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Snow damage to birch stands in Northern Moravia

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ABSTRACT: The condition and snow damage to stands dominated by birch were studied in the area of interest in Northern Moravia. Based on basal area, the share of birch ranged from 68 to 88%. The stands came to existence on fertile sites through natural regeneration and exhibited growth at a level of the best site classes for the Czech Republic. The most severe snow damage to the stands was recorded at the upper stand height of 8–15 m. The extent of damage in the analyzed stands amounted to 67–95% of all trees. The unambiguously predominant type of damage was bending while breakages were recorded only in up to 4% of trees. Slenderness ratios of intact trees differed according to the age (height) of stands. The highest values of about 180 were observed in the youngest, ca 5-years-old and about 5 m high stand. Slenderness ratio values of intact trees in a 17-m high stand ranged about 100. The analyzed stands did not show any differences in the slenderness ratio values between intact and damaged trees. Lower values of the ratio for solitary trees (ca 130) in a 5-years-old stand were accompanied by markedly longer crowns (80% of stem) as compared with trees growing in the stand (60% of stem). Differences in the root system architecture were revealed between intact and damaged trees within a stand of about 9 m in height.

Keywords: birch; fertile sites; growth; natural regeneration; snow damage; slenderness ratio; root system

Under conditions of the Czech Republic, silver birch (*Betula pendula* Roth) can be used as a commercial tree species only on a limited types of sites (pine sites poor in nutrients, mountain elevations, poor extreme sites and waterlogged sites). On the most part of the Czech territory including the fertile sites of lower and middle altitudes, the species is not prescribed even as a basic, admixed and interspersed or soil-improving and reinforcing species [Act No. 289/1995 of the Statute Book, on Forests and Amendments to some Acts (Forest Act), Decree of the Ministry of Agriculture of the Czech Republic No. 83/1996 of the Statute Book, on elaborating regional plans of forest development and on specification of economic complexes]. It is possible to use it on these sites only as an auxiliary species [Act No. 289/1995 of the Statute Book, on Forests and Amendments to some Acts (Forest Act), Decree No. 139/2004 of the Statute Book, laying down the details of the transfer of seeds and seedlings of forest tree species, on records of the origin of reproduction material and details of the renewal of forest tree stands and on afforestation of lands declared as lands intended to fulfil the functions of a forest].

Considering the current silvicultural trends, possible impact of climate changes and necessary transformation of allochthonous coniferous stands at lower altitudes, the birch is recommended for a wide range of sites (e.g. Götmark et al. 2005; Košulič 2006). Snow appears to be the most risky factor for growing this species.

Although the possibilities to prevent disasters in forest stands are limited, this kind of threat can be corrected by appropriate tending measures (e.g. Chroust 1968; Valinger, Fridman 1999). The issue of tending forest stands for higher snow resistance has been elaborated in details and theoretically formulated namely for spruce (Konôpka 1985; Míchal 1994). For tending birch in order to

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enhance its resistance to snow damage, there exists a recommendation only for substitute stands established in air-polluted areas (e.g. Pařez, Chroust 1988; Slodičák, Novák 2001, 2008). In older literature, recommendations can be found respecting the then approach to the forest, advocating a timely elimination of birch as a nurse and pioneer species in the stands of coniferous (spruce) species (Vyskot et al. 1978). A crucial point in the solution to the problem of birch resistance to snow and hence its tending is the silvicultural goal of these stands. Other useful starting points are the above-mentioned theoretical ground works of general tree stability, elaborated mainly for spruce (Sereda 1992) or the work dealing with snow damage to stands in Europe (Nykänen et al. 1997).

The aim of our survey was to assess the current condition, impact and to analyze possible causes of snow damage to birch stands in the Ostrava region.

MATERIAL AND METHODS

Surveys were conducted in forest stands in the Ostrava region, cadastral area of Velká Polom (9°51'39.887"N, 18°5'37.296"E). Local forests belong to Natural Forest Region (NFR) 29 – the Nízký Jeseník Foothills, and typologically rank for the most part in forest altitudinal vegetation zones (FAVZ) 2–4, trophic ecological series (HS 45), oak-beech vegetation zone. The altitude of the locality ranges from 300 to 350 m a.s.l. The mean air temperature of the nearest meteorological station (Hrabyně – ca. 5 km) was 9.6°C in 2009 and the mean annual precipitation amount in the same year was 794 mm. Long-term average temperature for this region is about 8°C and average precipitation varies from 700 to 800 mm.

Towards the end of the last century, the local, mainly allochthonous spruce stands of second to third generation showed massive drying out and gradual decline due to a number of biotic factors (bark beetle, honey fungus) with a predisposition factor of drought. The declining spruce stands were gradually returned to their original owners at that time. Thus, a mosaic of stands that were often small-sized and of diverse condition was coming to existence. Frequent were stands of pioneer species developed through natural regeneration that were left without management. Our research implemented in 2010 was focused on the above-characterized, birch-dominated stands.

