Effect of initial height of seedlings on the growth of planting material of Norway spruce (*Picea abies* [L.] Karst.) in mountain conditions

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ABSTRACT: Common ways of nursery cultivation and sorting the planting material of mountain provenances of Norway spruce (*Picea abies* [L.] Karst.) are connected with the risk of undesirable narrowing of the genetic spectrum of populations. Investigations in spruce plantations established by different planting materials found out very good growth (total height is 125 cm 9 years after outplanting) and health status of these slowly growing seedlings planted in extreme mountain conditions. In order to prevent the genetic spectrum narrowing, we recommend to cultivate all seedlings including smaller outsorted (commonly culled) ones. The smallest seedlings can be grown one year longer and subsequently planted out in the same locality as the remaining planting material of the same seed lot.

Keywords: Norway spruce; mountain conditions; mountain populations; reforestation

The reforestation of exposed mountain localities is more difficult than current forest regeneration at lower locations. The growing season in the mountains is shorter, with lower temperatures and long-lasting snow cover. Young trees may often be deformed and damaged by slides of snow layers in the course of thaw. Shoots projecting over the snow cover are damaged mechanically by snow and ice particles drifted by the wind. In bright weather when the soil is still too cold and the roots cannot take up water sufficiently, there occurs physiological (winter) drying up of sunlit shoots. Temperature extremes in the form of late or early frosts are also frequent.

Specific mountain conditions make greater demands on the choice and preparation of planting material that will survive and grow in such a frequently extreme environment. The relevant genetic quality of seed is self-evident.

Compared to spruce from lower altitudes, mountain populations of Norway spruce (*Picea abies* [L.] Karst.) are characterized by higher variability of seed and seedlings (Kotrla 1998), and by different growth intensity (Mauer 1985; Popov 1990; Kotrla 1998; Oleksyn et al. 1998) and growth rhythm (Lang 1989; Westin et al. 1999; Hannerz, Westin 2000; Westin et al. 2000b; Modrzynski, Eriksson 2002). When seedlings are grown in constant conditions, there also exist differences in growth intensity and dynamics (Holzer 1985; Holzer et al. 1987). Growth differences between spruce populations originating from various altitudes and grown in the same environment are the most marked in the first years of seedling life (Holzer 1985; Quamaruddin et al. 1995).

The lower growth intensity of mountain spruce populations seems to be connected with their in-

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creased adaptation to adverse mountain conditions (Oleksyn et al. 1998). It is also confirmed by data documenting that spruce populations from higher altitudes or northerly areas showed higher resistance to both frost (Simpson 1994; Hawkins, Shewan 2000; Westin et al. 2000a) and drought (Modrzynski, Eriksson 2002) than seedlings from lower altitudes or of southerly provenance.

Small seedlings characterized by slow growth in the first years after sowing, which are discarded in nurseries as culls in the course of current sorting, may be a very valuable part of the population from genetic aspects.

High growth variability within mountain spruce populations is mostly attributed to high genetic variability of seed. The spruce at various altitudes above sea level blossoms approximately at the same time and the pollen is borne across a wide range of altitudes. It may result in the pollination of spruce populations in the mountains by pollen from medium altitudes and *vice versa* (Holzer 1985). When growing the planting material for higher mountain altitudes, different criteria should be used for the sorting of seedlings and plants because the discarding of smaller, slowly growing plants may lead to the narrowing of the genetic spectrum and the plants that have adapted themselves to extreme mountain conditions in the best way might be culled (Holzer et al. 1987; Lang 1989; Jurásek, Martincová 1996, 2001).

The aim of the experiment is to investigate the development of slowly growing seedlings from a mountain population of Norway spruce after their planting in extreme mountain conditions compared to the development of seedlings of standard and large dimensions.

MATERIAL AND METHODS

Seeds used for the cultivation of planting material originated from the spruce forest vegetation zone (this zone is characterized by altitude 1,050–1,350 m above sea level with average temperature 2.5–4°C). In 1992 two-years-old seedlings were divided before transplanting into 3 size categories: smaller than 8 cm (small, usually considered as culls), 8–15 cm (medium) and 15–22 cm (large). Seedlings reaching just the height of 8 or 15 cm were included in the higher size category. After transplanting the plants were grown for another 2 years, then they were used for direct planting or they were put into Jiffy pots. Table 1 shows basic morphological characteristics of four-year plants.

