	10595	**10669**	10591	10281	9813	9396	8849	8269	7758	7212

Annex 5. Heureka simulation and calculation results of stand A thinned by MIMIC programme

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Period 13	Period 14
Financial Value	Gross Revenue	SEK/ha	MIMIC	11472	0	18739	0	0	32614	0	0	0	46288	0	0	0	0	182416
Financial Value	Net Revenue	SEK/ha		3692	0	11521	0	0	25100	0	0	0	38110	111602	127382	138828	150325	161657
Financial Value	Total Cost	SEK/ha		7780	0	7218	0	0	7515	0	0	0	8178	0	0	0	0	20759
Forest Data	Basal area (incl overstorey) After	m2/ha		20,3	25,8807	22,083	26,5774	31,1774	24,6972	28,0803	31,5811	34,709	26,3173	28,7914	31,4313	33,8556	36,1755	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		29	25,8807	31,5472	26,5774	31,1774	35,2818	28,0803	31,5811	34,709	37,5962	28,7914	31,4313	33,8556	36,1755	38,3837
Forest Data	Dgv After	cm		16,6	18,9	21,4	23,6	25,7	28	29,9	31,7	33,4	35,3	37	38,6	40	41,3	0
Forest Data	Dgv Before	cm		16,3	18,9	21	23,6	25,7	27,5	29,9	31,7	33,4	34,9	37	38,6	40	41,3	42,5
Forest Data	DominantHeight Before	m		14,1	16,5	18,57	20,37	21,91	23,28	24,46	25,45	26,32	27,08	27,76	28,3	28,8	29,23	29,6
Forest Data	Hgv After	m		13,1	15,4	17,5	19,3	20,9	22,3	23,4	24,4	25,3	26,1	26,7	27,3	27,7	28,1	0
Forest Data	Hgv Before	m		13	15,4	17,4	19,3	20,9	22,2	23,4	24,4	25,3	26	26,7	27,3	27,7	28,1	28,5
Forest Data	Mean Age (excl overstorey) Before	yrs		30	35,1	40,1	45,3	50,3	55,2	60,3	65,2	70,1	75,1	80	84,8	89,6	94,3	99,1
Forest Data	SIH (estimated) Before	m		29,08	29,14	29,18	29,2	29,22	29,23	29,24	29,25	29,25	29,26	29,22	29,22	29,22	29,22	29,22
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		1000,4	988,6	652,5	645,4	639,3	447,4	463,6	476,6	489,4	356,5	375,2	391,3	416,8	447,6	6146,3
Forest Data	Stems Before	Trees/ha		1500	988,6	977,2	645,4	639,3	653,7	463,6	476,6	489,4	500,3	375,2	391,3	416,8	447,6	474,2
Forest Data	Volume (incl overstorey) After	m3sk/ha		135,1	197	187,3	244,3	305,5	255,2	302,2	351,3	396,9	308,1	343,2	380,2	414,4	447,2	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		192	197	266,5	244,3	305,5	364	302,2	351,3	396,9	440	343,2	380,2	414,4	447,2	478,3
Treatments	Volume Harvested All Species	m³sk/ha		56,9092	0	79,2411	0	0	108,7559	0	0	0	131,9403	0	0	0	0	476,9695
	NPV	EUR/ha		369		945			1530				1563					4042
	SUMNPV	EUR/ha																8449
	KOEF																	1,16
		EUR/ha		204		522			845				863					2231
	Rotation NPV	EUR/ha																4665
	LEV	EUR/ha																5412
	NPV+LEV	EUR/ha																**9802**

