Growth and characteristics of old beech (*Fagus sylvatica* L.) trees individually dispersed in spruce monocultures

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ABSTRACT: We studied old beech trees individually dispersed in spruce monocultures after having found wildlings in their vicinity. The goal was to define stem and crown dimensions of the trees in dependence on their position in the primary spruce stand and to find out what kind of development they went through before reaching the current condition. We made an inventory of 883 trees in about 800 ha of stands growing in the fir-beech forest altitudinal zone (FAZ). A detailed biometric analysis conducted on two research plots of a total area 19 ha included 110 trees. Their age is 140–180 years as indicated by the analysis of annual rings. Thus, they grow in the second generation of the spruce stand. The fact gives them an absolute competitive advantage, which can be documented by their size (dbh = 49–93 cm as compared with the spruce = 15–66 cm, crown width 8–17 m as compared with the spruce = 1–10 m) as well as by the relation of their disposable (A_{DISP}) and social (A_{SOC}) areas to the size of horizontal crown projection. Regarding the size, the good condition of the crown and the expected recurrent fructification, we can consider these trees suitable for use in the systematic conversion of spruce monocultures into mixed forests for a long time.

Keywords: beech; old trees; interspersed trees; tree size; tree crown; competition; regeneration; spruce monoculture

Very old broadleaved trees have been arousing people's interest for many reasons since times immemorial. Artists are attracted by their size and weird crown forms, naturalists are interested in noteworthy objects important for the conservation of diversity of the biota contributing to the balanced functioning of the forest ecosystem, and foresters are also concerned professionally. The more the trees differ from the surroundings, the greater the attention. This is particularly true in the case of individually dispersed very old broadleaves in pure stands of spruce or pine. Foresters focused on the old oak and beech trees as soon as their capacity to fructify was found out. It was suggested that the potential could be used with an economic advantage especially in the conversion of coniferous monocultures (e.g. Mosandl, Kleinert 1998; Petermann 2000; Ganz 2005; Irmscher 2009; Dobrovolný, Tesař 2010). The idea is not new since already H. Cotta (1763–1844) considered using such trees for the conversion of pure stands into mixed forests immediately in the subsequent stand generation (Hartig 2008).

To be able to count on this capacity of late fructification at forest management planning, it had to be clarified whether the feature is reliable enough. This relates to a number of questions to be asked within a wide range of contents. While there are many works defining the dependence of fructification on weather behaviour, habitat and chemical quality of air, only few data are available about the dependence of fructification on the tree age. The general opinion that fructification and quality of beechnuts diminish with the increasing tree age is not consistent with the finding e.g. of Borrmann (1993) from a nature reserve, in which the beech could regenerate even at a very high age. A beech tree old 300–350 years yielded so abundant

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beechnuts in 1992 that the crop met the criterion of the mast year (> 250 beechnuts per m^2). Trees of dbh = 76–100 cm and 101–150 cm gave on average 198 and 309 beechnuts (standard average 263), respectively, and the average weight of beechnuts was higher than that of beechnuts from the trees of smaller diameters.

However, we know practically nothing about a relation between the abundance and quality of beechnuts and the crown morphology. This relation is only judged upon according to general physiological prerequisites of the tree, which are affected also by the tree position within the stand. This is why it may be useful to disseminate knowledge of the physical condition and development of such trees. Inspiring is in this respect a study by Petermann (2000) with 213 old beech trees interspersed in spruce stands in the Tharandter Forest. The author demonstrated that they attained the large size thanks to growing in the second and perhaps even in the third generation of spruce stands and fructifying.

The submitted study has also been instigated by the unusual long-term fructification of old trees, which was however assessed according to the occurrence of wildlings in their immediate vicinity. The goal of the work was therefore only to define the stem and crown dimensions of trees in relation to their position within the primary spruce stand and to find out what kind of development they passed before reaching the current condition. This will help us both to judge about the functional use of similar, already existing trees and to infer beech cultivation guidelines that would provide for the most effective fulfilment of the role of seeding in such trees.

Fig. 1. Common habitus of old beech tree dispersed in the spruce monoculture

MATERIAL AND METHODS

The object of research is cultivated Norway spruce stands in the Křemešník forest complex in the Bohemian-Moravian Upland, which cover a total area of about 800 ha and often on large continuous areas. The stands range from those at the growth stage of maturing high forest to older ones which are prepared for regeneration or are already regenerated. Individually dispersed old beech trees can be found within them (Fig. 1), and from these individuals beech is now spontaneously regenerating by seed. In the middle of the studied complex lies a beech forest reserve (Fig. 2). Therefore, we assume that the beech in the spruce stands is of autochthonous origin. Growing conditions of the area can be characterized by its classification of being in the fir-beech forest altitudinal zone with an elevation range of 620 to 765 m a.s.l., and with an average annual air temperature of about 6°C and average annual precipitation of 750 mm. On the crystalline bedrocks, predominantly biotitic paragneiss, Cambisols have developed, which are eutric, gleyic to gley in relation to the terrain. The absolutely dominant group of forest types is acidophilic fir-beech forests (5K), transforming into gleyic beech-fir forests (5O).

The direct objects of research are the group of forest stands (in total 798.6 ha) (Fig. 2) to record the situation in the area and two research plots (hereinafter RP) (Figs. 3 and 4) for a detailed mensurational analysis, in compartment 42 (designated A) and in compartment 35 (designated B) managed by the Forests of the Town of Pelhřimov (Fig. 2; Table 1).

