Health condition of spruce stands in the Orlické hory Mts. in relation to climatic, anthropogenic and stand factors

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ABSTRACT: In stands with the majority of spruce and aged over 70 years, 35 sample plots were laid out (in total 700 trees) in the vicinity of Anenský vrch Hill at altitudes over 800 m above sea level. In the course of the growing season 2005, the following parameters were determined: total defoliation, defoliation of the primary structure, percentage of secondary shoots, presence and extent of yellowing and browning. In 10 selected trees, branches were taken from crowns for morphological analyses and annual length increments of branches and numbers of secondary shoots in the particular years were determined. Total defoliation and the occurrence of yellowing were related to slope orientation and position of the plot towards the ridge. The number of shoots produced in the given year correlated with the level of annual NO_3 deposition. The determined difference in the occurrence of yellowing between limed and unlimed plots cannot be interpreted unambiguously because limed and unlimed plots differ in exposure at the same time. The determined importance of slope orientation for the health condition of a stand shows that under the simultaneous air pollution load climatic factors are a factor deciding on the resulting effect of the synergetic action of stressors on forest stands.

Keywords: *Picea abies*; defoliation; yellowing; deposition; climate

At the end of the 70s of the 20th century, forest ecosystems of the Orlické hory Mts. were affected by an increasing environmental load, particularly by SO_2 air pollution. As compared with other factors (drought, frost, insect pests, fungal and virus diseases) air pollution was a new extraneous factor and the response to this factor was very marked; at the beginning of the 80s, the intensity of air pollution steadily increased. Forest stands died on large areas and unreasonable measures or, on the other hand, neglected management contributed to the accelerated destruction of stands.

After a reduction in the input of SO_2 in the 90s of the 20th century, at present forest stands are affected by other air pollutants such as chlorine, fluorine and ground ozone (ČHMÚ 2004). High depositions of nitrogen oxides causing losses of nutrient cations from the soil, reduced resistance to frost and fungal pathogens, susceptibility to insect pest attack are marked loads (Vacek et al. 2000). In 2001–2005, these stands were repeatedly limed by calcic dolomite with a high proportion of magnesium to reduce the impacts of air pollution in summit parts of the Orlické hory Mts. (estates of Jan Kolowrat Krakovský, Kristina Colloredo-Mansfeld, Forests Janeček and Forests of the Czech Republic State Enterprise [LČR, s. p.], Forest District Lanškroun).

In the 80s, dying stands were promptly felled on large areas and finally reforested (using the planting stock of different quality and provenance). The stand microclimate was quite changed and climatic extremes of mountain and ridge locations were substantially increased. Moreover, in the 90s of the 20th century and at the beginning of the 21st century, climatically unfavourable episodes occurred which markedly affected (also due to the previous predisposition) the health condition of forest stands. In the mid-1990s, damage to young stands began to appear which was most often related to climatic factors – drought (Šach 1994) or other precipitation extremes (Čermák 2003), temperature extremes (Jankovský et al. 2002; Čermák 2003) and root deformities during planting (Nárovec 1998; Jankovský et al. 2002). As for biotic factors, the health condition of

Table 1. Basic parameters of monitoring – mean values from sample plots

Plot		Total defoliation		Defoliation of primary structure		% of secondary shoots		Degree of transformation	
No.	Stand	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
1	327B8	30.25	12.62	42.25	13.03	17.75	12.19	0.45	0.51
2	326D8a	28.00	11.52	34.50	12.97	8.75	7.23	0.20	0.41
3	327D8	34.50	9.99	46.50	10.01	18.75	9.16	0.55	0.51
4	327D12	47.00	11.29	61.50	8.13	24.75	13.33	0.95	0.51
5	326D14	36.00	9.95	49.00	9.40	21.00	9.68	0.70	0.47
6	46C8	42.50	10.70	57.00	9.09	24.00	14.65	0.85	0.59
7	46B8	35.50	6.86	48.25	6.93	20.50	8.87	0.65	0.49
8	47D8/1v	41.00	12.10	51.75	9.36	16.50	9.75	0.55	0.51
9	48B9	40.50	8.26	64.25	8.47	38.50	14.96	1.10	0.45
10	49A9	43.75	6.26	70.50	6.05	46.75	12.17	1.35	0.49
11	51C9	42.00	12.81	65.00	9.73	37.00	17.58	1.15	0.59
12	59A9	45.25	10.45	70.50	7.24	45.25	12.62	1.25	0.44
13	61C7	41.50	7.45	62.50	8.03	35.00	13.95	1.05	0.39
14	61B8	38.25	10.17	66.00	8.37	43.00	16.25	1.35	0.49
15	60C14	48.50	11.82	74.50	6.05	50.00	10.26	1.35	0.49
16	61D13	49.75	10.32	75.50	4.84	50.00	10.13	1.35	0.49
17	63C8	41.00	9.40	72.75	8.66	54.50	12.66	1.45	0.51
18	69A10	36.25	7.41	70.25	6.97	52.50	13.81	1.45	0.51
19	326A8a	37.75	9.24	64.50	7.24	42.75	8.35	1.05	0.22
20	325B10	44.00	8.05	81.00	6.61	65.50	9.58	1.90	0.45
21	328D10	41.50	6.90	72.75	7.86	53.25	11.15	1.40	0.50
22	328B11/1b	40.75	11.50	71.50	11.60	53.25	14.17	1.45	0.60
23	324D9	37.75	4.99	68.00	5.23	49.00	7.00	1.20	0.41
24	45E10	35.25	7.34	69.00	7.36	52.25	8.35	1.45	0.51
25	45B9	33.25	7.99	66.75	8.78	50.75	8.93	1.30	0.47
26	424A8	33.50	6.30	67.50	5.74	50.75	6.93	1.35	0.49
27	428A11	33.25	7.12	73.25	5.20	59.50	6.47	1.75	0.44
28	427B9	48.25	15.33	82.50	9.53	69.50	13.27	2.15	0.59
29	433A12a/1c	41.50	9.47	78.25	8.32	64.75	9.52	1.90	0.31
30	42F12	38.25	5.68	75.25	5.25	60.00	5.13	1.85	0.37
31	41B10	33.50	5.64	71.50	6.09	58.00	6.96	1.70	0.47
32	39C12	34.50	5.36	74.75	5.73	62.25	5.73	1.90	0.31
33	28B10	35.50	6.86	69.25	7.12	54.00	9.40	1.55	0.60
34	40A8	33.75	7.05	68.50	6.30	53.75	6.66	1.40	0.50
35	70B8/1v	36.50	4.01	67.75	5.25	50.00	7.07	1.30	0.47
Mean		38.86		65.84		44.39		1.27	