Annex 6. Heureka simulation and calculation results of stand B thinned by 35 %

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12 [0]
Financial Value	Gross Revenue	SEK/ha	Thinning intensity 35 %	18939	0	0	0	0	0	0	0	0	0	0	0	258871
Financial Value	Net Revenue	SEK/ha		9623	39323	57434	76307	95967	115329	136278	151929	169075	184326	198952	216781	228402
Financial Value	Total Cost	SEK/ha		9316	0	0	0	0	0	0	0	0	0	0	0	30469
Forest Data	Basal area (incl overstorey) After	m2/ha		18,2	22,4292	26,8731	30,9549	34,7173	38,1584	41,2873	44,0783	46,6933	49,1437	51,4229	53,5281	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	22,4292	26,8731	30,9549	34,7173	38,1584	41,2873	44,0783	46,6933	49,1437	51,4229	53,5281	55,464
Forest Data	Dgv After	cm		18,2	20,4	22,4	24,2	25,8	27,2	28,5	29,7	30,8	31,9	32,9	33,8	0
Forest Data	Dgv Before	cm		17,9	20,4	22,4	24,2	25,8	27,2	28,5	29,7	30,8	31,9	32,9	33,8	34,8
Forest Data	DominantHeight Before	m		21,42	23,28	24,77	26,1	27,25	28,23	29,08	29,81	30,44	31	31,47	31,89	32,25
Forest Data	Hgv After	m		19,6	21,4	23	24,4	25,5	26,5	27,4	28,2	28,8	29,4	29,9	30,3	0
Forest Data	Hgv Before	m		19,4	21,4	23	24,4	25,5	26,5	27,4	28,2	28,8	29,4	29,9	30,3	30,7
Forest Data	Mean Age (excl overstorey) Before	yrs		40	45,2	50,2	55,1	60,1	65,1	70	75	79,9	84,9	89,8	94,8	99,7
Forest Data	SIH (estimated) Before	m		31,65	31,69	31,72	31,74	31,76	31,78	31,79	31,81	31,82	31,82	31,83	31,84	31,84
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		735,9	727,7	721	735,9	747	753,9	757,3	758,2	757	759,5	759,7	757,6	6019,4
Forest Data	Stems Before	Trees/ha		1188	727,7	721	735,9	747	753,9	757,3	758,2	757	759,5	759,7	757,6	761
Forest Data	Volume (incl overstorey) After	m3sk/ha		166	219,6	278,4	335,4	390,2	442,2	490,7	535,1	577,1	616,5	653,3	687,3	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		253,6	219,6	278,4	335,4	390,2	442,2	490,7	535,1	577,1	616,5	653,3	687,3	718,5
Treatments	Volume Harvested All Species	m³sk/ha		87,5842	0	0	0	0	0	0	0	0	0	0	0	717,3485
	NPV	EUR/ha		962	3562	4712	5670	6458	7030	7524	7597	7657	7561	7392	7295	6961
	SUMNPV	EUR/ha			4524	5674	6632	7421	7992	8486	8559	8620	8523	8354	8257	7924
	KOEF			1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		436	2049	2570	3004	3361	3619	3843	3876	3904	3860	3783	3740	3589
	LEV	EUR/ha			3474	4089	4527	4834	5000	5124	5011	4911	4741	4549	4412	4163
	NPV+LEV	EUR/ha			7670	9028	9996	10674	11039	11315	11065	10844	10468	10044	9742	9192

Annex 7. Heureka simulation and calculation results of stand B thinned by 15 %

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12 [0]
Financial Value	Gross Revenue	SEK/ha	Thinning intensity 15 %	7697	0	0	0	0	0	0	0	0	0	0	0	271081
Financial Value	Net Revenue	SEK/ha		3223	49383	67592	88212	107327	129098	148500	165821	183471	198323	212689	227497	237932
Financial Value	Total Cost	SEK/ha		4474	0	0	0	0	0	0	0	0	0	0	0	33149
Forest Data	Basal area (incl overstorey) After	m2/ha		23,8	28,2007	32,7556	36,8629	40,6368	44,0821	47,2057	49,8719	52,2855	54,4506	56,3603	58,0203	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	28,2007	32,7556	36,8629	40,6368	44,0821	47,2057	49,8719	52,2855	54,4506	56,3603	58,0203	59,4499
Forest Data	Dgv After	cm		18,2	19,9	21,6	23,1	24,5	25,8	27	28,1	29,1	30,1	31,1	32	0
Forest Data	Dgv Before	cm		17,9	19,9	21,6	23,1	24,5	25,8	27	28,1	29,1	30,1	31,1	32	32,9
Forest Data	DominantHeight Before	m		21,42	23,36	24,92	26,28	27,44	28,43	29,28	30,02	30,66	31,22	31,7	32,12	32,49
Forest Data	Hgv After	m		19,6	21,4	23	24,4	25,5	26,5	27,4	28,2	28,8	29,4	29,9	30,4	0
Forest Data	Hgv Before	m		19,4	21,4	23	24,4	25,5	26,5	27,4	28,2	28,8	29,4	29,9	30,4	30,8
Forest Data	Mean Age (excl overstorey) Before	yrs		40	45,1	50,1	55,1	60,1	65,1	70,1	75,1	80	85	90	94,9	99,9
Forest Data	SIH (estimated) Before	m		31,65	31,69	31,73	31,76	31,78	31,8	31,81	31,82	31,83	31,84	31,85	31,85	31,85
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		973,5	962,9	951,7	955,8	956,4	952,8	945,8	935,7	923	912,6	899,3	883,4	6019,4
Forest Data	Stems Before	Trees/ha		1188	962,9	951,7	955,8	956,4	952,8	945,8	935,7	923	912,6	899,3	883,4	872,4
Forest Data	Volume (incl overstorey) After	m3sk/ha		216,7	276,5	340,4	401,3	459,5	514,2	565	610	651,3	688,8	722,3	751,8	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		253,6	276,5	340,4	401,3	459,5	514,2	565	610	651,3	688,8	722,3	751,8	777,5
Treatments	Volume Harvested All Species	m^3sk/ha		36,8634	0	0	0	0	0	0	0	0	0	0	0	776,4859
	NPV	EUR/ha		322	4473	5545	6554	7223	7869	8198	8292	8309	8135	7902	7655	7252
	SUMNPV	EUR/ha			4795	5867	6877	7545	8191	8521	8614	8632	8457	8224	7978	7574
	KOEF			1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		146	2172	2657	3114	3417	3710	3859	3901	3909	3830	3725	3613	3430
	LEV	EUR/ha			3682	4228	4694	4915	5124	5145	5043	4918	4704	4478	4263	3980
	NPV+LEV	EUR/ha			8130	9336	10364	10853	11315	**11361**	11136	10859	10387	9888	9412	8787

