Analysis of snow accumulation and snow melting in a young mountain spruce and beech stand in the Orlické hory Mts., Czech Republic

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ABSTRACT: The paper evaluates snow accumulation and the intensity of snow melting in a young spruce and beech stand. The study was carried out at the Deštné field research station in the Orlické hory Mts. (altitude 900 m, WSW aspect) in winter seasons 2005/2006, 2006/2007 and 2007/2008. The process of snow accumulation and melting was markedly affected or disturbed by the nearly total damage to the spruce stand by top breakage due to the extreme load of wet snow. Winter 2005/2006 was characterized by extreme parameters of snowpack (maximum depth of snow in spruce 157 cm, in beech 164 cm, maximum snow water equivalent in spruce 819 mm, in beech 833 mm). From the aspect of the snow cover duration, winter 2006/2007 was below the average, winter 2007/2008 was average. With respect to the significant reduction of the spruce crown biomass after snow breakage in winter 2005/2006, no significant differences were noted either in snow depth or in snow water equivalent in the spruce and beech stands. The rate of snow melting in the spruce and beech stands was never higher than 50 mm per day. If the spring final stage of snow melting is not accompanied by intensive rainstorms, mountain coniferous and broadleaved forest ecosystems reduce the danger of stormflows and floods within the required degree.

Keywords: snow accumulation; snow melting rate; spruce; beech; mountain site

Within the study and evaluation of the hydrologic efficacy of forest ecosystems, snow measurements show a quite specific position. In winter, snow is intercepted temporarily but also in the long term in tree crowns of coniferous stands in particular. Above all in mountain locations, the period of snow accumulation usually lasts for several months. However, from the aspect of the water-management effectiveness of forests, the period of spring melting is of decisive importance. Thus, in the course of several few weeks (in extreme cases even several days), all water accumulated in snowpack flows out of the forest.

In scientific literature attention is paid to the problem of the water regime of forest stands in winter seasons including snow measurements already for more than 50 years (Krečmer 1969; Valčičák 1974). In Hannover Münden in March 1984, a conference *Hydrological Research into Snow in Central Europe* was held. Findings there evaluated were coming particularly from Germany and Switzerland. Attention was particularly paid to regions with the

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significant creation of snowpack, especially mountain locations.

It has been proved through long-term measurements that parameters of the snowpack (snow depth, snow water equivalent) are always higher in open space than in spruce stands, namely by 15–50% (Brechtel 1984; Imbeck 1984; Brechtel et al. 1984; Ernstberger, Sokollek 1984; Kronfellner-Kraus, Schaffhauser 1984). On the other hand, snow water equivalent in beech stands is the same or even higher than in open space (Brechtel 1984). The snow melting rate is unambiguously higher on clear-cut areas and thus, it is possible to conclude that the forest exerts significant effects on the retardation and prolongation of the spring snow melting. Similar results were also proved in later studies (Mayer et al. 1997; Hribík, Škvarenina 2007; Hribík et al. 2007).

Generally, forest soils are in so far permeable that they are able to receive all water from snowmelt including potential rainfall without the origin of surface runoff. In mountain locations of Central Europe, freezing of the soil is quite exceptional because of the occurrence of early and continuous snow cover and practically not affecting soil retention (Schwarz 1984). Even in Finland, freezing of the soil is negligible in forests as well as on clear-cut areas if snow falls already in autumn and maintains a sufficient depth (Kubin, Poikolainen 1982).

In the Czech Republic, Zelený (1954) referred to the exceptional importance of snowpack as early as in the 50^{th} of the last century. Results of snow measurement studies in the Beskids showed that the snow depth was on average 63% higher in beech stands and the snow water equivalent 75% higher than in spruce stands.

In the Orlické hory Mts. on the Šerlich mountainside, Krečmer et al. (1971) investigated parameters of snowpack in a mature fully stocked spruce stand within the research into water regime of regeneration cuts. In the course of snowfall in spruce stands, the interception of solid precipitation occurred in crowns of trees representing up to 40% of new snow. Snow observations showed that about $^3/_4$ of that initial interception loss reached the ground. Krečmer (1973) also reported that coniferous mountain forests retained snow for a substantially longer period than the open area and that they participated effectively in the prolongation of the period of spring runoff.

In the Orlické hory Mts. at the Deštné field research station, the accumulation and intensity of snow melting have continually been studied within a broad research programme in an experimental spruce and beech stand since the winter season 1976/1977. Results of these studies were published in three original scientific papers (Kantor 1979, 1988; Kantor, Šach 2002). Due to the different interception process of snow precipitation in the spruce and beech stands, snow depth and snow water equivalent were always higher in the leafless broadleaved stand. At the same time, it has been proved that the rate of snow melting is always significantly higher in beech (Kantor 1988).

