Development of stratified spruce-birch stands in Latvia

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Abstract

Natural properties of Norway spruce (*Picea abies*) and birch (*Betula spp.)*suggest a good ecological ability to form a stratified mixture with birch in a upper and spruce in a lower stratum. Maintaining birch as the shelter over planted spruce in the beginning of rotation might result in higher overall yield than spruce monocultures. Other advantages such as higher ecological stability, increased biodiversity and better economic performance have been demonstrated by studies in other Northern European countries.

A stratified mixture of Norway spruce and silver birch and pure Norway spruce stand growing on fertile sites in north-east of Latvia were the study objects. The main objective of the study was to evaluate silvicultural aspects and economic performance of the mixed stand and make a comparison to spruce monoculture.

Production of spruce alone was 19, 15 and 14 % lower in the mixed stand compared to spruce monoculture over simulated rotations of 60, 80 and 100 years, respectively. However, birch shelter, which was removed latest at age 42 years, produced substantial wood volume, and overall yield was 8, 5 and 5 % higher in the mixed stand for the respective rotations. More frequent frost induced damage was observed in the pure spruce stand, however, whipping damages were evident in the mixed stand. Economic outcome, in terms of land expectation value, was higher for management alternatives in the mixture.

Key words: Latvia, Norway spruce, birch, mixed stands, volume yield, economic outcome.

Abbreviations

EEA- European Environment Agency

EFI- European Forest Institute

FSC- Forest Stewardship Council

LEGMC- Latvian Environment, Geology and Meteorology Centre

LVM- “Latvia‘s State Forests” (“Latvijas valsts meži” *in Latvian*)

PEFC- Programme for the Endorsement of Forest Certification

WWF- World Wildlife Fund

Contents

1. Introduction

1.1. Background

Latvia is located in the hemiboreal region which is a transitional zone between the boreal and temperate forests in Europe (EEA, 2007). Coniferous forests are often mixed with the broadleaf tree species such as *Betula spp*., *Populus tremula* and *Alnus spp*. in this region. Broadleaves generally characterise early-to-mid succession stages, but dominance of conifers increases with the age (EEA, 2007).

Climate in Latvia is moderate. Average air temperature over the year is 5.9°C and annual precipitation is 667 mm (LEGMC).

Based on the data from the statistical forest inventory, forest cover in Latvia reaches 50 % corresponding to 3.2 mill. ha (Fig.1), and the total growing stock is 631 mill. m^3 (Ministry of Agriculture). The main tree species are Scots pine (*Pinus sylvestris*), birch (*Betula spp*.) and Norway spruce (*Picea abies*), which represent 36, 24 and 16 % of the total wood volume, respectively. The distribution of pine is connected with poor and dry forest sites, while spruce and birch occupy more fertile soils (Kasparisnkis, 2012), however, these species are often met growing in one stand on mesic soils.

Silvicultural practices in Latvia have differed in the periods over the last century, however, clear-cutting system has been the main method for final felling and regeneration. Non-intensive silvicultural practices stressing more on the natural regeneration were applied after gaining independence in 1918 until 1930s, with an increase of artificial regeneration later on (Tērauds et al., 2011). During 1960-70s there was a drastic change and focus on spruce monocultures, where naturally regenerated birch and other species were eradicated. There were some changes in the forest management after collapse of Soviet Union and drift to free market economy. Budget in beginning of 1990s of state was low, and silvicultural operations such as artificial regeneration and pre-commercial thinning in large scale weren‘t practised.

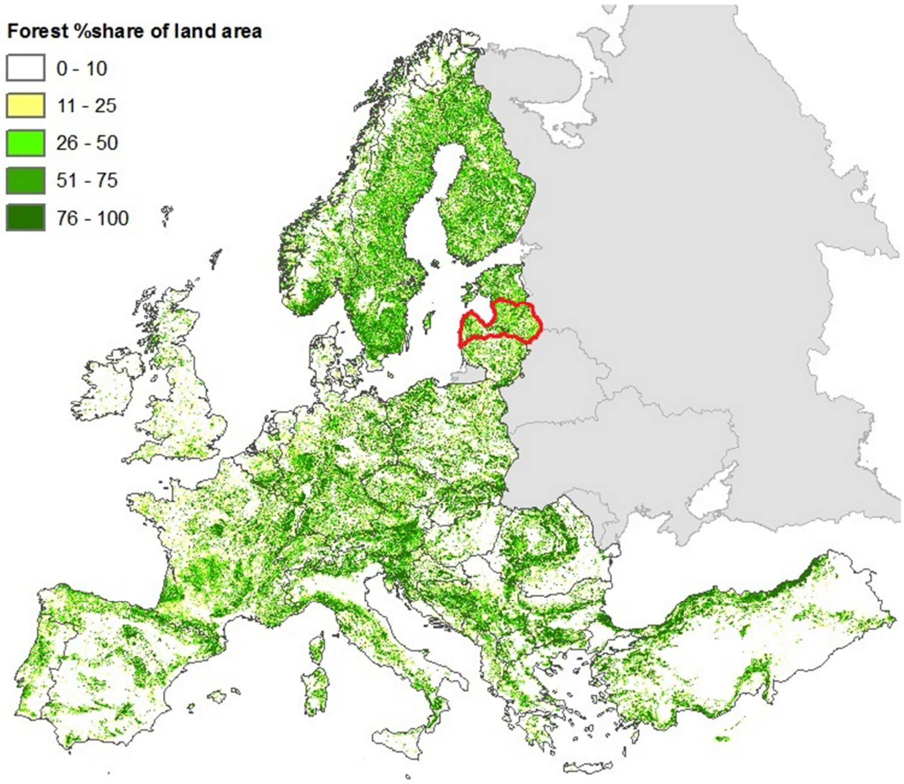

Fig.1. *Map of forest cover in Europe and location of Latvia (EFI, by Kempeneers et al. 2011)*

Mežole project (1995-1998, by WWF Latvia Programme) and establishment of state owned enterprise "Latvijas valsts meži" ("Latvia‘s State Forests") in 2000 were the cornerstones towards ecologically, economically and socially sustainable forest management in Latvia.

There has been an increased trend to perform pre-commercial thinnings during the last decade (State Forest Service). However, 63 % of clear-felled forest sites are still regenerated naturally, and most of the artificial regeneration (87 %) takes place in the state owned forests (State Forest Service).

Birch is often found in the composition of young stands in Latvia, since it emerges quickly after clear-felling. When planting spruce as the target species on the clear-felled site, forest owner (manager) has to decide whether to keep or remove birch during early thinnings of young stands.

Several studies in Nordic countries (e.g., Tham, 1988, Mård, 1996, 1997, Valkonen & Valsta, 2001, Fahlvik et al., 2011) have been dealing with the issues related to the mixed spruce and birch stands, both stratified and single-storied. However, specific case-study related to this topic hasn‘t been carried out in Latvia, while the growth conditions and economic related factors may differ from those described in the mentioned studies.

1.2. General aspects of the mixed stands

Mixed stands have more complex structure and biological diversity than monocultures (Bergstedt et al., 2001, Agestam et al., 2005). Furthermore, forests with higher tree species richness are positively related in providing ecosystem services such as biomass production, soil carbon storage, berry production and game production (Gamfeldt et al., 2013). Mixed stands are also expected to be more ecologically stable than monocultures, minimizing the risk of damage due to climatic extremes or pest outbreaks (Bergstedt et al., 2001, Drössler, 2010).

Mixed species stands almost always tend to stratify due to height growth patterns and different shade tolerance among species (Kelty, 1992). In theory, growth factors as nutrients, light and water might be utilized in economically more resulting growth and yield, however, due to lack of long-term yield experiments it hasn't been surely proved, and it varies form case to case depending on the stand structure (Agestam et al., 2005). However, the economy may be improved if species subject to earlier commercial thinnings are combined with species having higher value when they are old (Bergstedt, 2001). Flexibility in relation to timber markets is mentioned as another advantage of the mixed stands (Drössler, 2010).

Mixed stands in many cases are also preferred to single species stands for recreation purposes (Agestam et al., 2005).

1.3. Mixture of Norway spruce and birch

Norway spruce (*Picea abies*) and birch (*Betula spp.*) are the native species in the hemiboreal region. Birch is early successional, light demanding species, while spruce is late successional, rather a shade tolerant species. Natural relations between these species suggests a good ecological combining ability to form a stratified mixture (Mård, 1997), and a potential to have higher yield than spruce monoculture (Mård, 1996).

Several studies in Scandinavia have dealt with stratified birch and Norway spruce mixtures (Mård, 1996, Bergqvist, 1999, Klang & Ekö, 1999) showing that yield of spruce alone is reduced in the sheltered stand compared to spruce monocultures. However, the loss is more than compensated by a substantial birch volume production.

Model studies by Tham (1988) suggested that spruce has an ability to compensate the poor growth in the juvenile stage due to competition to higher birches with a better growth after the birch shelter is removed. One of the probable reasons for such growth reaction was spruce ability to use growth more efficiently due to disturbed early growth by a birch shelter, while the other was the birch positive influence on the site (Tham, 1988).

However, recent study by Fahlvik et al. (2011) analysing single-storied mixtures of Norway spruce and birch in Southern Sweden, showed that yield decreases with an increasing proportion of birch over rotation of 66 years.

The total production therefore may vary depending on whether birch is used just as the shelter in the beginning of rotation or it is kept as an admixture to spruce for the whole rotation. In addition, there are differences between the birch species. Silver birch (*Betula* *pendula*) has higher production compared to downy birch (*Betula pubescens*) on normal sites (Tham, 1988, Valkonen & Valsta, 2001).

Norway spruce growing under birch shelter is well protected from climatic extremes, until the shelter is removed, and spruce becomes exposed to increased light intensities, wind and air temperature fluctuations- subjected to substantial levels of stress. However, it is argued that spruce adapts to new environment within few years, and severe damage is not likely to occur, if only extreme weather, e.g., strong wind, occurs shortly after the release cutting (Mård, 1997).

Regarding the quality issues, (Klang & Ekö, 1999) showed that diameter of the thickest branch and number of branches was smaller for the sheltered spruce compared to open grown spruce. However, it was concluded that the quality improvement using shelter system was of little economic importance for timber pricing in Sweden.

There is no clear answer about economic performance of stratified mixture of Norway spruce and birch compared to pure spruce stand. There are many factors, primarily such as demand and prices for specific log assortments and costs of silvicultural operations that vary among the countries influencing the economic result. Furthermore, there is also a great source of uncertainty related to logging technology and damages (Valkonen & Valsta, 2001). However, (Valkonen & Valsta, 2001) showed that simulated treatments with birch shelter were more profitable than pure spruce treatment.

If net present value for rotation is calculated, length of rotation and interest rate are important variables (Agestam et al., 2005).

Other advantages related to birch and spruce mixture over spruce monoculture are reduced field vegetation and risk for frost damage (Tham, 1994). Furthermore, (Felton et al., 2010) concluded that change from spruce monocultures to spruce-birch polycultures in Southern Sweden would increase biological diversity for a variety of species, along with a decreasing climate change associated risks such as wind and pest species.

1.3.1. The "Kronoberg" method

The "*Kronoberg*" method was first introduced in Southern Sweden and described the technique how to manage mixed stand of Norway spruce and birch (Anon., 1985). The aims are to avoid frost damage to Norway spruce plants and control the number of sprouts that are able to establish after the removal of birch in each step (Johansson, 2011).

The method involves three steps:

1. The stand is cleaned when the birches are 3- 4 m tall, reducing number of birch stems to 3000- 4000 ha^{-1}. The Norway spruce is not cleaned.
2. The stand is cleaned again when the birches reach height of 6- 9 m. A total of 1000- 1500 birch stems ha^{-1} should be retained.
3. When the birch stand is 20- 25 years old the birches are felled. They will be 8- 12 m tall with a dbh of 8 cm. The mean height of the Norway spruce will be 3- 4 m. The spruce stand should be thinned to 2000- 2500 stems ha^{-1}.

Alternatively, instead of felling all the birches, 600- 800 birches ha^{-1} could be left for 10- 15 years, reaching mean dbh 15- 20 cm (Johansson, 2011).

1.4. Forest economy in relation to timber market

Spruce and birch timber are recognized as valuable raw materials for wood processing industries in Latvia. Spruce timber is mostly used for sawmilling- construction materials, while high quality and larger dimension birch logs are used for plywood manufacturing and sawmilling.

Demand for birch wood is an essential factor to ensure a good economic result when applying the birch shelter system over planted Norway spruce. In Latvia, demand for birch timber is at good level, since wood processing industries are developed. In Sweden the situation is different, since there is a small market for birch timber quality logs. Sawmilling of spruce timber is well developed in both countries, and demand is stable.

Spruce and birch pulpwood are much exported from Latvia to Sweden and Finland. However, demand is fluctuating and depends on how well pulpwood industry does in the region. There is also a panel manufacturer in Latvia using pulpwood quality wood, and is an important player in the market.

Increasing commercial thinning in young forest stands might be expected in the future due to growing demand for biomass, since the bioenergy sector in Latvia and other European countries is expanding.

1.5. Objectives

The main objective of this study is to evaluate silvicultural aspects and economic performance when using birch shelter over planted Norway spruce stands in Latvia. The study is constructed to compare results to planted pure spruce stands. Main questions to be answered are:

1. How does the birch shelter affect the growth of spruce?
2. Is higher total wood volume yield achieved? Is it economically more beneficial?
3. Is the wood quality of spruce improved?

2. Material and methods

2.1. Field work

Mixed spruce-birch and pure spruce stands were required for the study. Sites with similar growth conditions were looked for, and if possible close to each other. Spruce had to be well established and at least 6 m at height to be suitable for the quality assessments.

First, well managed 15 to 35 years old mixed spruce-birch stands were searched using LVM regional database, nearby located Mežole scientific research forests and questioning local private forest owners. Twelve objects (6- in LVM forests, 4- in Mežole scientific research forests and 2- in private forest owner property) were selected for inspection. Only one stand (private property) was accepted for this study. Other sites were rejected (Fig.2) on the basis of improper management for the present study (e.g., birch once cut in early tending, shoots from stumps then had emerged instead), uneven stand structure or unsuitable development stage (too young).

a)  b) 

Fig.2. *Examples of rejected forest sites: a) unsuitable development stage; b) improper management applied for the present study*

One pair of stands was accepted for the study. A mixed spruce-birch stand was located in a private forest owner property. Pure spruce stand with similar growth conditions and age was then looked for. It was found using LVM regional database.

2.1.1. Description of the stands

The area of the mixture of Norway spruce and birch was 1.0 ha and the total age was 32 years. The area of pure spruce stand was 0.9 ha and the total age was 34 years. The stands had similar growth conditions, growing on fertile well-aerated mineral soils (*Hylocomiosa*) in north-east of Latvia. Norway spruce was originally planted on both stands. Self-propagated birch was left as the shelter on the first stand. Birch was removed on the other during the tending of young stand. The spruce-birch mixture was thinned once in 2007 (age 27 years). Only birches were cut out during this thinning. The pure spruce stand had not been thinned.

