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Current possibilities of using Norway spruce (*Picea abies* [L.] Karst.) in forest regeneration in the air-polluted region of the northeastern Krušné hory Mts.

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ABSTRACT: The paper analyses possibilities of repeated use of Norway spruce (*Picea abies* [L.] Karst.) in the regeneration of existing Norway spruce stands, in the regeneration of large-area clearcuts, and in the reconstruction of the stands of substitute tree species (European white birch [*Betula verrucosa* Ehrh.]) after a change in the emission situation in the northeastern Krušné hory Mts., comparing the prosperity of these plantations with plantations in the unpolluted Bohemian-Moravian Upland. The survey included 26 research plots aged 1–12 years, situated predominantly on acidic sites in Forest Altitudinal Vegetation Zones (FAVZ) 6 and 7 in the northeastern Krušné hory Mts. (air pollution damage zones A and B) and 6 control plots aged 4–11 years on acidic sites of FAVZ 6 in the Bohemian-Moravian Upland (air pollution damage zone C). Total number of parameters and traits assessed in each tree was up to 14. Research results indicate that the current pollution and climatic situation in the Krušné hory Mts. allow a switch to the classical spruce management system of higher elevations. The best method of regeneration is seen in small-size regeneration elements – clearcuts of up to 1 ha. The spruce can also be used on large-area clearcuts, but it suffers from a long transplanting shock and frost injuries there. All plantations must be protected against game damage.

Keywords: air pollution; forest regeneration; Norway spruce; clearcuts; reconstruction of stands of substitute woody species

The pollution and ecological status of the Krušné hory Mts. was gradually worsening in the period from the turn of the 19th and 20th century to the early 1990s (Materna 1988; Vala 1988; Kubelka et al. 1992). Damage culminated at the turn of the 1970s and 1980s when a massive dieback occurred in Norway spruce. As to forest management measures, characteristic was a transition from small-scale management to large-scale measures, which was brought about by new technologies and procedures in soil preparation and reforestation. Krečmer (1982) pointed to profound and specific changes of bioclimatic processes following the elimination of mountain spruce stands such as changed radiation status (change of the albedo, pronounced cooling at night, development of frost lakes), increased soil water supply and changed air flowing due to the change in terrain roughness.

Great losses in reforestation led to the elimination of main commercial tree species from the regeneration objectives. Artificial stands of Norway spruce and silver fir totally failed (Bradáč 1986).

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In contrast, European beech was considered a species considerably tolerant to air pollution, its use was however made impossible due to the climatic extremity of extensive clearcuts (Šindelář 1982; Tesař 1985). Thus, new species started to be used in the changed air-pollution and ecological conditions in addition to the European white birch and European mountain ash such as spruce and pine exotic species, European larch and mountain pine. Their stands are referred to as the stands of substitute species (SSS). In the 1970s and 1980s, more than 30,000 ha of SSS were established in the region concerned.

Since the coming into existence of the stands of substitute species, an emphasis has been put on their soil-protective function and water-management role. Mauer and Tesař (1998) stated that the stands of substitute species had fulfilled expected functions and that the regeneration of large-scale clearcuts would have failed without them. However, some SSS show decreased vitality in the course of cultivation and dynamically worsening general health condition. A considerable share in the impaired vitality is attributable to biotic agents and namely to the technologies of carried out works – e.g. whole-area soil preparation with the removal of humus and overlaying soil horizons (Jirgle 1982; Mauer et al. 2005).

Currently existing adult or juvenile stands are used only to a limited extent for regeneration by underplanting or undersowing both in this country and abroad. This is due to experience gained from the regeneration under shelterwood whose virtue is – as compared with the regeneration of even-aged stands – a more favourable microclimate, vegetation status and cycling of nutrients (Greguš 1976). In air-polluted regions, it is useful to underplant in advance so that young plantations of more tolerant species are already established in case that the stands are severely affected by air pollution (Plíva 1987; Lokvenc, Vacek 1993; Schwartz 1997). It was found out that a disintegrating stand has a favourable effect on reducing wind velocity, on counterbalancing temperature oscillations, it slows down snow melting, reduces ground storey coverage etc. (Lokvenc, Vacek 1991a).

The height growth of artificial crops from the 1990s underplanted in dying stands and on clearcuts in the Krušné hory Mts. essentially differed at juvenile stage. The height growth differentiation began to show only after 4 or 5 years of cultivation when the plants passed over the shock induced by transplanting. Mortality was higher in the underplanted crops than in the young plantations on clear-felled areas (Kriegel 2002). In the majority of cases, the plantations of individual species reached lesser mean heights and biomass weights under the stand than on the clearcut, and the recorded cumulative damage to trees was greater under the stand than on the clearcut. The highest values of contaminants were found in the snow sampled in tree crowns (snow and frost), under crowns, and the lowest values were detected on the clearcuts (Lokvenc, Vacek 1991a,b).

The goal of this paper was to assess the current state, prosperity and damage to the planted and underplanted Norway spruce in the air-polluted region of the northeastern Krušné hory Mts. in various stand situations, and to compare the condition of young Norway spruce plantations and younger stands growing on similar sites and in similar stand situations in the air-polluted region of the Krušné hory Mts. and in the unpolluted region of the Bohemian-Moravian Upland.