young stands was discussed particularly with respect to the occurrence of the fungus *Ascocalyx abietina* (Lagerb.) Schläpfer-Bernhard (Nárovec 1998, 2001). However, the *Ascocalyx* evidently played the role of an initiatory stressor in the decline of young stands, and it was not either mortality or predisposition stressor (Jankovský et al. 2002). At the end of the 90s, non-specific decline (particularly yellowing) occurred also in older stands. In these stands, above all the deficiency of basic cations was mentioned in connection with high depositions of nitrogen (Šrámek et al. 2000).

The aim of the paper was to determine the general health condition of mature (aged 73–141 years) stands of Norway spruce (*Picea abies* [L.] Karst.) in the vicinity of Anenský vrch Hill, Rychnov nad Kněžnou Forest District, Forests of the Czech Republic, and in two forest districts, viz. Říčky and Černá voda – Kolowratské lesy Forests in Rychnov nad Kněžnou. Possible abiotic, biotic and anthropogenic factors affecting the present health condition of stands were sought.

MATERIAL AND METHODS

In selected stands with the majority of spruce aged over 70 years occurring at altitudes above 800 m above sea level, 35 sample plots were laid out in the course of the growing season 2005. In the representative number of trees – 20 trees on each plot (700 trees in total), basic habitual characteristics according to Cudlín et al. (2001) were evaluated by means of field-glasses. The growth habit of a tree was described: social position, type of branching, type of tree top, crown form, the occurrence of stem, crown and top breaks. The crown of tree was visually divided into three parts: upper juvenile part, central production part and lower saturation part. In the juvenile part, its form was evaluated (according to the modified method of Lesinski and Landman 1995), in the production part, total defoliation, defoliation of the primary structure, percentage of secondary shoots and types of damage (Cudlín et al. 2001) (see Table 1). Subsequently, discoloration was assessed, i.e. yellowing and browning, as the percentage of the total volume of assimilatory tissues with the presence of discoloration (in an interval of 5%).

On ten plots, one sample tree branch was taken from the upper part of the crown production section for the morphological analysis of the branching structure transformation (according to Cudlín et al. 2001). In branches, the following parameters were subsequently determined: the length of the particular annual sections of a branch and the number of secondary shoots in the particular annual sections of the branch. Based on these characteristics, curves were constructed depicting trends of the annual length increment of branches and of the number of secondary shoots in particular years. Mean annual increments and numbers of secondary shoots were compared with climatic and deposition trends. Climatic data from the Czech Hydrometeorological Institute (ČHMÚ) in Rokytnice in the Orlické hory Mts. were used. To outline the deposition load of the studied area, we used data on the mean monthly content of NO_3 and SO_4 in throughfall (mg/l), mean monthly values of NO_3 and SO_4 (kg/ha) depositions in the soil under the stand and mean monthly pH values of throughfall – all measured in the U Dvou louček experimental watershed (a plot of the Forestry and Game Management Research Institute, Opočno Research Station), which is situated in the centre of the studied area.

The relationships between climatic parameters and depositions on the one hand and mean numbers of

