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Effect of Breeding on Income at First Commercial Thinning in Silver Birch Plantations

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Abstract: The economic importance of fast-growing tree species like silver birch (*Betula pendula* Roth.) is increasing due to growing demand for timber. Tree breeding provides the opportunity to increase the timber supply and thus ensure the most efficient use of forest land. Application of the results of a breeding program—the planting of young stands—is costly, and information on (potential) early income for the landowner from this investment is scarce. Therefore, the aim of this study was to characterize the gain from the use of improved silver birch material at the first commercial thinning. Material was collected from an open-pollinated progeny trial of 524 silver birch plus-trees at the age of 14 years in the central part of Latvia. Incomes from the first thinning were calculated at low and high timber prices. Heritability of growth traits (assessed as diameter at breast height) and timber value at first thinning were similar. Both timber market fluctuations and genetics had a notable impact on economic outcome: the internal rate of return for the selected best-performing families was 9.4% and 8.3% in the case of high and low timber prices, respectively; on average, for all families in the trial the figures were 8.1% and 6.7%, respectively. Results indicate profitability for investments in planting of improved regeneration material, even at a young age, in hemiboreal forests.

Keywords: *Betula pendula*; genetic gain; revenue; forest regeneration

1. Introduction

The economic importance of fast-growing pioneer tree species is increasing due to the growing demand for timber both for solid wood products and chemical processing [1,2]. Silver birch (*Betula pendula* Roth), with its high productivity on agricultural land, is suitable for such purposes and less affected by biotic factors (browsing, insect and fungus damages) than conifers [3]. Therefore, it has been included in tree breeding programs to select the most productive genotypes [4]. However, tree-breeding programs are costly; therefore, the assessment of practical economic gain is essential [5]. Moreover, silver birch usually has abundant natural regeneration and most clear-cuts of the species are regenerated this way, rather than by replanting [6]. Solid information on the economic gains realized from the rather high establishment costs of planting is needed to encourage this practice (and the use of germplasm from tree breeding). In northern Europe, the internal rate of return for improved Norway spruce was 5.3%, but for Scots pine from a third round of seed orchards was 7% [7,8]. Such rates were notably higher than in stands regenerated from unimproved material [9]. It demonstrates the economic gains possible for forest owners and the potential to reduce the rotation period, thus ensuring higher wood supply for processing [10,11]. However, the values were estimated (calculated) based on the genetic gain, not actual harvests, and did not include information on silver birch.

Improved birch ensures the opportunity to achieve tree dimensions suitable for sawlogs and plywood in a reduced period of time [3,12]. For example, use of improved Scots pine resulted in a 20-year shorter rotation cycle and a substantial financial benefit: an increase of net present value (at a 2% interest rate) by up to 32%–60% [13]. However, profitability from the use of improved material depends not only on the predicted income but also a reduction of expenses such as establishment and management costs, e.g., less tending necessary [8]. Furthermore, improved material might be more resistant to several environmental factors, which reduces risks [14]. The gain from improved material can be achieved even at a young age [2], but economic evaluations of effect on income from early thinning are still quite rare [14]. The aim of the study is to characterize the gain from improved silver birch material from the first commercial thinning at the age of 14 years.

2. Materials and Methods

2.1. Trial and Measurements

The studied trial of silver birch was located in the central part of Latvia (56°44′ N, 24°49″ E). The elevation was ca. 220 and 75 m a.s.l., and the topography was flat. The mean annual temperature was 6.4 °C; the mean monthly temperature ranged from −4.4 °C in February to +17.4 °C in July. The mean annual precipitation was ca. 630 mm.

The trial was established in 1999 on former agricultural land, corresponding to the *Oxalidosa* forest type with mesotrophic, dry, silty soil. It consisted of open-pollinated (half-sib) families of plus-trees of silver birch, selected across the whole territory of Latvia (55°40′–58°05′ N, 20°58′–28°14′ E). One-year-old containerized seedlings with an initial density of 2500 trees ha^{-1} (2 × 2 m) were planted. No management except weed control during the first year was done prior to thinning. The experimental design was complete randomized blocks. Each family was represented in one to five replications (32-tree blocks); only families represented in at least 3 replications (524 in total) were assessed. In 2014, at the age of 14 years, stem diameter at breast height (DBH) and tree height were measured for each living tree before the harvest and removed trees noted after the harvest. In total, 84% of the initially planted trees had survived until harvesting; each replication (block-plot) contained from 24 to 32 trees. The harvesting was performed by chain saws (motor-manual) to reduce damage to the remaining trees; timber was transported by a forwarder. Thinning from below was performed; basal area was reduced from 14.62 to 7.52 m^2 ha^{-1}.

