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Preliminary results from simultaneous planting of *Fagus sylvatica* and pioneer species on calamity clearings

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Abstract: We compared the biological and economic effects of simultaneous artificial regeneration of mixtures of pioneers (birch – *Betula pendula* Roth or aspen – *Populus tremula* L.) and beech (*Fagus sylvatica* L.) with plots of monospecific beech. During the period of two years, the height of young beech trees, their mortality, and the regeneration cost were analysed in the following treatments: monospecific beech (9 000 pcs·ha^{-1}), monospecific beech (5 000 pcs·ha^{-1}), beech/birch (5 000/2 500 pcs·ha^{-1}) and beech/aspen (5 000/2 500 pcs·ha^{-1}). Four plots (differing in soil and altitude) were established in the region of the Czech Republic in autumn 2021. The positive biological effect of these pioneers was detected only in the treatments where the initial planting stock of the pioneers was substantially higher than in that of beech (on average 39 cm *vs.* 100 cm, respectively). However, the expenses of simultaneous regeneration were about 15% lower compared to plots with monospecific beech in densities like 9 000 pcs·ha^{-1}, and around 35% higher than in the monospecific beech plots with a density of 5 000 pcs·ha^{-1}.

Keywords: early growth; European aspen; nurse crop; regeneration cost; silver birch

European beech (*Fagus sylvatica* L.) is a dominant tree species in the potential vegetation of Central Europe (Ellenberg 2009; Wagner et al. 2010). Currently, the percentage share of this species in its natural habitat is lower, compared with its natural composition. For example, in the Czech Republic, the potential composition of this species is around 40% and, at present, it is only 9.6% (MoA 2023). This is because of long-term utilisation of beech wood during the Middle Ages and the silviculture of short-term, economically interesting coniferous species, mainly Norway spruce [*Picea abies* (L.) Karst.] from the end of the Middle Ages to the present (Fanta 1997; Klimo et al. 2000; Hansen, Spiecker 2005).

Silviculture of Norway spruce, in areas where beech occurs naturally as a dominant species, is linked with low forest stability and often with disturbance events, too. Disturbances in Norway spruce stands often lead to large clearings where

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reforestation is necessary (Hlásny, Sitková 2010; Souček et al. 2016; Tiebel et al. 2016; MoA 2023). Presently, due to the climatic change and reflecting the closer-to-nature forestry movement, the process of reforestation is connected with forest conversion of the composition of species and wider use of natural processes (Pommerening, Murphy 2004; Kulla, Sitková 2012; Martiník et al. 2014;). More drought-tolerant species are recommended for the reforestation of the clearings after Norway spruce, such as oak (*Quercus* spp.), lime (*Tilia* spp.) and also beech (Hlásny et al. 2011; Stark et al. 2015; FORRISK 2022; European Commission 2023). On the other hand, beech, as a typical shade-tolerant species, grows better under shelter (Wagner et al. 2010; Bednář et al. 2012; Podrázský et al. 2019). In clearings, beech grows slowly, is damaged by frost and rodents, and the quality of these stands is low (Ningre, Colin 2007; Bednář et al. 2012; Martiník et al. 2014). In order to cultivate beech or other sensitive species on clearings, nurse-crop regeneration methods are used, where the fast-growing pioneer tree species are cultivated in the same plots, before or at the same time as the target (sensitive, shade tolerant) species (Zakopal 1955; Pommerening, Murphy 2004; Stark et al. 2015).

In the case of underplanting of beech within a pioneer (preparatory) birch stand, Polách and Špulák (2022) recommended a decrease in the canopy closure from ten (i.e. full) down to seven. This degree of canopy closure balances a sufficient cover (to protect young beech seedlings from frost damage) and growth depression (that occurred in dense birch stands). We did not find scientific results that deal with the effects of simultaneous planting of beech with pioneer species in clearings. On the other hand, these results are for another shade-tolerant species – silver fir (*Abies alba* Mill.) (Martiník et al. 2018). These authors found positive effects of pioneer species (birch and aspen) on the height growth of silver fir that were planted in rows, together with these species, but only on a site with a normal water regime. On water-logged sites, the authors recommend a few-year delay in fir regeneration, i.e. underplanting (Martiník et al. 2018). Pioneer species tolerate extreme environment conditions of large clearings; they grow very fast when young, and their utilisation in clearings leads to reduced regeneration cost (Brzeziecki, Kienast 1994; Šafránek et al. 2018; Dubois et al. 2020).