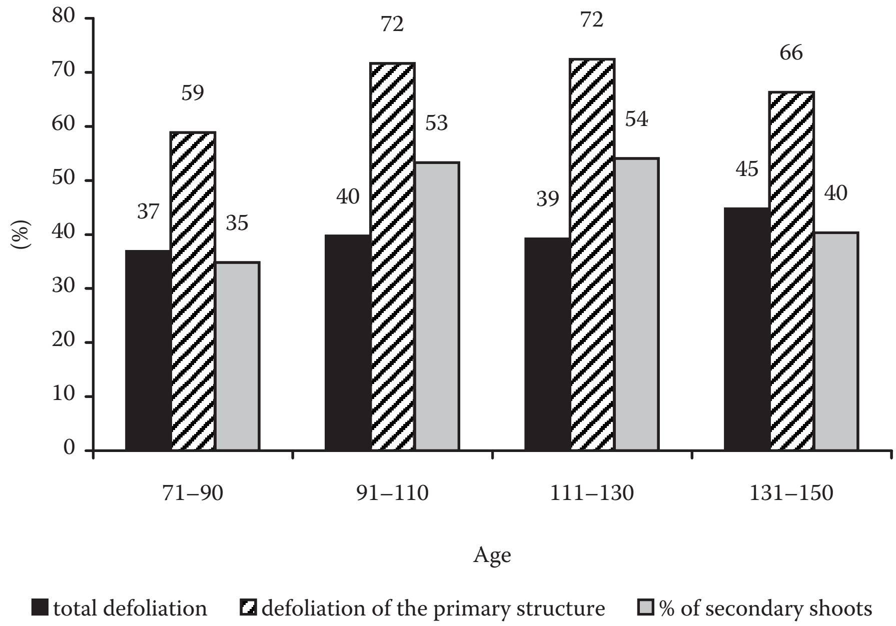

Fig. 1. Mean values of defoliation and of the percentage of secondary shoots according to the stand age

secondary shoots and length increments of sample tree branches on the other hand was tested using correlation analysis; the response delay by 1 year was also taken into account. Resulting correlation coefficients were tested by the pair test of significance – $t_R = [R \times (n-2)^{1/2}]/[(1-R^2)^{1/2}]$; $|t_R| > t_{0.05;\, n-2}$.

RESULTS AND DISCUSSION

Total defoliation, defoliation of the primary structure, percentage of secondary shoots

Mean values of basic habitual characteristics are given in Table 1. Considerable differences were found in the main studied parameters between the particular sample plots. The smallest differences were noted in total mean defoliation on the particular plots ranging from 28.00% (2) to 49.75% (16). The percentage of secondary shoots varied most markedly, namely from minimum 8.75% (2) to maximum 69.50% (28). Defoliation of the primary structure ranged from 34.50% (2) to 82.50% (28).

Within the evaluation of data relationships were determined between various stand and site factors (age, altitude, aspect, location in relation to the ridge, edaphic category, stocking, AHC, mean stem volume of spruce) and total defoliation, defoliation of the primary structure and percentage of secondary shoots. Only the following factors show significant effects on the values of basic characteristics: age (plots were divided into 4 age classes by 20 years), location in relation to the ridge, aspect and the mean stem volume of spruce (division into 4 categories) (see Figs. 1 to 3).

Total defoliation, defoliation of the primary structure and percentage of secondary shoots between the age class of 71–90 years and 91–110 years increased, in the following class of 111–130 years they virtually stagnated, in the age class 131–150 years total defoliation further increased defoliation of the primary structure, the percentage of secondary shoots being lower than in the previous class (in the class of 131–150 years, however, only 3 plots were monitored) (see Fig. 1). In the primary structure defoliation, this decrease can be explained by selective intermediate felling.

Thanks to felling, trees with symptoms of decline mostly belonging to heavily exhausted trees with the high defoliation of primary structure were cut down from overmature stands of the fourth age class. The fall in the percentage of secondary shoots can be interpreted as a result of impaired adaptation and regeneration potential of these overmature spruce stands (trees are not able to replace lost shoots).

Increasing total defoliation with the age of trees is a logical result of senescence when the gradual exhaustion of adaptation capacity and lowering of the regeneration potential occur; nevertheless, this trend is commented in detail in a number of papers (e.g. Gruber 1994; Cudlín et al. 1999).

Total defoliation was notably higher on plots of southern (on average 45.5%), southeastern (44.63%) and southwestern aspect (39.57%) as compared with the other plots and with the total average (38.86%). On plots situated west of the ridge, total defoliation was higher than on plots east of the ridge (Fig. 2).

These differences can be interpreted in several ways. The first possibility is that west of the ridge, synergistic effects of climatic and air pollution stress factors continue to act – the loss of assimilatory organs dominate over the regeneration. East of the summit parts of the ridge, effects of these stressors

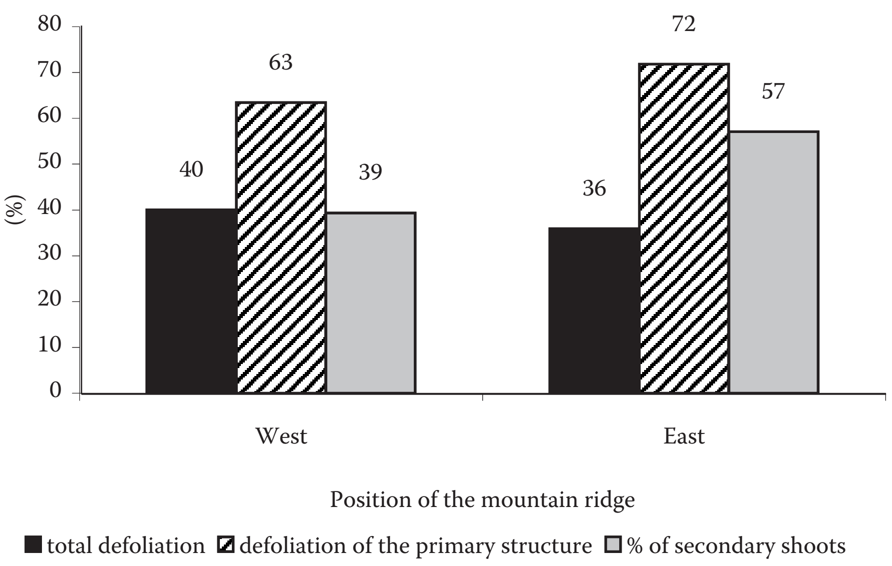

Fig. 2. Mean values of defoliation and of the percentage of secondary shoots according to the position of the stand to the mountain ridge