Tree measurements and descriptions

An area inventory of beech trees in the forest complex was conducted as a part of Master thesis (Dobrovolný 2006). The positions of a total of 883 interspersed beech individuals were drawn, 543 of them had a description of their characteristics, and whether or not regeneration occurred within their direct range. Those individuals were excluded for which it was assumed that their

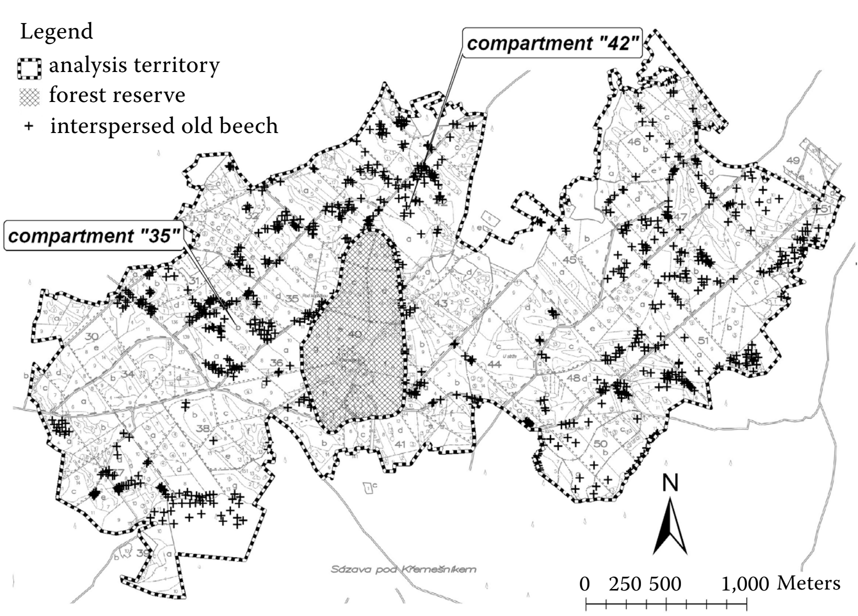

Fig. 2. Kremesnik forest complex – position of interspersed beeches

growth situation was distorted due to other factors (e.g. a path, stand margin). Diameter at breast height was measured. Visually ascertained data on the trees included: stand level classification according to Kraft (1 – dominant; 2 – codominant; 3 – partly codominant; 4 – subdominant, i.e. partially shaded, or intermediate; 5 – suppressed, i.e. able to live or dying and dead) – only trees in class 2–4 were analyzed, signs of the effects of damaging agents, both biotic and abiotic, crown condition

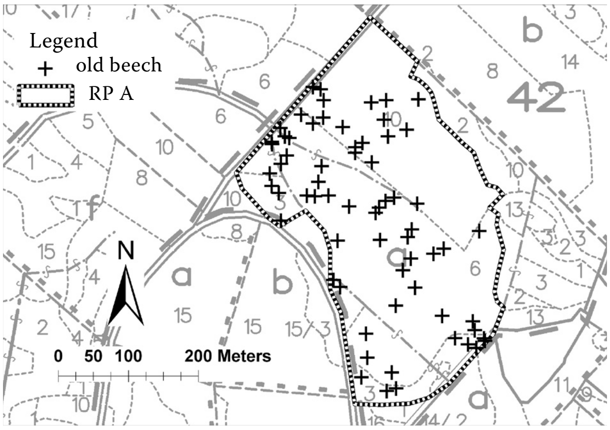

Fig. 3. Position of trees in research plot (RP) A

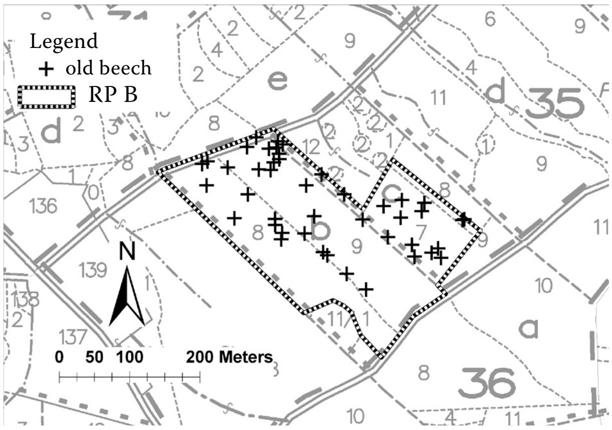

Fig. 4. Position of trees in research plot (RP) B

Table 1. Mensurational description of stands (data for 1999)

RP	Stand	Area (ha)	Age (y)	Species	Composition (%)	Height (m)	dbh (cm)	Localization
A	42a10	4.48	101	spruce	95	28	32	49°24'43''N 15°19'41''E
				larch	5	30	36	
	42a6	6.38	62	spruce	100	20	18	
B	35b9	2.7	94	spruce	90	30	32	49°24'17''N 15°18'54''E
				Scots pine	10	28	35	
	35b8	2.62	83	spruce	85	26	26	
				Silver fir	5	24	25	
				Scots pine	5	25	30	
				beech	5	24	31	

RP – Research plot

based on symmetry and size (we – well developed, de – deformed, po – poor). For regeneration its abundance is given (+ = isolated (1–3 specimens), ± = rare, 1 = relatively abundant) or absent (0).