Annex 8. Heureka simulation and calculation results of an unthinned stand B

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12 [0]
Financial Value	Gross Revenue	SEK/ha		0	0	0	0	0	0	0	0	0	0	0	0	273162
Financial Value	Net Revenue	SEK/ha		37436	54399	72748	91865	112278	132147	149829	166429	183100	197394	212229	224552	238942
Financial Value	Total Cost	SEK/ha		0	0	0	0	0	0	0	0	0	0	0	0	34219
Forest Data	Basal area (incl overstorey) After	m2/ha		28	32,3818	36,4178	40,1546	43,5715	46,6798	49,4877	52,0007	54,2229	56,1666	57,8431	59,2701	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	32,3818	36,4178	40,1546	43,5715	46,6798	49,4877	52,0007	54,2229	56,1666	57,8431	59,2701	60,475
Forest Data	Dgv After	cm		17,9	19,4	20,8	22,2	23,4	24,5	25,6	26,7	27,7	28,6	29,6	30,5	0
Forest Data	Dgv Before	cm		17,9	19,4	20,8	22,2	23,4	24,5	25,6	26,7	27,7	28,6	29,6	30,5	31,4
Forest Data	DominantHeight Before	m		21,42	23,31	24,92	26,32	27,51	28,52	29,38	30,13	30,77	31,33	31,81	32,23	32,6
Forest Data	Hgv After	m	Not thinned	19,4	21,3	22,9	24,2	25,4	26,4	27,3	28,1	28,8	29,4	29,9	30,3	0
Forest Data	Hgv Before	m		19,4	21,3	22,9	24,2	25,4	26,4	27,3	28,1	28,8	29,4	29,9	30,3	30,8
Forest Data	Mean Age (excl overstorey) Before	yrs		40	45	50	55	60	65	70	75	80	85	89,9	94,9	99,9
Forest Data	SIH (estimated) Before	m		31,65	31,7	31,74	31,77	31,8	31,82	31,84	31,85	31,86	31,87	31,88	31,88	31,88
Forest Data	SIS (projected) Before	H100 m		32	32	32	32	32	32	32	32	32	32	32	32	32
Forest Data	Stand Age Before	yrs		40	45	50	55	60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		1188	1165,2	1140,7	1136,3	1126,7	1113,1	1095,8	1075,4	1052	1030,6	1006,6	980,6	6019,4
Forest Data	Stems Before	Trees/ha		1188	1165,2	1140,7	1136,3	1126,7	1113,1	1095,8	1075,4	1052	1030,6	1006,6	980,6	953,4
Forest Data	Volume (incl overstorey) After	m3sk/ha		253,6	316,4	377,9	437,1	493,2	545,5	593,8	638	677,7	713,1	744,2	771,2	0,5
Forest Data	Volume (incl overstorey) Before	m3sk/ha		253,6	316,4	377,9	437,1	493,2	545,5	593,8	638	677,7	713,1	744,2	771,2	794,5
Treatments	Volume Harvested All Species	m^3sk/ha		0	0	0	0	0	0	0	0	0	0	0	0	793,5757
	NPV	EUR/ha		3744	4927	5968	6826	7556	8055	8272	8322	8292	8097	7885	7556	7283
	SUMNPV	EUR/ha		3744	4927	5968	6826	7556	8055	8272	8322	8292	8097	7885	7556	7283
	KOEF			1,83	1,70	1,59	1,51	1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		1695	2231	2703	3091	3422	3648	3746	3769	3756	3667	3571	3422	3298
	LEV	EUR/ha		3099	3783	4301	4659	4922	5039	4995	4872	4725	4504	4293	4037	3826
	NPV+LEV	EUR/ha		6843	8354	9496	10287	10869	**11126**	11029	10758	10432	9944	9480	8915	8449