Selection of stands

The stands were chosen to represent different heights, hence diverse stand ages. The criterion for the selection was a dominant share of birch in the stands. For working purposes, the chosen stands were designated with capital letters of the alphabet and ordered by height. The youngest stands (A, B and C) were left without intentional management measures since their emergence. In stand D, a tending measure was carried out ca. 1–2 years ago. In other older stands (E, F and G), it was impossible to

Table 1. Basic characteristics of Stand C

Tree species	*N* (trees·ha^{-1})	*G* (m^2·ha^{-1})	*N* (%)	*G* (%)
Birch (*Betula pendula* Roth)	12,650	11.50	68.75	78.57
Spruce (*Picea abies* [L.] Karst.)	2,150	2.00	11.68	13.57
Rowan (*Sorbus aucuparia* L.)	1,150	0.23	6.25	1.58
Buckthorn (*Frangula alnus*)	900	0.21	4.89	1.41
Pine (*Pinus sylvestris* L.)	500	0.34	2.72	2.31
Willow (*Salix caprea* L.)	450	0.16	2.45	1.09
Aspen (*Populus tremula* L.)	250	0.17	1.36	1.15
Hornbeam (*Carpinus betulus* L.)	150	0.02	0.82	0.15
Hazel (*Corylus avelana*)	150	0.02	0.82	0.15
Larch (*Larix decidua* Mill.)	50	0.00	0.27	0.01
Total	18,400	14.62	100.00	100.00

N – number of trees per hectare, *G* – stand basal area per hectare, *N* (%) – composition of tree species by number of trees, *G* (%) – composition of tree species by basal area find out whether and to what extent a tending measure was taken in the past. Nonetheless, no tending measures were probably carried out there either.

Detailed surveys were done in one stand (C). The stand (sized ca. 0.7 ha) was established in 1997(98) following the salvage felling of approximately 70-years-old coniferous stand. The original stand had the following representation of tree species: spruce 68%, pine 24%, birch 2.5%, alder 2.5%, aspen 2.5%. Clear felling was followed by the planting of spruce on the clear-cut area and the stand has been left unmanaged since then. Basic parameters of this stand in 2010 are presented in Table 1.

Assessment of stand condition and damage

The condition and damage to individual stands were evaluated on sample plots. The size and number of these plots were given by the condition and size of stands (the number of sample plots ranged from 1 to 4, their total size from 40 to 225 m^2). All trees of the height over 2 m occurring on the sample plots were recorded and classified into groups according to stem diameter (≤ 1 cm, 1.1–3.5 cm, 3.6–7.0 cm) at breast height (DBH). Trees of DBH over 7 cm were gauged in two mutually perpendicular directions.

All measured trees were classified according to snow damage as follows:

I – upright (intact),
O – Z – bent from the ground (inclined),
O – K – bent in the crown,
O – U – bent on the stem,
Z – breakage,
V – windthrow.

Snow damage was not detected in the oldest stand (G).

Stand height was measured to the nearest 0.5 m using a measuring rod (H up to 10 m) or hypsometer (H over 10 m) and it was expressed as the average of three height measurements of upright (I) birch individuals in the upper storey of the stand.

The following parameters of particular stands were calculated from the above data:

- stand density (number of trees per hectare),
- stand basal area (in m^2 per hectare),
- representation of tree species:
  (a) according to the number of trees (species abundance to the total number of trees),
  (b) according to the stand basal area (species basal area to the total stand basal area),
- mean stem diameter of birch for the group of intact and damaged trees.

Snow damage to stands was evaluated according to the type of damage both for the stand (the number of damaged trees to the total number of trees in the stand) and for the birch species (the number of damaged birches to the total number of birch trees in the stand). The calculated values served for the establishment of the number of birch trees and basal area in the experimental stand, possibly also for the trees of other species – intact (I) and damaged (D) in the above-mentioned diameter classes.

Analysis of slenderness ratio

In all analyzed stands, seven sample trees were chosen at random from the group of intact birch trees in order to determine the slenderness ratio. The ratio was determined by the standard method as the ratio of tree height (in m) to tree diameter at breast height (in cm). The height was measured to the nearest 0.5 m using a measuring rod (up to 10 m) or hypsometer (over 10 m). Diameter at breast height was determined as the average of two values measured in N-S and E-W directions. The measurement was done with a standard calliper with the resolution in mm. The calculated values were ordered graphically using the STATISTICA software (box plot – Kruskal-Wallis test) and mutually compared.

Furthermore, differences in the values of slenderness ratio were determined for the groups of intact (I), damaged (D) individuals and solitary trees (S) growing in the immediate vicinity of the stand. This survey was conducted in Stand A (height 4–6 m), which was the only continuous stand with solitary birch trees of the same height. Ratios of seven solitary and damaged trees chosen at random were determined similarly like in the case of upright trees with the exception of damaged trees whose height was measured only after their felling as the length of the aboveground part. Crown setting height was established in solitary birch trees and in birch trees growing in the stand (both damaged and intact) concurrently with the measurement of their height and diameter. Results of the survey were evaluated by the STATISTICA software (*t*-test: differences between DBH of damaged and intact birch, differences in the crown setting height between damaged trees and intact trees; Kruskal-Wallis test: comparisons of slenderness ratio for the groups of intact (I), damaged (D) and solitary (S) birch trees; Mann-Whitney *U*-test *P*-value 0.0500: differences between the crown setting heights in trees growing within the stand and in solitary trees).

