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Current use of European beech (*Fagus sylvatica* L.) for artificial regeneration of forests in the air-polluted areas

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ABSTRACT: The paper deals with the use of European beech in the reconstruction of substitute species stands and in the regeneration of existing spruce stands in the air-polluted region of the north-eastern Krušné hory Mts. (air-pollution damage zones A, B, forest altitudinal vegetation zones 6 and 7, acidophilic sites). Twenty stand situations were analyzed during the study. The study objective was to compare the growth of European beech plantations in the Krušné hory Mts. with the growth of plantations of the same age in similar sites in the unpolluted region of the Bohemian-Moravian Upland (air-pollution damage zones C, D, forest altitudinal vegetation zone 6, acidophilic site). Each plant was assessed for eight growth and visually classified parameters and traits. Results of the survey showed that in the existing air-pollution and climatic situation, it is possible to switch to normal (shelterwood) beech management of higher elevations in the north-eastern Krušné hory Mts. The stands of substitute species and the current stands of Norway spruce may effectively eliminate injuries caused by late frost.

Keywords: European beech; stand of substitute species; reconstruction; shelterwood system

For the forest stands of the north-eastern Krušné hory Mts. the years 1970 and 1980 were characterized by the culminating air pollution load with a large-scale disintegration of existing Norway spruce stands and extensive felling due to air pollution (Materna 1988; Kubelka et al. 1992). Apart from the Norway spruce (*Picea abies* [L.] Karst.), which was entirely eliminated from regeneration in air-pollution damage zones A and B, the changed conditions of environment restricted also the use of European beech (*Fagus sylvatica* L.), which is otherwise relatively resistant to air pollution. The developing large clear-cuts created microclimatic conditions unfavourable for reforestation with beech. The occurrence of late frosts, weed infestation of the localities, water-logging of the soil profile, occurrence of small rodents and the absence of an effective ecological protection led to a decision to plant the European beech only at sheltered places and in sloping localities (Kubelka et al. 1992).

The elimination of main commercial species from the regeneration aims led to the establishment of a new species composition of emerging stands, so called substitute species stands (SSS). The total area of newly established substitute species stands amounted to more than 30,000 ha while blue spruce (*Picea pungens* Engelm.), birch sp. (*Betula* sp.), European larch (*Larix decidua* Mill.), European mountain ash (*Sorbus aucuparia* L.) and black alder (*Alnus glutinosa* Gaertn.) became the most important trees in these stands. These species are tolerant not only to air-pollution but also to extreme microclimatic and site conditions (Šindelář 1982; Mauersberger et al. 1991). Also, their beneficial influence was expected to last long as no pronounced change could be foreseen as to unfavourable ecological conditions.

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A general improvement of the air-pollution situation brought moderate optimism as to the regeneration and reconstruction of forest stands in the Krušné hory Mts. Some realistic considerations in regeneration objectives suggested that a return to the growing of commercial species would be possible and the Norway spruce started to be planted again from the mid-1990s. There were also some first plantations of European beech (Nebe 1994, 1997; Kriegel 2002a). The issue of the reintroduction of beech in air-polluted regions was studied, often with controversial results, by many authors (Lokvenc, Vacek 1991; Nebe 1994; Helbig 1994; Balcar 1996; Vacek 1996; Hering 1997; Kriegel 2002b; Balcar, Kacálek 2003). Yet there is not enough experience with growing beech in these localities with largely changed habitats and no principles for its use have been determined so far.

At present, there are three basic silvicultural technologies in which beech can be used for reforestation:

- SSS reconstruction – the reconstruction is a procedure in which a substitute species stand is converted by means of silvicultural measures to a stand of target species composition. Studies into the development and growth of SSS pointed to impaired vitality of some stands and to dynamic deterioration of their general health condition (Nebe 1997; Mauer, Palátová 1999; Slodičák 2001; Hering, Irrgang 2005; Mauer et al. 2005). Tending measures focused on sanitation felling are not enough and the most injured stands call for expedite reconstruction in order to prevent recurrent development of clearcuts, ground surface denudation and overall degradation of the site.
- Regeneration of existing Norway spruce stands – in this procedure, affected or gappy spruce stands which have survived the adverse effect of air pollution are regenerated. The stands of middle age were young at the time of the culminating air-pollution disaster, their low height protecting them from its fatal impact. Other maturing stands could reach the age only thanks to a less exposed mesorelief, which protected them from the air-pollution load.
- Recultivation of sites after dozer soil preparation – this is a procedure in which longitudinal or transversal spreading of the created organomineral mounds is done. The organic material is spread in this manner once again across the scarified plot and the planting follows subsequently.

The paper deals with the use of European beech in the reconstruction of SSS and in the regeneration of existing spruce stands. The works do not result in any greater site changes. The issue of recultivating the former dozer plots is an entirely specific problem in terms of technological realization and ecotope change.