The presented paper is the fourth report analyzing the depth/weight investigation of snowpack at this field research station. It includes three winter seasons: 2005/2006, 2006/2007 and 2007/2008.

Characteristics of the field research station and methods of the study

The field research station was established in 1976 in a mature spruce and beech stand in the district of Deštné in the Orlické hory Mts. Since 1. 11. 1976, all components of the water balance of both stands have been studied in an uninterrupted series (interception, transpiration, evaporation, overland flow, lateral flow of water through soil (interflow), vertical flow to bedrock, soil water content, and snow measurement). Both stands are situated near apart from each other on a WSW slope, mean inclination 16°, altitude 890 m. The depth/weight measurement of snowpack in the mature spruce and beech stands was carried out in five successive winter seasons (1976/1977 to 1980/1981). In winter 1981/1982, both stands were clear cut and in the following year, planned harvest cutting was concentrated also into neighbouring stands. New clear cuts of an area of about 20 ha were reforested by spruce and beech immediately after logging.

Since 1982/1983, the uninterrupted study of particular components of the water balance of both tree species has continued in newly established stands. Thus, the 32-year remarkable series of findings is available on the water balance of spruce and beech in mid-mountain locations at present. Detailed methodology and results of studies have already been published in a number of papers (e.g. Kantor 1984, 1995). In winter and in the period of spring melting, overland and lateral flow of water through soil (interflow) was also measured on runoff plots of a size 20 m^2 in both stands.

The presented study shows only a fragment of those results, namely the comparison of snow measurement studies in a young spruce and a young beech stand (age 25 to 27 years) in winter seasons 2005/2006, 2006/2007 and 2007/2008.

Table 1. Basic parameters of snow cover at the permanent field research station Deštné in the spruce and beech stands in the winter period 2005/2006

Date of measurements	Precipitation (mm)	Type of precipitation	Stand	Snow cover parameters		
				depth (cm)	snow water equivalent (mm)	density (g/cm^3)
22. 11. 2005	34.0	*	spruce	25.3	24.8	0.098
			beech	27.0	28.4	0.105
28. 11. 2005	28.0	*	spruce	19.8	29.8	0.150
			beech	23.5	48.0	0.204
9. 12. 2005	53.0	●*	spruce	38.5	51.2	0.133
			beech	46.8	57.2	0.122
15. 12. 2005	64.2	●*	spruce	39.7	66.0	0.166
			beech	42.0	69.6	0.166
23. 12. 2005	90.8	*	spruce	92.2	192.3	0.209
			beech	94.0	198.1	0.211
30. 12. 2005	26.4	●*	spruce	91.4	167.2	0.183
			beech	104.7	206.9	0.198
4. 1. 2006	73.0	*	spruce	105.3	212.3	0.202
			beech	108.6	223.1	0.205
12. 1. 2006	0.0		spruce	106.3	289.9	0.273
			beech	111.7	298.7	0.267
24. 1. 2006	128.0	*	spruce	120.0	424.3	0.354
			beech	128.5	451.9	0.352
30. 1. 2006	0.0		spruce	115.7	362.5	0.313
			beech	118.3	389.1	0.329
9. 2. 2006	158.4	*	spruce	147.4	455.1	0.309
			beech	148.6	475.1	0.320
18. 2. 2006	17.0	●*	spruce	138.4	481.3	0.348
			beech	142.3	495.9	0.348
27. 2. 2006	95.0	*	spruce	148.4	561.8	0.379
			beech	152.4	602.6	0.395
6. 3. 2006	19.0	*	spruce	156.3	608.6	0.389
			beech	157.9	613.8	0.389
13. 3. 2006	182.2	*	spruce	157.2	819.0	0.496
			beech	164.1	832.7	0.537
20. 3. 2006	25.0	●	spruce	132.0	526.3	0.399
			beech	144.6	550.6	0.381
27. 3. 2006	63.0	●*	spruce	123.5	483.9	0.392
			beech	133.1	520.3	0.391
10 .4. 2006	71.6	●*	spruce	91.5	295.9	0.323
			beech	67.5	249.5	0.370