Differences in the values of slenderness ratio between the upright and damaged birch trees were determined also in the experimental stand (C). For this purpose, twenty-three birch trees were felled (9 intact and 14 damaged). The resulting set of slenderness ratios was statistically evaluated by the STATISTICA software (Mann-Whitney *U*-test, *P*-value 0.0500).

Analysis of aboveground and underground parts of sample trees

Three sample trees were chosen to represent upright (intact) trees (I), trees bent from the ground (O–Z) and trees bent on the stem (O–U) in order to study differences between the aboveground part parameters and the root-system architecture.

The following biometrical parameters of the aboveground part were analyzed: total length of aboveground part, crown length, crown setting height, stem diameter – at 20 cm above the ground, at breast height and under the crown, number and length of branches. Root systems were lifted manually by an archaeological method and parameters determined after their cleaning were as follows: number, diameter and length of horizontal skeletal roots (HSR), occurrence of anchors and their diameter, rooting depth and number of lateral branches. The measured values were used for the calculation of area index (Ip). The area index expresses the relation between the size of the root system and the aboveground part. It is calculated as the ratio of root cross-sectional areas in mm^2 to the tree length in cm; the higher the Ip value, the larger the root system of the tree. The distribution of branches in the crown and the distribution of the root system in the soil were evaluated according to the direction of stem bending (inclination). Branches and horizontal skeletal roots should be distributed in a regular circular pattern (360 degrees) in the centre of which the stem is. In both measurements, 0 degrees were oriented in the direction of stem bending. It follows that when the circle was divided into four quadrants by 90 degrees, quadrants 1 and 4 were oriented in the direction of the stem bending and quadrants 2 and 3 in the opposite direction. All measured values were subjected to *t*-test ($\alpha = 0.05$). Statistical significance is graphically expressed in tables as + (significant difference) and – (insignificant difference); results of the test between the damaged and upright trees are behind the standard error; results of the test among the damaged trees are in front of the arithmetic mean.

The attention was also paid to the immediate surroundings of the sample tree in order to assess partial density. For this purpose, girths of all trees were measured at a height of 0.20 m above the ground at a radius of 1 m from the sample tree centre (partial plot 3.14 m^2). The basal area of trees at 0.20 m ($G_{0.2}$) was established from the measured girths. In order to express the position of the sample tree, the ratio of its basal area to the basal area of other species on this partial plot was determined at a height of 0.20 m ($G_{S0.2}$).

RESULTS

Condition of stands and their damage

Basic characteristics of the seven analyzed stands are shown in Tables 1 and 2. Apart from birch, there were other 3–9 tree species occurring in the stands. The stand heights ranged from 4–6 m to 23–25 m. In addition to birch, the dominant level of these

Table 2. Basic stands parameters and the position of birch in the stands

Stands indication	H (m)	Stand age	N-Sp.	*N* (trees·ha^{-1})	*G* (m^2·ha^{-1})	*N* (%)	*G* (%)
A	4–6	4–6	4	26,500	11.01	65.1	67.74
B	8–9	7–8	10	50,600	19.53	78.3	83.91
C	9–10	7–10	10	18,400	14.62	68.8	78.57
D	13–14	10–13	8	4,622	19.86	59.7	87.65
E	14–15	10–13	6	5,689	14.88	89.8	88.02
F	16–17	20	10	8,756	23.12	27.6	72.84
G	23–24	25	5	1,778	34.45	52.5	74.54

H – top height of stand, N-Sp. – number of woody trees species, *N* – number of trees per hectare, *G* – stand basal area per hectare, *N* (%) – composition of birch by number of trees, *G* (%) – composition of birch by basal area

Table 3. Extend and type of damage to birch and all trees (stand) in stands

Stand	Birch/stand	I (%)	Z (%)	V (%)	O (%)	Total damage (%)
A	birch	42	0	0	58	58
	stand	57	1	0	42	43
B	birch	3	4	4	89	97
	stand	5	4	3	88	95
C	birch	9	0	1	89	91
	stand	20	1	1	78	80
D	birch	11	0	5	84	89
	stand	28	0	3	69	72
E	birch	30	2	0	68	70
	stand	33	3	1	63	67
F	birch	31	2	0	67	69
	stand	58	2	2	39	42

I – intact trees, Z – trees with stem break, V – blow-down trees, O – bending trees

stands included the rarely occurring aspen. Willow and a wide range of shrubs (hazel, buckthorn and elderberry) were other “pioneer” species. Similarly like the target broadleaves (beech, oak, sycamore maple or hornbeam), the target conifers (spruce, pine, larch) constituted the insignificant intermediate level in terms of abundance and/or their negligible counts reached the main stand level.