MATERIAL AND METHODS

In 2005, permanent research plots (27) were established in the air-polluted area (natural forest region 1 – Krušné hory Mts.) for the continual monitoring and assessment of plantations of European beech. The analyzed plantations were aged from 2 to 11 years. The research plots lie at altitudes from 740 m to 810 m a.s.l., in air-pollution damage zones A or B. Typologically they are classified in the forest type groups 6K and 7K. The analyses included only plots with a higher representation of beech, i.e. 9 plots in the existing stands of Norway spruce and 11 plots in the substitute species stands. The research plots are situated on forest properties of the Chomutov Municipal Forests and Forests of the Czech Republic, state enterprise (Lesy ČR, s. p.), Forest Administration Litvínov (districts Kalek and Načetín).

The minimum number of plants assessed on each research plot was 100 in the case of 100% representation of beech in the given locality, or 50 in the case of mixed plantations (European beech up to 25%). All plants were assessed for 2 primary growth parameters, 5 visually classified traits and for a total loss since planting.

Selection of stand situations and characterization of hitherto regeneration procedures

Substitute species stands

Stands of the species with highest representation in the region were chosen, i.e. blue spruce (*Picea pungens* Engelm.) and birch (*Betula* sp.). Management systems used in reconstruction are a shelterwood system (underplanting), border felling (cutting face) and/or clear-felling (clearcut). Important indicators in underplanting are average stand height, choice of the initial SSS stocking at the beginning of reconstruction and the progress of its reduction in further cultivation. Indicators important in border felling and clear-felling are surface area, regeneration element form and height of the surrounding stand. Site preparation at establishing the SSS could also have a considerable influence on the growth of plantations.

Brief characterization of stand situations and hitherto reconstruction procedures:

- Plot SSS 1 – in 2005, the stocking of blue spruce stand was reduced to 0.5 (current average height is

6 m) and existing trees were pruned up to a height of 2 m. The underplanting of beech followed (100%). The current stocking of the blue spruce stand is identical.

- Plot SSS 2 – in 2004, the stocking of blue spruce stand was reduced to 0.5 (current average height is 5 m) and beech was underplanted at 100%. The blue spruce continues in being vital and the stocking is identical now.
- Plot SSS 3 – in 2004, a small clear-felled area sized 0.25 ha (average width 30 m, length 80 m) was created inside a blue spruce stand and the beech was planted on it at 100%. The clearcut is sheltered by the blue spruce stand on the one side (current average height 5 m, stocking 0.5) and by a birch stand (current average height 9 m, stocking 0.9) on the other side.
- Plot SSS 4 – in 2004, a large clear-felled area sized 0.70 ha (average width 35 m, length 165 m) was created inside a blue spruce stand and beech was planted on it at 100%. The clearcut is sheltered by the blue spruce stand (current average height 5 m, stocking 0.5) on the one side and by a stand of Norway spruce (current average height 13 m, stocking 1.0) on the other side.
- Plot SSS 5 – in 2004, the stocking of birch stand was reduced to 0.5 (current average height is 10 m) and underplanting of Norway spruce (80%) and beech (20%) was done. The birch stand is vital and its stocking is currently the same.
- Plot SSS 6 – at launching the reconstruction in 2003, the stocking of birch stand (current average height 7 m) was reduced to 0.5 and the stand was underplanted with Norway spruce and beech at 80% and 20%, respectively. The birch stand is rapidly disintegrating and its current stocking is 0.3.
- Plot SSS 7 – in 2002, the stocking of birch stand was reduced to 0.5 (current average height 12 m) and the stand was underplanted with Norway spruce and beech at 80% and 20%, respectively. The birch stand is vital and its stocking is now identical.
- Plot SSS 8 – in 2001, the birch stand (current average height 9 m, stocking 1.0) was underplanted with beech (100%). Due to decline, the current birch stand stocking is 0.9.
- Plot SSS 9 – in 2000, the birch stand stocking was reduced to 0.6 (current average height 11 m) and the stand was underplanted with beech (100%). The current stocking of the stand is the same and the birch stand is vital.
- Plot SSS 10 – in 2003, a strip (width 15 m, length 200 m) was clear-felled in the birch stand (current average height 9 m) and the stand was underplanted with Norway spruce (75%) and beech (25%). The stand stocking was 0.6 at the beginning of reconstruction; the stand currently exhibits a gradual disintegration and its stocking is 0.4.
- Plot SSS 11 – in 2000, the stocking of the blue spruce stand was reduced to 0.6 (current average height 6 m) and beech was underplanted at 100%. The current stocking is identical and the blue spruce stand is vital.

Existing Norway spruce stands

The currently existing spruce stands are regenerated under shelterwood – by shelterwood felling and subsequent underplanting. In selecting the stand situations, average height of Norway spruce stands, initial stocking at the beginning of regeneration and its progressing reduction in the following years were taken into account.

