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State of beech pole stands established at the clear-cut and in the underplanting

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Abstract: European beech (*Fagus sylvatica* L.) represents the major climax tree species in the forests of Central Europe growing at many sites. The reintroduction of this species is an important silvicultural topic because of stability and diversity of forest ecosystems and vitality of forest soils in this region. The present study documents the growth, quality of growth and vitality of beech plantations in two positions at the same site (580 m a.s.l., forest habitat type 5K8 – acid fir-beech site, soil type Cambisol): underplantings at 50% of the light intensity of open space and clear-cut. Plantations were established in 1994 by bare-root plants on the same day of April, at a 1 × 1 m spacing, the shelter at the underplanted locality was removed in 2010. In 2017, the plantations showed very different characteristics (underplanting/clear-cut position): density 5,900/3,750 trees·ha^{-1}, mean DBH 6.8/7.0, mean height 8.7/6.9 m, basal area 21.41/14.42 m^2·ha^{-1}. Underplanting was documented as a very proper way of beech reintroduction into the species composition of Czech forests. The reintroduction of beech at the newly originated clearcuts should be done with the use of ecological shelter of the mature stands.

Keywords: European beech; growth; stem quality; silviculture

European beech (*Fagus sylvatica* L.) represents the most common tree species in Central European forests, including the Czech Republic. It is estimated that in natural forests it covered slightly more than 40% of the forest area, from 3rd to 7th forest altitudinal zones (Kupka 1999). Its proportion was drastically lowered due to forest exploitation in the Middle Ages, while the forest lands were reforested mostly by Norway spruce (*Picea abies* [L.] Karst) and Scots pine (*Pinus silvestris* L.) in the 18th and 19th century later. The even-aged (class age) silviculture of monospecific stands (monocultures) was introduced and dominated the forestry in Central Europe for centuries, with many management and economic benefits, but with lower stability of these forests (Štefančík et al. 2018). During this process, the original sites occupied by broadleaved and mixed forests were converted into spruce (and pine) monocultures, in European conditions the share of broadleaves decreased from 2/3 to 1/3 only (Kenk, Guehne 2001; Löf et al. 2007), resulting in 6–7 mil. ha of spruce growing at non-native sites in Europe (Bednář, Černý 2014). In the last decades, reintroduction of beech has been supported as well as an increase in the share of broadleaved species in general to increase forest stability (Podrázský 2006; MZE 2017). This trend is similar also in the neighbouring countries, despite many problems connected with this approach (Malcolm et al. 2001). These topics were summarized in the Czech conditions by Bednář and Černý (2014).

Another stimulus of interest in beech reintroduction arose with the air-pollution disaster in Cen-

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tral Europe in the 1970's. Also in this case the main targets were diversity and stability of forests. Many projects were launched aiming at beech reproduction material, nursery planting stock production, tending of stands, regeneration and structure of beech stands and stands with considerable beech admixture (Peřina et al. 1984). The research basis was represented by a variety of research plots focused on provenance trials, plantation technologies, protection and prosperity of plantations on clear-cuts as well as in underplantings (Lokvenc, Vacek 1991; Balcar, Hynek 2000; Špulák et al. 2010). The forest tending research was focused on spatial structure, coenotic position, quality of production and radial increment (Novák et al. 2015; Remeš et al. 2015). In older stands, research was focused on the quantity and quality of beech production (Souček 2007), structure and biodiversity of beech stands (Vacek et al. 1996, 2014, 2015; Dobrovolný 2016), modelling of structural parameters in relation to forest management (Sharma et al. 2016, 2017), natural regeneration of beech stands (Vacek et al. 1999; Špulák 2008; Dobrovolný, Tesař 2010; Bílek et al. 2014) and damage caused by game to beech (Ambrož et al. 2015).

Beech is also considered as one of the main site improving and stabilizing species according to Czech legislation for forest regeneration (Novák et al. 2015). Its reintroduction and coniferous stand conversion can be assured through planting, direct seeding or natural regeneration of broadleaves following clear-cutting or planting under conifer shelterwoods (Lüpke, Hauskeller-Bullerjahn 2004).

European beech is documented as highly shade-tolerant species, which underlies its strong competitiveness in favourable conditions and determines dominance at sites convenient for this species. Many authors documented its shade tolerance and suitability for underplantings in European conditions, this was summarized e.g. by Bednář and Černý (2014).

The aim of the present study was to compare the status of European beech thicket established on a clear-cut and in shelter position from both the quantitative (*H* – mean height, DBH – dimeter at breast height, *G* – basal area) and qualitative (health status, stem form) point of view. The hypothesis was formulated that the growth and quality of beech stands established in the shelter are better compared to clear-cut localization.