The site index in the pure spruce stand corresponded to G 38, and to G 36 in the mixed stand. Estimating the site index for spruce in the stand with birch shelter, 5 % growth reduction of top height was considered. The index shows expected top height at age of 100 years (Hägglund & Lundmark, 1977).

The geographical locations of the stands (Fig.3) were:

- Mixed spruce-birch stand: 57°22' N 25°56' E;
- Pure spruce stand: 57°27' N 25°58' E.

The straight distance between the study sites was 9.7 km.

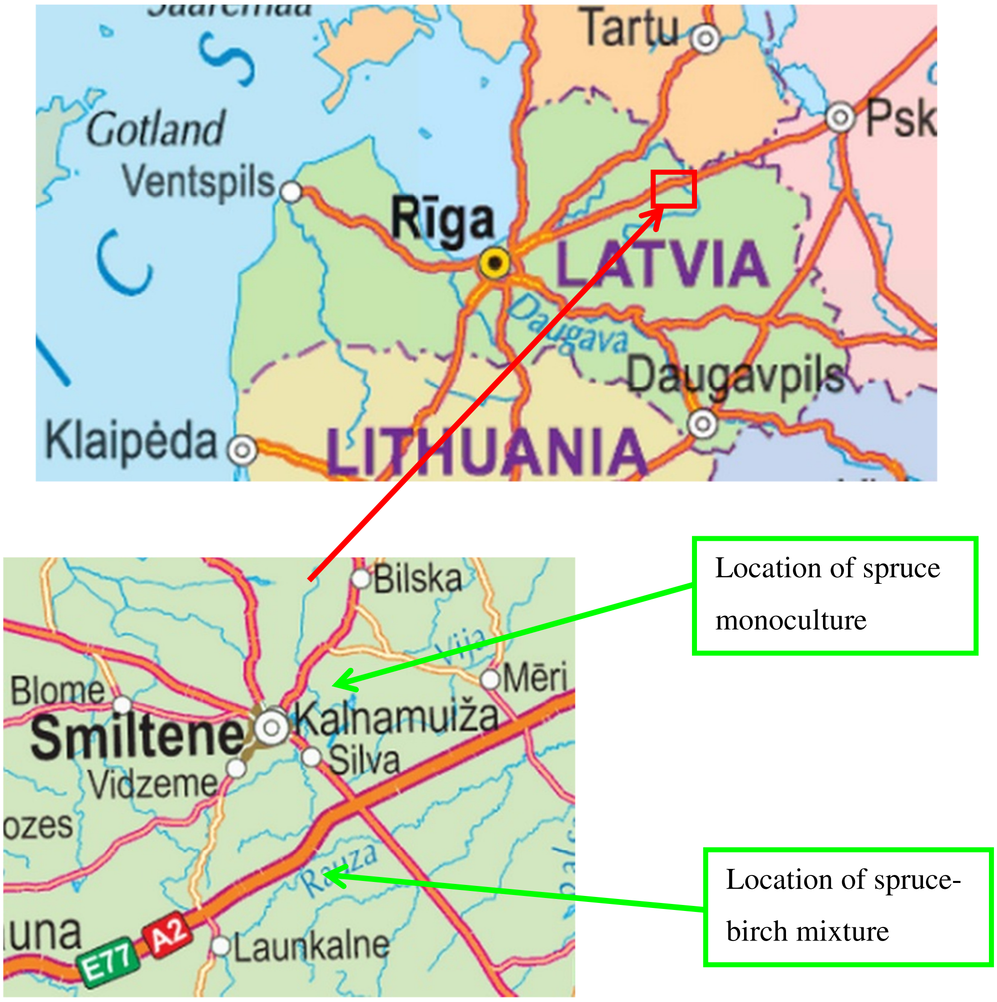

Fig.3. *Geographical locations of the study sites in north-east of Latvia (Baltic maps)*

2.1.2. Plot layout

Three circular plots with a radius of 10 m (one plot corresponding 314 m^2) were established in each study site. Measuring tape was used to arrange the plots.

The mixed spruce-birch stand was almost of L-type shape. One plot was arranged along the shortest edge, but the remaining two- along the longest edge (Fig.4a).

The shape of pure spruce stand was best characterised as an irregular rectangular. Plot centres were chosen subjectively locating them along the longest edge (Fig.4b).

The distance between the plots centres had to be at least 30 m. Plots were located so that the borderline was at least 5 m from the stand edge and not including strip roads (in the mixed stand). Plot centres (Fig.5.) were chosen subjectively considering these two parameters.

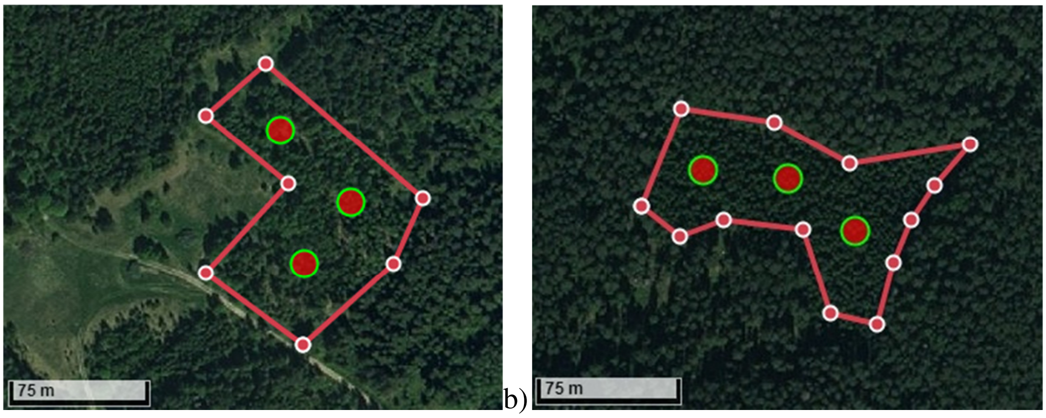

Fig.4. *Shape and approximate plot layout in the study sites: a) mixed spruce-birch stand, b) pure spruce stand (Baltic maps)*

Fig.5. *Plot centre in the mixed spruce-birch stand*

2.1.3. Collection of data

The diameter at breast height (dbh) was measured with a caliper for all trees. It was always cross measured. Sample trees were selected for the height measurement and quality assessment. Height was measured by Suunto PM 5.

<u>Mixed spruce and birch stand</u>

Five birch sample trees were selected in each plot. They were selected subjectively considering diameter distribution to represent all sizes. Futhermore, the dominant height (tree with the largest diameter) in each plot was measured. If there was a higher tree in the plot, it was also measured. The stump diameter was also measured for sample trees to be able to estimate the ratio between dbh and stump diameter. This ratio was then used to calculate dbh and volume of removed birches during the thinning operation in 2007.

Fifteen spruce sample trees were selected in each plot. Dominant height was measured with the same method as for birch. Sample trees were selected subjectively considering diameter distribution to represent all sizes. Quality of spruce trees were assessed as follows:

- Diameter of the thickest branch in the whorl closest to breast height was measured
- Judgement of the crookedness was conducted by a visual assessment of the first 6 m of the stem. Three classes of crookedness were used:
    - straight
    - slightly crooked- crooks that affect the timber quality, but logs should still be possible to use as sawn timber (Fig.6)
    - heavily crooked- not possible to use for sawn timber (Note: heavily crooked trees were not found in the present study)
- Occurrence of spike knots was determined by observing sample trees at the whole length. Spike knot was defined as in acute angle growing branch with the d_{max}:d_{min} relation at least 3:1 (Fig.8a)
- Occurrence of double tops was determined by observing sample trees at the whole length (Fig.8b)
- Whipping damages were judged by observing spruce tops in the mixed spruce-birch stand (Fig.7)
- Number of whorls between 0.5 and 2.0 m were counted

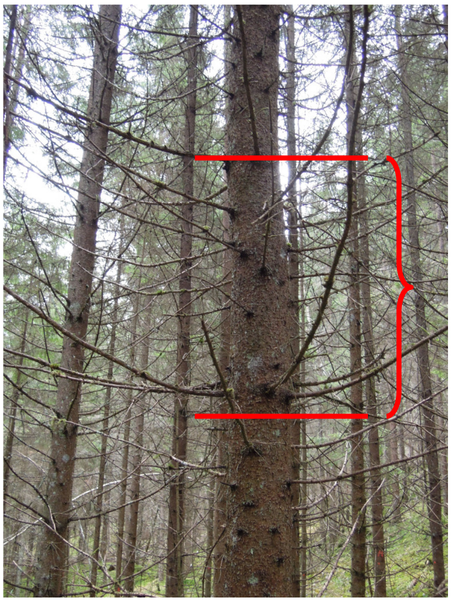

Fig.6. *Slightly crooked spruce tree on pure spruce stand*

Fig.7. *Spruce top whipped by birch*

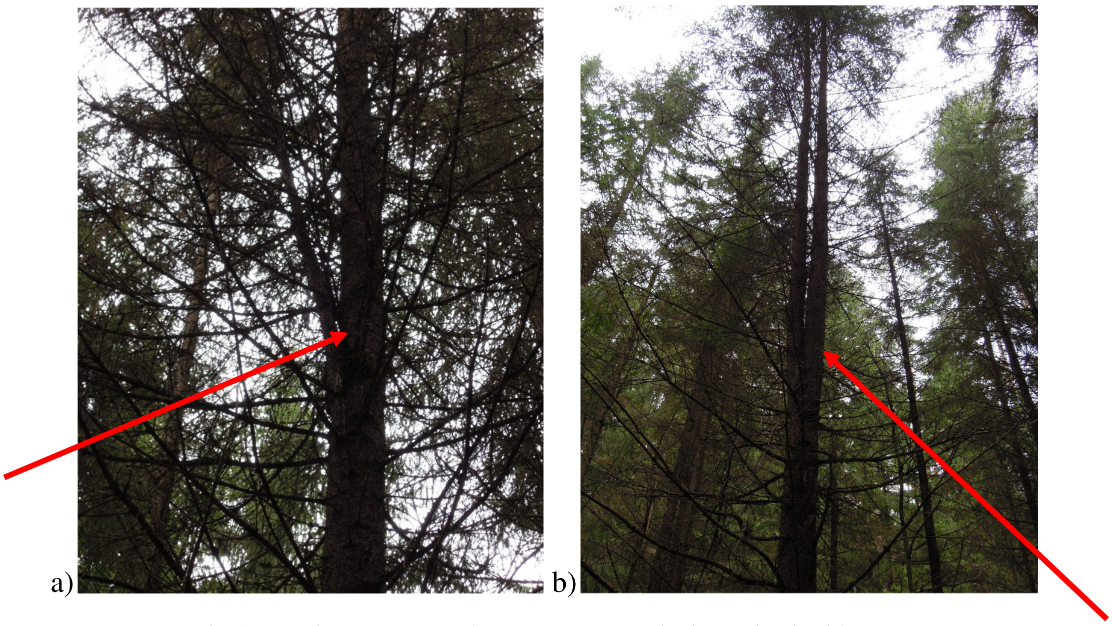

Fig.8. *Quality measures for spruce: a) spike knot; b) double top*

<u>Pure spruce stand</u>

There were fifteen to twenty sample trees in each plot. Dominant height was measured with the same method as on the other study site. Sample trees were selected subjectively considering diameter distribution to represent all sizes. Number of selected sample trees slightly differed from plot to plot when a necessity to reflect an extra sample tree in a specific dbh class was considered. Quality of spruce trees was assessed with the same method as on the shelter stand.

2.2. Further processing of data

The following functions were used to estimate height/diameter relationships within stands. The functions were based on a model by Näslund (1936):

- $H = 1{,}3 + \frac{D^3}{(5{,}397+0{,}1488 \times D)^3}$ for open grown spruce;
- $H = 1{,}3 + \frac{D^3}{(4{,}6118+0{,}1658 \times D)^3}$ for spruce in the mixed stand;
- $H = 1{,}3 + \frac{D^2}{(-1{,}802-0{,}05973732 \times D)^2}$ for birch in the mixed stand.

Abbreviations and units used in the functions:

- *H= height (dm),*
- *D= breast height diameter (mm).*

Both Swedish and Latvian functions were used to calculate individual tree volume (to see if there is any difference). The Swedish functions (Brandel, 1990) were:

- Spruce
  - $\mathbf{V = 10^{-1,02039} \times D^{2,00128} \times (D + 20,0)^{-0,47473} \times H^{2,87138} \times (H - 1,3)^{-1,61803}}$
- Birch
  - $\mathbf{V = 10^{-0,85480} \times D^{2,23818} \times (D + 20,0)^{-1,06930} \times H^{6,02015} \times (H - 1,3)^{-4,51472}}$

In Latvia functions for individual tree volume were developed by integrating statistically average tree stem taper curves (Ozoliņš, 1997):

- Spruce $V = \frac{\pi \times D^2 \times H \times I}{4 \times 10^4 \times (P(\frac{1,3}{H}))^2}$,

  Where:

  - $I = 5295{,}5$
  - $P = 113{,}939 - 203{,}061x + 827{,}209x^2 - 2161{,}251x^3 + 2732{,}076x^4 - 1699{,}667x^5 + 390{,}755x^6$, where $x = \frac{1,3}{H}$
- Birch $V = \frac{\pi \times D^2 \times H \times I}{4 \times 10^4 \times (P(\frac{1,3}{H}))^2}$,

  Where:

  - $I = 5028{,}5$
  - $P = 120{,}567 - 312{,}074x + 1388{,}288x^2 - 3725{,}819x^3 + 5197{,}005x^4 - 3788{,}858x^5 + 1120{,}891x^6$, where $x = \frac{1,3}{H}$

Abbreviations and units used in the individual tree volume functions:

- *V= volume (Swedish- dm^3; Latvian- m^3)*,
- *H= height (m)*,
- *D= breast height diameter (cm).*

2.3. Modelling

A computer based growth simulator; ProdMod (Ekö, 1985), was used to simulate management alternatives both for the mixed spruce-birch and pure spruce stands. The growth simulator is based on data from Swedish forest survey and used in this study as a good option. Simulations were done with a goal to find an optimal thinning regime for the mixed spruce-birch stand and compare to open grown spruce thinning alternative.

Mixture of spruce and birch has a more complex structure than pure spruce stands, and interaction between the two species defines much of each other growth. The general believe is that birch slows down the growth of spruce, and it gets more pronounced with an increasing age. Thus, management alternatives for the mixed spruce-birch stand were designed to take this aspect into consideration.