Table 1. to be continued

Date of measurements	Precipitation (mm)	Type of precipitation	Stand	Snow cover parameters		
				depth (cm)	snow water equivalent (mm)	density (g/cm^3)
18 .4. 2006	0.0		spruce	67.5	275.1	0.407
			beech	46.8	228.3	0.488
19. 4. 2006	0.0		spruce	61.7	268.3	0.435
			beech	46.5	209.9	0.452
20. 4. 2006	0.0		spruce	61.3	251.2	0.410
			beech	41.1	184.8	0.450
21. 4. 2006	0.0		spruce	56.5	234.5	0.415
			beech	35.1	159.7	0.455
22. 4. 2006	0.0		spruce	47.7	216.3	0.454
			beech	28.4	134.8	0.475
23. 4. 2006	0.0		spruce	42.8	199.5	0.466
			beech	19.1	90.8	0.475
24. 4. 2006	0.0		spruce	42.4	181.9	0.428
			beech	9.5	42.2	0.444
25. 4. 2006	0.0		spruce	31.6	137.6	0.435
			beech	1.8	7.2	0.400
26. 4. 2006	0.7	●	spruce	20.0	95.0	0.475
			beech			
27. 4. 2006	0.0		spruce	11.1	48.6	0.432
			beech			
28. 4. 2006	0.0		spruce	2.3	10.2	0.443
			beech			

● rain; ∗ snow; ●∗ rain and snow

Statistical significance of differences in the snow water equivalent in the spruce and beech stands in the period of snow accumulation (22. 11. 2005 to 13. 3. 2006). Paired *t*-test at the level of significance 0.05

Stand	Mean	Standard deviation of sample	Difference	Standard deviation of differences	*t*	*p*	Significance
Spruce	316.41	240.21					
Beech	332.74	243.79	–16.33	12.41	–5.10	0.00	yes

The process of snow accumulation and melting was markedly affected or disturbed in the assessed period by the practically total damage to the spruce stand due to top breakages in winter 2005/2006 in consequence of extreme load by wet snow. Snowstorms (e.g. in the first decade of February 158 mm, in a week from 6 March to 13 March even 182 mm) damaged up to 98% of spruce trees. In some cases, it referred only to top breakages but in about 50% of trees only 2 to 3 whorls of branches remained living on tree stems.

The beech stand was disturbed to a substantially lesser extent. Due to the snow load, about 10% of subdominant trees with the unfavourable slenderness ratio were bent or broken irreversibly. These trees were already removed from the stand. Thus, the situation in the spruce stand has to be taken into account at interpreting and analyzing results of depth/weight measurements of the snowpack.

For the actual measurement of snow a verified standard method of sampling snow by the depth/weight snow core measurement device was used (the sampler circular cross section 50 cm^2). In all three winter seasons, snow core samples were taken in weekly intervals always from five sites (3 samples from each of the sites) in a spruce and beech stand. The depth of the samples was measured, their weight was determined and the snow water equivalent and snow density were calculated.

Moreover, in spring 2006 in the period of final snowmelt, with respect to the extremely deep snow cover a daily frequency of measurements was used from 10 April.

In winter seasons 2006/2007 and 2007/2008, the measurement was extended by snow sampling even in open space.

Precipitation was measured with a rain gauge of circular cross-section 500 cm^2 on two "open areas" (stand gaps 20 × 30 m and 30 × 50 m) in the immediate vicinity of both stands. In the periods of snow accumulation when the air temperature did not exceed 0 degrees C, precipitation could be simultaneously determined also from differences in the snow water equivalent.

Differences in the snow water equivalent in the spruce and beech stands were statistically evaluated by paired *t*-test for dependent samples.

RESULTS AND DISCUSSION

From the aspect of the depth of snow precipitation and duration of snow cover the winter season 2005/2006 was markedly above-average. On the contrary, the winter season 2006/2007 was markedly subnormal. Thus, the last evaluated winter 2007/2008 can be characterized as average. In the following text, each of the winter seasons is evaluated separately.

Winter season 2005/2006

All basic data on snow measurements in the winter season 2005/2006 carried out at the long-term field research station Deštné are given in Table 1.

The assessed season was characterized by extremely high mainly snow precipitation and by the very long period of continuous snow cover. The first snow fell there on 20 November 2005 and melted in beech on 25 April 2006 (157 days with continuous snow cover). In spruce, snow melted 3 days later, i.e. 28 April 2006 (160 days with continuous snow cover).

The period of snow accumulation (from 20. 11. 2005 to 13. 3. 2006)

At the first measurement on 22. 11. 2005, the depth of powder snow recorded in spruce equalled 25.3 cm and in beech 27.0 cm. With progressing winter, the snow depth gradually increased (30. 12. 2005: spruce 91.4 cm, beech 104.7 cm; 24. 1. 2006: spruce 120.0 cm, beech 128.5 cm) until it reached its maximum on 13. 3. 2006 – in spruce 157.2 cm, in beech 164.1 cm. During the whole period, the snow depth in spruce was always a little lower (by 1 to 13 cm) than in beech (see Fig. 1).