MATERIAL AND METHODS

The research was conducted at the property of Lesy Kinský in the vicinity of the town of Žďár nad Sázavou in the Czech-Moravian Highlands (49°33'10.8''N, 15°54'07.2''E) in 1994. The altitude is around 580 m a.s.l., forest type is determined as 5K8 – acid fir-beech site, soil type as Cambisol. The plantations of beech were established in April 1994 as (a) plantation on the clear-cut Babín 1 (B1) plot, (b) plantation in the 50% canopy (total light intensity), i.e. as underplantings – Babín 2 (B2), spacing was 1 × 1 m in both cases. The light conditions were measured as total light intensity at the time of establishing at 20 places at regular spacing at each plantation site. The former stand was represented by the even-aged Norway spruce – Scots pine forest 114 years old at the experiment establishing.

The particular parcels had an area of 100 m^2; besides the shelter effects, the influence of the basic rock flours was tested – either 1 kg of finely pulverized limestone (Ca content 20.5%, Mg content 11.25%) or 2 kg of finely ground amphibolite per planting pit, mixed with the soil material just before planting. Each treatment was established in 3 replications. In the next years, the effects of microclimate on the mortality, growth and prosperity of both plantations were studied, and results were published (Podrázský 2006). The plots were re-evaluated in the spring 2017. Because the original subplots were not more to be differentiated, at each of the sites two randomly distributed plots of 100 m^2 in size were delimited, maximally eliminating the fertilization effects. The shading effect (shelter) was completely removed in 2010 and both sites are exposed only to side-shading from the south.

On the newly delimited plots, all trees were measured: height with a telescopic rod (to the nearest cm), DBH at two perpendicular directions with a standard calliper (to the nearest mm). The stem quality was assessed according to the 7-degree scale published by Poleno et al. (2009): upright current stem (1), not upright current stem (2), not current, not straight leading shoot (3), forked (4), multi-forked (5), multi-forked wolf tree (6), expanding wolf tree (7).

The damage was determined using a 5-degree scale: (1) no damage, (2) slight mechanical clearly visible damage, (3) medium-strong damage in-

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Table 1. Basic dendrometric parameters of compared variants of beech stands (spring 2017)

Site	Density (trees·ha^{-1})	DBH (cm)	*H* (m)	*G* (m^2·ha^{-1})
B1 clear-cut	3,750	7.0	6.9	14.42
B2 underplanting	5,900	6.8	8.7	21.41

B1 – Babín 1, B2 – Babín 2, DBH – diameter at breast height, *H* – height, *G* – basal area

fluencing the tree vitality, (4) strongly damaged, (5) deadly damaged.

Results were processed by the STATISTICA software (Version 12, 2013) for determination of significance of differences in total heights and diameters at BH (breast height) using the Wilcoxon test, and for the health status the χ^2 independence test was used. Stem quality classes represent simple arithmetic average of individuals in respective classes.

RESULTS

The basic characteristics of both stands are documented in Table 1. The higher mortality on the clear-cut, especially in the first years after planting, was reflected in lower density of the stand in the open area. The number of vital individuals was 3,750 trees·ha^{-1} only, compared to 5,900 trees·ha^{-1} of survivors in conditions registered in the shelter position. This represents the survival rate of 37.5% and 59.0%, respectively.

The mean DBH of both variants differed only slightly, differences were not significant. The differences can be easily ascribed to more space for individual trees in the clear-cut position. However, significant differences were determined in mean height, reaching 1.8 m. The beech individuals which were planted in the shelter position showed more intense height growth at the young stage.

A considerably higher number of individuals on the plot established in the underplanting position, accompanied by minimal differences in the mean DBH, resulted in much higher basal area on the Babín 2 plot. The plantations are just reaching coarse-wood dimensions, so determination of volume parameters is not relevant at this moment.

On the contrary, the slenderness quotient is lower in the stand established on the clear-cut, but the absolute values (0.99 and 1.28) do not represent any threat to the mechanical stability of neither beech stand.