In this paper, we focus on the effect of pioneer species on the success of the regeneration of beech that was planted in row spacing. We hypothesise that row planting of beeches and pioneer species increases the survival rate and yearly height growth of beech trees, and further reduces regeneration costs. The main goal of this work is to evaluate the ecological and economic effects of simultaneous regeneration of European beech and pioneers [silver birch (*Betula pendula* Roth) and European aspen (*Populus tremula* L.)] at different sites. The ecological effect means lower mortality and better early growth of planted beech; the economic effect means a reduction in regeneration costs.

MATERIAL AND METHODS

Experimental stands. For this experiment, we selected four sites in the eastern part of the Czech Republic (Table 1), differing in altitudes (middle and higher) and in soil richness (rich and acidic). On all sites, the experiment was established in large clearings (i.e. more than 1 ha in size) in autumn 2021. All clearings emerged after the dieback of Norway spruce stands in 2020–2021. The treatments were the same for all sites (Table 2):

- beech monoculture with a density of 9 000 pcs·ha^{-1} (spacing 1.1 m × 1 m);
- beech monoculture with a density of 5 000 pcs·ha^{-1} (spacing 2 m × 1 m);
- beech and birch – beech with a density of 5 000 pcs·ha^{-1} (spacing 2 m × 1 m), birch with 2 500 pcs·ha^{-1} (spacing 2 m × 2 m);
- beech and aspen – beech with a density of 5 000 pcs·ha^{-1} (spacing 2 m × 1 m), aspen with 2 500 pcs·ha^{-1} (spacing 2 m × 2 m).

The size of treatments varies from 0.1 ha to 0.2 ha.

Data collection. The heights of all originally planted trees were measured at the end of the 2022 and 2023 vegetation seasons. The mortality was calculated at the end of the 2023 vegetation season as the percentage of the trees that survived from the total originally planted. The input data for the calculation of silvicultural operations was downloaded from the comprehensive forestry and economic information system of the entity. The basis for modelling the costs of each permanent sample plot (TVP) was real economic data. Complete cost entries were available for the individual outputs and sub-outputs that were realised in the

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Table 1. Site conditions of experimental plots

Experimental plot/ GPS	Natural forest region*	Target management set*	Forest type group (Viewegh et al. 2003)	Slope	
				inclination (%)	exposure
Rejvíz 50°11'32"N, 17°19'58"E	27 – Hrubý Jeseník	53 – acidic soil at higher altitudes	5K – *Abieto-Fagetum acidophillum*	20	NNE
Supíkovice 50°17'38"N, 17°13'40"E	28 – Hrubý Jeseník foothills	43 – acidic soil at middle altitudes	4K – *Fagetum acidophillum*	20	N
Rajnochovice 49°23'49"N, 17°48'48"E	41 – Hostýnskovsetínské Hills and Javorníky Mts.	45 – rich soil at middle altitudes	4B – *Fagetum mesotrophicum*	40	NE
Chvalčov 49°22'45"N, 17°45'26"E	41 – Hostýnskovsetínské Hills and Javorníky Mts.	55 – rich soil at higher altitudes	5B – *Abieto-Fagetum mesotrophicum*	30	NW

*According to Czech Decree No. 298/2018 on the preparation of regional forest development plans and on the definition of forest management units

reference period. They were divided into the costs of reforestation and subsequent protection.