2.3.1. Management alternatives

The main principle of different management alternatives in the mixed spruce-birch stand was the timing of birch release. The following alternatives were outlined:

1. Birch (B32)
   - ⇒ Birch was completely removed at an age of 32 years (the year when the inventory for the study was done). This alternative represents the earliest release of birch. Mostly pulpwood, but also some birch timber is expected as the assortment outcomes. Probably this is the best option (compared to the other alternatives) in regard of logging complexity, since the crowns of most birches have not become too extensive.
2. Birch (B42)
   - ⇒ Birch was completely removed at an age of 42 years. This alternative was chosen to assess if longer period of birch growth could be used and how spruce growth would be affected. This alternative means no income from thinning operations for 10 more years. It also relates to higher logging complexity, since the stand will become denser, larger trees and crown of birch trees would also be more expanded.
3. Birch (B32&42)
   - ⇒ Birch was thinned at an age of 32 years, leaving 200 birches per ha for 10 more years. This alternative was designed to promote fewer birches leaving them to grow 10 more years with an aim to gain a larger proportion of timber.
4. Unthinned (Mix Unth.)
   - ⇒ This alternative means that no further interventions in the stand are carried out. This alternative would best demonstrate the interactions between spruce and birch growth.

Thinning of spruce was also made in each thinning operation. Thinning intensity and thinning interval for spruce were estimated using thinning guidelines- Swedish and Latvian (LVM, 2008). Thinnings were not recommended after a top height reached 25 m.

There were two management alternatives in pure spruce stand:

1. Thinned (S.Th.)
   - ⇒ Thinning intensity and timing were estimated using Latvian and Swedish thinning guidelines. Thinnings were not recommended after a top height reached 25 m.
2. Unthinned (S.Unth.)
   - ⇒ No thinning operations take place in this alternative.

These management alternatives were then combined with three rotation periods. Length of 80 years was considered as the reference point. Legislation in Latvia (Law on Forests) sets the minimum age of final felling- it is 81 year for spruce dominant forest stands. However, there is an option to shorten the rotation period if the target diameter is reached- 27 to 31 cm depending on the site quality. Another rotation was chosen to be 60 years. From production and economic point of view shorter rotation for the particular study sites was expected to be more beneficial. Longer rotation of 100 years was also chosen to see what outcome it would bring to the forest owner. It was also interesting to see which rotation maximizes mean annual increment (MAI), so called "biological rotation" (Klemperer, 1996).

Input data to simulate management alternatives was the actual data gathered in the field work.

2.3.2. Economic assessments

The economic result of each management alternative was analysed. Net values for thinning and final felling were calculated. Following functions and data were used:

1. Solid cubic metres:
   a. $Solid\ on\ bark\ (m^3 fpb) = m^3 sk \times (1 - \frac{0{,}86}{d_{gv} - d_{min}})$,

   Where m^3sk is forest cubic meters, d_{gv} is the average diameter weighted by the basal area and d_{min} is the smallest diameter for sellable assortments (Ollas, 1980).

   b. *Solid under bark (m^3fub)* was calculated to be 87 % of the solid volume on bark (Ollas, 1980).
2. Harvesting costs were calculated for thinning and final felling. Costs were estimated by the method LVM use to sell logging sites "on stump" for the long term partners. The cost of harvesting depends on the volume of an average tree and the forwarding distance (forwarding distance was set 301-400 m) in thinning or final felling (LVM, 2012).
3. Net income was then calculated by assortment price at the roadside minus harvesting costs.

Minimum dimension for specific assortments was set to calculate the assortment outcome. It was 6 cm for spruce and birch pulpwood. Minimum dimension for spruce timber was set to 12 cm, but for birch timber- 18 cm.

Actual costs of silvicultural operations for stand establishment were estimated by consulting LVM regional office specialists (Table 1).

Table 1. *Costs and timing of silvicultural operations (per ha)*

Operation	Cost (EUR)	Timing (year)	
		Mixed spruce-birch stand	Pure spruce
Soil scarification	140	0	0
Spruce seedlings (2000 pieces)	325	0	0
Planting	105	0	0
Cleaning	85	1	1
Pre-commercial thinning	140[a]	5 & 10	6 & 12

[a] Cost refers for each time of pre-commercial thinning

2.3.3. Economic calculations

Net present value (NPV) and land expectation value (LEV) were calculated for each management alternative. The calculations were made using 2, 3 and 5 % interest rates for comparison. Following formula was used to calculate NPV:

$$NPV = \sum_{y=0}^{n} \left[\frac{R_n}{(1+r)^n} - \frac{C_n}{(1+r)^n} \right]$$

Where:

- *NPV= net present value (EUR)*,
- *R_n= revenue received in year n (EUR)*,
- *C_n= cost incurred in year n (EUR)*,
- *n= year of a particular revenue or cost*
- *r= interest rate (decimal).*

The land expectation value (LEV) gives the value of bare land just before reforestation if the timber production continues in perpetuity. LEV represents the maximum value someone could pay for bare land and still earn the rate of return *r* (Klemperer, 1996).

The following formula was used to calculate LEV:

$$LEV = \frac{NPV\ (1+r)^t}{(1+r)^t - 1}$$

Where:

- *LEV= land expectation value (EUR)*,
- *t= length of rotation (years)*,
- *r= interest rate (decimal).*

Currency ratio 1 $EUR = 0{,}70\ LVL$ was used to transfer LVL to EUR.

3. Results

3.1. Stand data at the time of inventory

Stand data of the study stands at the time of inventory is shown in the Table 2, and data of cut birches during the previous thinning operation in the Table 3.

Table 2. *Stand data of mixed spruce-birch and pure spruce stands at the time of inventory (s-spruce; b- birch)*

Study site	Age (yrs)	Site index	Nr. of stems (ha^{-1})		Mean height (m)		DBH (cm)		Basal area (m^2 ha^{-1})		Volume (m^3 ha^{-1})	
			s	b	s	b	s	b	s	b	s	b
Mixed	32	G 36	1920	531	11,6	20,2	11,6	16,7	19,7	11,8	127	107
Pure spruce	34	G 38	1963	-	13,5	-	15,0	-	28,0	-	218	-

Table 3. *Data of cut birches during thinning operation in 2007 on the mixed spruce-birch stand*

Birch thinning in 2007						
Study site	Age (yrs)	Nr. of stems (ha^{-1})	Mean height (m)	DBH (cm)	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})
Mixed	27	594	14,3	11,8	6,6	46

The number of stems in the spruce stand with the birch shelter was 2451 per ha, spruce 1920 and birch 531. The number of stems in the pure spruce stand was 1963 trees per ha.

In the present study both height and diameter of spruce was higher in the pure spruce stand. The dominant height in the open grown spruce was 19.5 m compared to 16.2 m in spruce in the mixed stand. Corresponding values for mean height were 15.0 and 11.6 m, a relative difference of 23 %. The birch was taller with a mean height of 20.2 m. Relations of top and mean heights in spruce and birch is shown in the Fig.9.

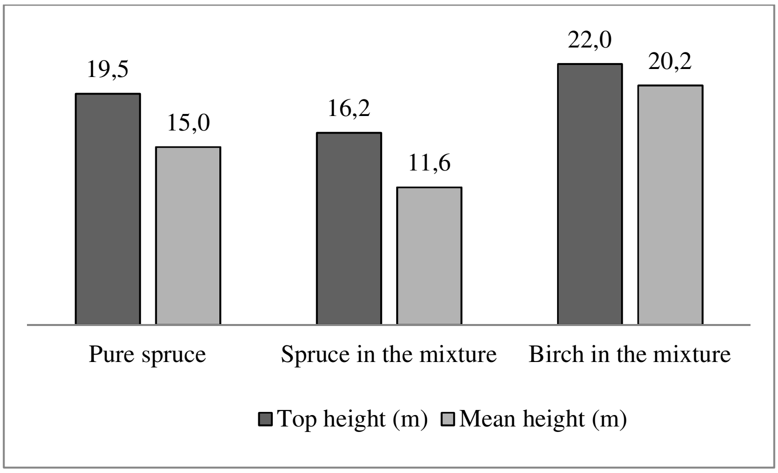

Fig.9. *Top and mean heights in the study stands*

The dbh in spruce in the pure spruce stand was 13.5 cm compared to 11.6 cm in the mixed stand (relative difference 14 %). The diameter distribution of spruce in the two stands show that the frequency of small diameter trees was higher in the mixed stand (Fig.10). The opposite was found for trees with larger diameters.

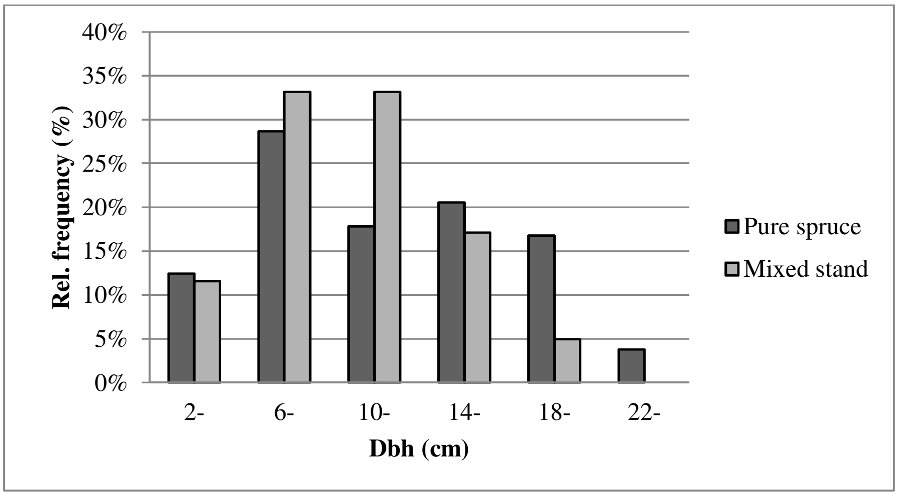

Fig.10. *Diameter distribution of spruce in the mixed and pure spruce stand*

The basal area at the time of inventory in the mixed stand was 31.5 m^2 ha^{-1}, of which spruce made up 19.7 m^2 ha^{-1} and birch 11.8 m^2 ha^{-1}. The removal of birch in 2007 was 6.6 m^2 ha^{-1}. The basal area in pure spruce stand was 28.0 m^2 ha^{-1}. The relations of basal area between species and study sites are visualised in the Fig.11a.

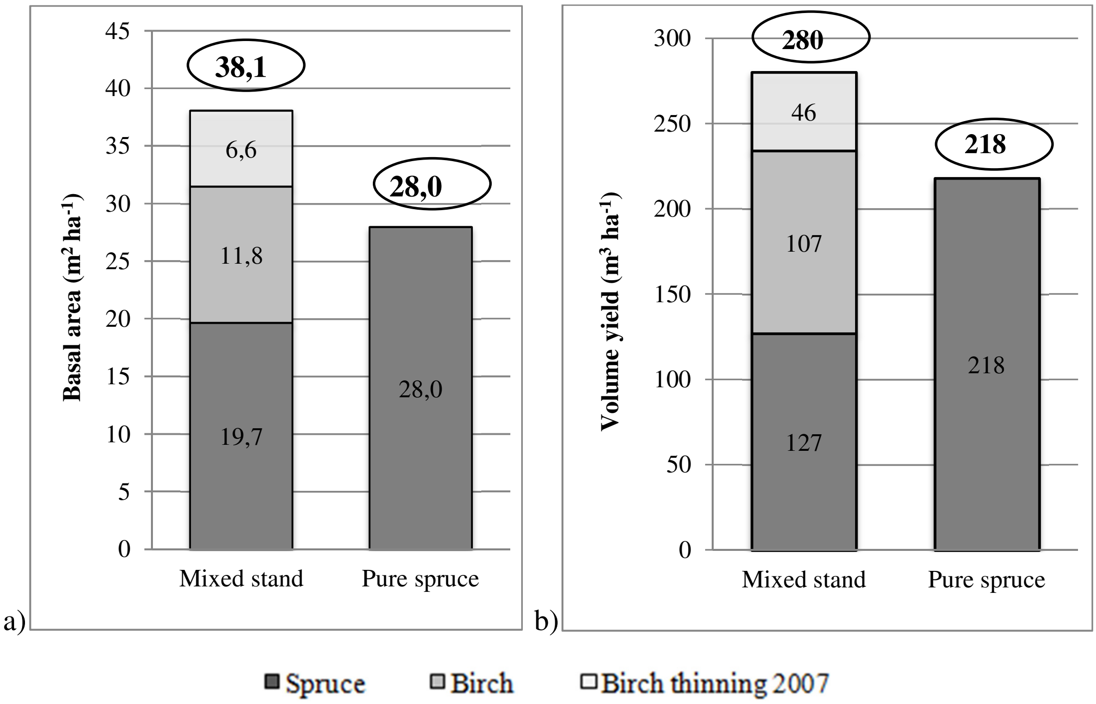

Fig.11. *Basal area (a) and volume yield (b) per species and study sites at the time of inventory (including data of birch thinning in the mixed stand in 2007)*

The standing volume at the time of inventory on the mixed stand was 234 m^3 ha^{-1}, of which spruce made up 127 m^3 ha^{-1} and birch 107 m^3 ha^{-1}. The removal of birch in 2007 was 46 m^3 ha^{-1}. Standing volume on the pure spruce stand was 218 m^3 ha^{-1}. The volume yield of spruce alone was 91 m^3 ha^{-1} (42 %) higher in the no-shelter stand. However, this loss was more than compensated by surplus volume of birch. The total volume yield in the mixed stand was 62 m^3 ha^{-1} (22 %) higher compared to monoculture. The relations of volume yield between species and study sites are visualised in the Fig.11b.

3.2. Parameters determining wood quality

The average number of whorls counted between 0.5 and 2.0 m height in spruce was higher in the mixed stand (6 whorls) compared to pure spruce stand (4 whorls). The number of whorls was in both cases negatively correlated to tree height. The diameter of the thickest branch was on average 3 mm smaller in the mixed stand compared to pure spruce stand (Table 4).

Table 4. *Parameters determining wood quality of spruce*

Study site	Nr. of whorls between 0,5 and 2,0 m	Diameter of thickest branch (mm)	Slightly crooked trees (%)	Spike knot occurence (%)	Double tops (%)	Whipped trees (%)
Mixed	6	17	4	2	-	24
Pure spruce	4	20	21	8	4	-

Slightly crooked trees were found in both stands. The frequency was higher in pure spruce stand (21 %) compared to spruce with birch shelter (4 %). Spike knots were present in both stands, 2 % in the mixed and 8 % in the pure spruce stand. Double tops (4 %) were observed on the spruce monoculture. 24 % of spruces in the mixed stand were whipped.

3.3. Results from growth simulations

Results from growth simulations of different management alternatives and rotation periods are demonstrated in the summary Tables 5, 6 and 7. Volume of cut birches during thinning operation in the mixed stand in 2007 is included in the calculations. More detailed growth simulation data of each alternative are demonstrated in the Appendix 1 (without birch thinning 2007 data).

Unthinned management alternatives on both stands showed the highest total production, independent of rotation period (Fig.12).

Natural mortality was around two times higher for the alternatives left for free growth compared to thinned management alternatives, and increased with a longer rotation period (Fig.13, 14 and 15).