MATERIAL AND METHODS

- Research plots were established on properties under the management of Forests of the Czech Republic, Ltd. (Lesy České republiky, a. s.). A total of twenty-nine young plantations and stands aged 1–12 years were analyzed in the Krušné hory Mts. in various stand situations. The number of control young plantations and stands of corresponding age assessed in the Bohemian-Moravian Upland was six (characteristics of research plots see Table 1).
- All measurements were done in 2006.
- The losses recorded before 2006 were computed using the number of plants set out per hectare and area of the study site.
- The research plots were marked with the following codes:
  - Clearcuts: H-3-0.11 (Clear-felled areas – Age [3 years] – Area [0.11 ha]);
  - Underplanting of existing Norway spruce stands: P-6-0.5 (Underplanting – Age [6 years] – Stand density [0.5]);
  - Underplanted birch (SSS reconstruction): RB-7-0.3 (Reconstruction of birch – Age [7 years] – Stand density [0.3]);
  - Control Bohemian-Moravian Upland:
    - KH-6-1.4 (Clear-felled area control – Age [6 years] – Clearcut size [1.4 ha]);
    - KP-8-0.5 (Underplanting control – Age [8 years] – Stand density [0.5]);
- Forest type groups:
  - Number = Forest Vegetation Zones (8 = spruce, 7 = spruce with beech, 6 = beech with spruce);

Table 1. Characteristics of research plots, total height, increment, vitality, stem and crown shape, damage to plants

Stand situation	Plot code	Forest type group	Air pollution damage zone	Clearing (ha)	Under-planting		Fencing	Total mean height (cm)	Mean increment 2006 (cm)	Losses since 2006 (%)	Vitality	Crown shape	Stem shape (in % of trees)						Damage to plants (in % of trees)									
					Stocking	Stand height (m)							Straight 06	Forked stem 06	Multiple 06	Straight older	Forked stem	Multiple older	Undamaged	Terminal browsing	Dry top	Lateral browsing	Frost	*Hylobius*	*Adelges*	Chlorosis	Defoliation	Transplanting shock
Regeneration of small-scale clearings	H-1-1.00	7K	A	1.00	–	–	no	31.6 ± 6.6	7.2 ± 3.6	14	2.0	1.0	100	0	0	100	0	0	26	22	3	0	3	58	0	0	0	11
	H-2-1.00	6K	B	1.00	–	–	no	57.9 ± 12.4	3.9 ± 3.9	12	1.3	1.0	76	5	19	100	0	0	55	12	5	2	0	0	0	24	0	14
	H-3-0.11	7K	A	0.11	–	–	no	39.6 ± 9.1	9.0 ± 5.0	6	1.1	1.2	78	17	5	90	7	3	50	30	3	14	19	0	2	0	0	0
	H-3-0.06	7K	A	0.06	–	–	no	36.2 ± 10.2	9.5 ± 4.9	8	1.2	1.1	92	6	2	67	21	12	62	18	3	9	19	0	0	0	0	0
	H-7-0.38	7K	A	0.38	–	–	yes	241.1 ± 50.9	59.7 ± 16.2	5	1.0	1.0	94	4	2	95	4	1	66	0	3	0	10	0	23	0	0	0
	H-8-0.22	6S	B	0.22	–	–	yes	265.5 ± 17.4	57.4 ± 17.4	7	1.0	1.0	100	0	0	96	4	0	47	1	3	6	0	0	49	0	0	0
	H-7-0.66	6S	B	0.66	–	–	no	172.7 ± 43.7	49.2 ± 18.2	2	1.0	1.6	84	11	5	50	34	16	68	11	0	19	0	0	9	0	0	0
	H-10-1.00	7K	A	1.00	–	–	yes	190.8 ± 66.5	43.2 ± 20.5	4	1.0	1.0	93	6	1	93	8	0	55	9	5	10	28	0	0	0	0	0
Regeneration of large-scale clearings	H-4-5.58a	7K	A	5.80	–	–	no	59.1 ± 11.0	12.1 ± 5.2	15	1.0	2.9	73	16	13	76	9	15	20	43	11	39	47	0	0	0	0	0
	H-4-5.58b	7K	A	5.80	–	–	yes	64.0 ± 16.6	13.5 ± 6.2	14	1.1	2.4	74	23	6	74	17	9	37	0	23	14	54	20	0	0	0	0
	H-9-2.10	7K	A	2.10	–	–	no	131.0 ± 27.9	31.2 ± 15.4	12	1.0	2.6	53	32	16	15	15	69	15	22	20	19	78	0	0	0	0	0
	H-9-3.40	8G	A	3.40	–	–	no	166.9 ± 42.9	42.3 ± 17.9	6	1.2	2.9	79	10	11	45	29	25	25	25	17	41	62	0	0	0	0	0
	H-10-5.30	8G	A	5.30	–	–	no	217.3 ± 73.6	50.2 ± 21.7	15	1.0	1.3	81	9	9	47	41	12	38	3	11	21	80	0	0	0	0	0
	H-12-10.00a	7K	A	10.00	–	–	yes	224.2 ± 92.6	42.8 ± 22.4	12	1.0	1.1	96	2	2	76	21	2	19	17	7	34	50	0	21	0	0	0
	H-12-10.00b	7K	A	10.00	–	–	no	112.1 ± 41.6	24.1 ± 17.8	14	1.0	3.7	50	14	38	50	42	10	0	66	0	76	64	0	8	0	0	0
	H-12-10.00c	7R	A	10.00	–	–	no	143.0 ± 53.1	29.4 ± 17.7	15	1.0	3.5	72	13	16	9	26	65	13	26	1	64	84	0	0	0	0	0
Underplanting of present stands spruce	P-6-0.5	7R	B	–	0.5	11	no	81.1 ± 16.9	11.1 ± 6.5	8	1.0	1.2	93	3	4	48	22	30	57	7	2	6	0	0	0	0	33	0
	P-6-0.4	7K	A	–	0.4	10	no	85.7 ± 32.7	13.7 ± 8.5	5	1.0	1.0	98	0	2	93	6	1	90	8	2	4	0	0	0	0	0	0
	P-9-0.3	7K	A	–	0.3	16	yes	297.4 ± 90.5	58.7 ± 20.0	2	1.0	1.0	97	0	3	96	4	0	79	0	1	0	20	0	2	0	0	0
	P-10-0.7	7K	A	–	0.7	15	yes	107.7 ± 34.6	16.6 ± 7.8	9	1.0	1.0	99	1	0	96	3	1	86	3	7	2	6	0	0	0	0	0