Detailed analysis of trees on research plots

Of the 110 trees on both RPs, those trees whose competitive situation with surrounding trees was distorted by being located near a path, ride or on the edge of a large clearing had to be excluded. 64 trees were analyzed in detail. The position of the trees was measured using a GPS system (Trimble ProXH) and Field-Map (an instrument for gaining geospatial data in the field, hereinafter FM). The competitive situation was evaluated on stand cells with a central beech tree [0,0] surrounded by individual spruce trees (Fig. 5). In each cell biometric data of the beech and the neighbouring tree competitors are recorded. Trees in the immediate vicinity of the central tree that visibly affect the formation and growth of the central tree's crown are considered to be competitors. The number of competitors and their distance from the central tree differs from case to case, which means the size of the stand cell is different as well. With the aid of FM, the position of all trees was measured to derive the distance as well as the height – h (for spruces only in counts representing diameter classes) and diameter at breast height – dbh in cm. The following crown measurements were taken from each beech: the projection of the widest part of the crown – P (m^2), height of crown base – h_{cb} (m) defined by the height of the first live primary branch, and the vertical profile from one side view. To evaluate the competitive situation the so-called disposable growth area of beech was measured in m^2 – A_{DISP} (for a definition of the term see below), from which the radius of spruce crown projection was derived – r (m).

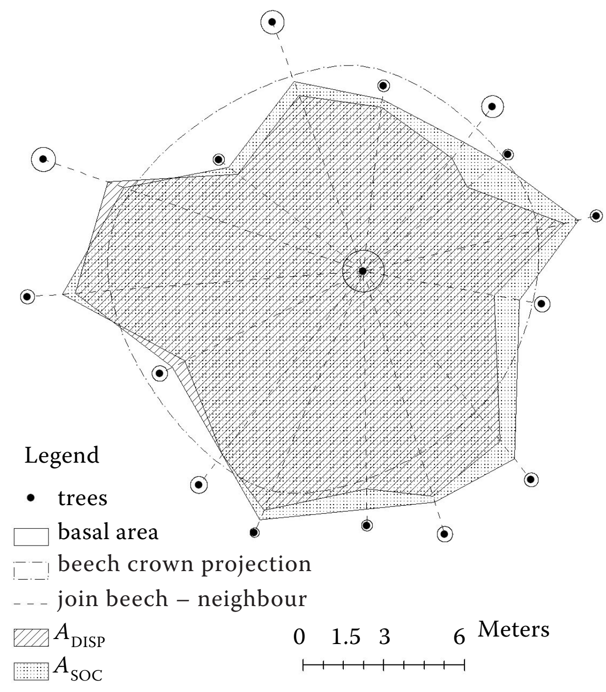

Fig. 5. Competition situation of central beech

Wood bores were taken through the entire breast height diameter from 26 beech trees (on RP A 17 and B 9) using a Pressler borer, and in a laboratory the width of growth rings was measured and growth ring curves were analyzed by the program PAST-32. Unfortunately, due to the frequent eccentric shape of the trees and due to advanced heartwood rot (most frequently at a length of about 5 cm on the tree radius) it was not possible to read the growth rings to the exact centre for most trees. Assuming that the age and the diameter at breast height of a tree are related, we estimated age with a regressive formula (x = dbh, y = age) calculated from the values of the relatively most intact growth ring curves of 14 trees. We are aware that the actual age (determined in 2007) will be somewhat higher after having added the number of years needed to reach a height of 1.3 m. To illustrate increment development trends on the RP we used the average growth ring curve averages of all analyzed trees.

Mathematical statistical data analysis

The basic spatial statistic of the point layer of beech trees was calculated by means of the ESRI "Nearest Neighbour Programme (VBA Macro)" external script in ArcInfo 9.2. The algorithm according to Clark, Evans (1954) with Donnelly's (1978) edge correction was used to calculate the aggregate index (NN Index). The results are conclusive for the level of statistical significance of 0.01. From the beech dimensions measured the following crown characteristics were derived:

$$r = \sqrt{\frac{CPA}{\pi}}$$

Where:

r – crown radius (m),

l – crown length (m).

Height of the base of the longest branch for deriving the length of the sunlit – l_{sun} and shaded – l_{shade} crown, both in (m). For calculating the volume of the sunlit crown – V_{sun} in (m^3) it was necessary to determine the parameters of the morphological curve of beech $y = f(x)$. For their calculation, the relationships from the SILVA 2.2 model (Pretzch

2001, 2009) were used. The form of the sunlit part of the beech crown was in general a cubic paraboloid. This form is adjustable by means of coefficient *a*:

$$a = \frac{l_{sun}}{l}$$

b: for the cubic paraboloid $b = 1/3$ and *c*:

$$c = \frac{r_0}{r_{max}},\ r_{max} = \frac{d}{2}$$

Where:

r_{max} – the crown radius at its widest part (m)

r_0 – the basal radius of the crown (m).