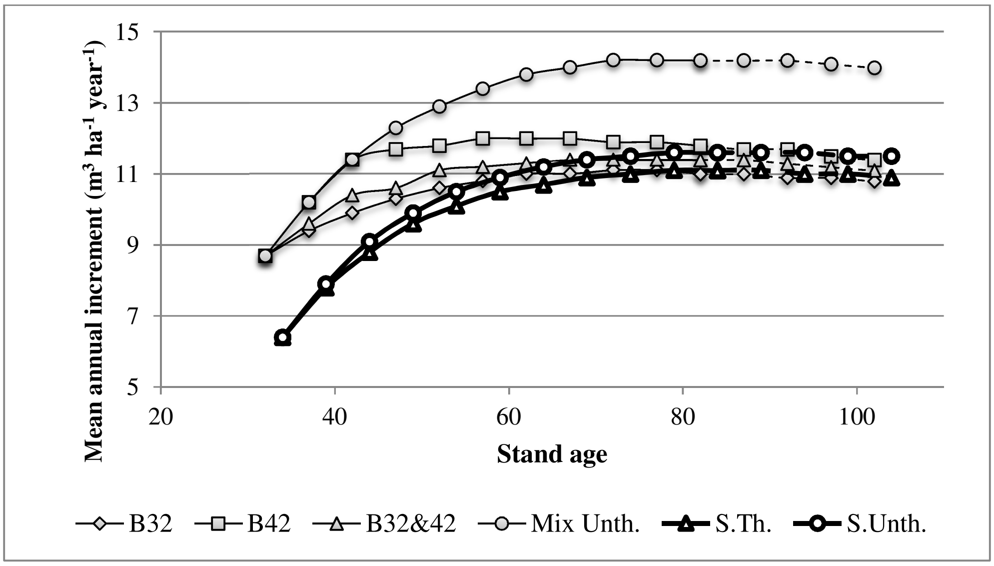

Fig.12. *Estimated total mean annual increment for management alternatives in both study stands*

Among all thinned management alternatives (B32, B42, B32&42 and S.Th.), production of spruce alone was, on average, 19, 15 and 14 % higher in the pure spruce stand, respectively on 60, 80 and 100 years long rotations. However, total volume production was 8, 5 and 5 % higher in the mixed stand (Fig.13, 14 and 15).

No significant differences were found in spruce production among management alternatives B32, B42 and B32&42 in the mixed stand. However, B42 showed the highest total volume production, followed by B32&42 and B32 (Fig.13, 14 and 15).

Merchantable wood production was, on average, 13, 13 and 10 % higher for the unthinned alternative compared to thinned ones in the mixed stand on the respective rotation periods. In the pure spruce stand, however, merchantable wood production was similar for both management alternatives on a 60 years long rotation. On rotation periods of 80 and 100 years thinned management alternative was 2 and 6 % more productive, respectively (Fig.13, 14 and 15).

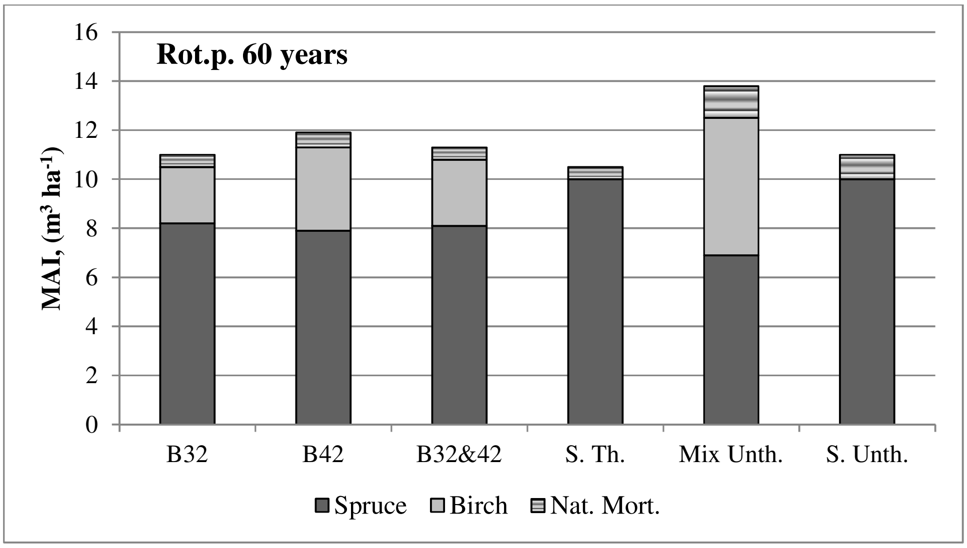

Fig.13. *MAI of different alternatives for a rotation period of 60 years*

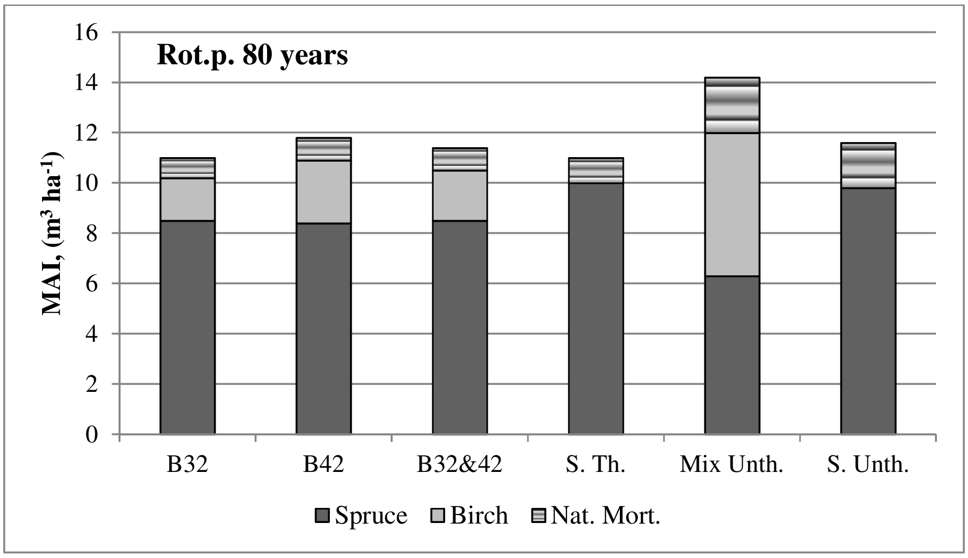

Fig.14. *MAI of different alternatives for a rotation period of 80 years*

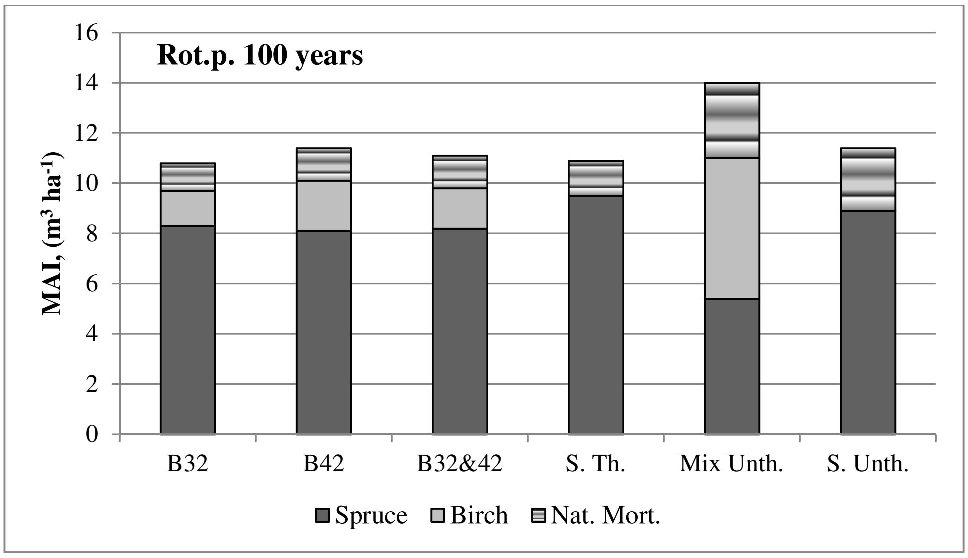

Fig.15. *MAI of different alternatives for a rotation period of 100 years*

DBH of spruce at the time of final felling was significantly lower for unthinned management alternatives compared to B32, B32&42, B42 and S.Th. (Tables 5, 6, 7). The difference in the mixed stand was 5.9, 9.6 and 12.1 cm, respectively on 60, 80 and 100 years long rotation periods. In the pure spruce stand the difference was 5.9, 8.3 and 9.8 cm on respective rotation periods.

“Biological rotation” which maximizes MAI for management alternatives B32, B42 and B32&42 was found to be between 60 and 80 years. For all other rotation period between 80 and 100 years would maximize MAI.

Table 5. *Calculation for a rotation period of 60 years*

Study site	Manag. alternative	Rot. per.	Thinning				Final felling (spruce)				Natural mortality	CAI	MAI
			Birch		Spruce		H_{dom}	Nr. of stems	dbh	Volume			
		Years	Year	$m^3 ha^{-1}$	Year	$m^3 ha^{-1}$	m	ha^{-1}	cm	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$
Mixed spruce-birch	B32	60	27; 32^{FF}	142	32; 37; 47	135	29,0	704	25,1	373	30	12,9	11,0
	B42	60	27; 42^{FF}	208	42; 47; 52	170	29,0	779	22,5	321	38	12,1	11,9
	B32&42	60	27; 32; 42^{FF}	167	32; 42; 52	159	29,0	703	24,2	344	33	12,5	11,3
	Mix Unth.	60	27; 62^{FF}	345	-	-	29,0	1664	18,0	428	81	17,8	13,8
Pure spruce	S. Th.	60	-	-	32; 42; 52	225	31,6	643	27,0	392	36	13,5	10,5
	S. Unth.	60	-	-	-	-	31,6	1714	21,1	624	60	14,7	11,0

Table 6. *Calculation for a rotation period of 80 years*

Study site	Manag. alternative	Rot. per.	Thinning				Final felling (spruce)				Natural mortality	CAI	MAI
			Birch		Spruce		H_{dom}	Nr. of stems	dbh	Volume			
		Years	Year	$m^3 ha^{-1}$	Year	$m^3 ha^{-1}$	m	ha^{-1}	cm	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$
Mixed spruce-birch	B32	80	27; 32^{FF}	142	32; 37; 47; 62	214	33,5	508	31,8	486	63	10,7	11,0
	B42	80	27; 42^{FF}	208	42; 47; 57	190	33,5	692	28,1	499	74	10,9	11,8
	B32&42	80	27; 32; 42^{FF}	167	32; 42; 52	159	33,5	649	29,8	539	72	11,0	11,4
	Mix Unth.	80	27; 82^{FF}	468	-	-	33,5	1467	20,3	518	182	14,5	14,2
Pure spruce	S. Th.	80	-	-	32; 42; 52	225	35,9	591	32,4	598	80	11,4	11,0
	S. Unth.	80	-	-	-	-	35,9	1529	24,1	802	146	12,0	11,6

Table 7. *Calculation for a rotation period of 100 years*

Study site	Manag. alternative	Rot. per.	Thinning				Final felling (spruce)				Natural mortality	CAI	MAI
			Birch		Spruce		H_{dom}	Nr. of stems	dbh	Volume			
		Years	Year	$m^3 ha^{-1}$	Year	$m^3 ha^{-1}$	m	ha^{-1}	cm	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$	$m^3 ha^{-1}$
Mixed spruce-birch	B32	100	27; 32[FF]	142	32; 37; 47; 62	214	36,2	467	36,4	629	112	9,0	10,8
	B42	100	27; 42[FF]	208	42; 47; 57	189	36,2	633	32,1	641	127	9,1	11,4
	B32&42	100	27; 32; 42[FF]	167	32; 42; 52	159	36,2	593	33,8	677	129	9,0	11,1
	Mix Unth.	100	27; 102[FF]	568	-	-	36,2	1273	22,0	552	310	12,3	14,0
Pure spruce	S. Th.	100	-	-	32; 42; 52	225	38,6	538	36,4	738	145	9,2	10,9
	S. Unth.	100	-	-	-	-	38,6	1347	26,6	908	258	10,0	11,4

3.4. Economic calculations

Interest rates of 2, 3 and 5 % were used for land expectation value (LEV) calculations. The choice of interest rate used for economic calculations depends much on forest owner goals. The chosen interest rates were considered to be appropriate for timber production as the main goal.

Interest rate r= 2 %

The unthinned management alternative showed the highest LEV (5655 EUR per ha) in the mixed stand on a 60 years long rotation. However, B42 was more beneficial in cases of 80 (5226 EUR per ha) and 100 years (4525 EUR per ha) long rotations (Fig.16).

Among all thinned management alternatives, those in the mixed stand (B32, B42 and B32&42) had, on average, 509, 589 and 726 EUR per ha higher LEV than in pure spruce, respectively for rotations of 60, 80 and 100 years (Fig.16).

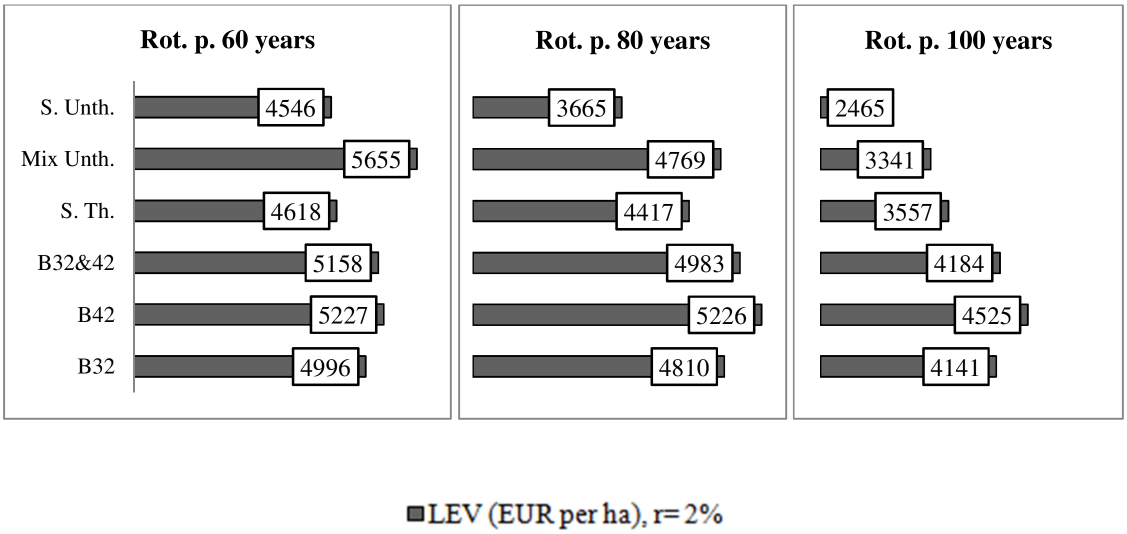

Fig.16. *LEV per management alternatives and rotation lengths, r= 2 %*

Interest rate r= 3 %

When an interest rate of 3 % was used, B42 among all management alternatives gave the best economic results for all simulated rotation periods. Land expectation value of B42 on the respective rotation periods were 2330, 2174 and 1760 EUR per ha (Fig.17).