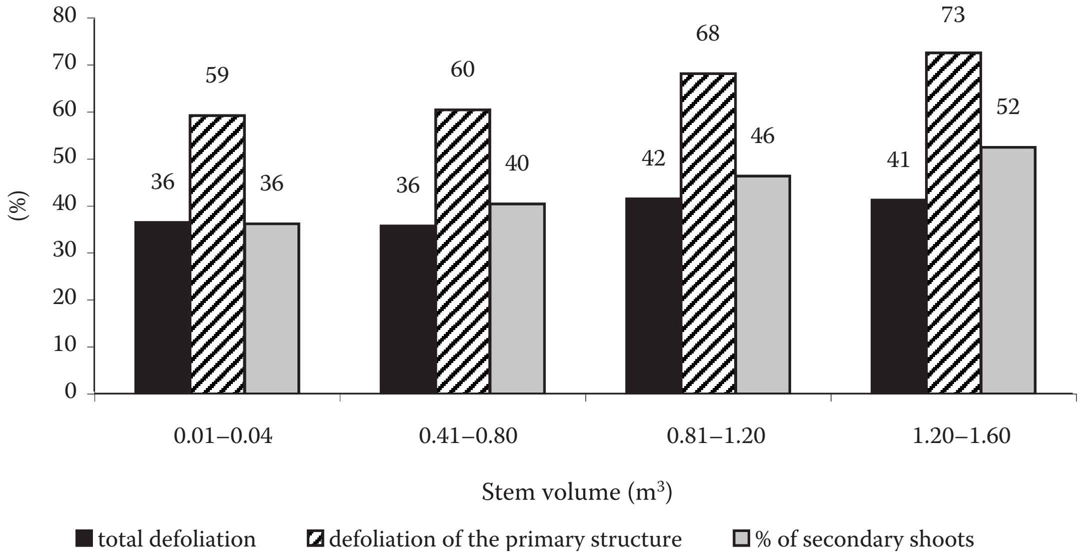

Fig. 3. Mean values of defoliation and the percentage of secondary shoots according to the stem volume

subside and stands already replaced the major part of the lost primary assimilatory tissues (57.08%) by secondary tissues. Another possibility is that at present, trees west of the ridge respond to marked yet short-term effects of stressors whereas trees east of the ridge are rather affected by long-term chronic stressors of lower intensity.

Different responses of trees on both sides of the ridge can indicate the effects of both anthropogenic (air pollution) and climatic stressors. With respect to determined differences in total defoliation on differently exposed plots, it is evident that the exposure climate plays an important role. Plots of SE, S and SW aspect are more insolated, summer temperature maxima reach higher values, drying of the stands is easier (particularly in open stands); in winter during the day, temperatures rise markedly above the freezing point being followed by night frosts; on southern and southwestern aspects, an increased load of ground ozone also occurs most frequently (ČHMÚ 2004). It is possible to suppose that also prevailing air circulation and its consequences will show marked effects.

Under SW circulation (together with NE circulation), higher concentrations of nitrogen oxides occur most frequently in the Orlické hory Mts. (ČHMÚ 2004); in summer, SW circulation results in the drying of stands. With respect to the ridge orientation, this circulation affects above all its western part. The high effect of air circulation is also demonstrated by greater damage to plots at the end of the ridge on SE, S and SW slopes of Anenský vrch Hill; mean total defoliation on plots 20, 21, 22, 28 and 29 is 44.55%, defoliation of the primary structure 77.2%, the percentage of secondary shoots 61.3% – all these values notably exceed the mean of all plots in the studied area (Table 1).

On these plots, also SE circulation occurs. In this part of the Orlické hory Mts., it brings (similarly like SW circulation) higher concentrations of nitrogen oxides (ČHMÚ 2004). In summer, this circulation can result in the drying-up of thinned stands thanks to ascending warm currents conditioned by the topography of the U Dvou louček watershed (Černohous 2000).

The increase of the characteristics with mean stem volume (Fig. 3) points to the indirect effect of age. It holds true on monitored plots that the older the trees, the larger the volumes.

Comparing the mean values of basic characteristics with plots monitored by the same method in the last years in the Krkonoše Mts. (Cudlín et al. 2001), in the Drahanská vrchovina Upland (Jankovský et al. 2004; Čermák et al. 2005) and in the Krušné hory Mts. (Čermák et al. 2006), it is possible to state that the values of total mean defoliation on the particular sample plots are on average higher than the values of other localities with the exception of the Krkonoše Mts. Defoliation of the primary structure, percentage of secondary shoots and the rate of transformation are below-average as compared with other evaluations. The determined values of total defoliation markedly exceed the mean values of defoliation found in spruce stands aged over 60 years within the monitoring of the 1st level of the Forest Focus program network (Boháčová et al. 2004).