The snow water equivalent showed a similar trend like snow depth in the assessed season (see Fig. 2). From the aspect of hydrologic efficacy, this parameter shows a higher informative value than the snow depth. From the initial value at the first measurement on 22. 11. 2005 (spruce 24.8 mm, beech 28.4 mm) it

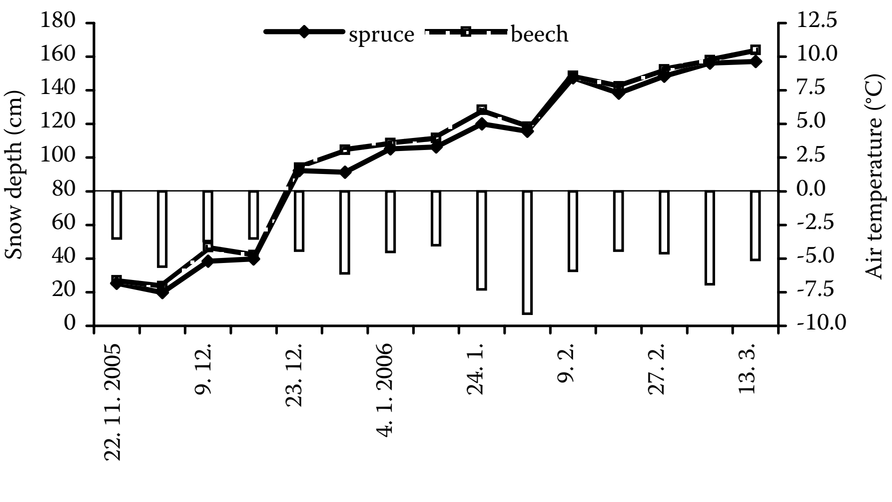

Fig. 1. The depth of snow in the period of snow accumulation (22. 11. 2005 to 13. 3. 2006)

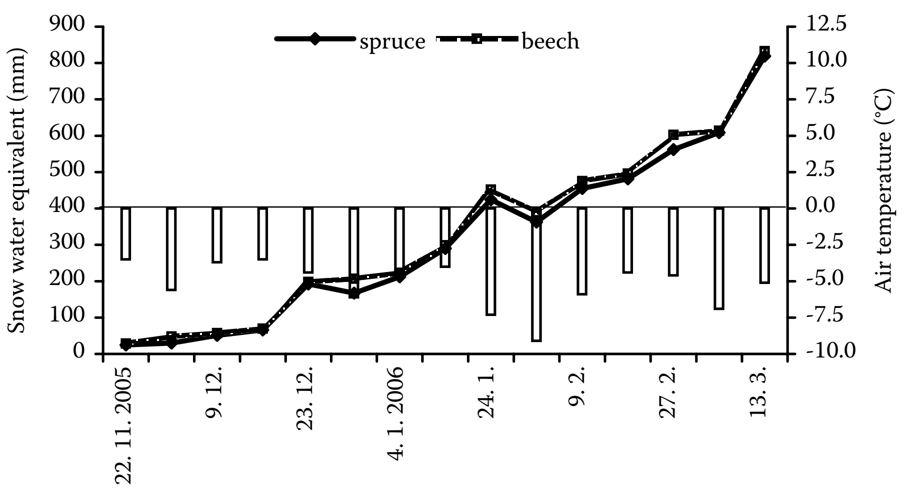

Fig. 2. The snow water equivalent in the period of snow accumulation (22. 11. 2005 to 13. 3. 2006)

gradually increased (30. 12. 2005: spruce 167.2 mm, beech 206.9 mm; 24. 1. 2006: spruce 424.3 mm, beech 451.9 mm) up to respectable 819.0 mm in spruce and 832.7 mm in beech on 13. 3. 2006.

The importance of the "temporary" interception of snow precipitation results from Table 1. For example, at the first two measurements in November, the precipitation of an open area amounted to 56 mm, but practically 50% of snow (26.2 mm) was intercepted in crowns of spruce trees. During winter, more than 100 mm snow precipitation was even temporarily intercepted in tree crowns. This snow fell for the most part to the soil surface sooner or later but its spatial variability was great and these values have to be regarded as approximations. For example, from 4 January to 24 January, precipitation amounting to 128 mm was recorded on the open area but the storage of water in snow increased by 212 mm or 229 mm. Especially high amounts of snow intercepted in tree crowns were the cause of the total damage to a spruce stand by top breakages.