Table 1 to be continued

Stand situation	Plot code	Forest type group	Air pollution damage zone	Clearing (ha)	Under-planting		Fencing	Total mean height (cm)	Mean increment 2006 (cm)	Losses since 2006 (%)	Vitality	Crown shape	Stem shape (in % of trees)						Damage to plants (in % of trees)									
					Stocking	Stand height (m)							Straight 06	Forked stem 06	Multiple 06	Straight older	Forked stem	Multiple older	Undamaged	Terminal browsing	Dry top	Lateral browsing	Frost	*Hylobius*	*Adelges*	Chlorosis	Defoliation	Transplanting shock
Reconstruction of stands underplanting birch	RB-3-0.5	7K	A	–	0.5	10	no	71.0 ± 15.5	22.0 ± 8.6	14	1.1	1.3	85	9	6	92	8	1	65	6	9	11	34	0	0	0	0	0
	RB-5-0.5	7K	A	–	0.5	12	no	115.1 ± 20.7	21.8 ± 7.5	9	1.0	1.1	96	4	0	84	8	7	72	6	8	2	44	0	0	0	0	0
	RB-3-0.3	8G	B	–	0.3	7	no	71.1 ± 12.6	17.8 ± 8.2	8	1.0	1.3	83	15	2	92	3	5	55	13	14	7	32	0	0	1	0	0
	RB-5-0.3	7K	A	–	0.3	7	yes	154.6 ± 55.3	36.3 ± 17.2	15	1.0	1.1	95	5	1	97	2	1	76	0	1	0	35	0	2	0	0	0
	RB-6-0.4	7K	A	–	0.4	5	yes	164.9 ± 44.9	39.3 ± 16.6	9	1.0	1.0	92	7	1	93	5	2	43	0	4	0	74	0	0	0	0	0
	RB-7-0.4	7K	A	–	0.4	5	yes	166.0 ± 52.6	35.5 ± 15.8	7	1.1	1.0	97	3	0	92	6	2	70	2	0	0	27	0	4	0	0	0
Inspection Bohemian-Moravian Upland	KH-6-1.4	6K	C	1.40	–	–	no	159.6 ± 43.3	46.3 ± 15.2	4	1.1	1.0	93	4	3	82	16	1	66	1	4	32	0	0	0	0	0	0
	KH-8-0.05	6K	C	0.15	–	–	no	193.9 ± 53.0	44.3 ± 16.7	5	1.0	1.0	93	3	4	70	28	1	81	1	1	10	0	0	0	0	0	0
	KH-11-0.10	6K	C	0.56	–	–	no	451.0 ± 71.8	72.2 ± 15.9	12	1.0	1.0	97	0	3	95	5	0	100	0	0	0	0	0	0	0	0	0
	KP-4-0.5	6K	C	–	0.5	25	no	75.8 ± 17.1	26.6 ± 10.7	5	1.0	1.0	93	7	0	97	3	0	91	6	1	2	1	0	0	0	0	0
	KP-8-0.5	6K	C	–	0.5	25	no	243.1 ± 57.7	51.0 ± 23.3	10	1.0	1.0	88	10	3	78	19	4	96	0	3	3	0	0	0	0	0	0
	KP-6-0.5	6K	C	–	0.5	24	no	157.4 ± 35.8	41.9 ± 13.0	6	1.0	1.0	88	7	5	77	17	5	85	3	1	12	1	0	0	0	0	0

▨ mechanically drained stand

- Letter = Edaphic categories (K = acidic, S = fresh nutrient-medium, G = nutrient-medium wet, R = peat).