In common with an interest rate of 2 %, LEV of management alternatives B32, B42 and B32&42 was higher than S.Th. The difference was, on average, 441, 532 and 619 EUR per ha, respectively on 60, 80 and 100 years long rotations (Fig.17).

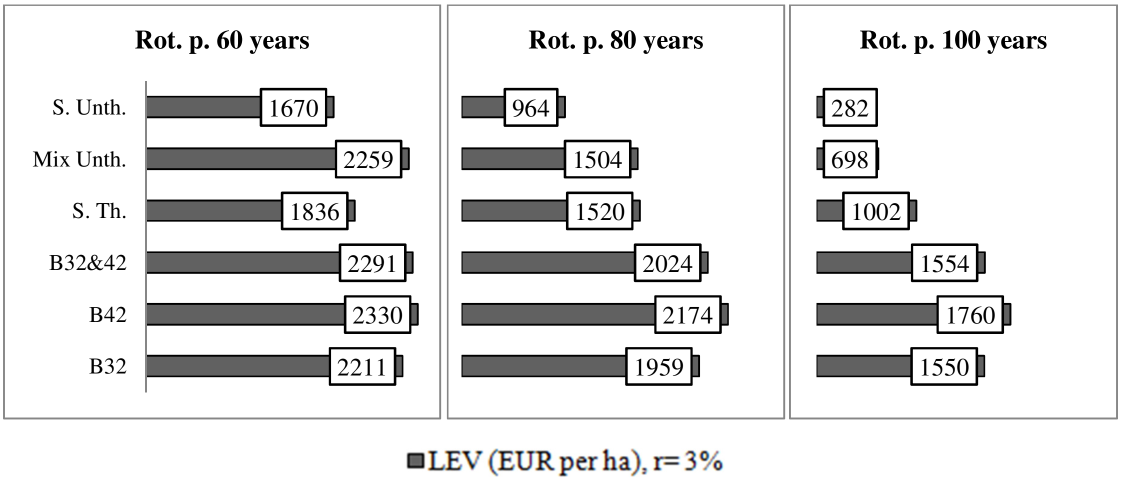

Fig.17. *LEV per management alternatives and rotation lengths, r= 3 %*

Interest rate r= 5 %

The first negative values occurred in calculations when an interest rate of 5 % was used. However, management alternatives B32, B42 and B32&42 had an ability to keep LEV positive for all rotation periods (Fig.18).

Among thinned management alternatives, those in the mixed stand had, on average, 292, 344 and 371 EUR per ha higher LEV than S.Th. on the respective rotation periods (Fig.18).

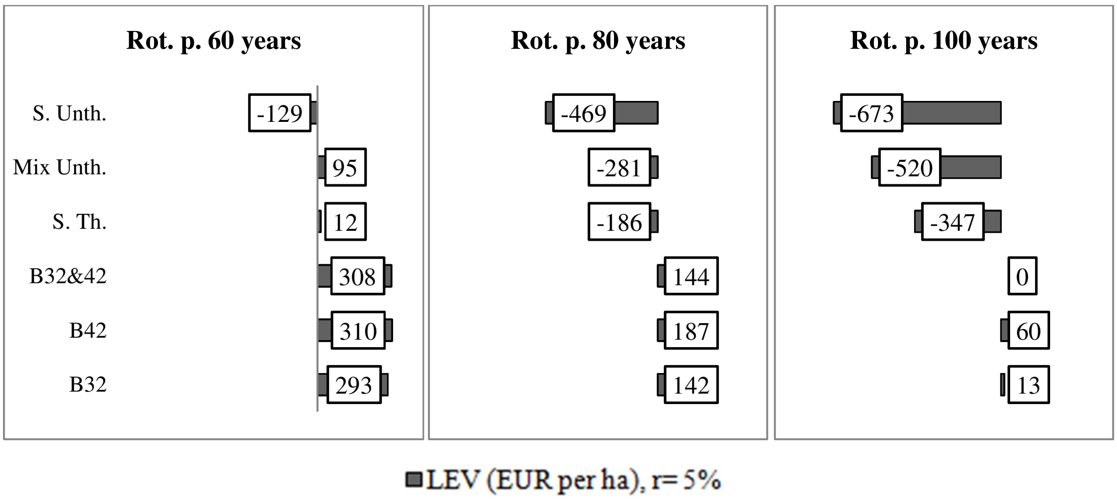

Fig.18. *LEV per management alternatives and rotation lengths, r= 5 %*

To summarize the economic calculations, management alternatives in the mixed stand were more beneficial in terms of LEV. Thinned management alternatives had higher LEV than unthinned on both stands, except one case- mixed stand, r= 2 %, rotation 62 years. Land expectation value decreased more dramatically with an increased rotation period for the alternatives left for free growth compared to other.

Land expectation value decreased by increasing interest rate. It is explained by time factor‘s significance with an increased interest rate.

4. Discussion

4.1. Stand structure

The mean height in spruce was significantly lower (43 %) than birch in the mixed stand, indicating a stratified stand. This is explained by birch being early-successional, light demanding species with higher initial height growth and spruce being a late-successional and a rather shade-tolerant species. Particular silviculture and favourable growth conditions on the studied stand may also have had an impact on the current height growth pattern. The birch had already established before planting spruce, since the total age of both species were 32 years at the time of stand inventory.

Reduction in size of Norway spruce, in terms of dbh and height, at the time of stand inventory was a probable effect of the birch shelter. Higher relative difference was observed in height (23 %) compared to dbh (14 %). Similar results were demonstrated in a study conducted by Klang & Ekö (1999). Experimental studies by Mård (1996) also showed that Norway spruce growth under the birch shelter is hampered. In this study a larger amount of whorls counted between 0.5 and 2 m supported the fact of a negative shelter influence on spruce growth. However, it has to be considered that pure spruce stand had higher site index, and was two years older. For equal growth conditions and stand age differences in size of spruce would probably have been smaller.

4.2. Volume production

At the time of stand inventory volume yield of spruce alone was 91 m^3 ha^{-1} lower in the stand with birch shelter compared to open grown spruce, however, this loss was more than compensated by birch wood (153 m^3 ha^{-1}), and the total volume yield was 62 m^3 ha^{-1} higher in the mixed stand. Considering differences in site index and stand age, for equal conditions total volume production would be even larger. These results were in accordance with studies by Mård (1996) and Klang & Ekö (1999). Growth pattern, where slowly-starting shade tolerant Norway spruce is combined with fast growing pioneer species as birch, was probably the main reason to ensure higher overall yield. It also has to be noted that silver birch (*Betula pendula*) was the only birch species in this study, which has higher volume production than downy birch (*Betula pubescens*) on normal sites (Tham, 1988, Valkonen & Valsta, 2001).

The discussed volume yield pattern comparing mixed stand and spruce monoculture was present at the time of inventory and for all simulated rotation periods. However, the influence of birch surplus yield decreased with increased rotation period, since it was removed latest at age of 42 years for management alternatives B32, B42 and B32&42. Among these alternatives B42 achieved the highest production, followed by B32&42 and B32. The reason was longer, thus higher production of birch, and small influence on spruce production was forecasted. Management alternative B32, however, had the highest production of spruce in the mixed stand, since the birch shelter was removed sooner.

Similar results were demonstrated in model studies by Tham (1988, 1994), who simulated stand development for 50 years. It was concluded that yield of Norway spruce is not reduced with 500-600 birches in the shelter removed at age 25 (Tham, 1988) or with 1200 birches cut in two steps at age 20 and 30 (Tham, 1994). It was substantiated with spruce ability to grow more rapidly and compensate poor growth in the juvenile stage due to competition from higher birches after the birch shelter is removed. However, in the present study yield of Norway spruce was always reduced, since the birch shelter was totally removed either at age 32 or 42.

The unthinned mixture showed the highest volume production among all the management alternatives. It also had the highest natural mortality, since the growth of spruce was much hampered and birch may experience some health issues with an increased age.

4.3. Damages

Whipping damages on spruce was an evident effect of the birch shelter. Almost a quarter of all trees (24 %) in the mixed stand were affected. Both growth and future timber quality might be reduced by this damage, however, it does not seem to be a severe problem (Fahlvik et al., 2011), and most of whipped trees would overheal after the birch shelter is removed. Other defects as spike knots, double tops and slightly crooked trees were more frequent in the pure spruce stand. Occurrence of spike knots and double tops was more rare in the mixed stand probably due to that the birch shelter protected seedlings from frost induced damages (Örlander, 1993, Tham, 1994). Similar results were obtained by Klang & Ekö (1999). Differences in size of the thickest branch wasn‘t significant, and did thus not affect the timber outcome on the current market conditions.

Some damages to spruce are expected in connection with the removal of birch trees in the mixed stand. First, mechanical damages during logging of birch trees are likely to appear. Management alternative B42 will probably cause most damages due to more expanded crowns and higher stem density compared to B32 and B32&42. Second, when the shelter is thinned or removed, spruce is exposed to substantial levels of stress, e.g., increased light intensity and wind. However, Mård (1997) argued that stands adapt to the new environment within a few years, and damage is not likely to have severe negative effect on the growth and yield, only if extreme weather occurs shortly after the release cutting.

4.4. Stand economy

In general, higher land expectation value (LEV) in both stands was calculated for the management alternatives which were thinned. The only exception was in the mixed stand for 62 years long rotation with r= 2 %. It was related to a comparatively short rotation, the fact of income from thinning in 2007 and low interest rate.

Management alternatives B32, B42 and B32&42 were more economically beneficial in terms of LEV than thinned open grown spruce (S.Th.) for all rotation periods. Similar results were obtained in the study by Valkonen & Valsta (2001) who studied productivity and economics of mixed two-storied spruce and birch stands in Southern Finland simulated with empirical models. Stable demand and high prices for birch timber and pulpwood was an essential assumption in the calculations. One of the main reasons of a better economy for the management alternatives in the mixed stand was earlier income from birch thinning.

Among the management alternatives in the mixed stand the highest LEV was calculated for B42, which was probably related to higher production of birch wood.

Regarding forest economy, the outcome much depends on the market situation-prices for timber and pulpwood, and costs of silvicultural operations and harvesting.

4.5. LAT and SWE comparison

Comparison of volume yield calculated with Swedish and Latvian functions and stand economy which may differ between both countries are briefly discussed in this section.

4.5.1. Volume yield

Comparison of volume yield according to Swedish and Latvian functions is demonstrated in the Table 8. No significant differences in results were recognized between the functions. Relatively the largest difference (6 %) was on the volume functions for cut birches in 2007. This could be explained by differences in stem shape in Latvia and Sweden.

Table 8. *Comparison of volume yield calculated with Swedish and Latvian individual tree volume functions*

Study site	Spruce			Birch			Birch thinning 2007		
	Volume yield (m^3 ha^{-1})			Volume yield (m^3 ha^{-1})			Volume yield (m^3 ha^{-1})		
	LAT	SWE	Abs. diff. (LAT-SWE)	LAT	SWE	Abs. diff. (LAT-SWE)	LAT	SWE	Abs. diff. (LAT-SWE)
Mixed	127	126	1	107	107	0	46	43	3
Pure spruce	218	223	-5	-	-	-	-	-	-

4.5.2. Stand economy

There are differences regarding costs of silvicultural operations, e.g., planting and pre-commercial thinning in Latvia and Sweden. Labour cost is higher in Sweden. Silvicultural operations which are mainly operated in the beginning of rotation therefore may have a great effect on LEV.

As an example, comparison of LEV for management alternatives B32 and S.Th. in Latvia and Sweden is demonstrated in the Fig.19. The same silvicultural operations were applied in the simulation, rotation period was 60 years and interest rate was 3 %.

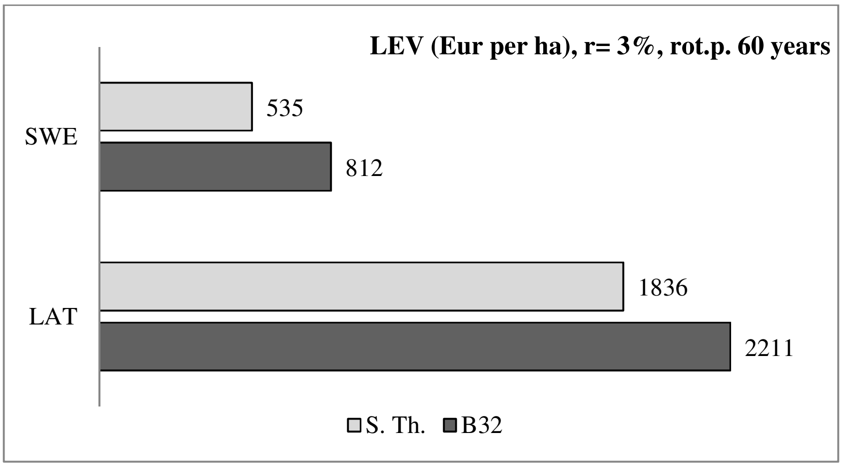

Fig.19. *Comparison of LEV for management alternative B32 and S.Th. in Latvia and Sweden*

Land expectation value was significantly lower in Sweden with a reduction of 1301 and 1399 EUR per ha, respectively for S.Th. and B32 management alternatives. It was mainly related to higher stand establishment and tending costs which take place in the beginning of the rotation. Costs were calculated for Southern Sweden. Pulpwood was the only birch assortment used in the calculations for Swedish conditions, since there is a small market for timber quality logs.

4.6. Situation and perspectives in Latvia

Forest management in Latvia is diverse. In production forests, even-aged pine and spruce dominant stands, which often contain some admixture of birch, are the main focus in the state-owned forests. However, different solutions to diversify the management have been looked for, e.g., increase of selective cutting. In contrast, private forest owners mostly rely on natural regeneration. Pioneer species such as *Betula spp*., *Populus tremula* and *Alnus spp*. are the first to occupy the site after the clear-cut. Different species mixtures develop under such kind of conditions, and target species are promoted during the pre-commercial thinnings.

Use of birch shelter over planted spruce in Latvia has not been practised in a large scale. Only a few forest owners have seen advantages in the high initial growth of birch and left it to grow over spruce. This kind of structure sometimes form naturally when both species regenerate naturally, however, this study doesn‘t deal with those issues in details.

Mixtures of Norway spruce and birch may have several advantages of ecological, economical and social aspects compared to pure spruce stands, and thus can be applied. Moreover, certification systems in Latvia (FSC, 2012, PEFC, 2010) suggest favouring development of coniferous and deciduous tree species mixtures in young stands, and keeping some admixture of broadleaves in the coniferous stands until the end of rotation.

Forest legislation in Latvia is quite neutral to this silvicultural practice, since the use of the birch shelter over planted Norway spruce. Forest Law states that thinning has to be performed not to reduce the basal area below a specified minimum, which is set in the normative acts. The birch shelter cannot be removed until the spruces have reached a sufficient basal area, stated in the legislation. Since the traditional management hasn‘t practised such a method in a large scale, in some cases there might be a necessity to convince the accountable authorities who issue the permit for commercial thinning that the shelter practice is a sustainable forest management.