For beech generally $c = 1/3$. The morphological curve is then determined according to

$$y = x^{\frac{1}{3}}\alpha,\ \alpha = \frac{r_{max}}{(al)^b}$$

For volume

$$V = \pi \int_0^{l_{sun}} (\alpha\sqrt[3]{x})^2\, dx,$$

is valid, and after adjustment

$$V_{sun} = \pi \frac{3}{5} r_{max}^2 l_{sun}.$$

The outline of the shaded part of the beech crown is generally a truncated cone. The volume of the shaded part of the crown V_{shade} in (m^3) was calculated using the formula

$$V_{shade} = \frac{1}{3}\pi l_{shade}\left(r_{max}^2 + r_0^2 + \left(r_{max} r_0\right)\right).$$

For beech and spruce data sets, basic mathematical and statistical characteristics were calculated. Mean values, standard deviations, minimums and maximums are given. For beech the differences in mensurational and competitive characteristics between RPs were compared using non-parametric ANOVA (Kruskal-Wallis test), because the conditions for parametric ANOVA were grossly violated. Multiple comparisons of non-parametric tests were used. The parameters of the height curves for beech and spruce were calculated with the nonlinear formula according to Michailov:

$$y = 1.3 + ae^{-\frac{b}{x}}$$ (Korf 1972).

Other relationships were studied by means of the simple linear regression $y = a + bx$, and for the relationship between the diameter at breast height and the radius of the spruce crown the exponential function $y = \exp^{a + bx}$ was used.

For assessing the competitive situation, we introduce two parameters: the disposable growth area – A_{DISP} (m^2) (the author's term) and the social area – A_{SOC} (m^2) (Čermák 1990; Čermák et al. 2006) (Fig. 5). The first parameter is a polygon with vertices located on the connecting lines of the central tree (beech) to the competitor (mostly spruce). The distance of the point from the competitor is equal to the radius of its crown. The social area is a similar polygon, however with the difference that the distance of the point from the competitor corresponds to the so-called social radius – L_{SOC}, where $L_{SOC} = L \times [\ A_{basSamp}/(A_{basSamp} + A_{basNeighb})]$. The strength of the competitive relationship was studied by a simple linear regression, where the independent variable is either A_{DISP} or A_{SOC}, and the dependent variable is the crown projection of the beech (*CPA*).

For the mathematical and statistical evaluation and graphic output Statistica 8 and Microsoft Excel software was employed, and for the analysis of geospatial data ESRI ArcInfo 9.2 software was used.

RESULTS

Full-area inventory of old trees and their regeneration

In the forest complex of 800 ha spruce stands, 883 trees were found, which means one tree per hectare. The arrangement of the trees is significantly clustered (NN index = 0.52, Z value = 27.5), thus it is non-random with an average spacing of 24.5 m. Trees are mainly clustered around paths and lines dividing the forest (Fig. 2). Inside the stand, there are usually several trees standing close to each other or exceptionally as individuals (Figs. 3 and 4). We can infer from this that the beech trees were left there intentionally after cutting down the stands.

Of the 543 described beech individuals two thirds of the trees are located in the codominant level and a third in the subdominant level (Table 2). Three fourths of the trees have a sufficiently developed more or less symmetrical crown; only 13% of trees have a crown that is clearly deformed and 10%, mostly subdominant trees, have insufficiently developed crowns, with predicted decreasing vitality. The average values of beech diameter at breast height are lower in the lower levels. Regeneration has been formed in the vicinity of most trees (72%); it is abundant at 44%, sparse at 20% and isolated at 8%.

Reconstruction of beech development in spruce stands

The age range of beech trees is 140–180 years, and the values of diameter at breast height correspond

Table 2. Percentage of trees in characteristic classes

Stand level	dbh (cm)	*N*	Rot	Crown quality (%)			Regeneration (%)			
		(%)		we	d	po	0	+	±	1
2+3	–	63.2	4.8	55.3	6.2	1.7	15.0	4.1	12.9	31.3
2	61.1	30.4	2.4	27.3	1.8	1.3	7.4	2.6	5.2	15.3
3	57.3	32.8	2.4	28.0	4.4	0.4	7.6	1.5	7.7	16.0
4	44.7	36.8	0.6	21.2	7.2	8.5	12.9	4.2	7.0	12.7
∑(2+3+4)	–	100.0	5.4	76.5	13.4	10.2	27.9	8.3	19.9	44.0

we –Well developed, d – deformed, po – poor, *N* – number of trees

with this age (Fig. 6). The age range provides an evidence of differentiated history of beech trees in the spruce stands. We have reconstructed the development of the coenotic position of beech until today from average annual diameter increment curves (Fig. 7). On RP A we can infer from the initial diameter increment that at that time beech was still freely distributed in the spruce stand and about 15 years later around 1850, the increment started to decrease

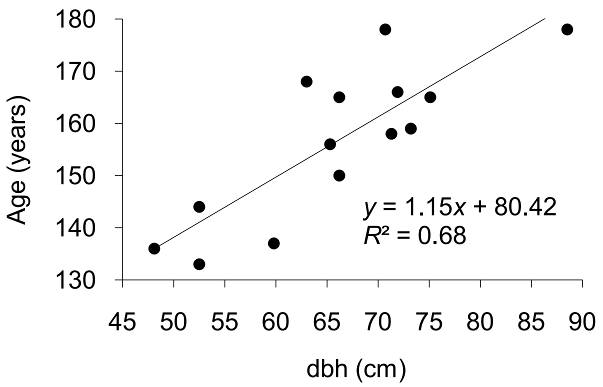

Fig. 6. Relationship of age and diameter at breast height

under competitive pressure from the dominant spruce. A sudden turn occurred in 1920, when the increment started to steadily rise until 1950, since when it has been declining permanently. The accuracy of this reconstruction is evidenced by a written record (Peikert 1901) of the fact that in ca 1900, interspersed trees were to be found in the subdominant level of the spruce stand. On RP B during the first recorded 100 years beech certainly grew permanently pressured from spruce, as we can infer from the diameter increment, which during the entire period remained at a low level. Sharp, steady increment growth from 1905 to 1935 reflects the position of beech as until it reached the pole stand stage, it was not crowded by spruce. The influence of this growth stage on the spruce stand is clear on RP A as well. From that year until 1990, we have recorded clear fluctuations about the imaginary mean value. After 1990, the increment has decreased.