Annex 9. Heureka simulation and calculation results of stand C thinned by different thinning methods

Result type	Variable	Unit	Thinning intensity 35 %	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Financial Value	Gross Revenue	SEK/ha		20284	0	0	0	0	0	0	0	139765
Financial Value	Net Revenue	SEK/ha		10970	37642	48831	61356	73278	85043	96898	108187	119398
Financial Value	Total Cost	SEK/ha		9314	0	0	0	0	0	0	0	20367
Forest Data	Basal area (incl overstorey) After	m2/ha		18,2	21,1408	24,2967	27,2125	29,9557	32,5185	34,8988	37,0793	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	21,1408	24,2967	27,2125	29,9557	32,5185	34,8988	37,0793	39,1822
Forest Data	Dgv After	cm		18,9	20,4	21,9	23,3	24,6	25,8	26,8	27,8	0
Forest Data	Dgv Before	cm		18,5	20,4	21,9	23,3	24,6	25,8	26,8	27,8	28,7
Forest Data	DominantHeight Before	m		22,87	23,93	24,74	25,46	26,11	26,68	27,18	27,64	28,06
Forest Data	Hgv After	m		21	22	22,9	23,6	24,3	25	25,5	26	0
Forest Data	Hgv Before	m		20,7	22	22,9	23,6	24,3	25	25,5	26	26,4
Forest Data	Mean Age (excl overstorey) Before	yrs		60	65,2	70,1	75	80	84,9	89,8	94,7	99,6
Forest Data	SIH (estimated) Before	m		27,58	27,6	27,62	27,64	27,65	27,66	27,67	27,68	27,69
Forest Data	SIS (projected) Before	H100 m		28	28	28	28	28	28	28	28	28
Forest Data	Stand Age Before	yrs		60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		682,4	697,3	709,6	720,1	728,6	734	736,8	744,3	5808,9
Forest Data	Stems Before	Trees/ha		1100	697,3	709,6	720,1	728,6	734	736,8	744,3	758,1
Forest Data	Volume (incl overstorey) After	m3sk/ha		176	211,7	250,5	287,5	323,3	357,5	389,8	419,9	0,4
Forest Data	Volume (incl overstorey) Before	m3sk/ha		268,6	211,7	250,5	287,5	323,3	357,5	389,8	419,9	448,8
Treatments	Volume Harvested All Species	m³sk/ha		92,6517	0	0	0	0	0	0	0	447,687
	NPV	EUR/ha		1097	3409	4006	4559	4931	5184	5349	5410	5407
	SUMNPV	EUR/ha			4506	5103	5656	6028	6281	6446	6507	6504
	KOEF			1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		334	1373	1555	1724	1837	1914	1965	1983	1982
	LEV	EUR/ha			1897	2074	2228	2311	2351	2362	2340	2300
	NPV+LEV	EUR/ha			6225	6804	7312	7584	7714	7751	**7677**	7546