Data analysis. All datasets were tested by the Shapiro-Wilk test of normality, but most of them did not have a normal distribution. Due to this, the nonparametric one-way ANOVA (analysis of variance – Kruskal-Wallis test), with a combination of the nonparametric post-hoc test of multiple comparisons, was used for a comparison of the mean values of selected variables between three (or

Table 2. Experimental design

Experimental plot	Target management set	Tree species and design	Planting densities (thousand pcs·ha^{-1})	Designation	Planting stock height (cm)	Mortality (%)
Rejvíz	53 – acidic soil at higher altitudes	beech	9	53B9	26–50	20
		beech	5	53B5	26–50	–
		beech/birch	5/2.5	53BB5	26–50/36–50	34/11
		beech/aspen	5/2.5	53BT5	26–50/36–50	40/20
Supíkovice	43 – acidic soil at middle altitudes	beech	9	43B9	26–50	34
		beech	5	43B5	26–50	4
		beech/birch	5/2.5	43BB5	26–50/81–120	8/3
		beech/aspen	5/2.5	43BT5	26–50/81–120	8/22
Rajnochovice	45 – rich soil at middle altitudes	beech	9	45B9	51–70	42
		beech	5	45B5	51–70	40
		beech/birch	5/2.5	45BB5	51–70	38/0
		beech/aspen	5/2.5	45BT5	51–70	41/3
Chvalčov	55 – rich soil at higher altitudes	beech	9	55B9	15–25	25
		beech	5	55B5	15–25	–
		beech/birch	5/2.5	55BB5	15–25/51–70	42/4
		beech/aspen	5/2.5	55BT5	15–25/26–50	51/19

53, 43, 45, 55 – target management sets; B9 – monospecific beech stand with a density of 9 000 per ha; B5 – monospecific beech stand with a density of 5 000 per ha; BB5 – mixed stand of beech and birch with a density of 5 000 beech saplings per ha; BT5 – mixed stand of beech and aspen with a density of 5 000 beech saplings per ha

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four) treatments (i.e. the number of beech saplings in a monospecific and mixed forest stand). The sapling heights in 2022 (H_{22}) and 2023 (H_{23}) and the height increment of the saplings between the years 2022 and 2023 (I_h) were selected as dependent variables. Since the datasets did not have a normal distribution, we used the median as a characteristic of the mean value (instead of the average). These analyses were repeated for all four target management sets. All statistical analyses were evaluated at the significance level alpha = 0.05 using STATISTICA software (Version 13.4.0.14, 2018).

Regeneration costs per 1 ha between treatments (for all four sites together) were compared using boxplots. The structure of regeneration costs, among treatments and sites, was also compared graphically.

We compared the differences in the heights of pioneer species (birch, aspen) and beech (using a graph of median, minimum and maximum values) two years after simultaneous (row spacing) artificial regeneration for all four tested sites.

RESULTS

Regarding all sites, beech mortality in monospecific plots ranged from 20% (Rejvíz) to 42% (Rajnochovice); in mixtures with pioneers from 8% (Supíkovice) to 51% (Chvalčov). The positive effect of pioneers on beech mortality was detected in acidic soil of middle altitudes (Supíkovice), where the beech mortality in the monospecific plot reached 37% and in the mixture only 8%. Only in this plot, the planting stock of pioneers was higher than 80 cm (Table 2). The height of beech planting stock was lower than in the pioneers, but there was a similar difference in the height of planting stock also in the Chvalčov plot that represents rich soil of middle altitudes. In rich soil, strong competition of weeds can be considered a limiting factor of successful beech regeneration and can overgrow the effect of the nurse crop (see Tables 2 and 3).

Kruskal-Wallis ANOVA showed that the mean values of all tested variables (H_{22}, H_{23}, I_h) are the same in all treatments of the target management sets 53 and 55 (Tables 3 and 4).

The mean values of H_{22}, H_{23}, and I_h were significantly different among the tested treatments at the target management set 43 (Table 3). The mean height of the saplings in 2022 in treatment B9 was the smallest, and the mean sapling height in treatment B5 was significantly higher. The mean sapling heights in treatment BB5 and BT5 were the same but were statistically significantly higher than those in treatments B9 and B5 (Table 4). Although the mean sapling height in 2023 was the highest in treatment BB5 and significantly higher than in treatments B9 and B5, and the same as in treatment BT5 (Table 4), the sapling height increment in treatment B9 was significantly higher than that in all other treatments (Table 4).