The value of total defoliation from the adjacent plot of the network (E190 – Luisino údolí) amounted to 31.40% in 2003, i.e. 7.46% less than the mean values of total defoliation from our measurements.

Table 2. Yellowing and browning of crowns

Plot		Yellowing				Browning			
No.	Stand	number of trees	mean % of the crown (of trees with its presence)	mean % of the crown (of all trees)	maximum value (%)	number of trees	mean % of the crown (of trees with its presence)	mean % of the crown (of all trees)	maximum value (%)
1	327B8	3	7.00	1.05	15	1	1.00	0.05	1
2	326D8a	0	0.00	0.00	0	2	7.50	0.75	10
3	327D8	5	14.00	3.50	20	6	18.33	5.50	30
4	327D12	1	5.00	0.25	5	4	8.75	1.75	10
5	326D14	0	0.00	0.00	0	3	15.00	2.25	20
6	46C8	4	13.75	2.75	20	12	16.67	10.00	30
7	46B8	2	5.00	0.50	5	5	6.00	1.50	10
8	47D8/1v	0	0.00	0.00	0	11	9.09	5.00	30
9	48B9	1	5.00	0.25	5	5	6.00	1.50	10
10	49A9	7	12.14	4.25	30	14	7.50	5.25	10
11	51C9	0	0.00	0.00	0	4	7.50	1.50	10
12	59A9	3	13.33	2.00	20	3	6.67	1.00	10
13	61C7	0	0.00	0.00	0	6	6.67	2.00	10
14	61B8	1	5.00	0.25	5	6	7.50	2.25	10
15	60C14	4	5.00	1.00	5	7	5.71	2.00	10
16	61D13	4	6.25	1.25	10	3	6.67	1.00	10
17	63C8	0	0.00	0.00	0	0	0.00	0.00	0
18	69A10	1	5.00	0.25	5	0	0.00	0.00	0
19	326A8a	0	0.00	0.00	0	0	0.00	0.00	0
20	325B10	20	21.25	21.25	40	17	8.53	7.25	20
21	328D10	7	9.29	3.25	20	0	0.00	0.00	0
22	328B11/1b	8	9.38	3.75	20	0	0.00	0.00	0
23	324D9	2	7.50	0.75	10	0	0.00	0.00	0
24	45E10	0	0.00	0.00	0	1	5.00	0.25	5
25	45B9	0	0.00	0.00	0	3	8.33	1.25	10
26	424A8	1	5.00	0.25	5	2	5.00	0.50	5
27	428A11	14	11.79	8.25	20	8	5.63	2.25	10
28	427B9	18	16.11	14.50	30	12	6.25	3.75	10
29	433A12a/1c	18	16.11	14.50	35	12	5.83	3.50	10
30	42F12	1	10.00	0.50	10	4	5.00	1.00	5
31	41B10	0	0.00	0.00	0	1	5.00	0.25	5
32	39C12	0	0.00	0.00	0	0	0.00	0.00	0
33	28B10	1	5.00	0.25	5	1	10.00	0.50	10
34	40A8	1	5.00	0.25	5	1	5.00	0.25	5
35	70B8/1v	2	5.00	0.50	5	1	5.00	0.25	5
Sum		129				155			
Mean		3.69	6.23	2.44	10.00	4.43	6.03	1.84	9.17

Discoloration – yellowing, browning

The occurrence of yellowing was focal, mostly on central parts of branches, foci were often distributed throughout the crown. Yellowing was noted on 24 plots (Table 2). On 11 plots (1, 3, 6, 10, 12, 20–22, 27–29), minimally one tree exceeded 10% of the crown volume, and on 4 plots (20, 27–29) the number of yellowing trees dominated over trees without any colour changes. The highest mean yellowing in % of the crown volume of all trees on the plot (thus also trees without colour changes) was recorded on plot 20 (21.25%); the highest % of the crown volume (40%) was observed in tree No. 5 from plot 20. Generally, yellowing occurred particularly towards the ridge end (plots 20, 21, 22, 27, 28 and 29).

The occurrence of browning in crowns was scattered, mostly from the basal part and particularly on older needles. Browning was found on 28 plots (Table 2). Only on 5 plots (3, 5, 6, 8, 20), minimally one tree was found with more than 10% of the crown volume. On 6 plots (6, 8, 10, 20, 28, 29), the number of browning trees is higher than the number of trees without colour changes. Plot 6 shows the highest (10%) mean % of the crown volume per plot (thus also trees without colour changes). The highest absolute value of the percentage of crown volume browning (30%) was observed in tree No. 15 and 18 from plot 3, tree No. 11 from plot 6 and tree No. 12 from plot 8.

As for stand and site factors under investigation (age, altitude, position in relation to the ridge, aspect, edaphic category, stocking, absolute height class, mean stem volume of spruce), aspect (Table 3) and altitude (Table 4) showed a noticeable effect on colour changes.