In 1994 the above-described planting material was set out in a model mountain area of the Krkonoše Mts. on the slope of Stoh Mt. at a height of 1,000 to 1,100 m above sea level (open area plot 2 ha in size, acid mountain spruce forest type, north-north-east orientation, slope of 25–30 grades).

A part of the plants was set out as bare-rooted ones (2 + 2) in spring 1994, the other part of the variants "small" and "medium" was put into containers (Jiffy pots) and set out onto the same research plot in summer of the same year as containerized planting material (2 + 2 + c0.5). Particular treatments were planted to 5 subplots by 100 plants. The distance between plants was 1.5 m.

Table 1. Morphological characteristics of four-years-old Norway spruce (*Picea abies* [L.] Karst.) plants used for planting or put into Jiffy pots (spring 1994)

Variant	Size at the time of transplanting		Shoot height (cm)	Root collar diameter (mm)	Sturdiness (height/diameter)
Small	smaller than 8 cm	mean	**23.8 a**	**5.8 a**	4.08
		S_x	7.39	1.71	
		n	109	109	
Medium	8–15 cm	mean	**33.8 b**	**6.8 b**	4.99
		S_x	8.48	1.72	
		n	112	112	
Large	15–22 cm	mean	**36.3 b**	**7.8 c**	4.66
		S_x	10.17	1.77	
		n	110	110	

The letters in columns indicate statistically significant differences at a 5% significance level (Student's *t*-test for unequal sample sizes and equal variance)

Table 2. Development of basic morphological characteristics in the size categories of Norway spruce (*Picea abies* [L.] Karst.) after planting to an extreme mountain locality (1994 plantation)

Measured characteristic	Year	Variant	Bare-rooted			Containerized (Jiffy pots)	
			small	medium	large	small	medium
		size at the time of transplanting	smaller than 8 cm	8–15 cm	15–22 cm	smaller than 8 cm	8–15 cm
Height (cm)	1995	mean	28.8 a	46.2 b	51.3 c	31.7 a	41.8 b
		S_x	8.290	8.367	8.936	7.579	8.791
		n	94	93	92	80	94
	2000	mean	71.4 a	69.6 a	68.1 a	80.3 a	73.4 a
		S_x	21.870	21.968	18.039	23.621	26.857
		n	80	93	70	80	91
	2003	mean	125.3 b	129.7 b	101.2 a	154.5 b	132.1 a
		S_x	46.159	43.964	42.623	35.627	48.135
		n	64	75	63	71	88
Height increment (cm)	1995	mean	4.1 a	4.0 a	3.7 a	3.9 a	3.7 a
		S_x	2.910	3.030	1.861	2.123	2.508
		n	94	93	90	80	94
	1996	mean	3.7 c	2.6 b	1.8 a	5.5 b	3.9 a
		S_x	2.951	1.823	1.051	3.080	4.047
		n	84	91	92	82	95
	1999	mean	10.0 b	6.1 a	5.4 a	11.8 b	7.7 a
		S_x	5.438	4.412	4.624	5.621	5.480
		n	86	95	73	82	83
	2004	mean	21.7 c	12.1 b	7.9 a	18.9 b	14.4 a
		S_x	14.035	7.400	6.156	11.538	8.692
		n	60	72	71	81	80
Root collar diameter (mm)	1995	mean	6.4 a	8.7 b	11.3 c	7.5 a	8.4 b
		S_x	1.901	1.504	2.018	2.120	1.792
		n	52	64	50	50	64
	1998	mean	9.5 a	8.5 a	13.4 b	13.2 a	13.3 a
		S_x	2.727	2.659	3.664	4.612	3.516
		n	32	33	32	32	32
	2000	mean	14.3 a	12.9 a	14.1 a	16.3 a	18.3 a
		S_x	5.354	4.877	4.662	4.998	7.067
		n	32	30	32	32	31
	2004	mean	36.6 b	35.0 a	27.4 a	38.7 a	43.7 a
		S_x	13.296	9.928	12.860	12.657	12.131
		n	28	30	30	30	28

The letters in rows (treatments) indicate statistically significant differences at a 5% significance level (Student's *t*-test for unequal sample sizes and equal variance – separately for bare-rooted and containerized plants)

In the growing-up plantation growth and health of spruces of the described size categories have been repeatedly examined since 1995. Height and collar diameter growth (in cm) and health condition (as percentage of foliage in 10% intervals) were assessed always in autumn; the height increment was measured every year as one-year increment. Statistical significance was evaluated by Student's t-test for unequal sample sizes and equal variance by comparison to p-value for 95% significance.