The proportion of stem quality classes on particular research plots is documented in Fig. 1. The highest quality class 1 – upright current stem, was

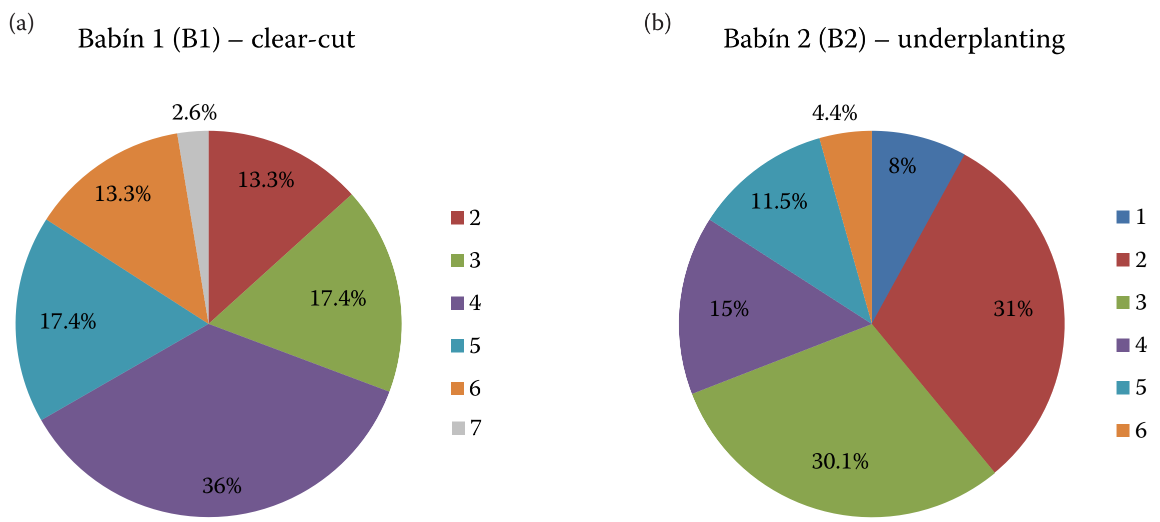

Fig. 1. Percentage of stem quality classes on the plots in 2017: Babín 1 (B1) (a), Babín 2 (B2) (b); (the scale by Poleno et al. 2009: 1 – upright current stem, 2 – not upright current stem, 3 – not current not straight leading shoot, 4 – forked, 5 – multi-forked, 6 – multi-forked wolf tree, 7 – expanding wolf tree)

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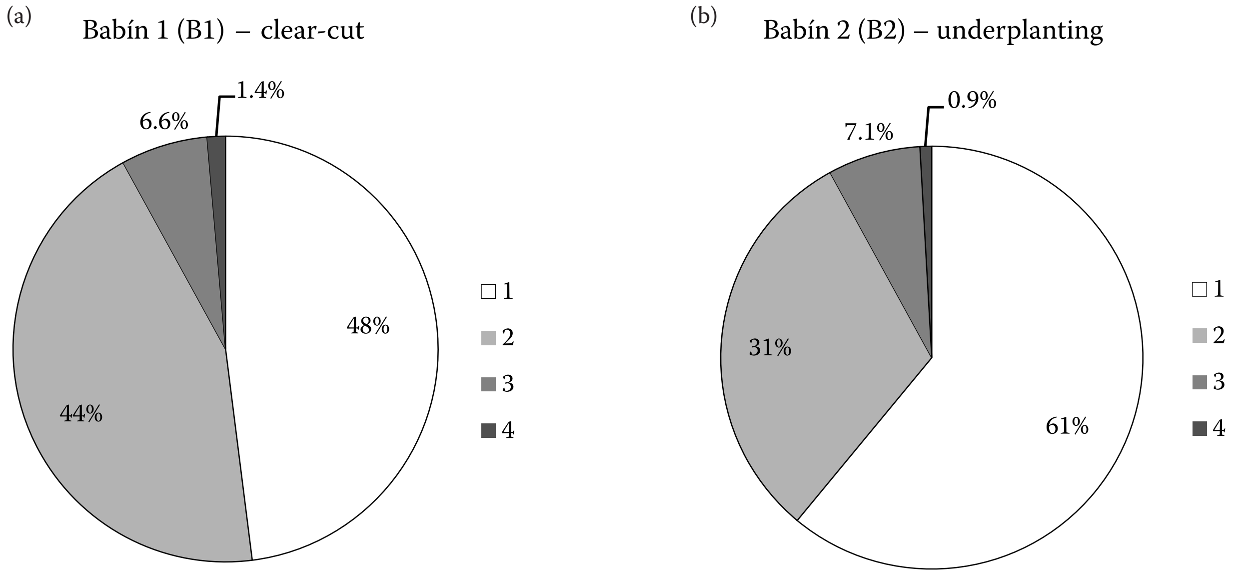

Fig. 2. Comparison of damage frequency in the plots: Babín 1 (a), Babín 2 (b); (the scale: 1 – no damage, 2 – slight mechanical clearly visible damage, 3 – medium-strong damage influencing the tree vitality, 4 – strongly damaged, 5 – deadly damaged)

not registered in the clear-cut position at all. Also the proportion of class 2 was negligible, prevailing were classes 3, 5 and 6.