- Each research plot contained a minimum of 100 plants. All plants were measured and assessed for 2 parameters and for up to 12 traits of the above-ground part:
  - *Total height of the above-ground part* – was measured from the ground surface to the tip of the terminal bud. If the terminal bud was damaged, the height was measured up to the terminal bud of the highest-reaching lateral branch, which was likely to substitute the terminal shoot. The height was measured with an accuracy of 1 cm.
  - *Above-ground part increment* – is to express the terminal shoot increment in the growing season. The value was measured with an accuracy of 1 cm.
  - *Vitality* – is to characterize the colour of assimilatory organs (assessed according to colour tables). A 4-grade classification scale was selected as follows: 1 – green, 2 – yellowish, 3 – yellow, 4 – dying.
  - *Stem form 2006* – is to express the shape of the newly accrued part of terminal shoot in the given year. A 3-grade scale was chosen for the stem form classification:

Straight – terminal shoot is not branching and consists of only one shoot.

Fork – terminal shoot splits into two shoots with neither of the two being shorter and smaller in diameter than a half-length or half-diameter of the other shoot.

Multiple – terminal shoot branches into three and more equal shoots of the same diameter.

  - *Older stem form* – is to express the terminal shoot (stem) shape in the previous years. The stem form was classified according to the same 3-grade scale as in Stem form 2006.
  - *Game damage* – each plant was surveyed for terminal and lateral browsing. Terminal browsing was registered in the case of any damage to the terminal shoot; lateral browsing was registered in the case of damage to at least 10% of lateral shoots in a plant.
  - *Frost* – is to characterize damage to assimilatory organs by late frost.
  - *Crown form* – was classified according to a 4-grade scale: 1 – cylindrical stem, regular and symmetrical crown form, relatively regular increments; 2 – relatively cylindrical stem, lateral damage to crown form, relatively regular increments; 3 – profound damage to stem and crown, one of the lateral branches assumed the position of terminal shoot; 4 – profound damage to stem and crown, obscure terminal shoot (bonsai shaped plant).
  - *Dry top* – was registered in the case that the terminal bud/shoot had dried out due to reasons other than game browsing.
  - *Gall aphid* – damage to plants by gall aphids of the genus *Sacchiphantes*. The injuries were registered if a minimum of three galls occurred on one plant.
  - *Chlorosis* – assessment was made of needle colour change. Registered were those cases in which more than 20% of needles on one plant exhibited damage.
  - *Pine weevil* – damage due to the pine weevil (*Hylobius abietis*).
  - *Transplanting shock* – the size of the assimilatory apparatus was conspicuously reduced in the year concerned.
  - *Defoliation* – was registered if a minimum loss of 20% needles occurred on one plant.
- Vitality and crown form are expressed as arithmetic means; the other traits were classified according to the percentage of tree occurrence on the respective plots.
- The surveyed plots had not been improved.
- Exponential and/or linear smoothing of total heights and increments on the control plots (Figs. 1–4) was constructed using the regressive measurement of total heights and increments by individual whorls.
- Young spruce plantations suffer from a relatively long transplanting shock, which may last up to 4 years. This is why we not only related the assessment of growth parameters to the age of young plantations and underplanted crop but also we made a comparison of research plots in the Krušné hory Mts. with the control plots in the Bohemian-Moravian Upland in order to survey the share of statistically insignificant differences in mean increments in the case of insignificant differences in total mean heights in the same comparison – the height increment in plants of identical height was compared (Table 2). The conformity of total heights was taken as a basis and the share of cases in which the increments agreed was additionally calculated. If the plots agreed only in the total height and the increment in the Krušné hory Mts. was greater, conformity was registered in both parameters. In order to simplify the text, the statistically insignificant difference was marked as conformity.
- The data were processed by Statistica and MS-Excel software. We carried out the analysis of

Table 2. The proportion of statistically insignificant differences in mean increments of terminal shoots in the case of insignificant differences in total mean heights between the Krušné hory Mts. and the Bohemian-Moravian Upland

Plant condition	Small-scale clear-felled areas		Large-scale clear-felled areas		Underplanting of Norway spruce		Underplanting of white birch	
	All plants	Plants without damage to terminal shoots	All plants	Plants without damage to terminal shoots	All plants	Plants without damage to terminal shoots	All plants	Plants without damage to terminal shoots
The number of plots with the same total height of the above-ground part	7	6	6	9	6	6	13	15
The number of plots with the same total height and increment of the above-ground part	3	5	3	4	0	0	3	7
Proportion (%)	**43**	**83**	**50**	**44**	**0**	**0**	**23**	**47**

research data, calculated the correlation analysis, one-factor analysis of variance, Duncan's test of multiple comparison, and the data were fitted by the regression model.

RESULTS AND DISCUSSION

Underplanting in the existing stands of Norway spruce and European white birch

Growth parameters of underplanted crops were conspicuously affected by the stand situation (density) or in other words by available light (warmth). The dependence showed more in underplanting the Norway spruce in which the access of light to plants was lower than in the underplanted birch even at a lower stocking. Curves fitted with mean total heights and increments in dependence on age exhibited a different character according to the underplanted species (Figs. 1 and 2).