The quite exceptional winter 2005/2006 is distinguished as compared with data from 1976/1977 to 1986/1987 (Table 2). Particularly the maximum

Table 2. Snow measurement studies at the field research station Deštné in winter seasons 1976/1977 to 1986/1987 and in the winter season 2005/2006

Winter season	Stand	Number of days with snow cover	Snow cover parameters		
			maximum depth (cm)	maximum snow water equivalent (mm)	mean density (g/cm^3)
1976/1977	spruce	124	63.1	170.2	0.266
	beech	129	81.7	245.0	0.266
1977/1978	spruce	141	67.2	174.9	0.276
	beech	146	83.7	222.2	0.284
1978/1979	spruce	140	47.9	146.8	0.252
	beech	141	69.7	211.8	0.275
1979/1980	spruce	142	43.6	120.8	0.257
	beech	142	63.8	189.4	0.276
1980/1981	spruce	117	78.3	242.1	0.290
	beech	120	113.5	309.9	0.291
1986/1987	spruce	120	84.0	268.5	0.295
	beech	126	124.6	406.5	0.298
2005/2006	**spruce**	**160**	**157.2**	**819.0**	**0.427**
	beech	**157**	**164.1**	**832.7**	**0.445**

Table 3. Snow-cover parameters in the period of snow melting in spring 2006

Date	Stand	Snow depth (cm)	Snow water equivalent (mm)	Intensity of snow melting (mm/day)		Average daily air temperature (°C)
13. 3. 2006	spruce	157.2	819.0	spruce 41.8	beech 40.3	
	beech	164.1	832.7			
20. 3. 2006	spruce	132.0	526.3	spruce 6.1	beech 4.3	
	beech	144.6	550.6			
27. 3. 2006	spruce	123.5	483.9	spruce 13.4	beech 19.3	
	beech	133.1	520.3			
10. 4. 2006	spruce	91.5	295.9	spruce 2.6	beech 2.7	
	beech	67.5	249.5			
18. 4. 2006	spruce	67.5	275.1	spruce 6.8	beech 18.4	4.5
	beech	46.8	228.3			
19. 4. 2006	spruce	61.7	268.3	spruce 17.1	beech 25.1	5.9
	beech	46.5	209.9			
20. 4. 2006	spruce	61.3	251.2	spruce 16.7	beech 25.1	7.8
	beech	41.1	184.8			
21. 4. 2006	spruce	56.5	234.5	spruce 18.2	beech 24.9	8.9
	beech	35.1	159.7			
22. 4. 2006	spruce	47.7	216.3	spruce 16.8	beech 44.0	10.8
	beech	28.4	134.8			
23. 4. 2006	spruce	42.8	199.5	spruce 17.6	beech 48.6	7.3
	beech	19.1	90.8			
24. 4. 2006	spruce	42.4	181.9	spruce 44.3	beech 35.0	8.9
	beech	9.5	42.2			
25. 4. 2006	spruce	31.6	137.6	spruce 42.6	beech 7.2	11.3
	beech	1.8	7.2			
26. 4. 2006	spruce	20.0	95.0	spruce 47.0		11.5
	beech					
27. 4. 2006	spruce	11.1	48.0	spruce 37.8		11.9
	beech					
28. 4. 2006	spruce	2.3	10.2			8.3
	beech					

Statistical significance of differences in the snow water equivalent in the spruce and beech stands in the period of snow melting (10. 4. to 28. 4. 2006). Paired t-test at the level of significance 0.05

Stand	Mean	Standard deviation of sample	Difference	Standard deviation of differences	t	p	Significance
Spruce	184.51	92.88					
Beech	108.93	97.20	75.58	37.76	6.93	0.00	yes

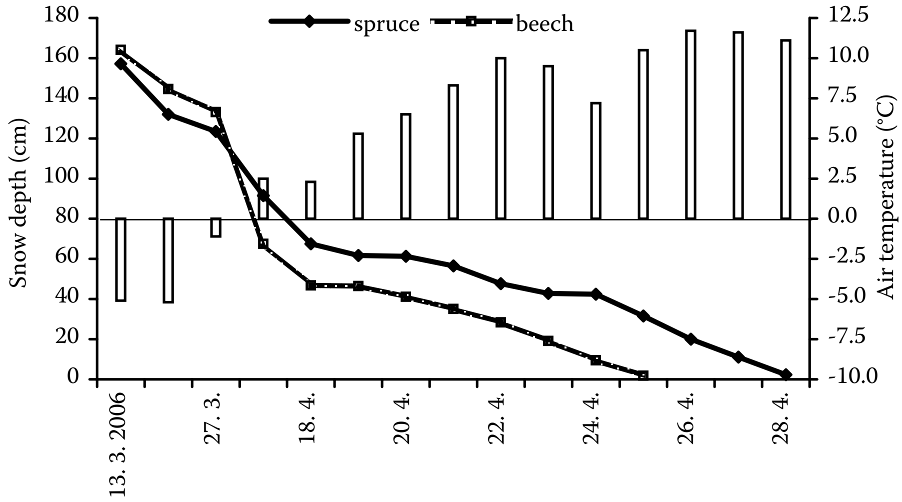

Fig. 3. The depth of snow in the period of snow melting (13. 3. to 28. 4. 2006)

snow water equivalent in the last winter amounting to more than 800 mm exceeds 2× to 6× the values given in Table 2.