Result type	Variable	Unit	Thinning intensity 15 %	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Financial Value	Gross Revenue	SEK/ha		8169	0	0	0	0	0	0	0	157911
Financial Value	Net Revenue	SEK/ha		3738	47907	59955	72499	84709	97686	110174	121971	134102
Financial Value	Total Cost	SEK/ha		4431	0	0	0	0	0	0	0	23809
Forest Data	Basal area (incl overstorey) After	m2/ha		23,8	26,8505	30,0822	33,0224	35,7907	38,3827	40,7947	42,9117	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	26,8505	30,0822	33,0224	35,7907	38,3827	40,7947	42,9117	44,8869
Forest Data	Dgv After	cm		18,8	20,1	21,3	22,5	23,6	24,7	25,7	26,6	0
Forest Data	Dgv Before	cm		18,5	20,1	21,3	22,5	23,6	24,7	25,7	26,6	27,5
Forest Data	DominantHeight Before	m		22,87	23,98	24,84	25,6	26,26	26,85	27,37	27,83	28,25
Forest Data	Hgv After	m		20,9	21,9	22,8	23,7	24,4	25	25,6	26,1	0
Forest Data	Hgv Before	m		20,7	21,9	22,8	23,7	24,4	25	25,6	26,1	26,5
Forest Data	Mean Age (excl overstorey) Before	yrs		60	65,2	70,1	75,1	80	85	90	94,9	99,8
Forest Data	SIH (estimated) Before	m		27,58	27,6	27,63	27,64	27,66	27,67	27,69	27,7	27,71
Forest Data	SIS (projected) Before	H100 m		28	28	28	28	28	28	28	28	28
Forest Data	Stand Age Before	yrs		60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		902,4	911,4	916,8	918,9	918,9	916,3	911,2	903,9	5808,9
Forest Data	Stems Before	Trees/ha		1100	911,4	916,8	918,9	918,9	916,3	911,2	903,9	899,8
Forest Data	Volume (incl overstorey) After	m3sk/ha		229,7	269,1	311	350,5	388,6	424,8	459,1	490	0,4
Forest Data	Volume (incl overstorey) Before	m3sk/ha		268,6	269,1	311	350,5	388,6	424,8	459,1	490	518,9
Treatments	Volume Harvested All Species	m³sk/ha		38,923	0	0	0	0	0	0	0	518,031
	NPV	EUR/ha		374	4339	4918	5387	5701	5954	6082	6099	6073
	SUMNPV	EUR/ha			5436	6015	6484	6798	7051	7179	7196	7170
	KOEF			1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		114	1657	1833	1976	2072	2149	2188	2193	2185
	LEV	EUR/ha			2289	2445	2555	2606	2639	2631	2588	2535
	NPV+LEV	EUR/ha			7509	8021	8382	8552	**8660**	8632	8490	8319

Result type	Variable	Unit	Not thinned	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Financial Value	Gross Revenue	SEK/ha		0	0	0	0	0	0	0	0	163946
Financial Value	Net Revenue	SEK/ha		42074	52897	64630	76462	89561	101412	112711	125062	138140
Financial Value	Total Cost	SEK/ha		0	0	0	0	0	0	0	0	25806
Forest Data	Basal area (incl overstorey) After	m2/ha		28	30,9902	33,8239	36,4996	39,0158	41,3695	43,5536	45,5559	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		28	30,9902	33,8239	36,4996	39,0158	41,3695	43,5536	45,5559	47,3666
Forest Data	Dgv After	cm		18,5	19,7	20,7	21,7	22,7	23,6	24,5	25,4	0
Forest Data	Dgv Before	cm		18,5	19,7	20,7	21,7	22,7	23,6	24,5	25,4	26,2
Forest Data	DominantHeight Before	m		22,87	23,91	24,81	25,6	26,29	26,9	27,43	27,89	28,31
Forest Data	Hgv After	m		20,7	21,8	22,7	23,5	24,2	24,9	25,4	26	0
Forest Data	Hgv Before	m		20,7	21,8	22,7	23,5	24,2	24,9	25,4	26	26,4
Forest Data	Mean Age (excl overstorey) Before	yrs		60	65	70	74,9	79,9	84,9	89,8	94,8	99,7
Forest Data	SIH (estimated) Before	m		27,58	27,61	27,63	27,66	27,67	27,69	27,7	27,71	27,73
Forest Data	SIS (projected) Before	H100 m		28	28	28	28	28	28	28	28	28
Forest Data	Stand Age Before	yrs		60	65	70	75	80	85	90	95	100
Forest Data	Stems After	Trees/ha		1100	1103	1101,4	1096,3	1088,2	1077,4	1064	1048,1	5808,9
Forest Data	Stems Before	Trees/ha		1100	1103	1101,4	1096,3	1088,2	1077,4	1064	1048,1	1034,1
Forest Data	Volume (incl overstorey) After	m3sk/ha		268,6	309,2	348,7	386,9	423,4	458,1	490,7	521	0,4
Forest Data	Volume (incl overstorey) Before	m3sk/ha		268,6	309,2	348,7	386,9	423,4	458,1	490,7	521	548,7
Treatments	Volume Harvested All Species	m³sk/ha		0	0	0	0	0	0	0	0	547,846
	NPV	EUR/ha		4207	4791	5302	5681	6027	6181	6222	6253	6256
	SUMNPV	EUR/ha		4207	4791	5302	5681	6027	6181	6222	6253	6256
	KOEF			1,44	1,38	1,33	1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		1282	1460	1616	1732	1837	1884	1896	1906	1907
	LEV	EUR/ha		1845	2017	2155	2238	2311	2314	2280	2249	2212
	NPV+LEV	EUR/ha		6052	6618	7069	7344	7582	**7592**	7481	7378	7258