In the birch underplanting, mean total heights and increments are comparable with the control plots; in some stand situations, the parameters of young plantations in the Krušné hory Mts. even surmounted those recorded in young plantations growing in the Bohemian-Moravian Upland. The plantations showed 47% of corresponding increments in the case of identical total height with the elimination of plants with the damaged terminal shoot. The share was 23% if all plants were included. The prosperity and health condition of young Norway spruce plantations in birch reconstructions can be considered satisfactory. Game damage was observed only in unfenced young crops – up to 15%. Late frost damage is the only more significant injury that is more conspicuous in younger underplanted crops. It is possible to claim that the rate of damage to underplanted Norway spruce by late frosts is statistically significantly dependent on the stocking of birch stands and that the number of injured plants decreases with the increasing stand density (Kubík 2007).

The smoothing of total heights and increments of underplanting in the current Norway spruce stands is considerably affected by the high degree of area stocking H-10-1.00 (Figs. 1 and 2). Yet the growth characteristics do not reach the same values as in the Bohemian-Moravian Upland. Better access of lateral light into the stands growing in the Bohemian-Moravian Upland (with underplanting realized in marginal parts of the stands) than in the Krušné hory Mts. (with underplanting realized inside the stands) was also a reason for the relative failure of underplanting in the existing spruce stands in the Krušné hory Mts. as compared with the Bohemian-Moravian Upland. The mutual comparison did not show any agreement of increments either in the case of identical total height with all plants included in the comparison or in the case of comparing only plants without the injured terminal shoot. The health condition of underplantings is satisfactory (Table 1) although, as it follows from our assessment, they are under permanent pressure of wildlife, which shows most in

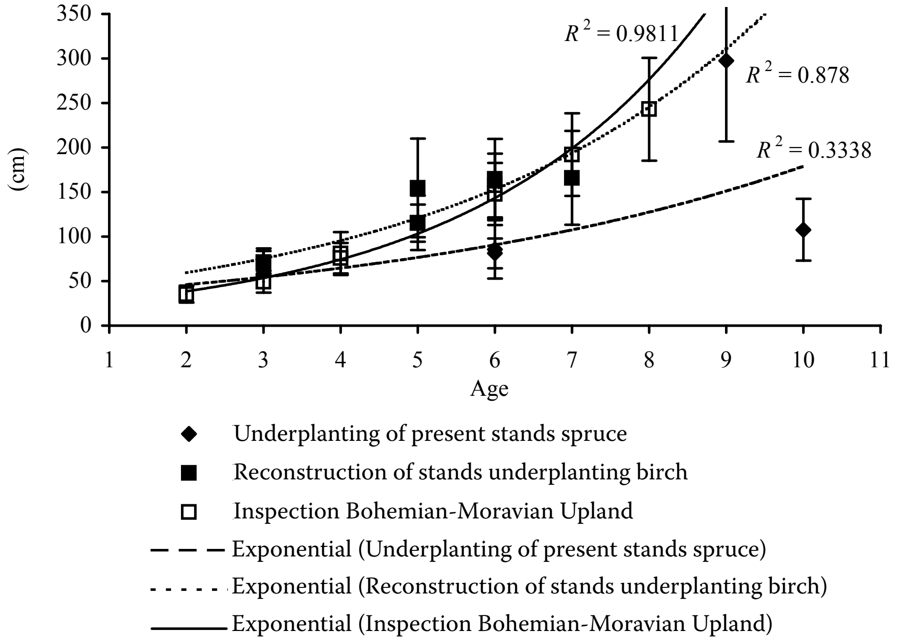

Fig. 1. Total mean height of underplantings, exponential smoothing, height of the above-ground part (cm)

unfenced plantations. Closely related to the damage of terminal shoots by game browsing is also the stem form with the number of older forks and multiple stems increasing in plantations exposed to recurrent severe attacks of game (plots P-6-0.5 and P-6-0.4). Frost damage was recorded only on plot P-9-0.3 (20%). Permanently restricted access to direct radiation may result even in partial defoliation such as was observed e.g. on plot P-6-0.5, where 33% of plants had lost more than a fifth of needles.

Planting on the clear-felled area

Clearcuts were divided into small (up to 1 ha) and large (over 1 ha) clearcuts. The two variants exhibit considerable differences that are best documented by regression models of mean total heights and mean