RESULTS

Height and diameter growth

The initial average tree height of variant "small" was 24 cm and 11 years later it increased to 125 cm. The average height of "large" plants increased at the same time from 36 cm to 101 cm (Fig. 1). The same trend was observed in diameter growth (Fig. 2). Initially slowly growing seedlings of spruce from the mountain localities (spruce vegetation zone) that are discarded by the current method of sorting before transplanting, grow up very well after being set out in a mountain environment. After they had overcome the transplant shock, their relative height and diameter growth was more intensive compared to larger plants. On the contrary, plants of the "large" category produced from dominant seedlings lagged behind markedly in their height and diameter growth after transplanting into mountain conditions. In six years after planting the initial statistically significant differences between the categories were fully wiped out, and after another four years the plants grown from slowly growing seedlings were significantly higher and more robust than the plants grown from the largest seedlings (Table 2). The same trend was observed both in bare-rooted and in containerized plants. In the last year of investigation (i.e. 10 years after planting) the mean height increment of plants in variant "small" was 22 cm and in variant "large" 8 cm.

We found the significantly faster height growth of containerized plants of the "small" variant in the first five years after planting compared to the same size variant of bare-rooted plants and to plants of the "medium" variant (Fig. 3). During five years these plants overtook the initially higher plants of the "medium" variant by their height. Eleven years after outplanting, the average tree height in variant "small" was 154 cm while in variant "medium" it was only 132 cm.

Health condition

The mean foliage of trees in the plantation from seedlings of the categories "small", "medium" and

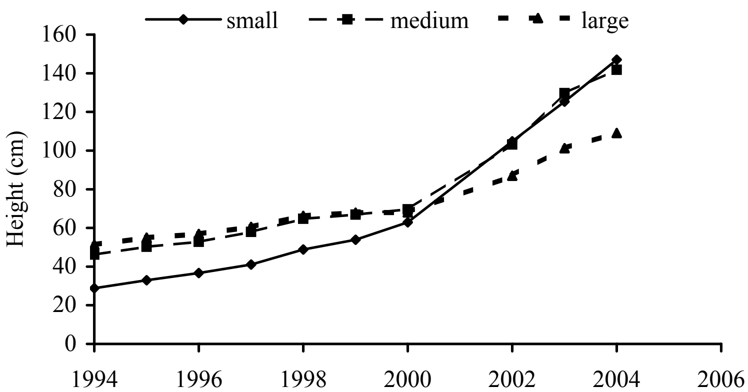

Fig. 1. Height growth of the sorted planting material of Norway spruce (*Picea abies* [L.] Karst.) in the course of 11 years after planting to a mountain locality

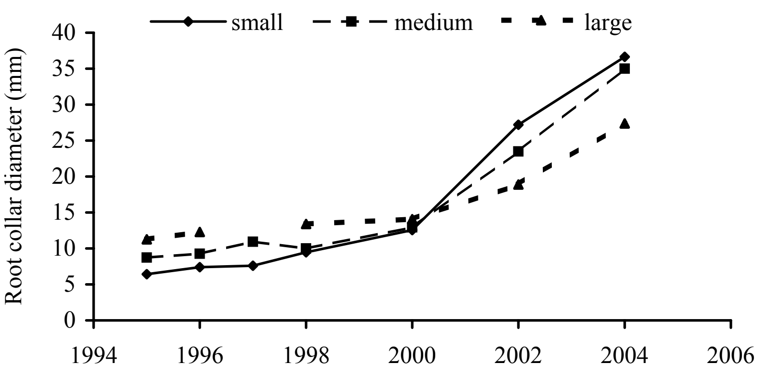

Fig. 2. Diameter growth of the sorted planting material of Norway spruce (*Picea abies* [L.] Karst.) in the course of 11 years after planting to a mountain locality