Annex 10. Heureka simulation and calculation results of stand D thinned by different thinning methods

Result type	Variable	Unit	Thinning intensity 35 %	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Financial Value	Gross Revenue	SEK/ha		38674	0	0	0	0	0	154518
Financial Value	Net Revenue	SEK/ha		26412	78810	91598	104699	115608	124835	133014
Financial Value	Total Cost	SEK/ha		12261	0	0	0	0	0	21504
Forest Data	Basal area (incl overstorey) After	m2/ha		30,15	32,7324	35,5032	37,8115	39,8216	41,5132	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		45	32,7324	35,5032	37,8115	39,8216	41,5132	42,8961
Forest Data	Dgv After	cm		23,6	24,8	26	27,2	28,2	29,2	0
Forest Data	Dgv Before	cm		23,3	24,8	26	27,2	28,2	29,2	30,2
Forest Data	DominantHeight Before	m		24,6	25,41	26,02	26,57	27,06	27,5	27,89
Forest Data	Hgv After	m		23,2	23,9	24,6	25,1	25,7	26,1	0
Forest Data	Hgv Before	m		23	23,9	24,6	25,1	25,7	26,1	26,6
Forest Data	Mean Age (excl overstorey) Before	yrs		74,5	79,7	84,7	89,6	94,6	99,6	104,6
Forest Data	SIH (estimated) Before	m		26,95	26,96	26,97	26,98	26,99	27	27
Forest Data	SIS (projected) Before	H100 m		25	25	25	25	25	25	25
Forest Data	Stand Age Before	yrs		74,5	79,5	84,5	89,5	94,5	99,5	104,5
Forest Data	Stems After	Trees/ha		710,8	711,7	712,7	708,7	702,5	693	6111,8
Forest Data	Stems Before	Trees/ha		1100	711,7	712,7	708,7	702,5	693	680,7
Forest Data	Volume (incl overstorey) After	m3sk/ha		312,1	347	383,9	416,1	444,9	469,9	0,4
Forest Data	Volume (incl overstorey) Before	m3sk/ha		463,4	347	383,9	416,1	444,9	469,9	491,3
Treatments	Volume Harvested All Species	m³sk/ha		151,34	0	0	0	0	0	490,593
	NPV	EUR/ha		2641	7138	7514	7779	7780	7609	7343
	SUMNPV	EUR/ha			9779	10155	10420	10421	10250	9985
	KOEF			1,30	1,26	1,23	1,20	1,18	1,16	1,14
	Rotation NPV	EUR/ha		604	2237	2323	2383	2383	2344	2284
	LEV	EUR/ha			2821	2859	2871	2817	2724	2614
	NPV+LEV	EUR/ha			12334	12501	**12554**	12317	11911	11427