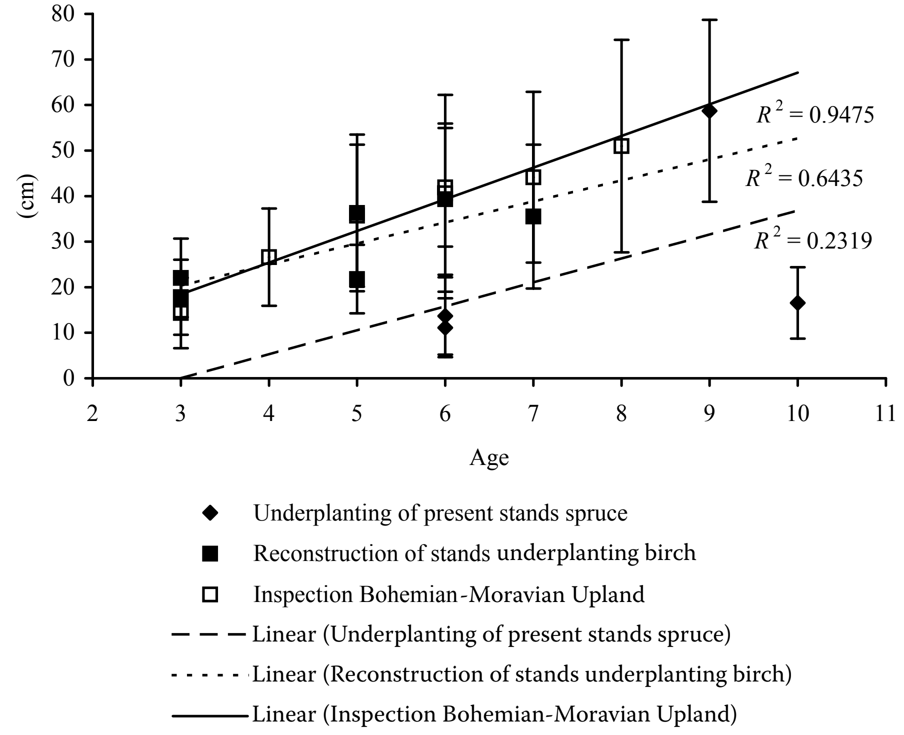

Fig. 2. Mean increment of underplantings in 2006, linear smoothing, increment (cm)

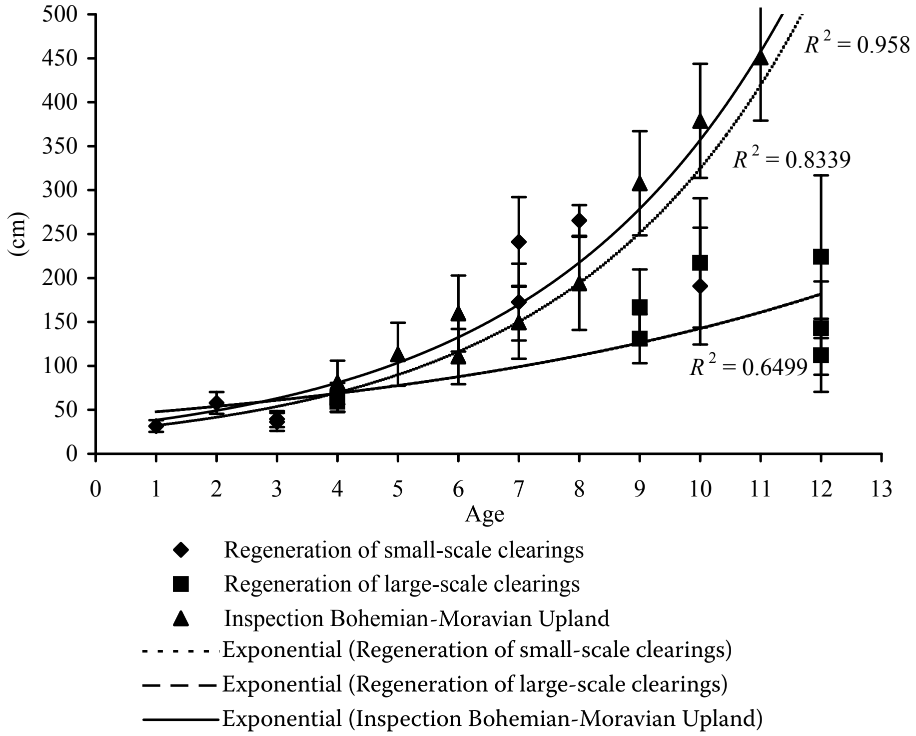

Fig. 3. Total mean height of plantings on clear-felled areas, exponential smoothing

increments (Figs. 3 and 4) where the curve characterizing artificial stands on the large-area clearcuts shows an apparent diversion from curves characterizing the small clearcuts and the control plots, which have a nearly identical course.

The smoothing of total height and increments of planted crops on the large clearcuts has a profoundly flat character namely due to two reasons. The first of them is a permanently decreasing increment in the individual years due to terminal browsing (up to 40%). The second is severe damage to the young plantations by late frosts, i.e. by the phenomenon that is typical of large clear-felled areas in the Krušné hory Mts. By comparing the growth characteristics with the control plots in the Bohemian-Moravian Upland in dependence on the age of artificial stands,