Relatively small (at the limit of statistical significance) differences in depth but particularly in the snow water equivalent in both compared stands can be considered to be the most important and somewhat unexpected finding from depth/weight measurements in the period of snow accumulation at the Deštné field research station in winter 2005/2006. Because of the important interception of even winter precipitation in spruce stands, both basic values of snow are generally markedly higher in the leafless beech stand (Zelený 1954; Brechtel 1984). This fact is also documented by data from Table 2 (Kantor 1988). In our case, high values of the snow depth and snow water equivalent in the coniferous stand can be ascribed to the already mentioned extensive snow breakage when due to top and stem breakages the biomass of crowns was reduced by about 50%. Subsequently, under the crowns of spruce stand, such an amount of solid precipitation occurred that was practically comparable with solid precipitation in the beech stand.

The period of snow melting (from 13. 3. to 28. 4. 2006)

The period of snow accumulation culminated at the field research station Deštné in the assessed winter season in mid-March (13. 3. 2006) when maximum values of snow depth were recorded in both stands (spruce 157.2 cm, beech 164.1 cm) as well as of the snow water equivalent (spruce 819.0 mm, beech 832.7 mm).

The second half of March (13. 3. to 27. 3. 2006) was already characterized by the gradual melting of snow, which was relatively very intensive particularly from 13. 3. to 20. 3. 2006 (spruce 41.8 mm, beech 40.3 mm daily) (see Table 3).

The depth of snow decreased by 33.7 cm to 123.5 cm in spruce until the end of March, in beech by 31.0 cm to 133.1 cm. Nevertheless, the snow water equivalent decreased very markedly in this period,

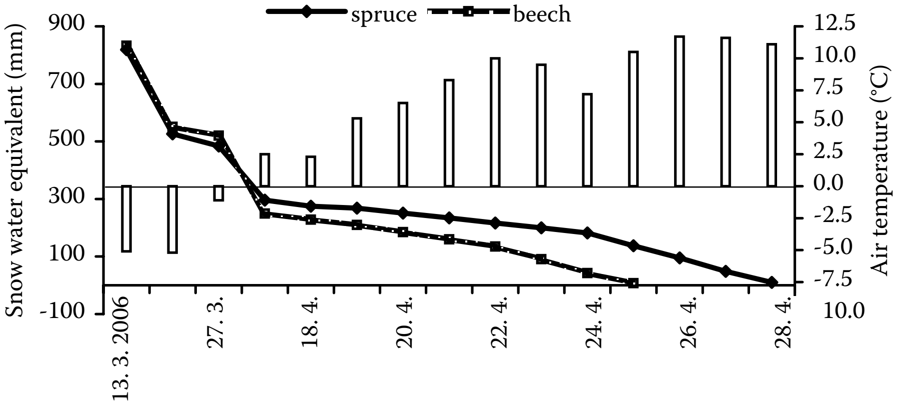

Fig. 4. The snow water equivalent in the period of snow melting (13. 3. to 28. 4. 2006)

Table 4. Basic parameters of snow cover at the permanent field research station Deštné in the spruce and beech stands and in the open area in the winter period 2006/2007

Date of measurements	Precipitation (mm)	Type of precipitation	Spruce stand		Beech stand		Open area	
			snow depth (cm)	snow water equivalent (mm)	snow depth (cm)	snow water equivalent (mm)	snow depth (cm)	snow water equivalent (mm)
12. 12. 2006	24.2	●∗	4.7	10.2	5.8	12.0	5.9	12.9
19. 12. 2006	7.8	●∗	1.7	5.2	3.3	8.9	2.4	7.7
27. 12. 2006	11.5	∗	5.1	13.4	6.3	14.9	7.2	19.2
2. 1. 2007	30.4	∗	13.9	31.2	23.9	56.4	20.7	48.0
9. 1. 2007	23.0	●	–	–	–	–	–	–
16. 1. 2007	20.2	●	–	–	–	–	–	–
22. 1. 2007	26.4	●	–	–	–	–	–	–
1. 2. 2007	112.4	∗	32.5	86.0	48.6	107.8	51.5	112.4
6. 2. 2007	12.0	∗	42.9	104.4	50.5	122.8	50.7	124.4
13. 2. 2007	45.6	∗	44.1	142.4	51.2	160.0	53.1	170.0
21. 2. 2007	18.6	∗●	38.2	155.6	44.3	169.6	42.2	177.6
27. 2. 2007	13.4	∗●	43.0	164.8	47.1	180.0	45.9	179.6
5. 3. 2007	52.0	∗●	44.2	168.0	46.1	181.6	48.9	181.6
15. 3. 2007	17.6	●	33.2	145.2	36.6	150.4	40.6	152.4
28. 3. 2007	24.0	●	18.4	56.8	20.3	64.0	27.3	84.8
3. 4. 2007	0		–	–	–	–	12.1	61.4
6. 4. 2007	0		–	–	–	–	–	–