On all described sections of the increment curve of both stands the values oscillate around the imaginary mean value, which is undoubtedly a response to weather conditions. Absolute diameter incre-

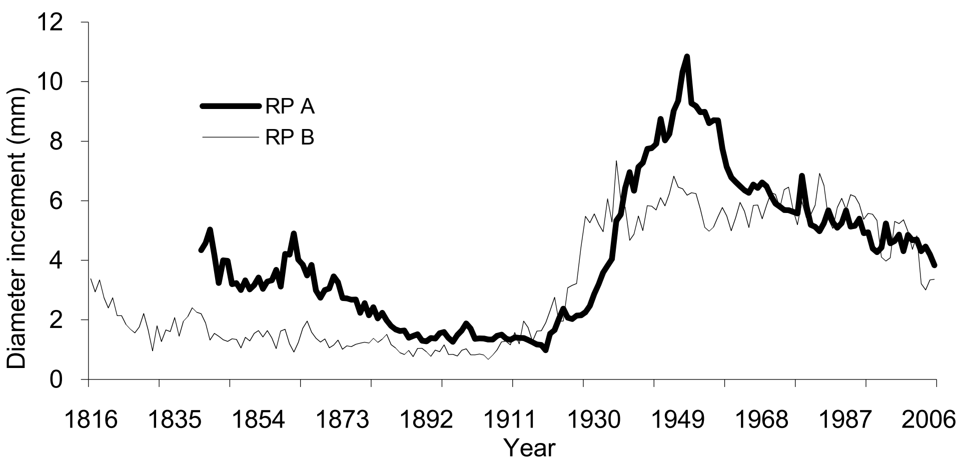

Fig. 7. Course of beech diameter increment

Table 3. Stem and crown dimensions by tree species and RP (ø | σ | min–max)

	Beech		Spruce	
RP	A	B	A	B
N	40	24	375	141
dbh (cm)	69.6 | 11.3 | 46.2–93.3	63.0 | 10.9 | 48.4–89.4	32.1 | 8.7 | 15.0–62.0	35.0 | 9.0 | 19.0–66.0
h (m)	31.0 | 2.5 | 24.2–36.5	31.8 | 1.5 | 29.1–34.6	27.6 | 3.4 | 17.9–35.6	28.9 | 3.2 | 21.3–35.4
r (m)	5.9 | 1.2 | 4–8.3	5.4 | 1.1 | 3.4–7.6	1.6 | 0.9 | 0.1–5.3	1.7 | 0.9 | 0.2–5.4

h – tree height, *r* – crown radius, dbh – diameter at breast height, RP – research plot, *N* – number of trees

Table 4. Beech crown parameters (ø | σ | min–max)

RP	A	B
h_{cb} (m)	8.4 | 3.0 | 2.4–14.7	8.5 | 3.1 | 2.5–13.0
l_{sun} (m)	12.7 | 4.1 | 4.6–19.7	12.7 | 3.9 | 3.7–19.9
l_{shade} (m)	9.9 | 3.5 | 3.2–16.9	10.7 | 4.4 | 4.0–23.9
l (m)	22.6 | 3.0 | 16.5–29.1	23.4 | 3.2 | 17.9–31.1
CPA (m^2)	115.1 | 44.3 | 50.6–215.8	94.0 | 39.1 | 37.0–182.3
V_{sun} (m^3)	917.7 | 537.3 | 211.1–2,124.8	748.9 | 449.5 | 145.7–1,884.9
V_{shade} (m^3)	547.8 | 282.9 | 79.7–1,235.4	468.5 | 256.5 | 159.2–1,194.7
V (m^3)	1,465.6 | 701.5 | 486.5–3,015.5	1,217.4 | 604.7 | 449.8–3,079.5
A_{SOC} (m^2)	106.8 | 44.6 | 37.9–223.4	78.8 | 42.3 | 24.5–163.1
A_{DISP} (m^2)	132.7 | 47.4 | 59.0–241.6	106.7 | 47.6 | 45.3–248.2

RP – research plot, h_{cb} – height of crown base, l_{sun} – sunlit crown lenght, l_{shade} – shaded crown lenght, l – crown lenght, *CPA* – crown projection area, V_{sun} – sunlit crown volume, V_{shade} – shaded crown volume, A_{SOC} – social area, A_{DISP} – disposable growth area

ment values of both RPs vary, and come close to each other during a short section of time around 1910. The increment trend however is identical. A sharp increment increase on both RPs can be explained only by a sudden release of trees when, certainly after cutting down the spruce stand, beech was left. Today this is evidenced by sometimes extreme crown length (Table 4). Beech on RP A indicated a sharper increment increase and significantly higher average annual increment after release (ø 4.42 mm, σ = 3.31, min. 0.10 mm, max. 21.00 mm) than on VP B (ø 3.83 mm, σ = 2.84, min. 0.12 mm, max. 21.68 mm).