In the target management set 45, the mean values were statistically different between treatments only in sapling height in 2022 and 2023 (Table 3). The mean values of sapling height increment were the same. In 2022, there was only one statistical difference in the heights between the treatments. The mean sapling height in treatment B9 was higher than that in treatment BB5. The same results were found for sapling heights in 2023 (Table 4).

Regarding site and treatment, the total regeneration cost during the first two years ranged from 4 900 EUR to 8 900 EUR per ha. The lowest cost was found for B5 treatment – around 5 500 EUR per ha; the mixture of pioneers and beech reached around 7 000 EUR per ha and the cost for monospecific beech plots (B9) ranged from 8 000 EUR to 8 500 EUR per ha (Figure 1). About 50% of the total cost accounted for planting stock and the planting process, the rest of the cost comprises early care for regeneration (Figure 2). This is vari-

Table 3. Results of Kruskal-Wallis ANOVA for heights and increment of saplings between different treatments

TMS	Variable	*H*	*P*-value
53	H_{22}	0.8336	0.6592
	H_{23}	0.4585	0.7951
	I_h	2.0247	0.3634
43	H_{22}	75.9598	< 0.0001
	H_{23}	16.5333	0.0009
	I_h	14.9844	0.0018
45	H_{22}	13.0299	0.0046
	H_{23}	10.3114	0.0161
	I_h	2.5719	0.4624
55	H_{22}	0.9076	0.6352
	H_{23}	3.3313	0.1891
	I_h	2.7399	0.2541

ANOVA – analysis of variance; TMS – target management set; *H* – *H* value of Kruskal-Wallis ANOVA; H_{22} – sapling height in 2022; H_{23} – sapling height in 2023; I_h – height increment of saplings in the period 2022–2023

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Table 4. Mean values (median value in cm) of sapling height and increment in different treatments

TMS	Variable (cm)	B9	B5	BB5	BT5
53	H_{22}	22.5[a]	–	25.0[a]	24.0[a]
	H_{23}	29.0[a]	–	30.0[a]	31.0[a]
	I_h	8.5[a]	–	5.0[a]	6.0[a]
43	H_{22}	23.0[a]	30.0[b]	39.5[c]	38.0[c]
	H_{23}	43.0[a]	45.0[a]	53.5[bc]	50.0[ac]
	I_h	22.0[a]	15.0[b]	14.0[b]	15.0[b]
45	H_{22}	58.0[a]	49.5[ab]	40.0[b]	50.0[ab]
	H_{23}	60.0[a]	57.0[ab]	49.0[b]	57.0[ab]
	I_h	6.0[a]	7.5[a]	7.0[a]	8.0[a]
55	H_{22}	20.0[a]	–	20.0[a]	21.0[a]
	H_{23}	28.0[a]	–	23.0[a]	24.0[a]
	I_h	6.0[a]	–	9.0[a]	3.0[a]

[a–c] Groups of treatments with statistically insignificant (*P*-value > 0.05) differences between mean values; TMS – target management set; H_{22} – sapling height in 2022; H_{23} – sapling height in 2023; I_h – height increment of saplings in the period 2022–2023; B9 – monospecific beech stand with a density of 9 000 per ha; B5 – monospecific beech stand with a density of 5 000 per ha; BB5 – mixed stand of beech and birch with a density of 5 000 beech saplings per ha; BT5 – mixed stand of beech and aspen with a density of 5 000 beech saplings per ha

able, depending on the site and management treatments, and the success of regeneration depends on the quality of the planting stock, weather and quality of work.

From the comparison of plantings height of pioneer species and beech two years after regeneration, we found that the heights of pioneers were higher than those of young beeches (Figure 3).