Brief characterization of stand situations and hitherto regeneration procedures:

- Plot SM 1 – in 2001, the spontaneously opening stand (stocking 0.6, current average height 20 m) was underplanted with beech (100%). At present, the stocking is identical.
- Plot SM 2 – in 2000, the stand stocking was reduced to 0.7 by sanitation felling (current average height is 10 m) and beech was underplanted at 100%. The present stocking is 0.6.
- Plot SM 3 – in 2000, the stand stocking was reduced to 0.7 by sanitation felling (current average height is 10 m) and beech was underplanted at 100%. In 2005, the Norway spruce stand was extracted and a clear-felled area sized 0.15 ha (width 20 m, length 80 m) was created. The beech crop is thus currently sheltered only on the side by a Norway spruce stand (average height 10 m, stocking 0.7).
- Plot SM 4 – in 1999, the stand stocking was reduced to 0.5 (current average height is 19 m) and beech and fir were underplanted at 50% and 50%, respectively. The current stocking is identical.
- Plot SM 5 – in 1999, the stand stocking was reduced to 0.6 (current average height is 13 m) and beech was underplanted at 100%. The current stocking is identical.
- Plot SM 6 – in 1999, the stand stocking was reduced to 0.6 (current average height is 13 m) and beech was underplanted at 100%. In 2003, the stand stocking was reduced to 0.3, and in 2006, the Norway spruce stand was completely felled. The new clear-cut of 0.20 ha (width 40 m, length 50 m) is on the side sheltered by a Norway spruce stand (current average height 13 m, stocking 0.3).

– Plot SM 7 – in 1998, the stand stocking was reduced to 0.7 (current average stand height is 14 m) and beech and fir were underplanted at 50% and 50%, respectively. The current stocking is 0.6.
– Plot SM 8 – in 1998, the stand stocking was reduced to 0.5 (current average stand height is 16 m) and beech was underplanted at 100%. In 2006, the stocking was 0.2.
– Plot SM 9 – in 1996, the spontaneously opening stand (stocking 0.6, current average height 14 m) was underplanted with beech at 100%. The current stocking is identical.

Assessed parameters and traits

In 2006, the most important growth parameters were *total aboveground height* (measured to the nearest 1 cm) and *terminal shoot increment* (measured to the nearest 1 cm). Plants not included in the assessment were those with browsed terminal shoot and plants with more than a half of the main stem girth damaged by small rodent nipping. The goal was to find out to what extent the plant growth was affected only by the site and stand conditions and to eliminate the impact of biotic agents to the largest extent possible.

Total loss from planting to the year 2006 is the loss of plants on a research plot for the given period in percent.

Vitality of plants was assessed visually according to the colour of assimilatory tissues and their vitality. Colour tables issued by Research Institute of Printing Industry (RIPI) were used as an aid for the establishment of colours. The scale included 4 colour shades:
1 – green (p. 3 in Table RIPI, 80–100%/80–100%),
2 – yellowish (p. 3 in Table RIPI, 80–100%/43–68%),
3 – yellow (p. 3 in Table RIPI, 80–100%/0–29%),
4 – dying plant. The table of results presents the arithmetic mean of all values established in each plot.

Stem form evaluates deviations from the normal cylindrical form of the main stem. The trait was classified by a scale of 3 degrees: *Straight* – the stem is not branched and consists of a single shoot only. If other shoots occur, their diameter must not be larger than a half diameter of the leader. *Fork* – the main stem is branched into two shoots with none of the two being of smaller diameter than a half diameter of the other. *Multiple* – the main stem is branched into three and more shoots of the same diameter.

Terminal damage to the plant is to express damage to terminal bud, a part of or entire terminal shoot. Damage is in the form of *browsing* which includes damage to terminal bud or terminal shoot by game or *dry terminal* which is recorded in case that a dieback of terminal bud or terminal shoot occurred due to other reasons than browsing.

Damage to assimilatory tissues by late frost. A detailed survey was done in June 2006. There were 3 degrees of damage: 0 – plants not damaged by late frost, 1 – less than 50% of the total leaf area damaged by late frost, 2 – more than 50% of the total leaf area damaged by late frost. Tables of results present percent proportions of individual damage degrees within the research plot.

Damage due to nipping by small rodents. The nipping of young stems and lateral branches damages the plants. There were 2 degrees of damage to assess the nipping by small rodents: 1 – nipping is recorded on lateral branches only; in the case of nipping of the main stem, not more than a half of the stem girth is damaged, 2 – more than a half of the main stem girth is damaged and a severe disturbance of water-conducting tissues occurs in the phloem. The table of results presents the total percentage of plants damaged by small rodent nipping, and in brackets the percentage of plants in which damage of degree 2 was recorded.

In order to obtain exact results, comparative plots (control) were established in 2006 in the region of Bohemian-Moravian Upland (forest property of Lesy ČR, s. p., Forest Administration Nové Město na Moravě, district Koníkov) unaffected by air pollution. The plots lie in forest altitudinal vegetation zone 6 (forest type group 6K), air-pollution damage zones C and D, at altitudes ranging from 700 to 780 m a.s.l. The total number of assessed control plots which were of varied age was eleven (designated K1–K11). The plots were either underplanted (stocking of existing stand 0.5) or planted on narrow border felled strips with the cutting face width not exceeding the height of the surrounding stand. A minimum number of plants measured on each plot was 100 and the plants were assessed for the same parameters and traits as those monitored on plots in the Krušné hory Mts. Data on losses were borrowed from the forest management records.