2.2. Data Analysis

For each tree, stemwood volume was calculated according to the local model [15] as:

$$V = 0.909 \cdot 10^{-4} H^{0.717} DBH^{0.167 \lg(H) + 1.757} \quad (1)$$

where, H is height of the tree (in m) and DBH is stem diameter at breast height (in cm).

The assortment outcome from each harvested tree was calculated using the model developed by Ozoliņš [16] and modified by J. Donis (unpublished). The parameters used in the calculation for each assortment are shown in Table 1. To demonstrate the influence of market fluctuations on the income, low (in 2014) and high (2018) timber prices were used (Table 1).

Table 1. Assortment classes by diameter at the top end and monetary value with low and high timber prices.

Assortment	Length, m	Diameter at the Top End, cm	Price, EUR m^{-3}		Proportion of the Harvested Volume, %
			Low (in 2014)	High (in 2018)	
Sawlogs	3.0	12.0	47	56	1.3
Firewood	3.0	10.0	37	50	14.3
Pulpwood	3.0	6.0	35	54	59.3
Energy-wood	3.0	3.0	22.5	30	25.1

Genetic parameters were calculated using three largest (by DBH) trees per family and replication. To assess the heritability of the traits (DBH, stemwood value, and proportion of industrial timber), variance and covariance components (σ) were estimated using the mixed model analysis with the restricted maximum likelihood approach in SAS (Version 9, SAS Institute, Cary, NC, USA) [17] as follows:

$$y_{jkl} = \mu + B_j + F_k + BF_{jk} + \varepsilon_{jkl} \tag{2}$$

where y_{jkl} is the observation of the lth tree from the kth family in the jth replication; μ is the overall mean; B_j is the fixed effects of the jth replication; F_k is the random effect of the kth family, and BF_{jk} is a random interaction effect of the jth replication and the kth family, respectively; ε_{jkl} is the residual error.

Considering the randomized block design of the trial, heritability (h^2) was estimated as:

$$h^2 = \frac{4 \times \sigma^2{}_f}{\sigma^2{}_f + \sigma^2{}_{bf} + \sigma^2{}_e} \tag{3}$$

where $\sigma^2{}_f$, $\sigma^2{}_{bf}$, and $\sigma^2{}_e$ are the estimated variance components of the family, family × replication interaction, and the residual, respectively. Standard errors of h^2 were calculated using Dickerson's approximation [18].

The coefficient of additive genetic variation (CVa) describing the extent of genetic variability for the quantitative traits [19], was calculated as:

$$\mathrm{CV_a} = \sqrt{4}\hat{\sigma}^2_f \times \frac{100}{\overline{x}} \tag{4}$$

where $\overline{x}$ is the phenotypic mean and $\hat{\sigma}^2_f$ is the additive genetic variance.

Genetic gain (GG) was calculated using a 10% selection intensity (i) [19]. The net wood value (NWV), net present value (NPV) and internal rate of return (IRR) were calculated as the economic indicators for the harvested timber. To assess the economic effect of breeding, the indicators were calculated for the trial mean, as well as for the top and bottom 10% of the families, ranked by the GG of DBH.

For each tree, sawlog income was calculated as:

$$I = \frac{\left(1.013 \times 0.958 + (-0.112) \times DBH^{0.203}\right)}{(0.958 + DBH^{0.203})} \tag{5}$$

where DBH is the stem diameter at the breast height (cm).

To calculate NWV, the following equation was used:

$$NWV = \mathrm{I}_{income} - \mathrm{H}_{costs} \tag{6}$$

where $\mathrm{I_{income}}$ is income from harvesting and $\mathrm{H_{costs}}$ is the harvesting costs (Central Statistical Bureau of Latvia).

Income and costs were included in the analysis by calculating NPV, which was calculated as the discounted value of the future expected net cash flow.

$$NPV = \frac{(NWV - E_{costs})}{(1 + r)^n} \tag{7}$$

where $\mathrm{E_{costs}}$ is the establishment costs (low and high prices), r is the discount rate (3% and 5%), and n is the number of years (14). The establishment costs were acquired from the Central Statistical Bureau of Latvia.