Management of the stratified mixture of Norway spruce and birch is more complex and requires more attention in order to meet all the benefits provided by the mixed stand. Each case is individual, and stand development has to be followed carefully.

From my point of view it is worth to consider birch shelter use over planted spruce, at least in the stage of young stands. If it is possible to follow the stand development frequently, good result is very likely to achieve. It is always possible to remove birch later during thinnings, while removing it in the very beginning of rotation, the advantage of its initial growth is immediately gone.

4.6.1. Practical implications

Based on the investigated literature and studies, I would like to give the following general guidelines how to maintain birch shelter over planted spruce.

Setting: Let‘s say we have clear-felled area with planted spruce (2000 stems ha^{-1}) and self-regenerated birch.

1. First option is to follow the steps of "*Kronoberg*" method described in the "Introduction" part.
2. Based on the model studies by Tham (1994) there are two modifications of the "*Kronoberg*" I would like to suggest:
    - I. During the last pre-commercial thinning (birch 6-8 m at height) number of birch stems is reduced to 1000-1200 ha^{-1}. Birch is thinned once at age 20 years (height of 12-14 m), leaving 300-400 birch stems ha^{-1} for 10 more years, when finally felled.
    - II. During the last pre-commercial thinning (birch 6-8 m at height) number of birch stems is reduced to 500-600 stems ha^{-1}, and finally felled at age 25 years (height of 14-16 m).

Management of the mixed spruce-birch stand used for investigation in this study doesn‘t perfectly fit to any above described methods, however, some parallels can be drawn with "*Kronoberg*" method. This study shows that birch shelter of 600 stems ha^{-1} might be even left till age of 40 years.

There is lack of experimental studies within this topic in Latvia, therefore, guidelines should be regarded with some caution. Stand development depends on the site quality, and adjustments in the practice might be needed.

4.7. Considerations of the conducted study

There are some aspects of this study such as limited material and use of growth simulator which is based on Swedish forest inventory data I would like to discuss.

First, this study is based on one comparison. The study stands are managed in production forests with no primary intention for experiments. Both stands grow on very fertile sites. It also has to be taken into account that pure spruce was 2 years older and had higher site quality. In the mixed stand birch had been established before spruce planting. All these things have to be taken account when drawing general conclusions.

Lack of well managed spruce-birch mixtures where birch is used as the shelter over planted spruce in the beginning of rotation was the main limiting factor, since this method in Latvia has not been widely practised.

Other important aspect of the study is stand growth simulations. They were done using growth simulator which is based on data from the Swedish forest inventory. This choice was considered as a good option. Southern Sweden is similar in climate and species composition to Latvia. Results from comparison of volume yield calculated with Swedish and Latvian individual tree volume functions also supports this fact. However, there could be some differences in stand development over years. Site quality is described differently in these countries. It may have influenced the result. However, if some deviations occur, it is likely to have the same effect on the all management alternatives.

5. Conclusions

This study indicates a reduced volume production of spruce in the mixture with birch compared to spruce monoculture over rotations of 60, 80 and 100 years. However, the loss of spruce is more than compensated by a birch surplus volume production, and the total volume production is higher in the mixed stand.

Less frequent frost induced damages in spruce are expected in the mixed stand. However, whipping damages are an obvious effect of the birch shelter.

Better economic result, in terms of LEV, was calculated for the management alternatives in the mixed stand compared to pure spruce stand. Stable demand for birch timber and pulpwood was an essential assumption in this calculation.

In order to gain more knowledge and develop practical guidelines for the forest owners, permanent plots on sites with different growth conditions should be established for further investigations. It would also be interesting to gain more knowledge about the stand structure and development if both species are regenerated naturally.

In summary, when choosing to regenerate a clear-felled site by planting spruce where birch has emerged naturally, it is worth to consider birch use as a shelter in the beginning of the rotation, since several benefits are linked to this method.

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Appendix

1. Growth simulations

I Mixed spruce-birch stand, rotation period 60 years

Table 1. *Birch32*

Table 2. *Birch42*

Table 3. *Birch32&42*

Table 4. *Unthinned*

II Mixed spruce-birch stand, rotation period 80 years

Table 5. *Birch32*

Table 6. *Birch42*

Table 7. *Birch32&42*

Table 8. *Unthinned*

III Mixed spruce-birch stand, rotation period 100 years

Table 9. *Birch32*

Table 10. *Birch 42*

Table 11. *Birch32&42*

Table 12. *Unthinned*

IV Pure spruce stand, rotation period 60 years

Table 13. *Thinned*

Table 14. *Unthinned*

V Pure spruce stand, rotation period 80 years

Table 15. *Thinned*

Table 16. *Unthinned*

VI Pure spruce stand, rotation period 100 years

Table 17. *Thinned*

Table 18. *Unthinned*

Apendix Growth simulations

I. Mixed spruce-birch stand, rotation period 60 years

Table 1. *Birch32*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	28	28	0,0	0	0,0	0,0	0	531	11,8	16,8	96	0,0	3,4
	Sum				**1440**	**15,8**		**108**	**1011**	**15,7**		**125**	**0,0**	**7,7**
2	Spruce	37	30	19,6	1413	22,2	14,1	172	27	0,3	11,8	3	13,6	5,6
3	Spruce	37	30	19,6	1060	17,7	14,6	137	353	4,4	12,6	35	13,6	5,6
4	Spruce	42	35	21,9	1040	23,5	17,0	201	20	0,3	14,6	4	13,6	6,5
5	Spruce	47	40	24,0	1021	28,9	19,0	267	19	0,4	17,0	5	14,3	7,4
6	Spruce	47	40	24,0	745	21,7	19,2	197	276	7,2	18,3	71	14,3	7,4
7	Spruce	52	45	25,9	731	26,4	21,4	257	14	0,4	19,2	5	13,0	7,9
8	Spruce	57	50	27,5	718	30,7	23,3	316	14	0,5	21,4	6	13,0	8,4
9	Spruce	62	55	29,0	704	34,7	25,1	373	14	0,6	23,3	7	12,9	8,7
10	Spruce	55	55	0,0	0	0,0	0,0	0	704	34,7	25,1	373	12,9	9,8

Table 2. *Birch42*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		**age**	**age**	**height(m)**	**st/ha**	**m2/ha**	**cm**	**m3sk/ha**	**st/ha**	**m2/ha**	**cm**	**m3sk**	**m3sk/ha**	**m3sk/ha**
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	42	35	21,9	1381	23,4	14,7	192	460	6,6	13,5	60	12,4	6,3
	Birch	38	38	0,0	0	0,0	0,0	0	505	16,1	20,2	162	7,6	4,5
	Sum				**1381**	**23,4**		**192**	**965**	**22,8**		**222**	**19,9**	**10,7**
4	Spruce	47	40	24,0	1355	29,1	16,5	258	26	0,4	14,7	5	14,3	7,1
5	Spruce	47	40	24,0	1057	23,3	16,8	204	298	5,8	15,8	54	14,3	7,1
6	Spruce	52	45	25,9	1037	28,3	18,6	266	20	0,4	16,8	5	13,4	7,7
7	Spruce	52	45	25,9	809	22,7	18,9	210	228	5,7	17,8	56	13,4	7,7
8	Spruce	57	50	27,5	794	27,0	20,8	266	15	0,4	18,9	5	12,2	8,1
9	Spruce	62	55	29,0	779	31,0	22,5	320	15	0,5	20,8	6	12,1	8,5
10	Spruce	55	55	0,0	0	0,0	0,0	0	779	31,0	22,5	321	12,1	9,5

Table 3. *Birch32&42*

Period		Total- age	Breast height age	Top- height(m)	After thinning: Nr of stems st/ha	After thinning: Basal area m2/ha	After thinning: Dbh cm	After thinning: Volume m3sk/ha	Removal/ Nat mortality: Nr of stems st/ha	Removal/ Nat mortality: Basal area m2/ha	Removal/ Nat mortality: Dbh cm	Removal/ Nat mortality: Volume m3sk	Annual increment: Current (CAI) m3sk/ha	Annual increment: Mean (MAI) m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	32	28	22,0	207	4,7	17,0	35	324	7,1	16,7	61	0,0	2,9
	Sum				**1647**	**20,5**		**143**	**804**	**11,0**		**89**	**0,0**	**7,3**
2	Spruce	37	30	19,6	1413	21,6	14,0	168	27	0,3	11,8	3	12,6	5,4
	Birch	37	33	24,2	202	5,6	18,8	47	5	0,1	17,0	1	2,6	2,9
	Sum				**1615**	**27,2**		**215**	**32**	**0,4**		**4**	**15,2**	**8,3**
3	Spruce	42	35	21,9	1385	27,1	15,8	230	27	0,4	14,0	5	13,4	6,4
	Birch	42	38	26,1	197	6,4	20,4	60	5	0,1	18,8	2	2,8	2,9
	Sum				**1582**	**33,5**		**290**	**32**	**0,6**		**6**	**16,2**	**9,3**
4	Spruce	42	35	21,9	1039	21,7	16,3	182	346	5,4	14,1	48	13,4	6,4
	Birch	38	38	0,0	0	0,0	0,0	0	197	6,4	20,4	60	2,8	3,2
	Sum				**1039**	**21,7**		**182**	**543**	**11,9**		**108**	**16,2**	**9,6**
5	Spruce	47	40	24,0	1020	27,1	18,4	247	19	0,4	16,3	5	14,0	7,2
6	Spruce	52	45	25,9	1000	32,1	20,2	312	19	0,5	18,4	6	14,2	7,9
7	Spruce	52	45	25,9	730	24,1	20,5	230	270	8,0	19,5	82	14,2	7,9
8	Spruce	57	50	27,5	717	28,5	22,5	288	13	0,4	20,5	5	12,7	8,3
9	Spruce	62	55	29,0	703	32,5	24,2	344	13	0,5	22,5	7	12,5	8,7
10	Spruce	55	55	0,0	0	0,0	0,0	0	703	32,5	24,2	344	12,5	9,7

Table 4. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		**age**	**age**	**height(m)**	**st/ha**	**m2/ha**	**cm**	**m3sk/ha**	**st/ha**	**m2/ha**	**cm**	**m3sk**	**m3sk/ha**	**m3sk/ha**
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	47	40	24,0	1800	34,1	15,5	304	42	0,7	14,4	7	11,9	6,9
	Birch	47	43	27,7	492	18,1	21,6	196	13	0,4	20,2	5	7,9	4,4
	Sum				**2292**	**52,2**		**501**	**54**	**1,1**		**12**	**19,7**	**11,3**
4	Spruce	52	45	25,9	1756	37,5	16,5	351	44	0,8	15,5	9	11,1	7,3
	Birch	52	48	29,2	480	20,0	23,0	231	12	0,5	21,6	6	8,1	4,7
	Sum				**2236**	**57,4**		**582**	**56**	**1,3**		**15**	**19,2**	**12,0**
5	Spruce	57	50	27,5	1711	40,2	17,3	392	45	1,0	16,5	10	10,3	7,5
	Birch	57	53	30,4	468	21,7	24,3	265	12	0,5	23,0	7	8,2	5,0
	Sum				**2179**	**62,0**		**657**	**57**	**1,5**		**17**	**18,5**	**12,6**
6	Spruce	62	55	29,0	1664	42,5	18,0	428	47	1,1	17,3	12	9,5	7,7
	Birch	62	58	31,6	456	23,4	25,6	299	12	0,5	24,3	8	8,3	5,3
	Sum				**2120**	**65,9**		**726**	**59**	**1,6**		**20**	**17,8**	**13,0**
7	Spruce	55	55	0,0	0	0,0	0,0	0	1664	42,5	18,0	428	9,5	8,6
	Birch	58	58	0,0	0	0,0	0,0	0	456	23,4	25,6	299	8,3	5,7
	Sum				**0**	**0,0**		**0**	**2120**	**65,9**		**726**	**17,8**	**14,4**

II. Mixed spruce-birch stand, rotation period 80 years

Table 5. *Birch32*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	28	28	0,0	0	0,0	0,0	0	531	11,8	16,8	96	0,0	3,4
	Sum				**1440**	**15,8**		**108**	**1011**	**15,7**		**125**	**0,0**	**7,7**
2	Spruce	37	30	19,6	1413	22,2	14,1	172	27	0,3	11,8	3	13,6	5,6
3	Spruce	37	30	19,6	1060	17,7	14,6	137	353	4,4	12,6	35	13,6	5,6
4	Spruce	42	35	21,9	1040	23,5	17,0	201	20	0,3	14,6	4	13,6	6,5
5	Spruce	47	40	24,0	1021	28,9	19,0	267	19	0,4	17,0	5	14,3	7,4
6	Spruce	47	40	24,0	745	21,7	19,2	197	276	7,2	18,3	71	14,3	7,4
7	Spruce	52	45	25,9	731	26,4	21,4	257	14	0,4	19,2	5	13,0	7,9
8	Spruce	57	50	27,5	718	30,7	23,3	316	14	0,5	21,4	6	13,0	8,4
9	Spruce	62	55	29,0	704	34,7	25,1	373	14	0,6	23,3	7	12,9	8,7
10	Spruce	62	55	29,0	549	27,8	25,4	295	155	6,9	23,9	79	12,9	8,7
11	Spruce	67	60	30,3	539	31,4	27,2	347	10	0,5	25,4	7	11,8	9,0
12	Spruce	72	65	31,5	529	34,6	28,9	396	10	0,6	27,2	8	11,3	9,1
13	Spruce	77	70	32,5	519	37,6	30,4	443	10	0,7	28,9	9	11,1	9,3
14	Spruce	82	75	33,5	508	40,3	31,8	486	10	0,7	30,4	10	10,7	9,3
15	Spruce	75	75	0,0	0	0,0	0,0	0	508	40,3	31,8	486	10,7	10,2

Table 6. *Birch42*

Period		Total-age	Breast height age	Top-height(m)	After thinning: Nr of stems st/ha	Basal area m2/ha	Dbh cm	Volume m3sk/ha	Removal/ Nat mortality: Nr of stems st/ha	Basal area m2/ha	Dbh cm	Volume m3sk	Annual increment: Current (CAI) m3sk/ha	Mean (MAI) m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	42	35	21,9	1381	23,4	14,7	192	460	6,6	13,5	60	12,4	6,3
	Birch	38	38	0,0	0	0,0	0,0	0	505	16,1	20,2	162	7,6	4,5
	Sum				**1381**	**23,4**		**192**	**965**	**22,8**		**222**	**19,9**	**10,7**
4	Spruce	47	40	24,0	1355	29,1	16,5	258	26	0,4	14,7	5	14,3	7,1
5	Spruce	47	40	24,0	1057	23,3	16,8	204	298	5,8	15,8	54	14,3	7,1
6	Spruce	52	45	25,9	1037	28,3	18,6	266	20	0,4	16,8	5	13,4	7,7
7	Spruce	57	50	27,5	1017	32,9	20,3	326	20	0,5	18,6	6	13,3	8,2
8	Spruce	57	50	27,5	763	25,6	20,7	251	254	7,2	19,0	76	13,3	8,2
9	Spruce	62	55	29,0	749	29,7	22,5	306	14	0,5	20,7	6	12,2	8,5
10	Spruce	67	60	30,3	735	33,4	24,1	358	14	0,6	22,5	7	11,8	8,8
11	Spruce	72	65	31,5	720	36,9	25,5	408	14	0,6	24,1	8	11,6	9,0
12	Spruce	77	70	32,5	706	40,0	26,8	455	14	0,7	25,5	9	11,3	9,1
13	Spruce	82	75	33,5	692	42,8	28,1	499	14	0,8	26,8	10	10,9	9,2
14	Spruce	75	75	0,0	0	0,0	0,0	0	692	42,8	28,1	499	10,9	10,1