The parameters of *total height of aboveground part* and *terminal shoot increment* are expressed in the tables of results by arithmetic mean with standard deviation. The linear regression line illustrating the general trend in the growth of beech plantations was fitted with average values of terminal shoot increment in the respective stand types (SSS, regeneration of existing spruce stands, control). Average increment values and regression equations including the R^2 determination coefficient are expressed graphically. Other traits were

Table 1. Stands of substitute tree species and existing Norway spruce stands – characteristics of analyzed plots, loss, growth of aboveground parts, damage

Variant							Total loss until 2006 (%)	Total aboveground height (cm)	Terminal shoot increment (cm)	Vitality	Stem form (straight/fork/multiple) (%)	Damage (in % of plants)			
Plot No.	No. of plants	Age	Species dominant in SSS	Underplantings (stocking)	Clear-cut (ha)	Fencing						Terminal browsing	Dry terminal	Frost damage (degrees 0/1/2)	Damage by rodents (of it deg. 2)
SSS 1	115	2	blue spruce	0.5	–	yes	10	57.9 ± 16.7	6.0 ± 5.6	1.1	93/7/0	10	7	70/24/6	0 (0)
SSS 2	113	3	blue spruce	0.5	–	yes	6	67.5 ± 10.2	4.5 ± 3.8	1.1	96/4/0	4	28	3/43/54	12 (1)
SSS 3	109	3	blue spruce	–	0.25	yes	25	63.0 ± 16.0	7.3 ± 4.8	1.3	91/9/0	1	39	14/54/32	22 (1)
SSS 4	108	3	blue spruce	–	0.70	yes	11	59.7 ± 9.2	2.9 ± 2.6	1.3	92/7/1	2	55	0/0/100	7 (0)
SSS 5	52	3	birch	0.5	–	no	10	45.8 ± 11.7	7.9 ± 4.8	1.0	22/67/11	7	16	40/60/0	4 (0)
SSS 6	54	4	birch	0.4	–	yes	10	80.7 ± 38.3	17.0 ± 9.9	1.0	67/33/0	3	2	59/23/18	8 (0)
SSS 7	52	5	birch	0.5	–	no	10	83.5 ± 26.0	17.8 ± 8.9	1.0	50/43/7	6	4	82/18/0	4 (0)
SSS 8	108	6	birch	0.9	–	yes	10	114.4 ± 31.6	24.8 ± 9.1	1.0	79/20/1	6	0	100/0/0	31 (12)
SSS 9	105	7	birch	0.6	–	yes	10	174.3 ± 57.6	30.2 ± 8.5	1.2	42/41/17	6	1	100/0/0	63 (25)
SSS 10	51	7	birch	–	0.30	yes	15	143.8 ± 32.1	29.7 ± 11.0	1.0	7/19/74	6	0	10/52/38	19 (0)
SSS 11	100	7	blue spruce	0.6	–	yes	10	148.9 ± 54.1	34.3 ± 12.1	1.1	76/21/3	0	3	81/14/5	48 (15)
SM 1	105	6	–	0.6	–	yes	15	117.4 ± 31.8	13.7 ± 6.9	1.0	75/24/1	45	6	100/0/0	14 (5)
SM 2	103	7	–	0.6	–	yes	15	85.6 ± 21.4	17.3 ± 9.8	1.1	60/25/15	68	6	100/0/0	15 (4)
SM 3	105	7	–	–	0.15	yes	15	113.8 ± 29.3	27.4 ± 14.3	1.0	74/22/4	24	5	14/63/23	1 (1)
SM 4	107	8	–	0.5	–	yes	15	181.5 ± 57.8	31.6 ± 12.8	1.1	37/37/26	6	6	100/0/0	6 (4)
SM 5	106	8	–	0.6	–	yes	15	148.3 ± 44.9	25.0 ± 12.6	1.0	51/37/12	0	0	100/0/0	0 (0)
SM 6	112	8	–	–	0.20	yes	15	178.8 ± 50.2	30.3 ± 10.9	1.2	77/17/6	7	6	100/0/0	10 (6)
SM 7	105	9	–	0.7	–	yes	15	143.7 ± 73.4	20.4 ± 13.2	1.0	30/54/16	7	0	100/0/0	0 (0)
SM 8	116	9	–	0.5	–	yes	15	217.5 ± 62.9	31.6 ± 13.8	1.1	90/10/0	0	0	97/3/0	5 (5)
SM 9	108	11	–	0.6	–	yes	15	255.7 ± 56.7	35.0 ± 10.0	1.0	81/19/0	0	3	100/0/0	0 (0)

valuated by the percentage of trees occurring in the respective stands.

RESULTS AND DISCUSSION

The substitute species stands (Tables 1 and 2)

The surveys showed that the average height of plantations in the Krušné hory Mts. is lower than the average height of coeval plantations in the Bohemian-Moravian Upland. The difference is apparent in all research plots in the plantations of up to 7 years (with the exception of SSS 9). The growth dynamics of plantations is added the parameter of terminal shoot increment in 2006. Apparent is a great difference especially in the increment of the youngest plantations. Plants in the Krušné hory Mts. suffer from a great transplant shock that shows in the suppressed increment, impaired vitality and sometimes even in the drying of terminal bud or terminal shoot. The transplant shock persists in the plants 3 to 4 years, which results in an obvious height difference between the coeval plantations in the two compared regions. Nevertheless, the height increment of plants becomes gradually equalized with the increasing age and plantations of 6 and 7 years exhibit a comparable increment, which is even higher on some research plots in the Krušné hory Mts.