In the underplanting position, the prevailing stem quality classes were 2 and 3, with 2.6% of individuals belonging to class 1. On average, the mean stem quality class was 3.1 in the underplanting variant and 4.1 in the clear-cut variant. The differences in stem quality were highly significant between variants (chi-squared = 31.039, df = 6, p-value = 2.492e-05).

Comparison of damage frequency in both variants revealed lower damage in the variant planted under the canopy shelter (Fig. 2). This supports the protecting role of the shelter position. The proportion of individuals without damage was 61% in the underplanting variant vs. 48% in the variant planted on the clear-cut.

Summarizing the results, the underplanting position ensures lower mortality, better height growth, larger basal area of the young pole stand, better stem quality and lower proportion of damaged trees.

DISCUSSION

The present study documents the continuation of research activities on these research plots, while their results were published earlier (Podrázský 1997, 2006). Differences of similar character were documented since the early stages of the development of both plantations. The cumulative mortality was 45% in the control variant and 55 and 38% in the fertilized ones, all in the clear-cut position. In the period 1994–1998 the frost damage varied between 25 and 40% among variants, being always lower in the amphibolite treatment. Also dead terminal shoots between 22 and 39% were observed on the clear-cut in 1994, promoting the forking in the next years. Damage and mortality in the shelter position were negligible (1–2%) in those years.

The total heights were 161, 129 and 228 cm on the clear-cut in 2003 (control, limestone and amphibolite variant), the respective values in the shelter position were 362, 501 and 408 cm, so 1.0–1.7 m higher. These differences have remained to the present time, since the removal of shading trees in 2010. It can be concluded that in the first years the mortality was negligible and the height growth was faster in the case of underplantings, representing much more favourable conditions in the shelter position at given sites (forest habitat group 5K).

Bednář and Černý (2014) analysed a similar experiment on the same property, but at higher altitudes (5th to 6th altitudinal zone). They compared the clear-cut, gap and shelter position of beech plantation aged 7 to 18 years. They concluded that between 7 and 18 years of age (1) DBH and total

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height of individuals increased with the light input in the order: shelterwood (Indirect Site Factor – ISF 28%), gaps (ISF 50%) and clear-cut (ISF more than 90%), (2) at the age of 18 years the differences showed the same trend without significant differences between clear-cut and gaps (DBH and total height followed the light input up to the value of 60%, (3) the best quality of individuals was documented for those growing in the shelter position, the lowest for the clear-cut.

It has to be emphasized that in this case the light conditions were similar to the shelter position documented in our case. Better growth of young beech seedlings was documented also by Larcher (1988) for light intensity 50%. Bednář et al. (2012) described also the best growth of beech plantation at smaller regeneration areas – gaps and small clear-cuts up to 0.3 ha.

Foreign sources also document an increase of total height increment up to the light intensity of 60% and only a minimum increase afterwards (Petritan et al. 2007). Löf et al. (2007) described similar height growth in sparse shelterwood and gaps and Kunstler et al. (2005) as well as Petritan et al. (2007, 2009) summarized that the best light conditions for beech underplantings are represented by ISF intensity of 30–40%. For light conditions approaching 50% ISF the best height growth was also reported by Rumpf and Petersen (2008).

Bednář and Černý (2014) found similar differences as for DBH and height. In our case, this trend was disrupted by high mortality of beech individuals in the clear-cut position. This was in agreement with other sources, i.e. a significant increase of DBH increment up to the ISF value of approximately 60% and then only a slight increase of this characteristic – but without data concerning stand densities (Petritan et al 2009).

The microecological conditions played a clear role for the quality of stems of young beech individuals. Bednář and Černý (2014) documented highly better quality for beech plantings in the shelter position compared to gaps and especially to the clear-cut. The latter was even worse during the research period. Positive effects of lowered light intensity on the better stem and branching quality were documented also by Ammer et al. (2007) and Leonhardt and Wagner (2006), as caused by both the high density of plantation and the shelter effect of the overtopping stand. A favourable influence of the shelter stand on the shape and quality of overtopped trees was also described by Kint et al. (2010).

It can be concluded that underplantings represent a proper way for reintroduction and regeneration of beech in comparable conditions, i.e. in the 5th vegetation altitudinal zone. The mortality and damage are much lower compared to plantations on clear-cuts. Also the height growth is faster and the necessity of protection against weed competition and game damage is considerably lower. The quality of young individuals is much better and underplantings seem to be the best method for beech regeneration. At higher altitudes, the problems can arise due to more harsh conditions and less favourable microecological conditions in underplantings, but in lower vegetation altitudinal zones the lack of soil moisture and competition of overtopping stand for water can be decisive. These sites strongly need further research. The reintroduction of beech at the newly originated clear-cuts should be done with the use of ecological shelter.

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