The number of trees in the stands ranged from a maximum of 50,600 per ha in Stand B (height 8 to 9 m) to 1,178 per ha in Stand G (height ca. 24 m). Basal area ranged from 34 $m^2 \cdot ha^{-1}$ in the oldest stand to 11 $m^2 \cdot ha^{-1}$ in the youngest stand. The share of birch according to the basal area (68–88%) was generally higher than the share of birch according to the tree number (28–90%), which shows the carrier role of birch in these stands.

The oldest Stand G, in which no snow damage was found out, was excluded from the assessment of damage to birch and other species (Table 3). Damage to birch in stands A–F ranged from 58% to 97%. Total damage to other species in the stands was lower at all times (Table 3) than damage to birch. The type of damage prevailing in all stands was bending (58–89% of all birch trees and/or 42% to 89% of all trees). The highest damage was recorded in young stands high ca. 9 m (stands B and C). The snow damage was decreasing with the increasing age of the stands. A lower extent of damage was recorded also in the youngest stand (A – height ca

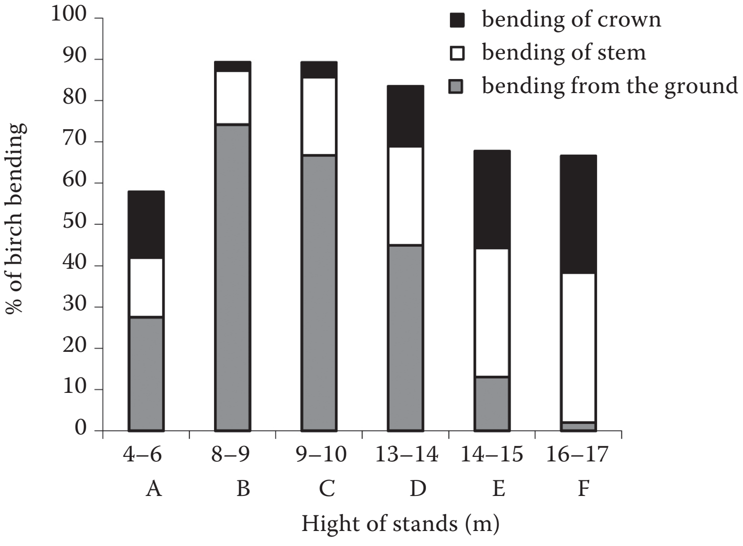

Fig. 1. Way and extend of birch bending in stands

Table 4. Diameter values DBH (cm) – result of statistical test for birch and all tree species in the analyzed stands

Stand	Mean D	Mean I	*t*-value	*P*-value	Number D	Number I	SD–D	SD–R
A	1.77	2.41	–2.288640	0.025260	40	29	0.791355	1.496147
B	1.79	2.40	–0.949983	0.343291	193	5	1.391232	2.601682
C	2.97	3.63	–2.013680	0.045111	229	24	1.456434	2.183177
D	8.06	8.51	–0.288035	0.774313	55	7	3.428130	6.760944
E	4.61	4.58	0.049961	0.960242	80	35	3.310453	3.639030
F	6.16	5.91	0.337447	0.736509	68	31	3.337584	3.716385

DBH – mean diameter values, SD – standard deviation, I – for the group of upright (intact) trees, D – for the group of damaged (bending, breakage, wind throw) trees

5 m – Table 3). Fig. 1 shows differences in the point of bending on damaged birch trees in the stands. With the exception of the youngest stand, the point of bending moved from the tree base to the tree crown with the increasing age.

In addition to differences in the size and type of damage to the particular stands, differences were also found in the diameter structure of affected trees. While in younger stands (A–D) the mean diameters of damaged birch trees were smaller (statistically significant in stands A, C) than those of intact birch trees, the situation in older stands was opposite (see Table 4). Thus, the younger stands exhibited signs of decline with the intact individuals of larger diameters whereas the overdense older stands were affected in their continuous upper level

Table 5. Size of damage to birch and all tree species (individuals·ha^{-1} and %) in Stand C by diameter intervals

Diameter interval (cm)	Birch						All trees	
	I		D		total		I	D
	(ind.)	(%)	(ind.)	(%)	(ind.)	(%)	(ind.)	(ind.)
0.1–1.0	150	23.1	500	76.9	650	30.2	800	1,350
1.1–3.5	500	5.9	8,000	94.1	8,500	71.1	1,950	10,000
3.6–7.0	450	13.6	2,850	86.4	3,300	80.5	850	3,250
7.0 +	100	50.0	100	50.0	200	100.0	100	100
Total	1,200	9.5	11,450	90.5	12,650	68.8	3,700	14,700

ind. – individuals; I – for the group of upright (intact) trees; D – for the group of damaged (bending, breakage, windthrow) trees

Table 6. Basal area structure (m^2·ha^{-1}) of damaged and intact trees in Stand C