The general trend of the growth of beech plantations in the reconstruction of substitute species stands and on the control plots in the Bohemian-Moravian Upland is illustrated in Fig. 1. High determination coefficients R^2 (0.9439, 0.9258, 0.9138) document a very tight dependence of the increment on the age of plantations. The diagram shows that from the age of 4 years the beech plantations in the Krušné hory Mts. equal in their growth with the underplanted beech in the Bohemian-Moravian Upland, and from the age of 7 years, they catch up even with the beech planted in the Bohemian-Moravian Upland on the narrow cutting faces. In the Bohemian-Moravian Upland, the beech plantations on the narrow cutting faces do better than the underplanted beech. In the Krušné hory Mts., the planting of beech on clear-felled areas represents a higher risk of damage by late frost, which results in a generally retarded growth (e.g. Plot SSS 4).

Transplant shock and suppressed increment in the first 3–4 years are typical of most beech plantations in the Krušné hory Mts. regardless of the species composition of substitute species stands, their stocking and site preparation. The transplant shock induces colour changes and the size of assimilatory tissues becomes much reduced. Plantations up to 3 years exhibit a higher percentage of yellowish to yellow plants. Kriegel (2002b) arrived at similar conclusions in his surveys on plots with the former whole-area soil preparation. According to this author, the reason may be a physiological injury of transplants or a major change of site conditions during the air pollution disaster. The prolonged transplant shock of plants may also originate from using improper plant-

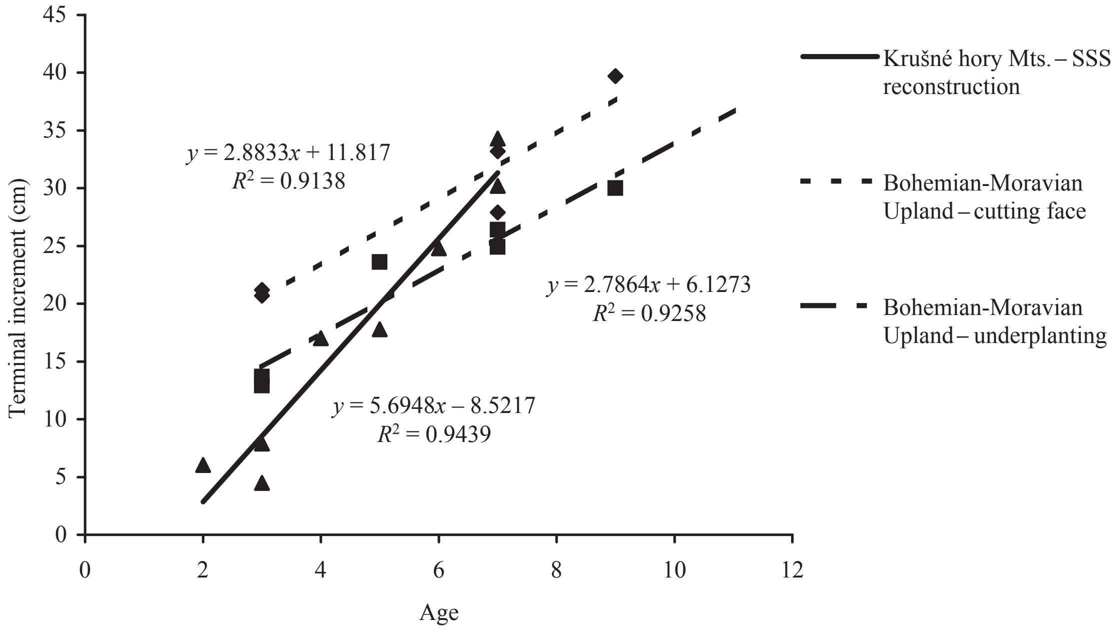

Fig. 1. Comparison of average terminal increment of beech in the Krušné hory Mts. (reconstruction of stands of substitute tree species) and in the Bohemian-Moravian Upland in 2006 (regression equations with determination coefficient)

Table 2. Control plots in the Bohemian-Moravian Upland – characteristics of analyzed plots, loss, growth of aboveground parts, damage