● rain; ∗ snow; ●∗ rain with snow; ∗● snow with rain

Statistical significance of differences in the snow water equivalent in the spruce and beech stands in the period of snow accumulation (12. 12. 2006 to 5. 3. 2007). Paired *t*-test at the level of significance 0.05

Stand	Mean	Standard deviation of sample	Difference	Standard deviation of differences	*t*	*p*	Significance
Spruce	80.38	72.66					
Beech	101.40	72.46	–21.02	28.55	–2.33	0.04	yes

in spruce by 335.1 mm to 483.9 mm, in beech by 312.4 mm to 520.3 mm. In both stands, roughly the same amount of snow melted away. In the spruce stand, the rate of snowmelt was slightly higher in this period.

From the aspect of hydrologic efficacy assessing the form of runoff from melting snow is, however, substantially more important. Thus, the fact when in a coniferous as well as in a broadleaved beech stand quite a decisive part of water from melting snow flowed through unfrozen soil to underlying rock and discharged to the drainage system practically without damage can be considered to be exceptionally important. Overland flow including the lateral flow of water through soil ranged at a level of about 13 to 16 mm in both stands for the whole March 2006.

The snow melt continued depending on the course of weather also in the first two decades of April. An important turnover in the process of snow melting in both stands occurred between 27. 3. and 10. 4. 2006 when because of the radiation type of weather snow began to melt away more intensively in the leafless beech stand (19.3 mm per day) than in the spruce stand (13.4 mm per day).

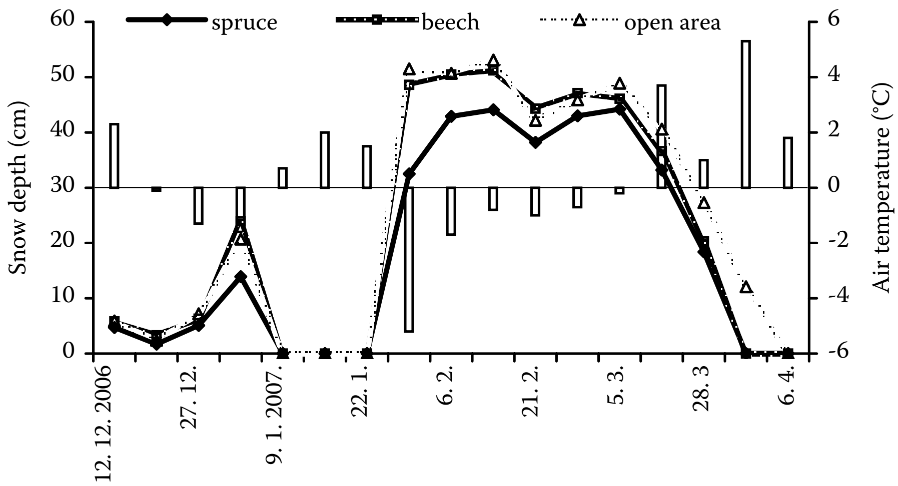

Fig. 5. The depth of snow at the field research station Deštné in winter 2006/2007

At the beginning of the final period of melting on 18. 4. 2006, the snow depth was decreased to 67.5 cm in spruce, to 46.8 cm in beech and the snow water equivalent in the spruce stand was reduced to 275.1 mm and in the beech stand to 228.3 mm.

In line with the presented and approved methodology, the daily frequency of data collection was used in the final period of snow melting from 18. 4. 2006. All basic data from this period are given in Table 3 and Figs. 3 and 4.

In spruce, the snowpack melted until 24. 4. with a favourable low intensity from 6.8 to 18.2 mm/day. In the beech stand, the rate of melting was significantly higher, particularly on 23. and 24. 4. 2006 (44.0 or 48.6 mm/day, respectively).

The most intensive melting of snowpack in the spruce stand was registered at the last measurements since 24. 4. when the rate of snowmelt ranged from 42.6 to 47.0 mm/day. At that time, the continuous snow cover in the beech stand decreased and the last snow melted away on 25. 4. 2006 in evening hours. In the spruce stand, the last remainders of snow melted three days later, in the evening 28. 4. 2006.