Diameter interval (cm)	Basal area						
	birch		other trees		all trees		total
	I	D	I	D	I	D	
0.1–1.0	0.00	0.01	0.01	0.02	0.02	0.03	0.04
1.1–3.5	0.20	3.18	0.58	0.80	0.78	3.98	4.75
3.6–7.0	0.97	6,17	0.87	0.87	1.84	7.04	8.88
7.0 +	0.50	0,46	0.00	0.00	0.50	0.46	0.95
Total	1.67	9.82	1.46	1.68	3.13	11.49	14.62
(%)	14.56	85.44	46.45	53.55	21.40	78.60	100.00

I – for the group of intact (upright) trees, D – for the group of damaged (bending, breakage, windthrow) trees with the relatively intact sublevel. Nevertheless, as it follows from the analysis of damage in Stand C, relatively lower damage to severely suppressed individuals up to 1 cm in diameter was also recorded in the younger stands (Table 5).

The impact of damage to stands can be seen on the example of Stand C. Only 1,200 birch trees per ha remained intact from the total number of 12,650 birch trees per ha in the stand. The total number of trees that remained intact in this stand was 3,700. The highest number of damaged birch trees was recorded in the diameter interval of 1.1 to 3.5 cm, where 94% of all birch trees were affected. The diameter interval of 3.6–7.0 cm showed 87% of damaged birch trees. The lowest number of birch trees (50%) was damaged in the diameter interval > 7 cm while it was 77% of damaged birch trees in the diameter interval < 1 cm.

Only 3.13 $m^2·ha^{-1}$ of the original basal area (14.62 $m^2·ha^{-1}$) remained intact. According to the basal area, the representation of birch reached 79% (Table 1). The share of birch in the "intact" basal area of 3.13 $m^2·ha^{-1}$ was 1.67 $m^2·ha^{-1}$, i.e. about 53% of the total intact stand basal area. Thus, the basal area of intact birch trees (1.67 $m^2·ha^{-1}$) accounted for less than 15% of the original basal area of this species (Table 6).

Analysis of slenderness ratio and crown setting height

Fig. 2 shows the distribution of slenderness ratio values for intact trees in the particular stands. The highest values were recorded in the youngest stand (age of ca 5 years, height 4–6 m). Then the values apparently decreased with the increasing stand age up to about 14 years. The slenderness ratio of these and older stands stabilized at a value of about 100.

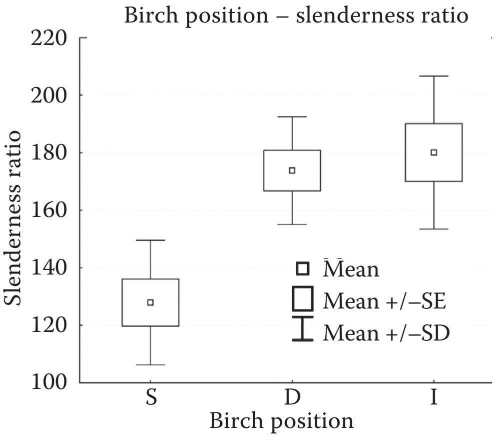

Fig. 3a. Stand A – slenderness ratio for the groups of upright birch (I), damaged (D) and solitary (S) birch trees

The calculated values of slenderness ratio (Stand A) for the groups of intact, damaged and solitary birches show statistically significant differences between solitary trees and the other two groups. The differences in the ratio values between solitary birch trees (100–160) and birch trees growing in the stand (> 200) are shown in Fig. 3a. On the other hand, the ratio values of damaged and intact birch trees were nearly identical (Fig. 3a). Similar insignificant differences (Mann-Whitney test, *P*-value 0.3950) between the groups of intact and damaged birch trees were recorded in Stand C (Fig. 3b).

Differences in the crown setting height between trees growing within the stand and solitary trees determined in Stand A were statistically significant (Mann-Whitney test, *P*-value 0.000787). While the mean crown setting height in the stand ranged from 1.1 to 2.8 m (mean 2.0 m) in the groups of upright and damaged trees, the group of solitary

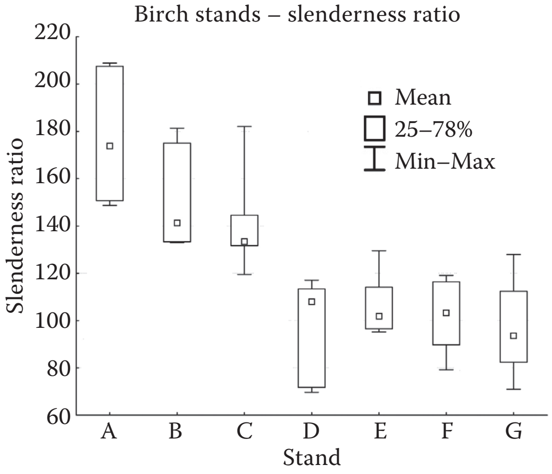

Fig. 2. Box plots of slenderness ratios for intact birch trees in the analyzed stands