Variable	Thinning intensity 15 %	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Gross Revenue		16805	0	0	0	0	0	168794
Net Revenue		10687	94947	107993	118488	128048	136696	145062
Total Cost		6118	0	0	0	0	0	23732
Basal area (incl overstorey) After		38,25	40,3012	42,2805	43,8166	45,0937	46,1528	0
Basal area (incl overstorey) Before		45	40,3012	42,2805	43,8166	45,0937	46,1528	47,0257
Dgv After		23,6	24,6	25,6	26,6	27,6	28,6	0
Dgv Before		23,3	24,6	25,6	26,6	27,6	28,6	29,5
DominantHeight Before		24,6	25,43	26,07	26,64	27,15	27,59	27,99
Hgv After		23,1	23,9	24,6	25,2	25,7	26,2	0
Hgv Before		23	23,9	24,6	25,2	25,7	26,2	26,6
Mean Age (excl overstorey) Before		74,5	79,7	84,7	89,7	94,7	99,7	104,7
SIH (estimated) Before		26,95	26,96	26,98	26,99	26,99	27	27,01
SIS (projected) Before		25	25	25	25	25	25	25
Stand Age Before		74,5	79,5	84,5	89,5	94,5	99,5	104,5
Stems After		908,8	890,6	868	842,1	815,9	789,5	6111,8
Stems Before		1100	890,6	868	842,1	815,9	789,5	763,3
Volume (incl overstorey) After		395,5	427,4	458,1	483,6	505,7	524,7	0,4
Volume (incl overstorey) Before		463,4	427,4	458,1	483,6	505,7	524,7	541,1
Volume Harvested All Species		67,929	0	0	0	0	0	540,506
NPV		1069	8600	8859	8804	8617	8332	8008
SUMNPV			11241	11500	11445	11258	10973	10650
KOEF		1,30	1,26	1,23	1,20	1,18	1,16	1,14
Rotation NPV		244	2571	2630	2618	2575	2510	2436
LEV			3243	3238	3153	3043	2916	2788
NPV+LEV			**14178**	14156	13788	13307	12751	12189

Variable	Not thinned	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Gross Revenue		0	0	0	0	0	0	175453
Net Revenue		97229	107730	117713	126636	136302	142892	150002
Total Cost		0	0	0	0	0	0	25451
Basal area (incl overstorey) After		45	46,1727	47,1732	48,0229	48,7404	49,3419	0
Basal area (incl overstorey) Before		45	46,1727	47,1732	48,0229	48,7404	49,3419	49,8417
Dgv After		23,3	24,2	25,1	26	26,9	27,7	0
Dgv Before		23,3	24,2	25,1	26	26,9	27,7	28,6
DominantHeight Before		24,6	25,37	26,04	26,63	27,15	27,61	28,02
Hgv After		23	23,8	24,5	25,1	25,6	26,1	0
Hgv Before		23	23,8	24,5	25,1	25,6	26,1	26,5
Mean Age (excl overstorey) Before		74,5	79,5	84,6	89,6	94,6	99,6	104,6
SIH (estimated) Before		26,95	26,97	26,98	26,99	27	27,01	27,02
SIS (projected) Before		25	25	25	25	25	25	25
Stand Age Before		74,5	79,5	84,5	89,5	94,5	99,5	104,5
Stems After		1100	1054,9	1011,5	970	930,3	892,6	6111,8
Stems Before		1100	1054,9	1011,5	970	930,3	892,6	856,8
Volume (incl overstorey) After		463,4	488,3	510,3	529,7	546,7	561,5	0,4
Volume (incl overstorey) Before		463,4	488,3	510,3	529,7	546,7	561,5	574,3
Volume Harvested All Species		0	0	0	0	0	0	573,704
NPV		9723	9757	9657	9409	9173	8710	8281
SUMNPV		9723	9757	9657	9409	9173	8710	8281
KOEF		1,30	1,26	1,23	1,20	1,18	1,16	1,14
Rotation NPV		2224	2232	2209	2152	2098	1992	1894
LEV		2883	2815	2719	2593	2480	2315	2168
NPV+LEV		**12606**	12307	11887	11336	10841	10121	9478

Annex 11. Heureka simulation and calculation results of stand E thinned by different thinning methods