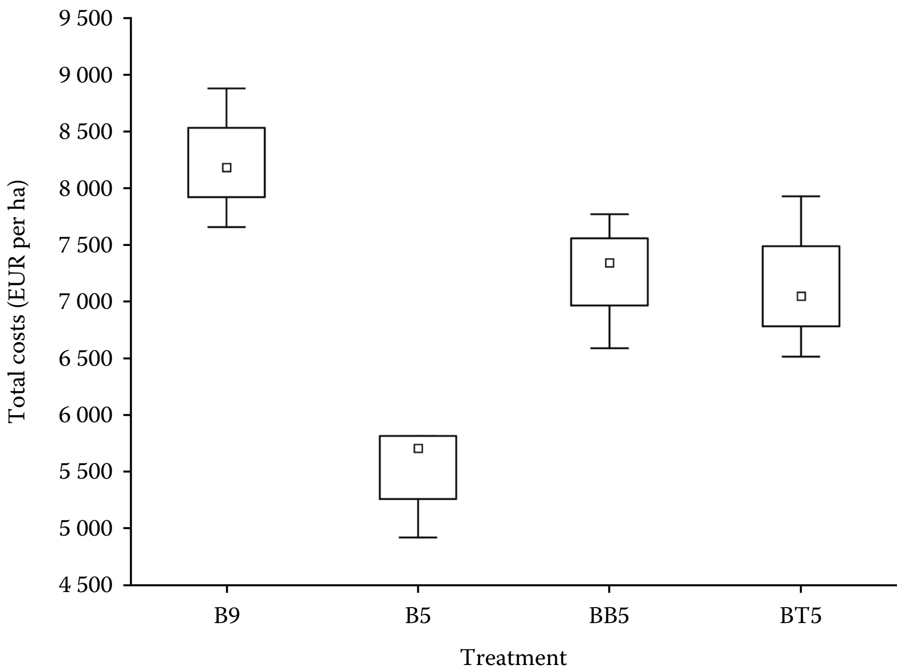

Figure 1. Variability (defined by boxplots) in regeneration costs (EUR per ha) of analysed treatments

B9 – monospecific beech stand with a density of 9 000 per ha; B5 – monospecific beech stand with a density of 5 000 per ha; BB5 – mixed stand of beech and birch with a density of 5 000 beech saplings per ha; BT5 – mixed stand of beech and aspen with a density of 5 000 beech saplings per ha

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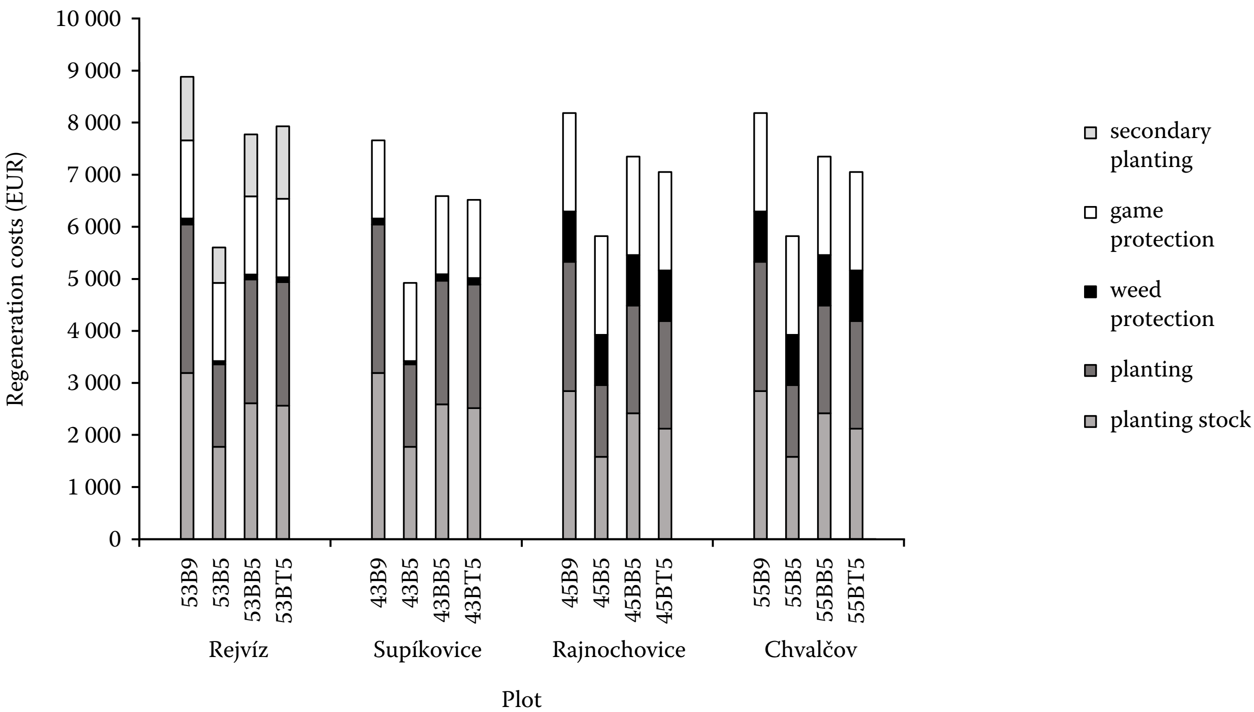