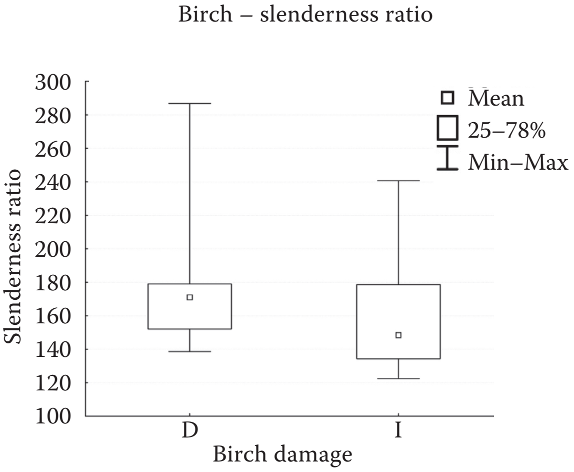

Fig. 3b. Stand C (height 9–10 m, age 7–10 years)– slenderness ratio for a group of intact (I) and damaged (D) birch trees

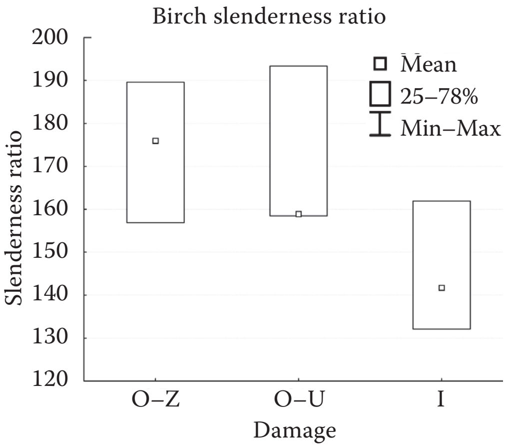

Fig. 4. Stand C (height 9–10 m, age 7–10 years) – slenderness ratio values for the groups of birch sample trees (O–Z – bending from the ground, O–U – bending of stem, I – intact trees)

trees showed the values ranging from 0.7 to 1.25 m (mean 1.0 m). Differences in the crown setting height between damaged trees (mean 1.9 m) and intact trees (mean 2.2 m) were negligible (*t*-test, *P*-value 0.226685).

Analysis of aboveground and underground parts of sample trees

Having compared the results from the analysis of shoot parts and root systems of intact and damaged trees, we can state that no statistically significant differences were detected in the growth of the aboveground part between upright and damaged trees. However, the most favourable values of slenderness ratio were found in the intact sample trees (I) and the highest values were recorded in the inclined trees (O–Z) (Fig. 4).

Table 7. Result of Kruskal-Wallis test, *P*-value; differences between slenderness ratio for the groups of intact birch (I), damaged (D) and solitary (S) birch trees in Stand A (height 4–6 m)

Birch position	Solitary	Damaged	Intact
S		0.019967	0.008875
D	0.019967		1.000000
I	0.008875	1.000000	

Nevertheless, significant differences were observed in the architecture of their root systems. Only the intact (upright) trees (I) had anchors from both the base and the horizontal skeletal roots. The inclined trees (O–Z) had no anchors; the bent trees (O–U) had anchors only from the horizontal skeletal roots. With the exception of the layout of anchors, no significant differences were found in the architecture of horizontal skeletal roots between the inclined (O–Z) trees and the bent (O–U) trees. Apart from the layout of anchors, significant dif-

Table 8a. Stand C (height 9–10 m, age 7–10 years): root architecture of birch trees; mean value and standard deviation

Type of damage	HSR – numbers in quadrants (pcs)		HSR – length in quadrants (cm)	
	1 + 4	2 + 3	1 + 4	2 + 3
I	10.0 ± 1.0	8.3 ± 1.5	111.1 ± 45.1	122.2 ± 37.3
O–Z	6.0 ± 1.1*	8.3 ± 2.8	91.6 ± 36.3	86.9 ± 38.8*
O–U	7.6 ± 1.1*	7.3 ± 3.5	106.9 ± 34.8	95.5 ± 31.2*
	HSR – diameter in quadrants (mm)		max. angle between ind. HSR (degree)	
	1 + 4	2 + 3	1 + 4	2 + 3
I	12.1 ± 4.4	11.4 ± 4.9	41.6 ± 2.8	61.6 ± 7.6
O–Z	12.0 ± 6.7	9.8 ± 5.2	45.0 ± 12.2	51.6 ± 3.8
O–U	12.4 ± 5.8	10.7 ± 3.5	50.0 ± 6.0	50.0 ± 4.5
Ip	root system as a whole	anchors only	roots in quadrants 1 and 4	roots in quadrants 2 and 3
I	7.88 ± 0.74	5.16 ± 0.82	4.92 ± 0.68	2.96 ± 0.73
O–Z	2.09 ± 0.79*	–	1.08 ± 0.32*	1.01 ± 0.84
O–U	*5.57 ± 0.96	3.17 ± 0.66*	2.72 ± 0.62*	2.65 ± 0.55