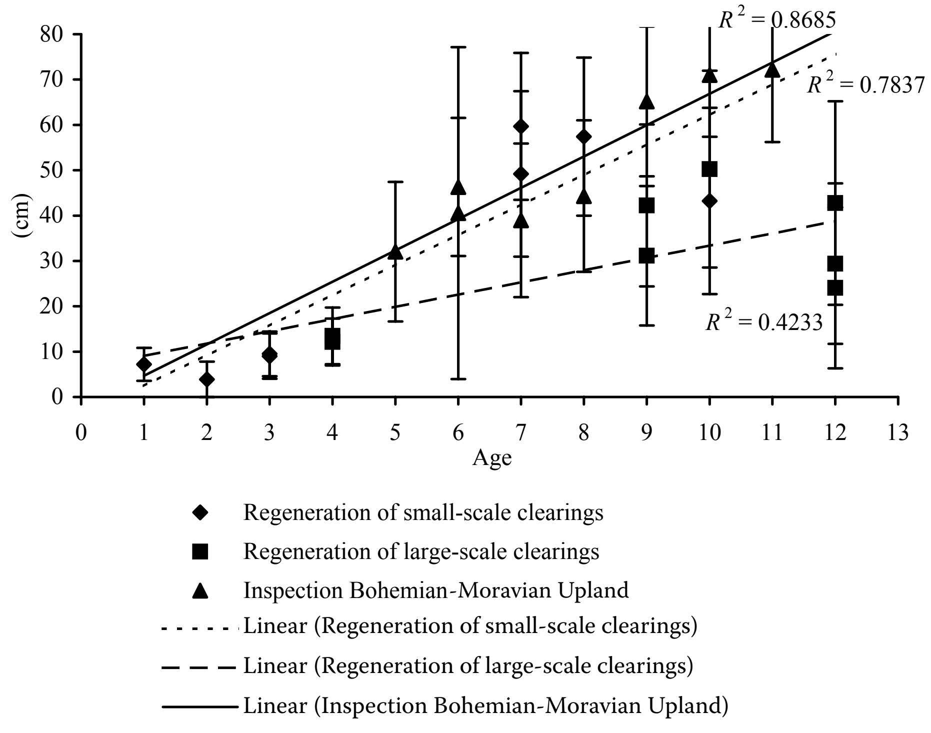

Fig. 4. The increment of plantings on clear-felled areas in 2006, linear smoothing

we found out that neither the total height nor the increments of young plantations in the Krušné hory Mts. achieve the values recorded on the control plots. The young crops on the large clearcuts exhibited a 44% share of corresponding increments in the case of identical height with the elimination of plants with the disturbed terminal shoot while the share was 50% if all plants were included. The game pressure being one of the limiting factors to successful growth of young plantations is documented by malformed stem expressed in the number of older and annual forks and individuals with multiple terminal shoots. Interesting with respect to game damage is a comparison of total height on the neighbouring plots H-12-10.00a and H-12-10.00b, where the difference amounted to more than 1 m notwithstanding the fact that the area in question was originally one plot (H-12-10.00a was fenced only three years ago). The percentage of damage to plants by late frost also reached very high values, which exceeded 80% at some places and resulted in a relatively profound drying out of terminal buds as compared with plants in other stand situations. Damage by frost and lateral browsing dramatically impair the value of crown form and prevailing "bonsai"-shaped plants are no exception at such places (crown form 4).

Comparing the growth parameters of plantations on small-sized clearcuts and on the control plots, we can conclude that the mean total heights on the small clearcuts are copying the mean total heights of young plantations in the Bohemian-Moravian Upland, conspicuously surmounting the mean total heights on the large clearcuts. A similar situation occurs if we compare the mean increments: young plantations on the small clearcuts agree with the control plots (the only variance being young artificial stands due to the transplanting shock) and surmount those on the large clearcuts. The young plantations on the small clearcuts exhibited 83% of corresponding increments in the case of identical total height with the elimination of plants with the disturbed terminal shoot (the agreement of total height and increment was higher than the agreement on the control plots), and with all plants included, the share was 43%. The comparisons related to age as well as to the agreement of total height and increment inform about the good prosperity of plantations on small-sized clearcuts. Results from the comparison of these plantations with the underplanted crops show that the system of regeneration is the best possible with respect to growth parameters. Similarly to growth parameters, the health condition of young plantations depends on their age. Shortly after planting, a relatively dramatic decrease of vitality occurs and the number of intact plants shows a marked drop due to the transplanting shock, which manifests by the growth of small needles and by the chlorosis of older needle years (plots H-2-1.00 and H-1-1.00), lasting up to 4 years. With the increasing age, the number of intact plants becomes stabilized and the symptoms of the transplanting shock gradually fade away. The plantations are most endangered by game browsing and late frosts. Damage due to the browsing of lateral and terminal shoots is bound predominantly to unfenced areas. Damage by late frost is markedly lower than on the large clearcuts. Gall aphid was recorded on plots H-8-0.22 and H-7-0.38.

General evaluation

- Losses did not exceed 15% and 12% in any of the analyzed stands in the Krušné hory Mts. and Bohemian-Moravian Upland, respectively, and they are comparable with losses after spruce planting on other sites and in other stand situations in the Czech Republic. The highest losses in the Krušné hory Mts. were recorded on unfenced large-sized clearcuts, being induced by the planting stock of lower quality, careless planting and impact of game. The vitality of plants is not affected by the current air-pollution situation.
- The predominant group of forest types in the Krušné hory Mts. is 7K. Therefore the majority of the analyzed stands are situated in this GFT. However, our analyses included also some stands on GFT 6K, 6S (in effort to near to the conditions of the Bohemian-Moravian Upland) and stands on the mechanically drained GFTs 7R and 8G. Results show that the growth of Norway spruce in the Krušné hory Mts. on these groups of forest types is identical to that on GFT 7K in the Krušné hory Mts. or on GFT 6K in the Bohemian-Moravian Upland. Nevertheless, the development of spruce on undrained GFTs 7R and 8G calls for a special survey.
- Total height and increment of plantations and stands have an increasing trend, depending on age in all surveyed stand situations (in most of them with a high value of reliability).
- Plantations in the Krušné hory Mts. suffer from transplanting shock relatively long, which may last up to 4 years (small needles, chlorosis of older needle years), the situation being induced by improper biotechnics of planting (Mauer, Hobza 2006).
- Regeneration through small-sized clearcuts appeared to be the most successful method of regeneration. The artificial stands on small-sized

clearcuts did better than the artificial stands in other stand situations in the Krušné hory Mts. and exhibited equal growth parameters and vitality as the control plots in the Bohemian-Moravian Upland in both comparisons (by age and by identical increment at the corresponding total height).