Dimensions and the competitive situation of beech

Whereas within the vast area of the forest complex beech is dispersed more or less in clusters, on a RP with an area of several hectares (Figs. 6 and 7) it is random, as evidenced by the values (RP A: 11.8 ha, *N* = 66, NN index = 0.87, Z = 1.83, average spacing = 19.6 m; RP B: 7.0 ha, *N* = 44, NN index = 0.85, Z = 1.76, average spacing = 18.3 m).

The statistically significant difference in the mean dbh and height values between beech and spruce corresponds to the age differences of the tree species and in both cases proves the advantageous position of beech. Thanks to this, it markedly exceeds spruce in diameter growth (Table 3) and it grows in the main layer and never in the subdominant position (Fig. 8). The average crown projection radius of beech also exceeds the value for spruce many times (Table 3; Fig. 9). The relatively long and wide-

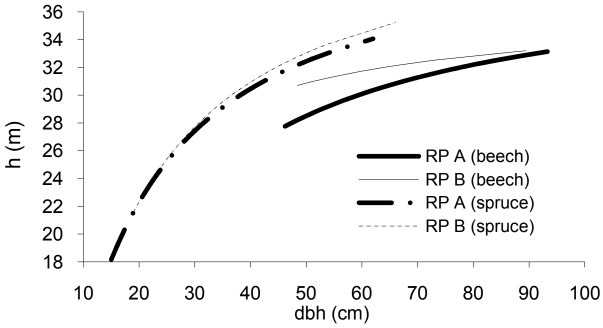

Fig. 8. Height curves (Michailov) – beech, spruce

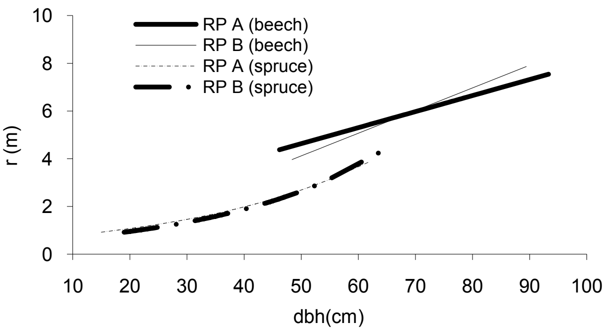

Fig. 9. Relationship of diameter at breast height and beech and spruce crown radius

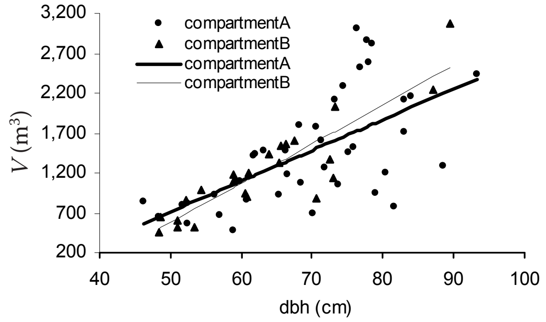

Fig. 10. Relationship of diameter at breast height and beech crown volume

branched beech crowns with greater volumes of areas receiving sunlight (Table 4) support the claim that during a certain period they made use of the long-lasting release. There is no statistically significant difference in beech crown dimensions between RP A and RP B. A close (P = 0.03) significant difference was determined only in the mean values of diameter at breast height between compared trees. With the higher mean value of diameter at breast height on RP A, slightly higher mean values of related characteristics can be observed (Table 4), including the already mentioned diameter increment. There is a relatively close relationship between the diameters at breast height of beech and spruce and other basic values (Table 5; Figs. 9 and 10), the course of which was almost identical on both RPs. Similar growth dynamics of interspersed beech can be inferred from this.

Different age may be a cause of higher mean values of stem and crown characteristics, however it is more likely to be due to the fact that beech grew longer in a free position. We can deduce this from significant differences in the mean values of disposable growth area and social area (Table 4). With higher social or disposable growth area, the values of other growth characteristics logically increase as well (Table 5; Figs. 11 and 12), so that a beech with an average crown diameter of around 11 m almost completely fills the disposable growth area (compare P with A_{DISP} and A_{SOC} in Table 4). Beech individuals on both RPs reacted to releases similarly – the trend of this relationship was almost the same.

Evaluation of the results and discussion

We were interested in a study from the Tharandter Wald in Germany (Petermann 2000) that shows the results that are surprisingly similar to ours (Table 6) despite the fact that the studied area, in comparison with ours, is located in a warmer and moister climatic zone (320–425 m a.s.l., average annual temperature 7.6°C, total precipitation 810 mm) and on richer soils.

Among the compared values of both cases, only the mean crown diameter differs. This brings us to an explanation of the ascertained facts and an attempt to address their general validity.