I – intact (upright) tree, O–Z – bending from from the ground, O–U – bending of stem, HSR – horizontal skeletal roots, Ip – area index (relation between the size of the root system and the above-ground part), *significant difference (α = 0.05) – between the damaged and intact (upright) trees are behind the standard deviation, among the damaged trees are in front of the arithmetic mean

Table 8b. Stand C (height 9–10 m, age 7–10 years): anchors in root architecture of birch trees; mean value and standard deviation

Type of damage	% of trees with anchors from the base	Anchors from base			
		number (pcs)	diameter (mm)	rooting depth (cm)	number of lateral branches per anchor (pcs)
I	100	2.33 ± 1.52	19.0 ± 13.7	51.8 ± 7.8	3.0 ± 0.8
O–Z	0	–	–	–	–
O–U	0	–	–	–	–
	% of trees with anchors in quadrants 1 and 4	Anchors of quadrants 1 and 4			
		number (pcs)	diameter (mm)	rooting depth (cm)	number of lateral branches per anchor (pcs)
I	100	3.3 ± 0.8	18.1 ± 7.1	54.7 ± 11.6	3.2 ± 1.6
O–Z	–	–	–	–	–
O–U	100	3.3 ± 1.2	15.0 ± 7.6	41.5 ± 11.2	3.3 ± 0.9
	% of trees with anchors in quadrants 2 and 3	Anchors of quadrants 2 and 3			
		number (pcs)	diameter (mm)	rooting depth (cm)	number of lateral branches per anchor (pcs)
I	100	3.3 ± 1.5	16.5 ± 8.1	54.8 ± 12.9	3.2 ± 2.2
O–Z	–	–	–	–	–
O–U	100	3.6 ± 1.1	17.7 ± 5.9	51.8 ±10.0	3.0 ± 1.1

I – intact (upright) tree, O–Z – bending from the ground, O–U – bending of stem

ferences were observed also in the architecture of horizontal skeletal roots between the intact (I) and inclined (O–Z) and bent (O–U) trees (Tables 8a, b). Unlike the upright trees, the inclined and bent trees exhibited a lower number of horizontal skeletal roots in the direction of bending and a smaller length of horizontal skeletal roots in the opposite direction. Having compared the relation between the shoot part and the root system, we found out that the anchors had a decisive share in the Ip value; compared with the intact trees, the bent and inclined trees had only 70% and 30% of the whole tree Ip value, respectively. The bent trees and the inclined trees showed significantly lower Ip values

Table 9. Stand C (height 9–10 m, age 7–10 years) – position of trees in area of radius 1 m from sample trees

Samples trees	No.	$D_{0.2}$	Nu.	$G_{0.2}$	$G_{S0.2}/G_{0.2}$
	1	10.60	6	0.5685	49.41
I	2	9.70	2	0.3723	63.19
	3	11.90	4	0.6216	56.96
	1	10.00	5	0.4882	51.21
O–Z	2	9.20	6	0.5169	40.94
	3	9.30	3	0.5222	41.41
	1	9.95	5	0.4959	49.91
O–U	2	10.65	1	0.3089	91.80
	3	9.05	5	0.3256	62.88

I – intact tree, O–Z bending from the ground, O–U – bending of stem, No. – indication of tree, $D_{0.2}$ – diameter of sample tree in height 20 cm from the ground (cm), Nu. – number of trees in partial area 3.14 m^2 (ind.), $G_{0.2}$ (%) – percentage of circular area at height 0.2 m of all trees on partial area (3.14 m^2), $G_{S0.2}/G_{0.2}$ – share of sample trees on circular area (%)

of all roots in quadrants 1 and 4 (in the direction of bending).

Differences in the position of the sample tree within its immediate surroundings are shown in Table 9. In spite of statistical insignificance of the difference in the position of the particular groups of sample trees it is quite obvious that I (intact) sample trees, i.e. intact trees, were dominant trees (basal area 50–63%) from dense (No. 1 – 0.57% and No. 3 – 0.62%) but also more open (No. 2 – 0.37%) parts of the stand. By contrast, the inclined sample trees (O–Z) from the relatively dense parts of the stand (0.48–0.52%) did not markedly overtop their surroundings (basal area 41–52%) as compared with the upright trees. Sample trees with the curved stem (O–K) were dominant individuals (basal area 50–92%) originating however from the relatively thinner surroundings (0.33–0.50%).

DISCUSSION

Pursuant to the current legislation, birch does not represent a target, soil-improving or reinforcing tree species for fertile sites in the Czech Republic. Nevertheless, some authors pointed out an urgent need for an amendment of this regulation (e.g. Košulič 2006).

In the region of our research on fertile sites of lower altitudes in Northern Moravia, birch proved to have a high potential for colonizing the space released after the allochthonous spruce stands. A prerequisite for such colonization is the occurrence of bearing individuals in the surrounding stands. Nevertheless, birch stands that have developed from natural regeneration and have been left without management are characterized by considerable instability in relation to snow. Repeated snow damage culminated in the autumn and winter 2009, when extensive disturbances were recorded due to wet and heavy snow. A snow disaster in the same year severely affected also pine stands in the Czech territory.