Variant											Damage (in % of plants)			
Plot No.	No. of plants	Age	Underplantings (stocking)	Clear-cut (ha)	Fencing	Total loss until 2006 (%)	Total aboveground height (cm)	Terminal shoot increment (cm)	Vitality	Stem form (straight/fork/multiple) (%)	Terminal browsing	Dry terminal	Frost damage (degrees 0/1/2)	Damage by rodents (of it deg. 2)
K 1	115	3	–	0.20	yes	10	89.3 ± 21.8	21.2 ± 13.9	1.0	74/25/1	3	6	100/0/0	17 (1)
K 2	100	3	–	0.40	yes	10	66.7 ± 15.6	20.7 ± 9.3	1.0	80/19/1	5	0	100/0/0	12 (1)
K 3	98	7	–	0.25	yes	20	186.7 ± 53.9	33.2 ± 10.5	1.3	83/17/0	12	4	100/0/0	70 (19)
K 4	101	7	–	0.40	yes	15	187.3 ± 42.1	27.9 ± 11.9	1.2	74/23/3	3	4	100/0/0	39 (21)
K 5	100	9	–	0.20	yes	20	227.4 ± 73.1	39.7 ± 16.1	1.2	75/21/4	8	5	100/0/0	24 (3)
K 6	125	3	0.5	–	yes	5	70.7 ± 14.8	12.9 ± 7.9	1.0	89/11/0	1	11	100/0/0	22 (1)
K 7	101	3	0.5	–	yes	10	74.3 ± 14.5	13.7 ± 7.8	1.0	92/8/0	1	13	100/0/0	5 (0)
K 8	100	5	0.5	–	yes	20	106.3 ± 29.5	23.6 ± 7.8	1.0	70/28/2	5	0	100/0/0	10 (1)
K 9	102	7	0.5	–	yes	15	121.4 ± 51.6	24.9 ± 8.4	1.2	73/26/1	1	2	100/0/0	15 (0)
K 10	101	7	0.5	–	yes	20	137.3 ± 42.1	26.4 ± 10.7	1.2	58/26/16	5	9	100/0/0	35 (22)
K 11	101	9	0.5	–	yes	20	153.8 ± 54.2	30.0 ± 16.9	1.1	85/13/2	1	9	100/0/0	17 (8)

ing stock and inappropriate biotechnics of planting (Mauer, Hobza 2006). Older plantations exhibited colour changes of their assimilatory tissues only rarely. Research plots on which a higher percentage of plants damaged by small rodent nipping was recorded are an exception.

Plants in the Bohemian-Moravian Upland overcome the transplant shock relatively soon, which can be documented not only by the higher value of terminal shoot increment in the youngest plantations but also by the demonstrably better vitality (high percentage of green plants). Worse vitality values in older plantations are again resulting from the excessive damage to plants by rodent nipping.

Damage to terminal bud or shoot is a serious injury which may result in changes of the stem and crown form and in general growth retardation. The hoofed game causes damage particularly to the plants in unfenced plots while the plants in fenced plots are most injured by the hare. In some localities, the browsing of terminal becomes a limiting factor to the successful growth of beech plantations. Drying of terminal bud, and in the worse case even of a part of terminal shoot, is observed most frequently in the youngest plantations – being also an accompanying phenomenon of the transplant shock. Late frosts in the spring of 2006 caused also the drying and fall of immature shoots. The youngest plantations in the Krušné hory Mts. exhibit the plant terminal drying more frequently than those in the Bohemian-Moravian Upland.

Late frost injuries that may cause retarded growth of plantations in the Krušné hory Mts. were not observed in the Bohemian-Moravian Upland. It follows from the results that the stands of substitute tree species can function as an effective ecological shelter against the complex of microclimatic stresses and soften down injuries induced by late frost in the underplanted beech. Most severe late frost injuries occur on large or insufficiently sheltered clear-felled areas (Plot SSS 3, Plot SSS 4, Plot SSS 10). High percentage of undamaged plants occurs in the beech underplanting in the reconstructed birch stands of higher stocking (Plots SSS 8 and SSS 9). The stand of blue spruce also provides ecological protection to the underplanting but its efficiency is lower as compared with the substitute birch stand of identical stocking. Blue spruce creates a narrow crown and its stands are gappier after the same tending measure due to the species lower average height, which facilitates an easy penetration of cold air. Balcar and Kacálek (2001, 2003) similarly concluded that at higher elevations the stands of substitute species can provide an effective ecological shelter against the complex of microclimatic stresses and beech plantations can successfully develop. The favourable influence of the ecological shelter is reflected not only in the increased increment of beech but also in smaller damage to its assimilatory tissues by late frosts (Kriegel 2002b).

Nipping by small rodents is a considerably negative factor in the growth of beech plantations. Most injured plants (damage degree 2) have typically suppressed increment and drying out crowns, which may lead to plant kill. The high population density of rodents in some localities markedly slows down the growth of beech plantations both in the Krušné hory Mts. and in the Bohemian-Moravian Upland, and no pronounced differences were found between the two surveyed regions.

The existing Norway spruce stands
(Tables 1 and 2)

The assessment of the average height of underplanted beech in the Krušné hory Mts. exhibited a great variety of results on individual plots. The pronounced heterogeneity is shown in Fig. 2, which compares the average terminal shoot increment in the two regions. The linear regression line fitted with the data has a lower determination coefficient R^2 (0.4885), which points to a lower dependence of increment on the age of plantations. Worse growth parameters of some plots result particularly from the repeated game damage (Plots SM 1, SM 2 and SM 3). On some plots, the underplanting exhibits higher heterogeneity in dependence on the stand situation (effect of stocking on the prosperity of underplanting).