To estimate the profitability of the potential investment, the IRR was calculated using the following equation:

$$IRR = r_a + \frac{NPV_a}{NPV_a - NPV_b}(r_b - r_a) \quad (8)$$

where r_a is the lower discount rate (3%); r_b is the higher discount rate (5%); NPV_a is NPV at r_a; and NPV_b is NPV at r_b discount rate.

3. Results

3.1. Heritability of Traits

The mean DBH and tree height (± confidence interval) in the silver birch trial at the age of 14 years was 9.1 ± 0.2 cm and 13.4 ± 0.2 m, respectively; standing volume (yield) was 91 ± 1.9 m^3 ha^{-1}. Heritability for timber value and for the usual trait of selection (DBH) was very similar. However, the proportion of industrial timber (sawlogs and pulpwood) was less heritable. The coefficients of additive genetic variation (CV_a) ranged from 3.7% to 22.7% for the proportion of industrial timber and timber value, respectively (Table 2). Genetic gain values had a similar trend as the CVa. There were negligible differences in genetic gain from direct selection or selection by DBH.

Table 2. Coefficients of heritability (h^2), genetic variation (CV_a) and genetic gain (GG) of progenies of plus-trees of silver birch plantation at the age of 14 years.

Trait	Heritability Coefficients h^2 ± Standard Errors	Coefficients of Additive Genetic Variation CV_a, %	Genetic Gain GG_10% direct	Genetic Gain GG_10% DBH
DBH	0.49 ± 0.08	8.4	8.9	8.9
Proportion of industrial timber (sawlogs and pulpwood)	0.18 ± 0.07	3.7	1.7	1.6
Timber value (low prices)	0.49 ± 0.08	22.7	26.9	26.3
Timber value (high prices)	0.50 ± 0.075	20.0	22.9	22.5

3.2. Monetary Value of the Selected Trees

For the trees subjected to thinning, the DBH and height were 8.0±0.3 cm and 13.0 ± 0.4 m, respectively. The remaining trees had a mean DBH of 10.0 ± 0.3 cm and height of 10.0 ± 0.4 m (Figure 1). The volume of harvested industrial timber on average was 28.0 ± 0.8 m^3 ha^{-1}.

Income from the thinning differed greatly with fluctuations of timber market: with low timber prices, it was 1275 ± 29 EUR ha^{-1} on average; with high, 1863±33 EUR ha^{-1} (Table 3). Similar differences were observed with NWV (Figure 1): the top-performing families reached 1424 ± 86 EUR ha^{-1} with high timber prices, and 616 ± 39 EUR ha^{-1} with low prices; corresponding mean figures in an open-pollinated plus-tree progeny trial were statistically significantly lower: 1030 ± 25 EUR ha^{-1} and 426±11 EUR ha^{-1}, respectively. Selected (best performing) families had NPVs (with a 3% discount rate) from 370 to 741 EUR ha^{-1}. Moreover, for the best-performing families, NPVs at a high timber price and low discount rate were 50% higher compared with the trial mean; at a low timber price, the improvements were 35%. IRR for the worst-performing families reached 2.9% in an unfavorable timber market, and 4.5% in a favorable one. These figures were very different for best-performing families: 8.3% and 9.4%, respectively (Table 3).