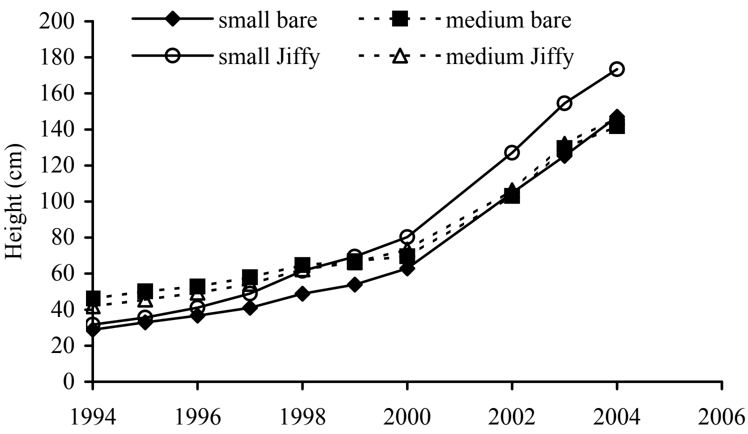

Fig. 3. Comparison of height growth in bare-rooted and containerized (Jiffy pots) plants

"large" was in the first year after outplanting 95%, 73% and 70%, respectively. During the next four years it decreased to 78%, 61% and 50% and after overcoming the transplant shock the mean foliage increased again to 98%, 86% and 89%, respectively (11 years after outplanting).

The differences between category "small" and other categories ("medium" and "large") were significant in the whole period of observation while the differences between category "medium" and category "large" were found insignificant (Fig. 4).

DISCUSSION

The results document very good growth and health of plants produced from small seedlings, i.e. seedlings characterized by slow growth in the first years after sowing. Hence these plants represent a very valuable part of Norway spruce seed lots originating from mountain areas. Among others, it confirms the conclusions drawn by Holzer et al. (1987) and Lang (1989) about the need of a specific approach to the sorting of seedlings of Norway spruce mountain populations in nurseries. When the planting material of Norway spruce originating from higher mountain altitudes is grown, the technology of sorting in a nursery should be modified so that transplants will be produced from these small seedlings that will be set out in mountain localities.

The results of investigations in a model plantation in the Krkonoše Mts. agree with the finding that the slow growth of a part of the population of spruce seedlings is the most marked in the first years after sowing and later it catches up with the rest of seed-

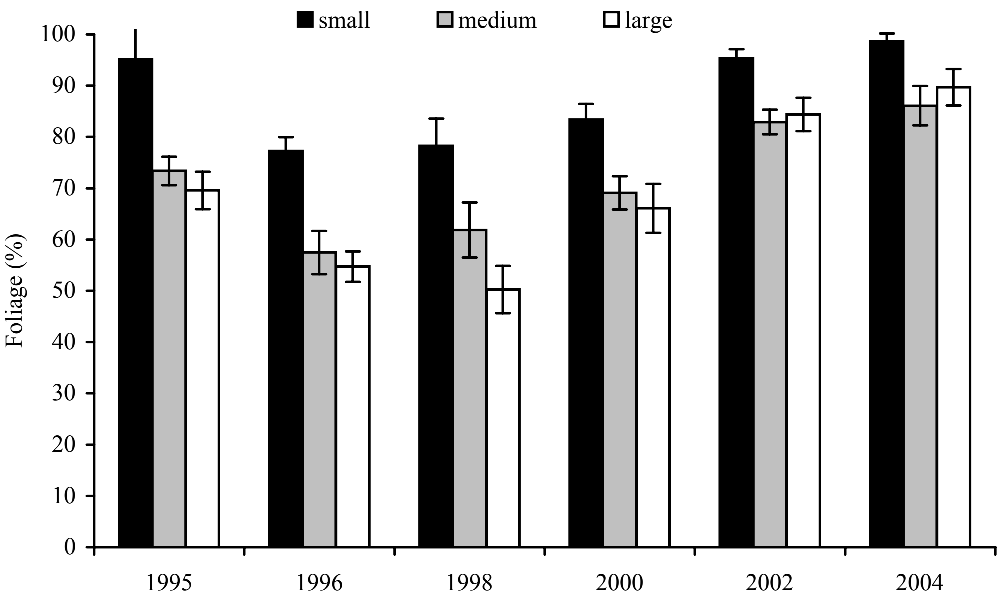

Fig. 4. Health status expressed as an average percentage of foliage in the Norway spruce (*Picea abies* [L.] Karst.) planting material sorted by height in the course of 11 years after planting to a mountain locality. Vertical bars show reliability intervals, the letters in columns indicate statistically significant differences (1% significance level)

lings (Holzer 1984; Mauer 1985; Quamaruddin et al. 1995).