Yellowing occurs most frequently on plots with SE, SW and S aspect, browning on plots with SE, SW and N aspect. While the interpretation of browning occurrence in relation to the aspect is problematic, the results of yellowing can be interpreted in the same way as in total defoliation – as the effects of high insolation related to higher temperature maxima (higher tendency to drying-out, higher effects of oxidation stress) and as the effect of SW and SE air currents.

The number of yellowing and browning trees on a plot decreases with increasing altitude. This trend is more marked in yellowing trees. If we take into account climatic factors, stands situated at lower locations show higher canopy closure and horizontal precipitation is used to a smaller extent, which can notably affect summer spells of drought. If we take into account the effects of air pollution (whether direct or indirect ones), this situation can be interpreted, for example, by slow air currents with the higher concentration of nitrogen oxides which often go through valleys above all at low temperatures, high relative humidity and low wind velocities (Bridgman et al. 2002) resulting in situations when the central parts of slopes are areas more affected by air pollution than the summit parts. It would also be possible to explain the conclusions of a study (Šrámek et al. 2000) aimed at analyses of assimilatory tissues, humus and soil in this way. This study mentions that spruce yellowing in the Orlické hory Mts. was caused by basic element (particularly Ca and

Table 3. Occurrence of yellowing and browning according to the plot aspect

Aspect	No. of plots	Yellowing		Browning	
		number of trees	% of trees on the plot	number of trees	% of trees on the plot
N	1	2	10	5	25
NE	4	4	5	6	8
E	2	1	3	2	5
SE	4	30	38	30	38
S	3	14	23	6	10
SW	11	57	26	71	32
W	4	0	0	9	11
NW	6	21	18	26	22
Sum		129		155	

Table 4. Yellowing and browning of forest stands in relation to their altitude

Altitude (m)	No. of plots	Yellowing		Browning	
		number of trees	% of trees on the plot	number of trees	% of trees on the plot
801–850	6	47	39	44	37
851–900	16	61	19	75	23
901–950	12	19	8	35	15
951–1,000	1	2	10	1	5
Sum		129		155	

Table 5. The occurrence of yellowing and browning on limed and unlimed plots

Liming	No. of plots			Yellowing		Browning	
	total	West	East	number of trees	% of trees on the plot	number of trees	% of trees on the plot
Limed	8	4	4	8	5	36	23
Unlimed	27	21	6	121	22	119	22
Sum	35			129		155	

Mg) deficiencies; a more favourable content of these elements was found in ridge parts of the area. The effects of long-term depositions of nitrogen on the supply of available magnesium at altitudes ≤ 850 m are also illustrated in a study of ČHMÚ (2004). Šrámek et al. (2000) explained the greater damage to stands at lower altitudes by the effect of liming which was carried out mainly in summit parts.

Relationships between liming and yellowing were also monitored in our study. In total 8 plots out of all 35 plots were limed in 2000–2002 and 2004. Calcic dolomite with a high content of magnesium and particle-size fraction to 2 mm was used at a rate of 3 t/ha. Liming affected plots 6, 7, 8, 11 and 24 in 2001 and plots 31, 33 and 34 in 2002. As for the occurrence of browning, there is no difference between limed and unlimed plots, however, in the case of yellowing, differences are marked (Table 5). Of course, the results obtained cannot be interpreted unambiguously as a positive effect of liming. Unlimed plots are situated west of the ridge (Table 5) and, moreover, none of the limed plots occurs in the part of Anenský vrch Hill most exposed to unfavourable air currents (see above) (plots 20–22, 27–29). Thus, detected differences between limed and unlimed plots can be caused by different load of nitrogen air pollution in the localities and by climatic factors.

Morphological analysis of sample tree branches

On sample tree branches, trees grew less in 2004 and then in 2005 and 1988 (Fig. 4). The mean number of secondary shoots produced in the given year (Fig. 5) was highest in 2000 followed by 2002 and 2005; the marked peak of the diagram occurred also in 1995.

Relationships between climatic characteristics, depositions and pH of throughfall on the one hand and the mean number of secondary shoots and the size of length increments of a sample tree branch on the other hand were tested using correlation analysis (Table 6). Correlations were found between the length increment and mean temperature during the growing season (negative correlation), between the number of secondary shoots and annual mean temperature and mean temperature during May and June (positive correlation); further, a relationship was found between the number of secondary shoots on sample tree branches and the sum of annual NO_3