- Neither the total height nor the increments of young plantations on large-sized clearcuts in the Krušné hory Mts. attain the values of control plots, yet the results of the agreement of increment and total height (44% and 50%, respectively) point to the potentially good growth of young plantations. However, these are very severely damaged by late frosts and wildlife as compared with other stand situations.
- The underplanted birch (reconstruction of the stands of substitute species) showed very good results in the comparison of growth parameters with the control plots and other stand situations in the Krušné hory Mts. Damage to the young plantations was moderate, frost damage depended on the density of the underplanted stand.
- The underplanting of existing Norway spruce stands does not reach the level of underplanted European white birch in the assessment of growth parameters. Total height and increment depend on the density of the current stand and do not reach the values recorded on control plots in the two comparisons.
- Young plantations in the Krušné hory Mts. suffer essentially more from game pressure and browsing is a limiting factor of their successful growth (mainly on unfenced plots).

CONCLUSION

The paper evaluates possibilities for a repeated use of Norway spruce in forest regeneration in various stand situations of the air-polluted northeastern Krušné hory Mts. The analyses were focused on the regeneration of existing Norway spruce stands, on the regeneration of large and small clear-felled areas and on the reconstruction of the stands of substitute species (European white birch). The condition of young spruce plantations and stands was compared with the young plantations and stands of identical age growing on similar sites in the unpolluted region of Bohemian-Moravian Upland.

We can state that the young plantations in the Krušné hory Mts. are in general vital. Impaired vitality is observed only in young plantations on large clear-felled areas and in young plantations up to 4 years after planting, which suffer from a relatively severe transplanting shock. Significant differences exist between the respective stand situations in the assessment of growth characteristics. Growth parameters fully comparable with the Bohemian-Moravian Upland were reached by young plantations in reconstructed birch stands (stocking 0.3–0.5) and plantations on clearcuts sized up to 1 ha. Planting in advance under the existing Norway spruce stand (stocking 0.4–0.7) and planting on large clearcuts gave only mediocre results.

In the Krušné hory Mts. artificial stands and underplanted crops are much more damaged by biotic and abiotic harmful factors than in the Bohemian-Moravian Upland. Recurrent game browsing on both terminal and lateral shoots is one of the factors considerably limiting the successful development of young plantations, mainly on unfenced plots. Late frost is an abiotic factor affecting young forest plantations to the greatest extent; its impact on the young forest crops is particularly heavy on large clearcuts; neither is it negligible in the reconstruction of European white birch.

We can conclude that Norway spruce is a species that should find use once again (as a target species) in forest regeneration in the northeastern Krušné hory Mts. The currently existing climatic situation and the amount of emissions in the region make it possible to switch to the classical spruce management of higher elevations. The use of high-quality planting stock, observation of all technological procedures of regeneration and consistent protection of young plantations against game damage are of key importance with respect to the successful growth of young plantations.

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Současné možnosti uplatnění smrku ztepilého (*Picea abies* [L.] Karst.) při obnově lesa v imisní oblasti severovýchodního Krušnohoří

ABSTRAKT: Práce analyzuje možnosti opětovného uplatnění smrku ztepilého (*Picea abies* [L.] Karst.) při obnově stávajících porostů smrku ztepilého, při obnově velkoplošných holin a při rekonstrukcích porostů náhradních dřevin (bříza bělokorá [*Betula verrucosa* Ehrh.]) po změně emisní situace v oblasti severovýchodního Krušnohoří a porovnává prosperitu těchto výsadeb s výsadbami v neimisní oblasti Českomoravské vrchoviny. Do šetření bylo zahrnuto 26 výzkumných ploch ve věku 1–12 let převážně na kyselých stanovištích 6. a 7. LVS v oblasti severovýchodního Krušnohoří (pásmo ohrožení A a B) a šest kontrolních ploch ve věku 4–11 let na kyselých stanovištích 6. LVS na Českomoravské vrchovině (pásmo ohrožení C). U každého stromu bylo měřeno a hodnoceno až 14 parametrů a znaků. Z výsledků vyplývá, že při současné imisní a klimatické situaci lze v Krušných horách přejít na klasické smrkové hospodářství vyšších poloh. Nejlepším způsobem obnovy jsou maloplošné obnovní prvky – holá seč do výměry 1 ha. Smrk lze uplatnit i na velkoplošných holinách, trpí však delším povýsadbovým šokem a škodami mrazem. Všechny výsadby je nutné chránit proti škodám zvěří.

Klíčová slova: imise; obnova lesa; smrk ztepilý; holiny; rekonstrukce porostů náhradních dřevin

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