Figure 2. Structure of regeneration costs for analysed plots and treatments

53, 43, 45, 55 – target management sets; B9 – monospecific beech stand with a density of 9 000 per ha; B5 – monospecific beech stand with a density of 5 000 per ha; BB5 – mixed stand of beech and birch with a density of 5 000 beech saplings per ha; BT5 – mixed stand of beech and aspen with a density of 5 000 beech saplings per ha

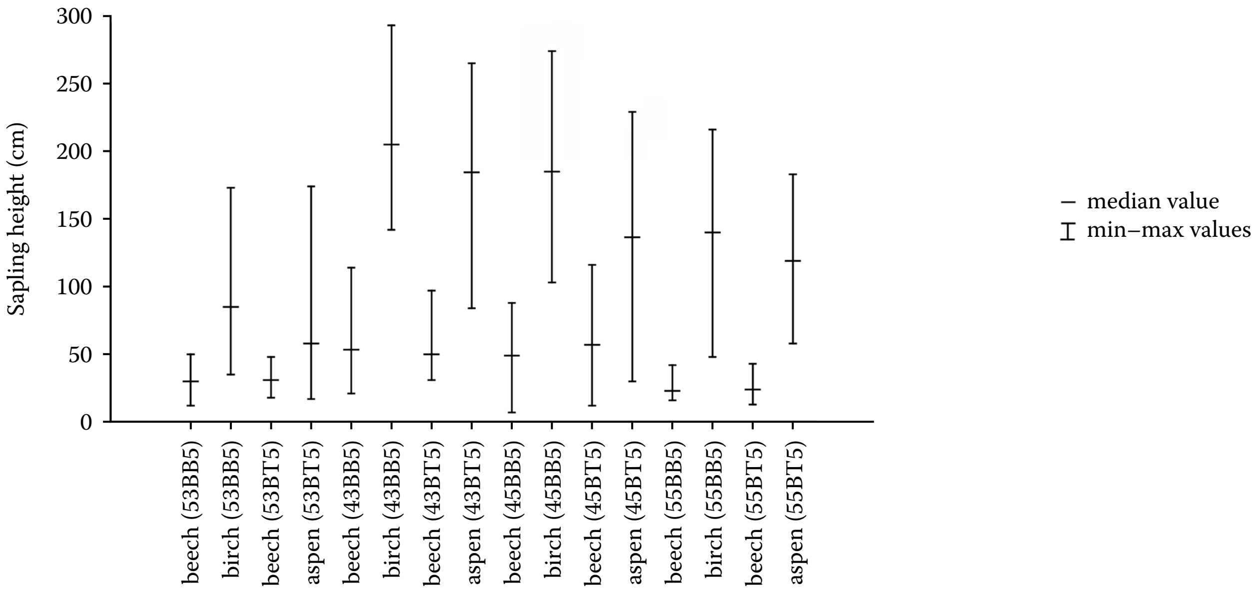

Figure 3. The differences in the heights of pioneers (birch, aspen) and beech young trees two years after simultaneous (row spacing) artificial regeneration at different sites

53, 43, 45, 55 – target management sets; B9 – monospecific beech stand with a density of 9 000 per ha; B5 – monospecific beech stand with a density of 5 000 per ha; BB5 – mixed stand of beech and birch with a density of 5 000 beech saplings per ha; BT5 – mixed stand of beech and aspen with a density of 5 000 beech saplings per ha

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DISCUSSION

The importance of silvicultural research increases with the duration of the experiment. Short-term silvicultural experiments are important only in specific cases (e.g. germination process evaluation, nursery practice). Contrariwise, the advantage of short-term experimentation is its immediate transfer to practice. In the case of reforestation of large clearings, fast data (related to the success of the regeneration method) are needed. In 2022, 67 700 ha of clearings were detected in the Czech Republic, mainly because of salvage cutting (MoA 2023).