Firstly, we have discovered that in both cases the forest went through a very similar, if not identical, stand history, established and cultivated with clear-cutting management. In our case, beech individuals are located in the second generation of the spruce stand. They grew in the shade of the dominant spruce stand, and after harvest they became solitary. They were never overgrown by the new spruce

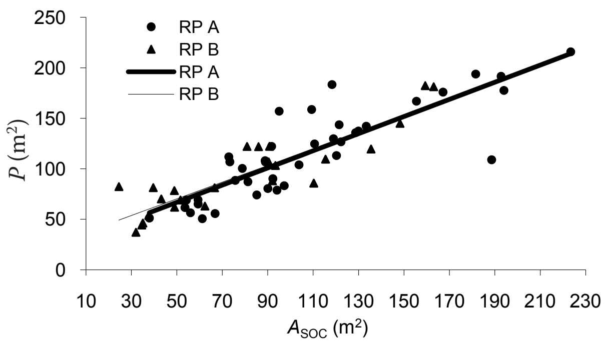

Fig. 11. Relaionship of social area and beech crown projection

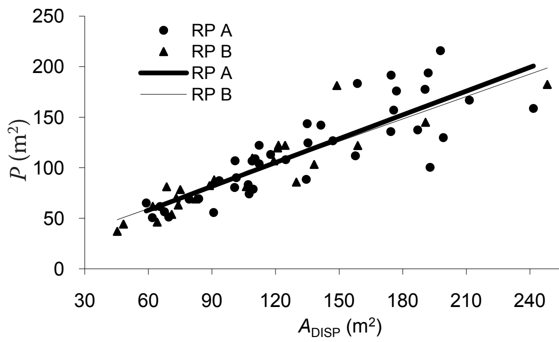

Fig. 12. Relationship of disposable growth area and beech crown projection

Table 5. Regression parameters

RP		Beech		Spruce	
		A	B	A	B
dbh vs *h*	*a*	38.17	35.11	40.5	41.79
	b	16.93	–8.59	–131.49	–137.46
	R^2	0.26	0.20	0.83	0.86
dbh vs *r*	*a*	1.27	–0.63	–0.54	–0.73
	b	0.07	0.10	0.03	0.03
	R^2	0.43	0.86	0.27	0.36
dbh vs *V*	*a*	–1,212.45	–1,896.41	–	–
	b	38.5	49.39	–	–
	R^2	0.39	0.79	–	–
A_{SOC} vs *P*	*a*	24.34	29.01	–	–
	b	0.85	0.82	–	–
	R^2	0.73	0.80	–	–
A_{DISP} vs *P*	*a*	10.84	15.05	–	–
	b	0.79	0.74	–	–
	R^2	0.71	0.81	–	–

RP – research plot, *a*, *b* – regression parameters, R^2 – coefficient of determination, dbh vs *h* – diameter at breast height versus tree height ,dbh vs *r* – diameter at breast height versus crown radius, dbh vs *V* – diameter at breast height versus crown volume, A_{SOC} vs *CPA* – social area versus crown projection area, A_{DISP} vs *CPA* – disposable area versus crown projection area

stand – they were only laterally crowded, and today they are to be found in the main stand level. Petermann (2000) reports the same development. For clarification as well as for decision-making on silvicultural measures, an answer to the question whether such trees were of random, spontaneous origin or if during the era of "spruce mania" they were the result of a certain management intention would be valuable. Unfortunately, we were unable to find the necessary historical documents. Petermann (2000) gives a little clue, when he mentions sources confirming that in the Tharandter Wald individual admixtures of beech regeneration were supported and beech was even purposefully cultivated as an agent for transforming monocultures into mixed forests. This occurred under the management of Augusta v. Cottas in the period 1836 to 1860 (Petermann 2000; Hartig 2008), when the trees analyzed by Petermann were already growing or had been planted, and the trees we analyzed were also already growing.

Secondly, from the above mentioned we can derive that beech manifested itself in the same way regardless of different habitat conditions, which is certainly due to the genetically conditioned growth rhythm that gives an advantage to beech over spruce during growth. Pretzsch, Schütze (2005) discovered during the comparison of the growth of

Table 6. Comparison of beech stem and crown dimensions (average, min.–max.)

	Age (y)	*h* (m)	dbh (cm)	h_{cb} (m)	*l* (m)	*d* (m)	i_d (mm)
Kremesnik	140–180	31.3	67.1	8.4	22.9	11.4	4.2
		24.2–36.5	46.2–93.3	2.4–14.7	16.5–31.1	6.9–16.6	0.1–21.7
Tharandter Wald	106–199	29.5	71.4	5.8	20.1	19.6	4.4
		13–35	41.0–115.0	1.5–13.5	11.0–30.5	6.0–28.0	0.1–21.8

h – tree height, dbh – diameter at breast height, h_{cb} – height of crown base, *l* – crown lenght, *d* – crown diameter, i_d – diameter increment spruce and beech that beech reached 57% greater crown projection increment than spruce thanks to the lateral crown expansion and thanks to that fact it was 60% more successful at taking up the growth space. However, measured by the growth performance, it uses the space 70% less efficiently.

On the basis of the comparison of both cases we can state that the beech crown dimensions we discovered are far from being the limits. The size of the crown is closely correlated with stem diameter at breast height and both characteristics are in proportion to the growth area. This relationship was similar on both RPs and perhaps it will be possible to generalize its validity. With further releases, proportional crown expansions can be expected and thus an increase in volume.

In the Tharandter Wald (Petermann 2000) 85% of trees showed no sign of regeneration and only in 4% of trees regeneration was worth noting. We cannot judge to what extent this fact was conditioned by rich fructification, because adverse stand conditions undoubtedly contributed to sparse regeneration – the microclimate and a layer of raw humus in particular. However, we see the main cause being the high levels of cloven-hoofed game and inadequate game management. We can support this statement by our discovery that in contrast 70% of trees spontaneously regenerated, and within the range of 40% of trees regeneration was abundant. Stand conditions are comparable with the Tharandter Forest, however in our territory there is a large beech complex with abundant regeneration, and game did not develop such a strong pressure on wildlings around isolated trees in the spruce monoculture.