Table 7. *Birch32&42*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		**age**	**age**	**height(m)**	**st/ha**	**m2/ha**	**cm**	**m3sk/ha**	**st/ha**	**m2/ha**	**cm**	**m3sk**	**m3sk/ha**	**m3sk/ha**
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	32	28	22,0	207	4,7	17,0	35	324	7,1	16,7	61	0,0	2,9
	Sum				**1647**	**20,5**		**143**	**804**	**11,0**		**89**	**0,0**	**7,3**
2	Spruce	37	30	19,6	1413	21,6	14,0	168	27	0,3	11,8	3	12,6	5,4
	Birch	37	33	24,2	202	5,6	18,8	47	5	0,1	17,0	1	2,6	2,9
	Sum				**1615**	**27,2**		**215**	**32**	**0,4**		**4**	**15,2**	**8,3**
3	Spruce	42	35	21,9	1385	27,1	15,8	230	27	0,4	14,0	5	13,4	6,4
	Birch	42	38	26,1	197	6,4	20,4	60	5	0,1	18,8	2	2,8	2,9
	Sum				**1582**	**33,5**		**290**	**32**	**0,6**		**6**	**16,2**	**9,3**
4	Spruce	42	35	21,9	1039	21,7	16,3	182	346	5,4	14,1	48	13,4	6,4
	Birch	38	38	0,0	0	0,0	0,0	0	197	6,4	20,4	60	2,8	3,2
	Sum				**1039**	**21,7**		**182**	**543**	**11,9**		**108**	**16,2**	**9,6**
5	Spruce	47	40	24,0	1020	27,1	18,4	247	19	0,4	16,3	5	14,0	7,2
6	Spruce	52	45	25,9	1000	32,1	20,2	312	19	0,5	18,4	6	14,2	7,9
7	Spruce	52	45	25,9	730	24,1	20,5	230	270	8,0	19,5	82	14,2	7,9
8	Spruce	57	50	27,5	717	28,5	22,5	288	13	0,4	20,5	5	12,7	8,3
9	Spruce	62	55	29,0	703	32,5	24,2	344	13	0,5	22,5	7	12,5	8,7
10	Spruce	67	60	30,3	690	36,1	25,8	398	14	0,6	24,2	8	12,3	8,9
11	Spruce	72	65	31,5	676	39,5	27,3	449	14	0,7	25,8	9	12,0	9,1
12	Spruce	77	70	32,5	662	42,5	28,6	496	14	0,8	27,3	10	11,5	9,3
13	Spruce	82	75	33,5	649	45,2	29,8	539	14	0,9	28,6	12	11,0	9,4
14	Spruce	75	75	0,0	0	0,0	0,0	0	649	45,2	29,8	539	11,0	10,2

Table 8. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		**age**	**age**	**height(m)**	**st/ha**	**m2/ha**	**cm**	**m3sk/ha**	**st/ha**	**m2/ha**	**cm**	**m3sk**	**m3sk/ha**	**m3sk/ha**
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	47	40	24,0	1800	34,1	15,5	304	42	0,7	14,4	7	11,9	6,9
	Birch	47	43	27,7	492	18,1	21,6	196	13	0,4	20,2	5	7,9	4,4
	Sum				**2292**	**52,2**		**501**	**54**	**1,1**		**12**	**19,7**	**11,3**
4	Spruce	52	45	25,9	1756	37,5	16,5	351	44	0,8	15,5	9	11,1	7,3
	Birch	52	48	29,2	480	20,0	23,0	231	12	0,5	21,6	6	8,1	4,7
	Sum				**2236**	**57,4**		**582**	**56**	**1,3**		**15**	**19,2**	**12,0**
5	Spruce	57	50	27,5	1711	40,2	17,3	392	45	1,0	16,5	10	10,3	7,5
	Birch	57	53	30,4	468	21,7	24,3	265	12	0,5	23,0	7	8,2	5,0
	Sum				**2179**	**62,0**		**657**	**57**	**1,5**		**17**	**18,5**	**12,6**
6	Spruce	62	55	29,0	1664	42,5	18,0	428	47	1,1	17,3	12	9,5	7,7
	Birch	62	58	31,6	456	23,4	25,6	299	12	0,5	24,3	8	8,3	5,3
	Sum				**2120**	**65,9**		**726**	**59**	**1,6**		**20**	**17,8**	**13,0**
7	Spruce	67	60	30,3	1615	44,3	18,7	457	48	1,2	18,0	14	8,7	7,8
	Birch	67	63	32,6	445	25,1	26,8	332	11	0,6	25,6	9	8,4	5,5
	Sum				**2060**	**69,3**		**789**	**60**	**1,8**		**22**	**17,1**	**13,3**
8	Spruce	72	65	31,5	1566	45,6	19,3	482	49	1,3	18,7	15	7,9	7,8
	Birch	72	68	33,5	434	26,6	27,9	364	11	0,6	26,8	9	8,3	5,7
	Sum				**2000**	**72,2**		**846**	**60**	**2,0**		**24**	**16,2**	**13,5**
9	Spruce	77	70	32,5	1517	46,7	19,8	502	50	1,4	19,3	16	7,3	7,8
	Birch	77	73	34,3	423	28,0	29,0	394	11	0,7	27,9	10	8,0	5,9

	Sum				**1940**	**74,7**		**896**	**60**	**2,1**		**27**	**15,3**	**13,6**
10	Spruce	82	75	33,5	1467	47,4	20,3	518	50	1,5	19,8	18	6,7	7,7
	Birch	82	78	35,1	412	29,3	30,1	423	11	0,7	29,0	11	7,8	6,0
	Sum				**1879**	**76,7**		**940**	**60**	**2,2**		**28**	**14,5**	**13,7**
11	Spruce	75	75	0,0	0	0,0	0,0	0	1467	47,4	20,3	518	6,7	8,4
	Birch	78	78	0,0	0	0,0	0,0	0	412	29,3	30,1	423	7,8	6,3
	Sum				**0**	**0,0**		**0**	**1879**	**76,7**		**940**	**14,5**	**14,7**

III. Mixed spruce-birch stand, rotation period 100 years

Table 9. *Birch32*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	28	28	0,0	0	0,0	0,0	0	531	11,8	16,8	96	0,0	3,4
	Sum				**1440**	**15,8**		**108**	**1011**	**15,7**		**125**	**0,0**	**7,7**
2	Spruce	37	30	19,6	1413	22,2	14,1	172	27	0,3	11,8	3	13,6	5,6
3	Spruce	37	30	19,6	1060	17,7	14,6	137	353	4,4	12,6	35	13,6	5,6
4	Spruce	42	35	21,9	1040	23,5	17,0	201	20	0,3	14,6	4	13,6	6,5
5	Spruce	47	40	24,0	1021	28,9	19,0	267	19	0,4	17,0	5	14,3	7,4
6	Spruce	47	40	24,0	745	21,7	19,2	197	276	7,2	18,3	71	14,3	7,4
7	Spruce	52	45	25,9	731	26,4	21,4	257	14	0,4	19,2	5	13,0	7,9
8	Spruce	57	50	27,5	718	30,7	23,3	316	14	0,5	21,4	6	13,0	8,4
9	Spruce	62	55	29,0	704	34,7	25,1	373	14	0,6	23,3	7	12,9	8,7
10	Spruce	62	55	29,0	549	27,8	25,4	295	155	6,9	23,9	79	12,9	8,7
11	Spruce	67	60	30,3	539	31,4	27,2	347	10	0,5	25,4	7	11,8	9,0
12	Spruce	72	65	31,5	529	34,6	28,9	396	10	0,6	27,2	8	11,3	9,1
13	Spruce	77	70	32,5	519	37,6	30,4	443	10	0,7	28,9	9	11,1	9,3
14	Spruce	82	75	33,5	508	40,3	31,8	486	10	0,7	30,4	10	10,7	9,3
15	Spruce	87	80	34,3	498	42,7	33,0	527	10	0,8	31,8	11	10,3	9,4
16	Spruce	92	85	35,0	488	44,9	34,2	564	10	0,9	33,0	12	9,8	9,4
17	Spruce	97	90	35,6	477	46,9	35,4	598	10	1,0	34,2	13	9,4	9,4
18	Spruce	102	95	36,2	467	48,6	36,4	629	10	1,0	35,4	14	9,0	9,4
19	Spruce	95	95	0,0	0	0,0	0,0	0	467	48,6	36,4	629	9,0	10,1

Table 10. *Birch 42*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	42	35	21,9	1381	23,4	14,7	192	460	6,6	13,5	60	12,4	6,3
	Birch	38	38	0,0	0	0,0	0,0	0	505	16,1	20,2	162	7,6	4,5
	Sum				**1381**	**23,4**		**192**	**965**	**22,8**		**222**	**19,9**	**10,7**
4	Spruce	47	40	24,0	1355	29,1	16,5	258	26	0,4	14,7	5	14,3	7,1
5	Spruce	47	40	24,0	1057	23,3	16,8	204	298	5,8	15,8	54	14,3	7,1
6	Spruce	52	45	25,9	1037	28,3	18,6	266	20	0,4	16,8	5	13,4	7,7
7	Spruce	57	50	27,5	1017	32,9	20,3	326	20	0,5	18,6	6	13,3	8,2
8	Spruce	57	50	27,5	763	25,6	20,7	251	254	7,2	19,0	75	13,3	8,2
9	Spruce	62	55	29,0	749	29,7	22,5	306	14	0,5	20,7	6	12,2	8,5
10	Spruce	67	60	30,3	735	33,4	24,1	358	14	0,6	22,5	7	11,8	8,8
11	Spruce	72	65	31,5	720	36,9	25,5	408	14	0,6	24,1	8	11,6	9,0
12	Spruce	77	70	32,5	706	40,0	26,8	455	14	0,7	25,5	9	11,3	9,1
13	Spruce	82	75	33,5	692	42,8	28,1	499	14	0,8	26,8	10	10,9	9,2
14	Spruce	87	80	34,3	677	45,3	29,2	540	15	0,9	28,1	12	10,4	9,3
15	Spruce	92	85	35,0	663	47,5	30,2	577	15	1,0	29,2	13	9,9	9,3
16	Spruce	97	90	35,6	648	49,5	31,2	611	15	1,0	30,2	14	9,5	9,4
17	Spruce	102	95	36,2	633	51,2	32,1	641	15	1,1	31,2	15	9,1	9,3
18	Spruce	95	95	0,0	0	0,0	0,0	0	633	51,2	32,1	641	9,1	10,0

Table 11. *Birch32&42*

Period		Total-age	Breast height age	Top-height(m)	After thinning: Nr of stems st/ha	After thinning: Basal area m2/ha	After thinning: Dbh cm	After thinning: Volume m3sk/ha	Removal/ Nat mortality: Nr of stems st/ha	Removal/ Nat mortality: Basal area m2/ha	Removal/ Nat mortality: Dbh cm	Removal/ Nat mortality: Volume m3sk	Annual increment: Current (CAI) m3sk/ha	Annual increment: Mean (MAI) m3sk/ha
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	32	25	17,0	1440	15,8	11,8	108	480	3,9	10,2	29	0,0	4,3
	Birch	32	28	22,0	207	4,7	17,0	35	324	7,1	16,7	61	0,0	2,9
	Sum				**1647**	**20,5**		**143**	**804**	**11,0**		**89**	**0,0**	**7,3**
2	Spruce	37	30	19,6	1413	21,6	14,0	168	27	0,3	11,8	3	12,6	5,4
	Birch	37	33	24,2	202	5,6	18,8	47	5	0,1	17,0	1	2,6	2,9
	Sum				**1615**	**27,2**		**215**	**32**	**0,4**		**4**	**15,2**	**8,3**
3	Spruce	42	35	21,9	1385	27,1	15,8	230	27	0,4	14,0	5	13,4	6,4
	Birch	42	38	26,1	197	6,4	20,4	60	5	0,1	18,8	2	2,8	2,9
	Sum				**1582**	**33,5**		**290**	**32**	**0,6**		**6**	**16,2**	**9,3**
4	Spruce	42	35	21,9	1039	21,7	16,3	182	346	5,4	14,1	48	13,4	6,4
	Birch	38	38	0,0	0	0,0	0,0	0	197	6,4	20,4	60	2,8	3,2
	Sum				**1039**	**21,7**		**182**	**543**	**11,9**		**108**	**16,2**	**9,6**
5	Spruce	47	40	24,0	1020	27,1	18,4	247	19	0,4	16,3	5	14,0	7,2
6	Spruce	52	45	25,9	1000	32,1	20,2	312	19	0,5	18,4	6	14,2	7,9
7	Spruce	52	45	25,9	730	24,1	20,5	230	270	8,0	19,5	82	14,2	7,9
8	Spruce	57	50	27,5	717	28,5	22,5	288	13	0,4	20,5	5	12,7	8,3
9	Spruce	62	55	29,0	703	32,5	24,2	344	13	0,5	22,5	7	12,5	8,7
10	Spruce	67	60	30,3	690	36,1	25,8	398	14	0,6	24,2	8	12,3	8,9
11	Spruce	72	65	31,5	676	39,5	27,3	449	14	0,7	25,8	9	12,0	9,1
12	Spruce	77	70	32,5	662	42,5	28,6	496	14	0,8	27,3	10	11,5	9,3
13	Spruce	82	75	33,5	649	45,2	29,8	539	14	0,9	28,6	12	11,0	9,4
14	Spruce	87	80	34,3	635	47,6	30,9	579	14	1,0	29,8	13	10,5	9,5
15	Spruce	92	85	35,0	621	49,7	31,9	615	14	1,0	30,9	14	10,0	9,5
16	Spruce	97	90	35,6	607	51,5	32,9	648	14	1,1	31,9	15	9,5	9,5
17	Spruce	102	95	36,2	593	53,1	33,8	677	14	1,2	32,9	16	9,0	9,5
18	Spruce	95	95	0,0	0	0,0	0,0	0	593	53,1	33,8	677	9,0	10,1