To improve the success of reforestation of beech, as a shade tolerant and late succession species, the nurse crop method is advisable (Pommerening, Murphy 2004; Podrázský et al. 2019; Polách, Špulák 2022). Successful underplanting of beech in spruce or pioneer stands is documented in many papers, whereas no results of simultaneous regeneration of this species with pioneers are available in scientific literature. In this kind of experiment, the high density of seedlings used to establish monospecific beech stands is replaced by a mixture with pioneers – they grow fast when young and the planting density should be low (Cameron 1996; Hynynen et al. 2010). This is the case of our experiment; the expected faster growth of birch and aspen will create shelter for slower-growing beech. Although the initial height of the planting stock was often similar for beech and pioneers, during two years, most pioneers overgrew young beeches (Table 2, Figure 3). A positive example of this method was documented for silver fir and pioneers (birch, aspen) growing in rich soil of middle altitudes (Martiník et al. 2018). In addition, light-demanding species, such as pedunculate oak (*Quercus robur* L.) can be cultivated with this regeneration method, as was published by Stark et al. (2015).

From the biological (ecological) point of view, the short-term results of our experiment do not fully support the working hypothesis that a mixture of pioneers leads to an increased survival rate and yearly growth of the planted beech. This presumption was confirmed only regarding the acidic soil of middle altitudes, where birch and aspen seedlings were 81–120 cm tall and beech only 26–50 cm. Thus, more experiments are necessary in different sites and with variable height of seedlings to support these results, but it seems that the early success of simultaneous regeneration is connected with the use of (significantly) higher planting stock of pioneers, compared to beech.

On the other hand, the results of this experiment confirm that the use of the simultaneous nurse regeneration method reduces regeneration costs, in comparison with monospecific beech plots. This reduction is connected mainly with the lower total number of trees per ha in the reforestation process. As was presented, pioneers do well on clearings; the use of pioneers after disturbances is an ecologically justified method of forest regeneration (in clearings) that provides economic profit (i.e. reduces regeneration costs) and this leads to the support of the forest economy (Zakopal 1955; Pommerening, Murphy 2004; Souček et al. 2016). In future, we expect better stem quality of beech planted with the pioneers (Podrázský et al. 2019; Polách, Špulák 2022); whereas beech in monospecific plots will suffer from frost and the stem quality will drop (Bednář et al. 2012; Tiebel et al. 2016; Polách, Špulák 2022). As was mentioned above, beech growing in clearings is sensitive to frost damage, and rodents can seriously destroy young beech trees (Ningre, Colin 2007; Gallo et al. 2017; Stloukalová 2021). Further, due to beech anatomy and growth morphology, the quality of monospecific beech in densities of 9 000 pcs·ha^{-1} will exceed that of beeches planted in densities of 5 000 pcs·ha^{-1} (Wagner et al. 2010; Bednář et al. 2012).

In this experiment, all treatments were fenced. Financial costs of this game protection (browsing) ranged from 17% to 34% of total regeneration costs (Figure 2). Following our experience and scientific knowledge (Tesař et al. 2011; Dubois et al. 2020; Fuchs et al. 2021), the browsing attractiveness is similar for beech and birch, depending on site and regeneration density. On the other hand, aspen seems to be more attractive and often strongly damaged by browsing (Myking et al. 2011). We considered the passive effect of simultaneous regeneration on game browsing. On the other hand, browsing is still a limiting factor of successful regeneration.

CONCLUSION

During two years of observation, a positive biological effect of simultaneous regeneration was found only in the treatment where the initial height of pioneer seedlings substantially exceeded that of beech and was growing in acidic soil at mid-

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dle altitudes. The use of tall planting stock of pioneers does not increase the regeneration costs of this method. On the other hand, the costs of the simultaneous regeneration method are about 15% lower, compared to those where a monoculture of beech is established.

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