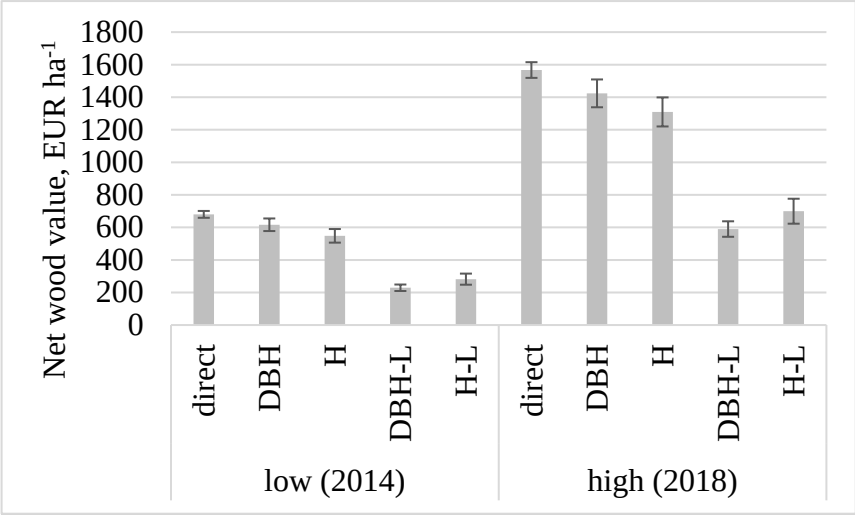

Figure 1. Net wood value of the thinning at the age of 14 years, based on low or high timber prices and selection of 10% best or worst (-L) families either directly (by value) or indirectly (by DBH or by height at the age of 10 years).

Table 3. The economic indicators of the selected trees of the silver birch trial at the first thinning at the age of 14 years.

Timber Price	Trial Mean				Top 10% Families			Bottom 10% Families		
	WV, EUR ha^{-1}	NPV		IRR, %	NPV		IRR, %	NPV		IRR, %
		3%	5%		3%	5%		3%	5%	
High (2018)	1863 ± 33	741	451	8.1	1484	1018	9.4	106	−33	4.5
Low (2014)	1275 ± 29	370	171	6.7	780	484	8.3	−7	−117	2.9

WV—total value of the harvested timber.

4. Discussion

The estimated heritability (Table 2) implies a high potential for improvement of DBH and timber value [20] by breeding. The estimated heritability was higher than observed for birch in Norway (0.23; [21]) and in Sweden (0.32; [2]). The increased values of higher genetic gain might be related to diverse population structures of birch in Latvia [22], which is a result of the post-glacial recolonization of vegetation in northern Europe. Accordingly, a higher genetic diversity allowed obtaining a broader spectrum of phenotypes, hence the intensive selection of the material was efficient [23]. The CV_a for DBH was relatively low, which might be explained by the effect of stand competition [2,3,24], but the higher coefficients for the timber value might be explained by the cumulative effect of DBH and tree height. Nevertheless, the estimated genetic gain from the 10% top-performing families was similar to other studies. For instance, Stener and Jansson [2] and Hagqvist and Hahl [25] found 18% and 11% gains for DBH when first-generation seeds were compared with ordinary seed material at the age of 7 to 12 years. Such genetic gains from improved material supports the reliability of genotypic selection and the effect of breeding [3].

The calculated sales value of the timber from the trial roughly corresponded to the actual value (obtained from the forest owner, pers. com.). NPV was positive for the mean and the top-performing families at the age of 14 years. This could, at least in part, be attributed to low establishment costs: good quality planting material ensured a need for only one tending. Compared to conventional stands of Scots pine in Sweden [12], the estimated NPV of the top-performing families of silver birch at the age of 14 was high: 2305 and 1488 EUR ha^{-1}, with high and low timber prices, respectively. It indicates high potential for the application of improved reproductive material of birch in commercial forestry

with the possibility of early return on investments. Simonsen et al. [26] and Jansson et al. [7] indicates that genetically improved material significantly increases tree growth with lower investment costs. However, Jansson et al. [7] indicated that, with 5.3% IRR, the income is still low due to increasing establishment and harvesting costs, which might not be met by the improved growth rates.

In Latvia, the establishment and management costs would not increase as fast as in Sweden, due to the parity of the costs. Estimated IRR for the mean and top-performing families resulted in good profitability even when timber price is low; the values ranged from 6.7% to 8.3%, thus exceeding those of naturally regenerating stands [7]. These values might be lower if lower planting density is used, due to smaller harvested volume. Similarly, the value would be reduced with an even earlier thinning, aiming to improve the growth of the remaining birch. Thus, additional calculations using growth models would be useful to optimize the planting density. The main value of this study is to demonstrate the practical gain obtained from an actual, large (23.1 ha) thinning area at an early age, and the actual value added by the tree breeding.

5. Conclusions

Breeding ensures substantial income for the landowner at the age of first commercial thinning. Net wood value (timber value minus harvesting costs) of the top-performing families was significantly higher than the mean in the trial in any of the assessed timber market condition. Investment in regeneration with improved planting stock can ensure a positive net present value (at a 3% interest rate) already at the age of 14 years in hemiboreal conditions.

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Conflicts of Interest: The authors declare no conflict of interest.

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