Table 12. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		**age**	**age**	**height(m)**	**st/ha**	**m2/ha**	**cm**	**m3sk/ha**	**st/ha**	**m2/ha**	**cm**	**m3sk**	**m3sk/ha**	**m3sk/ha**
0	Spruce	32	25	17,0	1920	19,7	11,4	137	0	0,0	0,0	0	0,0	4,3
	Birch	32	28	22,0	531	11,8	16,8	96	0	0,0	0,0	0	0,0	2,9
	Sum				**2451**	**31,5**		**232**	**0**	**0,0**		**0**	**0,0**	**7,3**
1	Spruce	37	30	19,6	1882	25,3	13,1	196	38	0,4	11,4	4	12,6	5,4
	Birch	37	33	24,2	518	14,0	18,6	128	13	0,3	16,8	3	7,2	3,5
	Sum				**2399**	**39,3**		**324**	**52**	**0,7**		**7**	**19,8**	**9,0**
2	Spruce	42	35	21,9	1842	30,0	14,4	252	40	0,5	13,1	5	12,4	6,3
	Birch	42	38	26,1	505	16,1	20,2	162	13	0,4	18,6	4	7,6	4,0
	Sum				**2346**	**46,2**		**414**	**53**	**0,9**		**10**	**19,9**	**10,3**
3	Spruce	47	40	24,0	1800	34,1	15,5	304	42	0,7	14,4	7	11,9	6,9
	Birch	47	43	27,7	492	18,1	21,6	196	13	0,4	20,2	5	7,9	4,4
	Sum				**2292**	**52,2**		**501**	**54**	**1,1**		**12**	**19,7**	**11,3**
4	Spruce	52	45	25,9	1756	37,5	16,5	351	44	0,8	15,5	9	11,1	7,3
	Birch	52	48	29,2	480	20,0	23,0	231	12	0,5	21,6	6	8,1	4,7
	Sum				**2236**	**57,4**		**582**	**56**	**1,3**		**15**	**19,2**	**12,0**
5	Spruce	57	50	27,5	1711	40,2	17,3	392	45	1,0	16,5	10	10,3	7,5
	Birch	57	53	30,4	468	21,7	24,3	265	12	0,5	23,0	7	8,2	5,0
	Sum				**2179**	**62,0**		**657**	**57**	**1,5**		**17**	**18,5**	**12,6**
6	Spruce	62	55	29,0	1664	42,5	18,0	428	47	1,1	17,3	12	9,5	7,7
	Birch	62	58	31,6	456	23,4	25,6	299	12	0,5	24,3	8	8,3	5,3
	Sum				**2120**	**65,9**		**726**	**59**	**1,6**		**20**	**17,8**	**13,0**
7	Spruce	67	60	30,3	1615	44,3	18,7	457	48	1,2	18,0	14	8,7	7,8
	Birch	67	63	32,6	445	25,1	26,8	332	11	0,6	25,6	9	8,4	5,5
	Sum				**2060**	**69,3**		**789**	**60**	**1,8**		**22**	**17,1**	**13,3**
8	Spruce	72	65	31,5	1566	45,6	19,3	482	49	1,3	18,7	15	7,9	7,8
	Birch	72	68	33,5	434	26,6	27,9	364	11	0,6	26,8	9	8,3	5,7
	Sum				**2000**	**72,2**		**846**	**60**	**2,0**		**24**	**16,2**	**13,5**
9	Spruce	77	70	32,5	1517	46,7	19,8	502	50	1,4	19,3	16	7,3	7,8
	Birch	77	73	34,3	423	28,0	29,0	394	11	0,7	27,9	10	8,0	5,9

	Sum				**1940**	**74,7**		**896**	**60**	**2,1**		**27**	**15,3**	**13,6**
10	Spruce	82	75	33,5	1467	47,4	20,3	518	50	1,5	19,8	18	6,7	7,7
	Birch	82	78	35,1	412	29,3	30,1	423	11	0,7	29,0	11	7,8	6,0
	Sum				**1879**	**76,7**		**940**	**60**	**2,2**		**28**	**14,5**	**13,7**
11	Spruce	87	80	34,3	1418	47,9	20,7	530	50	1,6	20,3	19	6,2	7,6
	Birch	87	83	35,9	402	30,5	31,1	449	10	0,7	30,1	12	7,6	6,1
	Sum				**1819**	**78,4**		**980**	**60**	**2,3**		**30**	**13,9**	**13,7**
12	Spruce	92	85	35,0	1369	48,2	21,2	540	49	1,7	20,7	19	5,8	7,5
	Birch	92	88	36,6	392	31,6	32,1	475	10	0,8	31,1	12	7,5	6,2
	Sum				**1760**	**79,8**		**1015**	**59**	**2,4**		**32**	**13,3**	**13,7**
13	Spruce	97	90	35,6	1320	48,3	21,6	547	48	1,7	21,2	20	5,4	7,4
	Birch	97	93	37,4	382	32,7	33,0	499	10	0,8	32,1	13	7,4	6,2
	Sum				**1702**	**81,0**		**1046**	**58**	**2,5**		**33**	**12,8**	**13,6**
14	Spruce	102	95	36,2	1273	48,3	22,0	552	47	1,7	21,6	21	5,0	7,3
	Birch	102	98	38,2	373	33,7	33,9	522	10	0,8	33,0	13	7,3	6,3
	Sum				**1645**	**82,0**		**1073**	**57**	**2,6**		**34**	**12,3**	**13,6**
15	Spruce	95	95	0,0	0	0,0	0,0	0	1273	48,3	22,0	552	5,0	7,8
	Birch	98	98	0,0	0	0,0	0,0	0	373	33,7	33,9	522	7,3	6,6
	Sum				**0**	**0,0**		**0**	**1645**	**82,0**		**1073**	**12,3**	**14,4**

IV. Pure spruce stand, rotation period 60 years

Table 13. *Thinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	34	27	19,4	1374	21,0	13,9	159	589	7,0	12,3	55	0,0	6,4
2	Spruce	39	32	22,1	1348	28,0	16,3	239	26	0,4	13,9	5	17,1	7,8
3	Spruce	44	37	24,4	1322	34,4	18,2	319	26	0,5	16,3	6	17,2	8,8
4	Spruce	44	37	24,4	926	25,8	18,8	237	397	8,6	16,6	83	17,2	8,8
5	Spruce	49	42	26,6	908	31,4	21,0	310	17	0,5	18,8	6	15,8	9,6
6	Spruce	54	47	28,4	891	36,3	22,8	380	18	0,6	21,0	7	15,5	10,1
7	Spruce	54	47	28,4	668	28,3	23,2	292	223	8,0	21,4	87	15,5	10,1
8	Spruce	59	52	30,1	656	32,8	25,2	356	13	0,5	23,2	7	14,1	10,5
9	Spruce	64	57	31,6	643	36,7	27,0	416	13	0,6	25,2	8	13,5	10,7
10	Spruce	57	57	0,0	0	0,0	0,0	0	643	36,7	27,0	416	13,5	11,9

Table 14. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	39	32	22,1	1925	35,4	15,3	299	38	0,5	13,5	6	18,1	7,9
2	Spruce	44	37	24,4	1885	41,9	16,8	381	39	0,7	15,3	8	18,1	9,1
3	Spruce	49	42	26,6	1845	47,5	18,1	457	41	0,9	16,8	10	17,2	9,9
4	Spruce	54	47	28,4	1802	52,2	19,2	526	42	1,1	18,1	12	16,3	10,5
5	Spruce	59	52	30,1	1759	56,4	20,2	589	43	1,3	19,2	14	15,5	10,9
6	Spruce	64	57	31,6	1714	59,9	21,1	646	45	1,4	20,2	17	14,7	11,2
7	Spruce	57	57	0,0	0	0,0	0,0	0	1714	59,9	21,1	646	14,7	12,5

V. <u>Pure spruce stand, rotation period 80 years</u>

Table 15. *Thinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	34	27	19,4	1374	21,0	13,9	159	589	7,0	12,3	55	0,0	6,4
2	Spruce	39	32	22,1	1348	28,0	16,3	239	26	0,4	13,9	5	17,1	7,8
3	Spruce	44	37	24,4	1322	34,4	18,2	319	26	0,5	16,3	6	17,2	8,8
4	Spruce	44	37	24,4	926	25,8	18,8	237	397	8,6	16,6	83	17,2	8,8
5	Spruce	49	42	26,6	908	31,4	21,0	310	17	0,5	18,8	6	15,8	9,6
6	Spruce	54	47	28,4	891	36,3	22,8	380	18	0,6	21,0	7	15,5	10,1
7	Spruce	54	47	28,4	668	28,3	23,2	292	223	8,0	21,4	87	15,5	10,1
8	Spruce	59	52	30,1	656	32,8	25,2	356	13	0,5	23,2	7	14,1	10,5
9	Spruce	64	57	31,6	643	36,7	27,0	416	13	0,6	25,2	8	13,5	10,7
10	Spruce	69	62	32,9	630	40,3	28,5	472	13	0,7	27,0	10	13,1	10,9
11	Spruce	74	67	34,0	617	43,5	29,9	524	13	0,8	28,5	11	12,6	11,0
12	Spruce	79	72	35,0	604	46,3	31,2	572	13	0,9	29,9	12	12,0	11,1
13	Spruce	84	77	35,9	591	48,8	32,4	615	13	1,0	31,2	14	11,4	11,1
14	Spruce	77	77	0,0	0	0,0	0,0	0	591	48,8	32,4	615	11,4	12,0

Table 16. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	39	32	22,1	1925	35,4	15,3	299	38	0,5	13,5	6	18,1	7,9
2	Spruce	44	37	24,4	1885	41,9	16,8	381	39	0,7	15,3	8	18,1	9,1
3	Spruce	49	42	26,6	1845	47,5	18,1	457	41	0,9	16,8	10	17,2	9,9
4	Spruce	54	47	28,4	1802	52,2	19,2	526	42	1,1	18,1	12	16,3	10,5
5	Spruce	59	52	30,1	1759	56,4	20,2	589	43	1,3	19,2	15	15,5	10,9
6	Spruce	64	57	31,6	1714	59,9	21,1	646	45	1,4	20,2	17	14,7	11,2
7	Spruce	69	62	32,9	1669	63,0	21,9	696	46	1,6	21,1	19	13,9	11,4
8	Spruce	74	67	34,0	1623	65,7	22,7	741	46	1,7	21,9	21	13,2	11,5
9	Spruce	79	72	35,0	1576	67,9	23,4	781	47	1,9	22,7	23	12,6	11,6
10	Spruce	84	77	35,9	1529	69,8	24,1	816	47	2,0	23,4	25	12,0	11,6
11	Spruce	77	77	0,0	0	0,0	0,0	0	1529	69,8	24,1	816	12,0	12,6

VI. Pure spruce stand, rotation period 100 years

Table 17. *Thinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	34	27	19,4	1374	21,0	13,9	159	589	7,0	12,3	55	0,0	6,4
2	Spruce	39	32	22,1	1348	28,0	16,3	239	26	0,4	13,9	5	17,1	7,8
3	Spruce	44	37	24,4	1322	34,4	18,2	319	26	0,5	16,3	6	17,2	8,8
4	Spruce	44	37	24,4	926	25,8	18,8	237	397	8,6	16,6	83	17,2	8,8
5	Spruce	49	42	26,6	908	31,4	21,0	310	17	0,5	18,8	6	15,8	9,6
6	Spruce	54	47	28,4	891	36,3	22,8	380	18	0,6	21,0	7	15,5	10,1
7	Spruce	54	47	28,4	668	28,3	23,2	292	223	8,0	21,4	87	15,5	10,1
8	Spruce	59	52	30,1	656	32,8	25,2	356	13	0,5	23,2	7	14,1	10,5
9	Spruce	64	57	31,6	643	36,7	27,0	416	13	0,6	25,2	8	13,5	10,7
10	Spruce	69	62	32,9	630	40,3	28,5	472	13	0,7	27,0	10	13,1	10,9
11	Spruce	74	67	34,0	617	43,5	29,9	524	13	0,8	28,5	11	12,6	11,0
12	Spruce	79	72	35,0	604	46,3	31,2	572	13	0,9	29,9	12	12,0	11,1
13	Spruce	84	77	35,9	591	48,8	32,4	615	13	1,0	31,2	14	11,4	11,1
14	Spruce	89	82	36,7	578	51,0	33,5	654	13	1,1	32,4	15	10,8	11,1
15	Spruce	94	87	37,4	565	52,9	34,5	689	13	1,2	33,5	16	10,3	11,0
16	Spruce	99	92	38,0	551	54,6	35,5	721	13	1,2	34,5	17	9,7	11,0
17	Spruce	104	97	38,6	538	56,0	36,4	749	13	1,3	35,5	18	9,2	10,9
18	Spruce	97	97	0,0	0	0,0	0,0	0	538	56,0	36,4	749	9,2	11,6

Table 18. *Unthinned*

					After thinning				Removal/ Nat mortality				Annual increment	
		Total-	Breast height	Top-	Nr of stems	Basal area	Dbh	Volume	Nr of stems	Basal area	Dbh	Volume	Current (CAI)	Mean (MAI)
Period		age	age	height(m)	st/ha	m2/ha	cm	m3sk/ha	st/ha	m2/ha	cm	m3sk	m3sk/ha	m3sk/ha
0	Spruce	34	27	19,4	1963	28,0	13,5	214	0	0,0	0,0	0	0,0	6,4
1	Spruce	39	32	22,1	1925	35,4	15,3	299	38	0,5	13,5	6	18,1	7,9
2	Spruce	44	37	24,4	1885	41,9	16,8	381	39	0,7	15,3	8	18,1	9,1
3	Spruce	49	42	26,6	1845	47,5	18,1	457	41	0,9	16,8	10	17,2	9,9
4	Spruce	54	47	28,4	1802	52,2	19,2	526	42	1,1	18,1	12	16,3	10,5
5	Spruce	59	52	30,1	1759	56,4	20,2	589	43	1,3	19,2	15	15,5	10,9
6	Spruce	64	57	31,6	1714	59,9	21,1	646	45	1,4	20,2	17	14,7	11,2
7	Spruce	69	62	32,9	1669	63,0	21,9	696	46	1,6	21,1	19	13,9	11,4
8	Spruce	74	67	34,0	1623	65,7	22,7	741	46	1,7	21,9	21	13,2	11,5
9	Spruce	79	72	35,0	1576	67,9	23,4	781	47	1,9	22,7	23	12,6	11,6
10	Spruce	84	77	35,9	1529	69,8	24,1	816	47	2,0	23,4	25	12,0	11,6
11	Spruce	89	82	36,7	1483	71,4	24,8	847	46	2,1	24,1	27	11,4	11,6
12	Spruce	94	87	37,4	1437	72,8	25,4	873	46	2,2	24,8	28	10,9	11,6
13	Spruce	99	92	38,0	1391	73,8	26,0	896	45	2,3	25,4	29	10,4	11,5
14	Spruce	104	97	38,6	1347	74,7	26,6	916	45	2,4	26,0	30	10,0	11,5
15	Spruce	97	97	0,0	0	0,0	0,0	0	1347	74,7	26,6	916	10,0	12,2