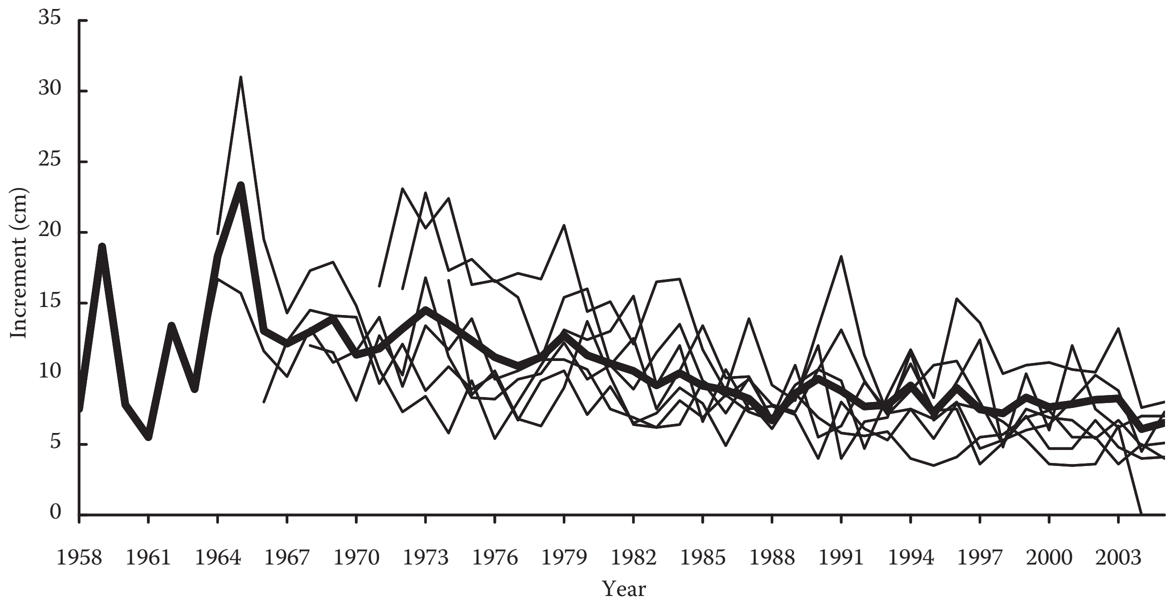

Fig. 4. Length increment of sample tree branches (particular branches – thin line, mean of 10 branches – boldface)

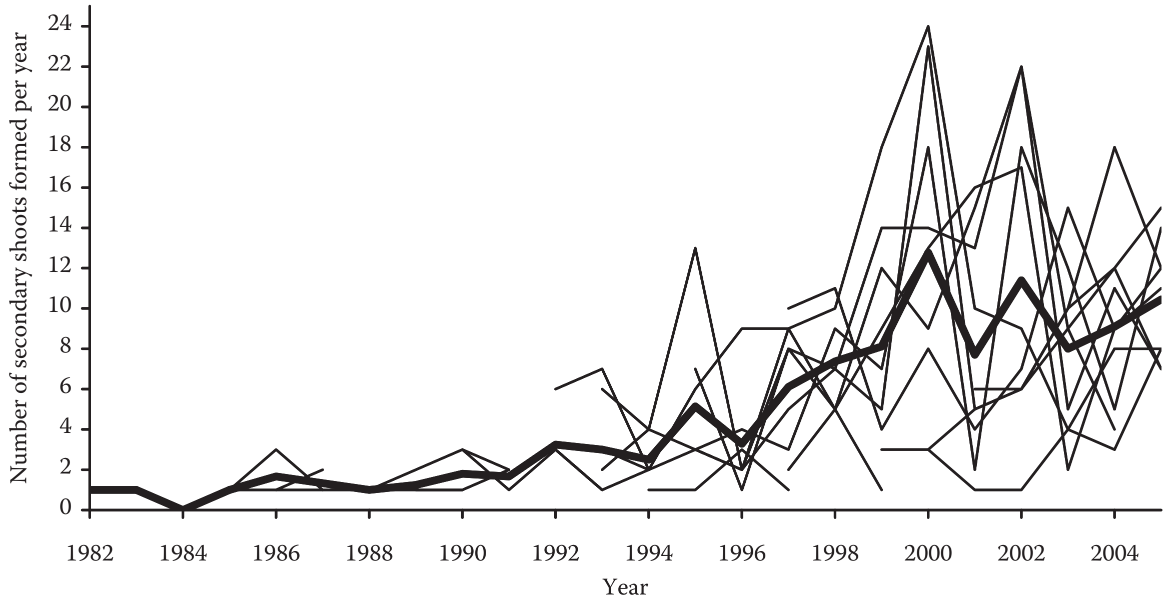

Fig. 5. Number of secondary shoots produced in particular years (particular branches – thin line, mean of 10 branches – boldface)

Table 6. Results of the correlation analysis of the relationships between parameters of the morphological analysis of branches and climatic and deposition characteristics

Characteristics	Correlation coefficient		Significance test of the correlation coefficient	
	length increment	number of secondary shoots	length increment	number of secondary shoots
Climatic characteristics*				
Total annual precipitation	–0.206	0.345	insignificant	insignificant
Mean annual temperature	–0.282	**0.451**	insignificant	**significant**
Total precipitation per growing season	0.018	0.207	insignificant	insignificant
Mean temperature per growing season	**–0.355**	0.379	**significant**	insignificant
Total precipitation per May	0.145	–0.044	insignificant	insignificant
Total temperature per May	–0.303	0.398	insignificant	insignificant
Total precipitation per June	0.038	–0.149	insignificant	insignificant
Total temperature per June	–0.015	0.310	insignificant	insignificant
Total precipitation per May and June	0.127	–0.149	insignificant	insignificant
Total temperature per May and June	–0.202	**0.413**	insignificant	**significant**
P/T year	–0.047	0.030	insignificant	insignificant
P/T growing season	0.116	0.098	insignificant	insignificant
Air pollution characteristics and pH**				
Mean annual pH	–0.197	0.597	insignificant	insignificant
Sum of the annual NO_3 concentration	–0.086	0.104	insignificant	insignificant
Sum of the annual SO_4 concentration	–0.19	–0.579	insignificant	insignificant
Sum of the annual NO_3 deposition	0.024	**0.757**	**significant**	insignificant
Sum of the annual SO_4 deposition	–0.026	–0.564	insignificant	insignificant

*from the ČHMÚ Meteorological station Rokytnice in the Orlické hory Mts., 1966–2005
**from an experimental watershed U Dvou louček (VÚLHM, VS Opočno), 1994–2003

deposition under the stand (positive correlation). The interpretation of correlations with climatic factors is rather difficult and, moreover, correlation coefficients show that it is a relatively low degree of the relationship. The effects of temperature on the formation of secondary shoots can be a result of generally better conditions for growth; of course, it can also be a spontaneous response to the loss of primary branches at higher temperatures and lack of precipitation.