If the impact of game is not taken into account, it is possible to state that the height increment of underplanting becomes equal in the two localities from the age of 7 years. Differences exist only if comparing the increment of underplanting in the Krušné hory Mts. and plantations growing on clear-cut faces in the Bohemian-Moravian Upland. Older underplanting exhibits a negative influence of higher stocking on its growth as exemplified on Plot SM 8 (original stocking 0.5), which exceeds the coeval Plot SM 7 (stocking 0.7) both by total height and by increment. Plot SM 8 exhibits even a marked growth response of the underplanting to release in 2006 (stocking reduced from 0.5 to 0.2). In releasing the underplanting it is however necessary to consider a risk that plants in the Krušné hory Mts. are much more exposed to late frosts than those on cutting faces in the Bohemian-Moravian Upland and they may therefore experience considerable damage (e.g. Plot SM 3).

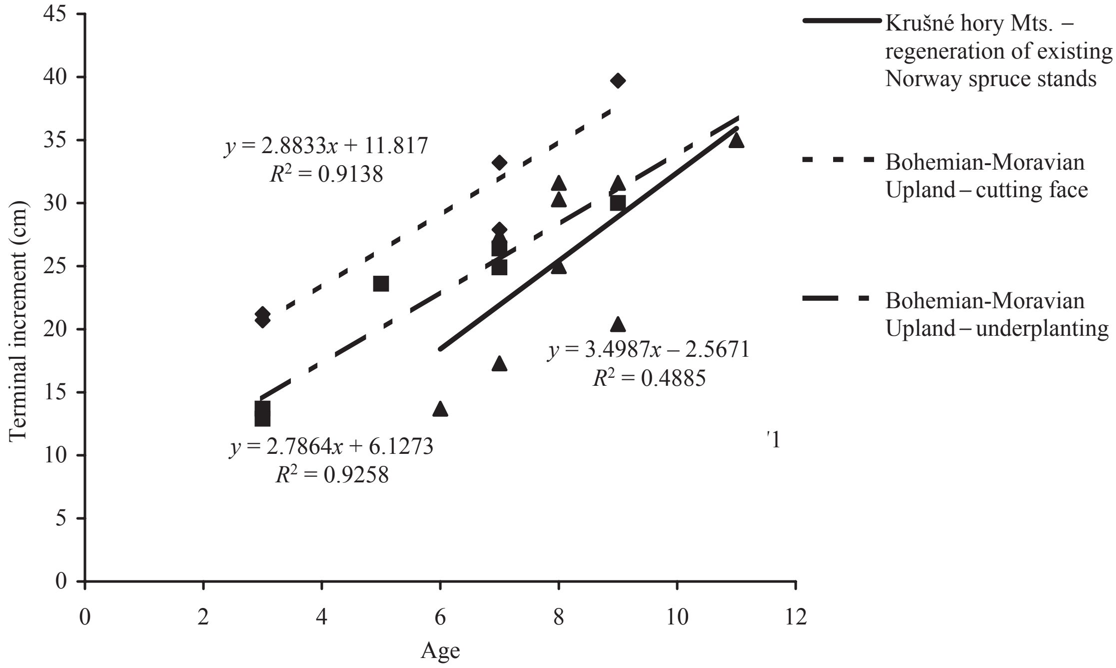

Fig. 2. Comparison of average terminal increment of beech in the Krušné hory Mts. (existing Norway spruce stands) and in the Bohemian-Moravian Upland in 2006 (regression equations with determination coefficient)

Hering and Irrgang (2005) also sought an optimum stocking of spruce stands for the successful growth of underplanted beech. Their research results indicate that light requirements of underplanted beech markedly increase from the elevation of 500 m a.s.l. and an optimum stocking for the altitude of 750 m a.s.l. is ranging from 0.3 to 0.4.

The situation in the assessment of underplanting vitality is similar like in the stands of substitute species. The colour changes of assimilatory tissues were not monitored from the age of 6 years with the exception of plots with a higher percentage of plants damaged by nipping of small rodents.

A considerable difference between the stands of substitute species and the existing stands of Norway spruce is in their possible influencing the negative impact of late frosts. Similarly like in the control plots of the Bohemian-Moravian Upland, no damage due to late frost was observed in the spruce stands of Krušné hory Mts. either. It follows from the survey that Norway spruce stands with a stocking of 0.5–0.6 and average height above 10 m have a more favourable ground microclimate and can eliminate the damage. Exceptional in this respect is Plot SM 3, in which the existing Norway spruce stand was completely extracted and damage due to late frost was observed on the newly created clear-cut as early as in the following spring. Differences in the temperature regime of clear-felled areas and under the maturing stand of Norway spruce were also corroborated by Lokvenc and Vacek (1991) and Kriegel (2002c) in their research works from the Orlické hory Mts. The greatest variances were found near the soil surface. While the clear-cut exhibited 95% of beech individuals injured by extreme late frosts (–6°C), there were only 17% of damaged plants under the stand. The same authors point also to mechanical injuries caused by falling snow and rime from tree crowns; these types of damage did not occur on our experimental plots.