Result type	Variable	Unit		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5		Period 0	Period 1	Period 2	Period 3	Period 4	Period 5
Financial Value	Gross Revenue	SEK/ha	Thinning intensity 35 %	56066	0	0	0	0	192274	Thinning intensity 15 %	16904	0	0	0	0	239688	Not thinned	0	0	0	0	0	251901
Financial Value	Net Revenue	SEK/ha		44288	108428	125364	142097	156906	171304		12692	144416	162233	180159	196501	213321		142576	159584	176497	193216	208690	223781
Financial Value	Total Cost	SEK/ha		11779	0	0	0	0	20970		4213	0	0	0	0	26367		0	0	0	0	0	28119
Forest Data	Basal area (incl overstorey) After	m2/ha		23,075	25,519	28,183	30,621	32,916	0		31,595	34,219	37,007	39,527	41,919	0		35,5	38,065	40,511	42,843	45,064	0
Forest Data	Basal area (incl overstorey) Before	m2/ha		35,5	25,519	28,183	30,621	32,916	35,067		35,5	34,219	37,007	39,527	41,919	44,184		35,5	38,065	40,511	42,843	45,064	47,179
Forest Data	Dgv After	cm		30,8	32,6	34,3	35,8	37,3	0		30,7	32,1	33,5	34,8	36	0		30,4	31,7	32,9	34,1	35,2	0
Forest Data	Dgv Before	cm		30,4	32,6	34,3	35,8	37,3	38,6		30,4	32,1	33,5	34,8	36	37,2		30,4	31,7	32,9	34,1	35,2	36,2
Forest Data	DominantHeight Before	m		33,03	33,64	34,13	34,55	34,92	35,23		33,03	33,68	34,18	34,62	35	35,33		33,03	33,65	34,18	34,63	35,02	35,35
Forest Data	Hgv After	m		31,5	32,1	32,7	33,1	33,5	0		31,5	32,1	32,7	33,1	33,5	0		31,4	32	32,6	33,1	33,5	0
Forest Data	Hgv Before	m		31,4	32,1	32,7	33,1	33,5	33,8		31,4	32,1	32,7	33,1	33,5	33,9		31,4	32	32,6	33,1	33,5	33,8
Forest Data	Mean Age (excl overstorey) Before	yrs		75	80,1	85	89,9	94,8	99,7		75	80,1	85	90	94,9	99,9		75	80	84,9	89,9	94,8	99,8
Forest Data	SIH (estimated) Before	m		34,53	34,54	34,54	34,55	34,55	34,56		34,53	34,54	34,54	34,54	34,55	34,55		34,53	34,53	34,54	34,55	34,55	34,56
Forest Data	SIS (projected) Before	H100 m		34,8	34,8	34,8	34,8	34,8	34,8		34,8	34,8	34,8	34,8	34,8	34,8		34,8	34,8	34,8	34,8	34,8	34,8
Forest Data	Stand Age Before	yrs		**75**	**80**	**85**	**90**	**95**	**100**		**75**	**80**	**85**	**90**	**95**	**100**		**75**	**80**	**85**	**90**	**95**	**100**
Forest Data	Stems After	Trees/ha		315,5	330,5	343,8	357,1	369,2	6155,5		436	446,1	454,3	462,2	469,1	6155,5		500	510,6	518,7	524,9	529,5	6155,5
Forest Data	Stems Before	Trees/ha		500	330,5	343,8	357,1	369,2	379,1		500	446,1	454,3	462,2	469,1	474,5		500	510,6	518,7	524,9	529,5	532,7
Forest Data	Volume (incl overstorey) After	m3sk/ha		311	348,2	388,3	425,3	460,3	0,4		425,6	467,5	511,3	551,4	589,4	0,4		477,4	519,3	559,4	597,6	634	0,4
Forest Data	Volume (incl overstorey) Before	m3sk/ha		477,4	348,2	388,3	425,3	460,3	493,2		477,4	467,5	511,3	551,4	589,4	625,4		477,4	519,3	559,4	597,6	634	668,5
Treatments	Volume Harvested All Species	m³sk/ha		166,31	0	0	0	0	492,37		51,766	0	0	0	0	624,58		0	0	0	0	0	667,63
	NPV	EUR/ha		4429	9821	10284	10558	10559	10442		1269	13080	13309	13386	13224	13003		14117	14312	14336	14215	13906	13506
	SUMNPV	EUR/ha			9821	10284	10558	10559	10442			13080	13309	13386	13224	13003		14117	14312	14336	14215	13906	13506
	KOEF			1,29	1,26	1,23	1,20	1,18	1,16		1,29	1,26	1,23	1,20	1,18	1,16		1,29	1,26	1,23	1,20	1,18	1,16
	Rotation NPV	EUR/ha		1003	2224	2329	2391	2391	2365		287	2962	3014	3031	2995	2945		3229	3273	3279	3251	3180	3089
	LEV	EUR/ha			2798	2860	2875	2821	2743			3726	3702	3645	3533	3416		4174	4118	4027	3909	3752	3584
	NPV+LEV	EUR/ha			12355	12631	**12694**	12458	12114			**16455**	16345	16094	15602	15085		**18250**	18005	17607	17090	16406	15669