All analyzed stands developed from natural regeneration and precious tending measures were traced only in one stand (D). Apart from the high density of these stands, the comparison of our experimental stands with the values of mensurational tables (Anonymous 1990) showed a considerable height (rapid growth): the high yield class of birch (site index 1 and +1, the most optimal site for the species), markedly decreased mean diameter (2–8 cm, tables min. 6–10 cm), but in fact the identical basal area at the same time. At that, the basal area of the analyzed stands (15–20 m^2) aged 10–15 years was considerably lower than 51.8 m^2 reported by Špulák et al. (2010) for a 9-years-old birch stand of 9 m in height that emerged on agricultural land.

The greatest extent of damage was recorded in stands aged from 10 to 15 years. The damage to all trees species in these stands ranged from 67 to 95% and damage to birch was 67–97%. The stands most threatened by snow are usually considered to be those of the height ranging between 10 and 20 m (Kangur 1973 in Nykänen 1997). Snow damage was not recorded in the locality only in the case of a stand aged about 25 years.

The prevailing type of tree damage in the stand was bending. Breakage, which is mentioned as the most frequent type of snow damage (Peltola et al. 1997), was recorded only in a negligible percentage of trees (Table 3).

Stand density can be considered as another important factor of snow damage to stands (e.g. Suominen 1963 in Nykänen 1997). In our research, the most severe damage was observed in the stand with the highest density (Stand B), while the stand with the lowest number of individuals (Stand G) remained intact. In spite of these facts, stand density (e.g. high snow damage in Stand D) cannot be considered as a sole and primary factor of snow damage to stands as shown also by our results.

An important factor of tree stability in relation to biotic factors is the slenderness ratio (e.g. Peltola et al. 1997). The results of our surveys showed different slenderness ratios of intact trees in younger and older stands, the fact undoubtedly connected with different dynamics of diameter and height growth in younger and older stands (Šebík, Polák 1990) where perceptible differentiation already occurred within the stand. Significant differences were found in slenderness ratio values of intact solitary birch trees (about 120) from the immediate surroundings of Stand A and birch trees growing within the stand. On the other hand, no differences were determined in the slenderness ratios of intact and damaged trees within Stands A and C. Differences in the crown setting height between solitary trees and trees growing within Stand A were also significant. While in solitary trees the crowns constituted ca 80% of the total tree height, in trees growing in the stand it was ca 60%. The crown setting height considerably influences the position of the centre of gravity of and hence the static stability of the tree (e.g. Chroust 1968; Peltola et al. 1997).

Slenderness ratio values of solitary intact trees (ca 120) in the case of younger stands as well as the recommendations of many authors (Míchal 1994; Peltola et al. 1997) can help to search for optimal spans and hence tending measures. Birch is generally considered as a more snow-resistant species than spruce or pine (Nykänen et al. 1997; Peltola et al. 1997). And the slenderness ratio value 80 is recommended for spruce similarly like for pine to ensure the stand stability in stands of middle age. Our results would correspond to that limit if the ratio were decreased because the snow damage was recorded in stands of about 14 m in height (D, E and/or F) in which the slenderness ratio ranged about 100.

The root system can be considered as a further important factor for tree stability (e.g. Sereda 1992). Little research has been conducted on the stability of birch trees and the root architecture until now. In general, stressed trees have a reduced root system and *vice versa* (Slodičák et al. 2008). The anchoring of trees in the soil is an important factor of tree resistance to windthrows (Peltola et al. 1997). Differences in the occurrence of sinkers (anchoring) and lateral roots with respect to tree positions in an 8-years-old birch stand were reported by Uri et al. (2006). Only lateral roots of suppressed trees can show the lower stability of these trees. Our surveys also revealed considerable differences in the architecture of root systems between damaged and intact trees, namely in the occurrence of anchors. Differences in the occurrence of anchors in dominant trees could be related with nutrition.

CONCLUSIONS

Silver birch (*Betula pendula* Roth) demonstrated an extraordinary potential to colonize the space after allochthonous, mainly spruce stands on the fertile sites of the studied area. The yield class of the species in this region is one of the best in the Czech Republic.

Dense stands with the dominant representation of birch that developed through natural regeneration suffered repeated snow damage in this region. The most severe damage was recorded in stands aged 8–15 years. The extent of damage in these stands reached up to 97% of all birch trees, and/or 95% of all trees. The most frequent type of damage was bending.

The crown setting height and the slenderness ratio were different for groups of birches from a stand and birches growing like solitary trees.

Individual differences between damaged and intact trees within a stand were detected mainly in the root system architecture.

In contrast to birch trees from the stand, intact solitary trees showed lower values of slenderness ratio, markedly lower crown setting height and hence a higher share of crowns in the tree length.

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