CONCLUSION

The reconstruction of the growth of beech surrounded by the connected spruce stand, which pressured beech for periods up to 100 years, confirmed great crown plasticity. It has the capability to increase its volume after release, especially the sunlit part, even at an advanced age. According to the standing assumption, such a crown is better prepared to regenerate in the case of appropriate external conditions. It can be derived from this that it would be most efficient to purposefully and systemically care for the crown development of interspersed beech individuals from a young age. If wildlings do not occur in the first generation of the spruce stand, it is well-founded to let them grow until the second rotation, despite the fact that they take up a large growth space. They will have an undeniable competitive advantage and will be able to apply fully their capabilities.

We cannot judge to what extent the appearance of trees, often with low-grade stems, strong branches and wide-branching crowns, is the result of their long-term formation alternately in spruce stands and in a free position, or if it is genetically given. We assume however that considering the existence of a natural beech forest in the middle of the forest complex this is the remnant of an autochthonous population. Even if this was not the case, there is no reason to exclude such trees from silvicultural use. For example in the next development, their offspring may be selected in the needed direction by silvicultural measures. Outside of reproduction itself, it is possible to assume their positive influence on forest soils and forest biodiversity, similarly to conclusions of Lehmann (2008) concerning the oak dispersed in pine monocultures.

The study shows that individually dispersed beech trees in spruce stands, which are neglected due to their insignificant representation, may have a far-reaching significance for forest development at a certain stage. We especially emphasize the ability to fructify at an age approaching 200 years. By utilizing this, costs of forest transformation could be reduced. Greater ecological stability could be achieved due to the fact that the autochthonous population is more capable of facing existential risks.

Our study could not specify how the characteristics of individual trees condition their fructification abilities, because it was judged indirectly on wildlings present. Research should focus on this problem.

References

Borrmann K. (1993): Zur Fuktifikation sehr alter Rotbuchen im Naturwaldreservat Heilige Hallen. Forst und Holz, ***48***: 700–701.

Clark P.J., Evans F.C. (1954): Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology, ***35***: 445–453.

Čermák J. (1990): Calculation of Operative Areas in Large Trees – A Manual. Brno, Mendel University of Agriculture and Forestry in Brno: 160.

Čermák J., Ulrich R., Staněk Z., Koller J., Aubrecht L. (2006): Electrical measurement of tree root absorbing surfaces by the earth impedance method: 2. Verification based on allometric relationships and root severing experiments. Tree Physiology, ***26***: 1113–1121.

Dobrovolný L. (2006): Population of European beech in forest stands of Křemešník and its integration into the silvicultural system [Master Thesis.] Brno, Mendel University of Agriculture and Forestry in Brno: 117. (in Czech)

Dobrovolný L., Tesař V. (2010): Extent and distribution of beech (*Fagus sylvatica* L.) regeneration by adult trees individually dispersed over a spruce monoculture. Journal of Forest Science. (in press)

Donnelly K. (1978): Simulations to determine the variance and edge-effect of total nearest neighbor distance. In: Hodder I. (ed.): Simulation Studies in Archaeology. New York, Cambridge University Press: 91–95.

Ganz M. (2005): Entwicklung von Baumartenzusammensetzung und Struktur der Wälder vom Schwarzwald bis auf die Schwäbische Alb – mit besonderer Berücksichtigung der Buche. [Ph.D. Thesis.] Freiburg im Breisgau, Albert-Ludwigs-Universität: 183. (in German)

Hartig M. (2008): Die sächsischen Walder auf dem Weg zu nachhaltiger Bewirtschaftung. Der Sächsische Waldbesitzer, ***3***: 10–13.

Irmscher T. (2009): Zoochores Ausbreitungspotenzial der Rotbuche (*Fagus sylvatica* L.) mit Blick auf die Minimierung der Eingriffsintensität beim Waldumbau in Wäldern mit Naturschutzstatus. Forstarchiv, ***80***: 29–32.

Korf V. (1972): Dendrometry. Praha, SZN: 371. (in Czech)

Lehmann B.W. (2008): Effekte einzelbaumweise eingemischter einheimischer Eichen in Wäldern der Gemeinen Kiefer (*Pinus sylvestris* L.) auf Standorten geringer Trophie und Wasserversorgung im Süden Brandenburgs. [Ph.D. Thesis.] Tharandt, TU Dresden: 137. (in German)

Mosandl R., Kleinert A. (1998): Development of oaks (*Quercus petraea* (Matt.) Liebl.) emerged from bird-dispersed seeds under old-growth pine (*Pinus sylvestris* L.) stands. Forest Ecology and Mangement, ***106***: 35–44.

Peikert G. (1901): Description of the Estate of the Town Česká lesnická společnost, Pelhřimov. Praha: 122. (in Czech)

Petermann L. (2000): Zustand und waldbauliche Bewertung von Altbuchensolitären im Nordostteil des Tharandter Reviers. [Master Thesis.] Tharandt, TU Dresden: 112. (in German)

Pretzch H. (2001): Modellierung des Waldwachstums. Parey Buchverlag, Berlin: 341.

Pretzch H., Schütze G. (2005): Crown allometry and growing space efficiency of Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.) in pure and mixed stands. Plant Biology, ***7***: 628–639.

Pretzch H. (2009): Forest Dynamics, Growth and Yield. Berlin, Springer Verlag: 664.

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