Browsing is again the most serious damage to terminal bud or shoot. In spite of the fact that all plots are fenced, wild animals often find the way to get into the fenced area and the beech underplanting is repeatedly devastated by browsing. Moreover, it is exactly the browsing that most affects the stem form and its development in the following years. Some plots display as many as 50% of plants in which deviations were recorded from the normal cylindrical stem form while the drying up of terminal bud or shoot hardly occurred at all.

Although the damage due to small rodents (stem nipping) occurs in the beech underplanting of spruce stands, it is not so severe as in some SSS plots or in control plots situated in the Bohemian-Moravian Upland. Maximum damage of 15% was recorded in Plot SM 2. On the other hand, no damage by nipping occurred in three stands at all. The fact may be explained by a much lower weed infestation of these stands and therefore less favourable conditions for rodents to settle down in winter. Similarly, Kriegel (2002b) informed that rodents could find ideal living conditions in a continuous sward layer.

CONCLUSIONS

Growth dynamics of 11 European beech plantations established during the reconstruction of substitute species stands and 9 European beech plantations established in the regeneration of existing Norway spruce stands was studied in the air polluted region of the north-eastern Krušné hory Mts. Results were compared with the growth of 11 coeval beech plantations in the unpolluted region of the Bohemian-Moravian Upland.

Conclusions drawn from the survey about the use of European beech in the reconstruction of substitute species stands in the north-eastern Krušné hory Mts. are as follows:

– European beech can at present be fully used for the reconstruction of substitute stand species.
– In the first years after planting, the plants exhibit smaller increments and their vitality is also affected adversely. The transplant shock persists up to 3 years. With the growing age, the height increment of plants is increasing; in 6- and 7-years old plantations, it is already comparable with the increment of plants growing in unpolluted regions, being even greater in some research plots in the Krušné hory Mts.
– Damage to terminal bud or terminal shoot (more than 30% of injured plants in some stands) considerably contributes to the general growth retardation of plantations in the Krušné hory Mts. The injuries are caused by wildlife, late frost, and in the youngest plantations by drying up due to the transplant shock.
– The continuous sward cover provides ideal conditions for colonization by small rodents. Nipping of young stems and branches leads to the drying up of the crown and to reduced increment, which slows down the growth of plants (some stands exhibiting up to 50% of injured plants).
– The stands of substitute species can effectively soften down injuries caused by late frosts. From this aspect it appears essential to retain a higher stocking at launching the reconstruction and not to reduce it markedly in the following years (until the beech grows out from the impact of late frost). The stands of birch represent a more effective ecological shelter against late frosts than the stands of blue spruce of the same stocking.

Conclusions drawn from the survey about the use of European beech in the regeneration of existing Norway spruce stands in the north-eastern Krušné hory Mts. are as follows:

– European beech can at present be fully used in the regeneration of existing Norway spruce stands.
– From 7 years of age, the growth dynamics of underplanting in the Krušné hory Mts. equals with the growth dynamics of underplanting in unpolluted regions. However, differences still exist in the height of plants underplanted in the Krušné hory Mts. and the plants growing on narrow cutting faces in the unpolluted region of Bohemian-Moravian Upland, the reason being insufficient light available to the underplanting.
– Beech underplanting in the existing spruce stands does not show either impaired vitality at the age of 6 years or increased drying up of the terminal bud or shoot. However, browsing by hoofed game and hare considerably affects the growth of plantations.
– Damage by small rodent nipping is lower because the stands of Norway spruce are less infested by weeds and do not provide ideal living conditions for the animals.
– The existing stands of Norway spruce can eliminate late frost damage and create a favourable ground microclimate for the underplanting. Advantageous in this respect appears to be the latest possible release of the underplanting (even at a cost of decreased increment due to the insufficient access of light).

The current climatic conditions and the air-pollution situation in the north-eastern Krušné hory Mts. make it possible to switch to the normal (shelterwood) beech management system of higher and mountain elevations.

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Současné uplatnění buku lesního (*Fagus sylvatica* L.) při umělé obnově lesa v imisních oblastech

ABSTRAKT: Příspěvek se zabývá uplatněním buku lesního při rekonstrukcích porostů náhradních dřevin a obnově současných smrkových porostů v imisní oblasti severovýchodních Krušných hor (pásmo ohrožení A, B, 6. a 7. lesní vegetační stupeň, kyselá stanoviště). Analyzováno bylo celkem 20 porostních situací. Cílem bylo porovnat odrůstání kultur buku lesního v Krušných horách s odrůstáním stejně starých kultur na obdobných stanovištích v neimisní oblasti Českomoravské vrchoviny (pásmo ohrožení C, D, 6. lesní vegetační stupeň, kyselá stanoviště). U každé rostliny bylo hodnoceno osm růstových a vizuálně hodnocených parametrů a znaků. Výsledky šetření ukázaly, že v současné imisní a klimatické situaci lze v oblasti severovýchodních Krušných hor přejít na normální (podrostní) bukové hospodářství vyšších poloh. Porosty náhradních dřevin i stávající porosty smrku ztepilého mohou účinně eliminovat poškození vyvolaná pozdními mrazy.

Klíčová slova: buk lesní; porost náhradních dřevin; rekonstrukce; podrostní hospodářství

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