A relationship between depositions and the formation of secondary shoots is more interesting (although the degree of the relationship is low with respect to the short period of measuring the deposition). A possible interpretation of the correlation consists in an interaction between high depositions and climate. High depositions of nitrogen substances in combination with dry weather, particularly in spring and summer, can result in serious physiological disorders (Šach et al. 1999). Cells enlarged in consequence of the luxurious uptake of nitrogen require sufficient amounts of water and if water is not available, the collapse of the cells may occur. Drought results in disorders of mineral nutrition and subsequently in the reduction of assimilatory tissues. High depositions markedly increase the effects of drought spells. Thus, problems in spruce arise under situations when, at another time, responses in the morphology of branching did not occur (which explains why no relationship between the amount of precipitation and the number of secondary branches was found).

If the supply of water is replenished, the tree tries to restore its assimilatory tissues; the high supply of nitrogen will enable the tree to intensively form secondary shoots (if other conditions are favourable, e.g. at least the mean supply of potassium, etc.). In all years with high depositions, apparent spells of drought occurred in the course of the growing season and often even repeatedly, e.g. in 1996 and 1999 (Černohous 2000). However, the unambiguous interpretation of the effect of depositions on the formation of secondary shoots is not possible. The impacts of depositions on the physiology of trees can be different in relation to site, stand and climatic factors. According to literature, different effects of increased depositions of nitrogen on growth were demonstrated e.g. in conifers, namely both decrease (Aber et al. 1995; Emmet et al. 1998, etc.) and increase (Binkley, Högberg 1997) in relation to humus conditions, stand age and a number of other factors.

In addition to regression analysis given in Table 6 regression analysis was also carried out for the same parameters using a shift by one year – climatic and deposition data from the given year and the increment and number of secondary shoots from the next year. In this case, the only correlation was found out, viz. the higher the pH value of throughfall in the previous year, the higher the number of secondary shoots produced in the given year (r = 0.776). However, it is a question how to interpret this relationship.

CONCLUSION

The study demonstrated particularly the effects of exposure climate on the health condition of mature spruce stands in the studied area. Total defoliation as well as the yellowing of spruce needles were highest on SW and SE aspects, particularly at the end of the mountain ridge where the plots were mostly exposed to SW and SE air currents. The high load of nitrogen depositions in the area shows significant effects on the formation of secondary shoots. It was not possible to demonstrate unambiguously the participation of nitrogen depositions in the yellowing of stands. An apparent difference was found between limed and unlimed plots, which could indicate the effects of depositions or deposition-induced Mg deficiency, however, limed and unlimed plots differ in their slope orientation at the same time. Thus, the differences cannot be interpreted unambiguously.

Norway spruce stands which underwent an air pollution disaster in the 70s are at present stressed by high nitrogen depositions, increased concentrations of ground ozone and by the extreme course of climate. The determined importance of exposure for the health condition of a stand shows that under conditions of the present air pollution load climatic factors are a factor that decides on the final effect of the synergetic influence of stressors on stands.

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Zdravotní stav smrkových porostů v Orlických horách ve vztahu k působícím klimatickým, antropogenním a porostním faktorům

ABSTRAKT: V porostech s převahou smrku a věkem nad 70 let v okolí Anenského vrchu v nadmořských výškách nad 800 m bylo vytyčeno 35 zkusných ploch (celkem 700 stromů). V průběhu vegetační sezony 2005 byly zjišťovány následující parametry: celková defoliace, defoliace primární struktury, procento sekundárních výhonů, prezence a rozsah žloutnutí a hnědnutí. U deseti vybraných stromů byly odebrány větve z koruny pro morfologickou analýzu, zjišťovaly se roční délkové přírůsty větve a počty sekundárních výhonů, vytvořených v jednotlivých letech. Celková defoliace i výskyt žloutnutí byly závislé na expozici a poloze plochy vůči hřebenu. Počet sekundárních výhonů vytvořených v daném roce pozitivně koreloval s výškou roční depozice NO_3. Zjištěný rozdíl výskytu žloutnutí mezi vápněnými plochami a plochami nevápněnými nelze jednoznačně interpretovat, plochy vápněné a nevápněné se totiž zároveň liší expozicemi. Zjištěný význam expozice pro zdravotní stav porostu ukazuje, že při současné imisní zátěži jsou klimatické faktory činitelem, který rozhoduje o výsledném efektu synergického působení stresorů na porosty.

Klíčová slova: *Picea abies*; defoliace; žloutnutí; depozice; klima

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