They also confirm an assumption that in the process of adaptation to adverse environmental conditions at higher altitudes spruce populations gain their resistance to the account of growth (Modrzynski 1995; Oleksyn et al. 1998).

The results from the Krkonoše Mts. also support the conclusions of some authors from the Alps Mts. area that high-elevation spruce provenances may partly be pollinated with pollen from medium altitudes and that such pollination markedly contributes to the high interprovenance variability of height growth of spruce mountain populations. Because the seedlings originating from pollination with pollen of high-elevation trees are generally smaller, the discarding of small seedlings in the course of sorting in a nursery may have a negative influence on genetic heterogeneity (Holzer 1985). The individuals with the best adaptation to growth in extreme mountain conditions, capable of surviving extreme climatic fluctuations that may occur once in several tens of years, are likely to be discarded (Lang 1989).

The results confirm well-known facts that the transplant shock is reduced and initial growth after planting is accelerated if a containerized planting material is used (Lokvenc 1990). However, they point to the need to use optimum growing technologies, in this case the adequate size of plants to be put into containers (Dušek et al. 1987). A comparison of the growth of containerized and bare-rooted plants indicates that the growth of small plants in the first years after planting may be stimulated by the use of containerized planting material. The stimulating effect of Jiffy pots was not evident in plants of the "medium" variant that were relatively large when they were put into these containers and so such an operation was a stronger intervention in their root systems and deteriorated the shoot to root ratio. Plants of the "large" variant were not suitable to be put into Jiffy pots due to their size and therefore no containerized plants were used in this variant.

There arises a question in what seedlings the slow growth is caused genetically and balanced by higher resistance to adverse mountain conditions and what seedlings are really to be considered as culls.

CONCLUSIONS

The monitoring of plantations on mountain research plots in the course of 10 years showed that the outplantings established from seedlings growing slowly in a nursery and discarded as culls by a current sorting method (designated as "small") were vigorous in mountain conditions and their growth was good.

Initial height differences from plants growing faster in a nursery were gradually reduced.

The health status of plantations from the seedling category "small", characterized by foliage and frequency of occurrence of colour changes of needles, is better than in plantations from larger categories.

Implications for forest practice

The discarding of these plants growing rather slowly in nurseries may pose a risk of impoverishment of the natural spectrum of individuals well adapted to extreme conditions of mountain localities.

When growing the planting material of spruce from the mountain localities, technologies used in tree nurseries should be modified to produce and to use the whole growth spectrum of seedlings and plants for setting out to clear-cut areas. The possible way is to put small plants into suitable containers (Jiffy pots) and to set them out subsequently in the same locality as the remaining planting material of the same seed lot.

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Vliv počáteční výšky semenáčků na růst výsadeb smrku ztepilého (*Picea abies* [L.] Karst.) v horských podmínkách

ABSTRAKT: Běžný způsob pěstování a třídění sadebního materiálu smrku ztepilého (*Picea abies* [L.] Karst.) v lesních školkách je spojeno s rizikem nežádoucího zúžení genetického spektra kultur. Šetření ve smrkových kulturách, založených výsadbou specificky tříděného sadebního materiálu do extrémních horských podmínek, ukázala velmi dobrý zdravotní stav sazenic vyznačujících se pomalým růstem ve školce. Jako prevenci zužování genetického spektra horských populací smrku ztepilého doporučujeme dopěstování všech semenáčků včetně těch, které jsou při běžném způsobu třídění vyřazovány jako výmět. Nejmenší jedinci přitom mohou být pěstováni o rok déle a následně vysazováni na stejnou lokalitu jako ostatní sazenice ze stejného oddílu.

Klíčová slova: smrk ztepilý; horské podmínky; horské populace; zalesňování

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