Similarly like in March, also in April practically all water from melting snow infiltrated to the underlying rock. Only 16 mm water in spruce and 17 mm in beech flowed out in the form of overland flow in the last winter month.

Winter season 2006/2007

Basic parameters of the snowpack in winter 2006/2007 at the long-term field research station Deštné in the spruce and beech stands as well as in the open area are given in Table 4 and Figs. 5 and 6. Generally, winter 2006/2007 can be evaluated as very mild with frequent temporary periods of thawing in the course of snow accumulation. The total number of days with continuous snow cover was also very low as compared with winter periods 1976/1977 to

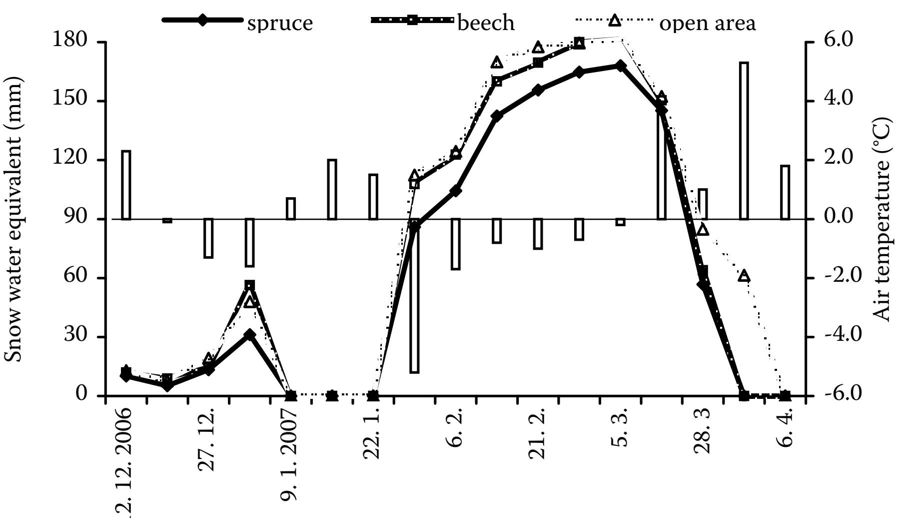

Fig. 6. The snow water equivalent at the field research station Deštné in winter 2006/2007

Table 5. Basic parameters of snow cover at the permanent field research station Deštné in the spruce and beech stands and in the open area in the winter period 2007/2008

Date of measurements	Precipitation (mm)	Tape of precipitation	Spruce stand		Beech stand		Open area	
			snow depth (cm)	snow water equivalent (mm)	snow depth (cm)	snow water equivalent (mm)	snow depth (cm)	snow water equivalent (mm)
6. 11. 2007	24.6	∗●	4.9	22.1	7.3	24.0	8.2	24.6
14. 11. 2007	55.0	●∗	21.2	53.6	24.6	69.4	30.8	80.0
20. 11. 2007	75.3	●∗	33.8	87.4	38.5	99.8	41.1	107.7
27. 11. 2007	27.1	●	0.0	0.0	0.0	0.0	0.0	0.0
4. 12. 2007	20.9	●	0.0	0.0	0.0	0.0	0.0	0.0
11. 12. 2007	32.4	●	0.0	0.0	0.0	0.0	0.0	0.0
22. 12. 2007	17.8	●	0.0	0.0	0.0	0.0	0.0	0.0
28. 12. 2007	17.1	●∗	5.2	9.0	6.6	9.5	7.3	11.6
4. 1. 2008	12.4	∗	10.2	20.0	10.8	22.6	12.6	24.0
11. 1. 2008	119.0	∗	33.7	116.4	37.1	122.8	45.3	148.0
18. 1. 2008	24.9	∗	40.5	144.4	53.0	165.6	58.8	172.4
25. 1. 2008	8.4	●∗	48.4	120.8	33.8	82.0	45.9	112.8
1. 2. 2008	26.4	∗	35.5	136.0	33.2	115.6	32.3	127.6
8. 2. 2008	13.0	●∗	32.3	124.8	37.3	137.6	43.0	145.2
15. 2. 2008	20.4	●∗	32.6	111.2	33.1	118.4	41.3	127.2
22. 2. 2008	14.7	∗	36.1	127.6	40.0	141.0	47.0	156.8
29. 2. 2008	15.0	●∗	25.0	77.6	28.5	82.4	26.8	81.6
7. 3. 2008	58.4	∗	33.6	130.8	36.3	134.8	37.3	107.8
14. 3. 2008	48.4	●	27.4	72.0	33.9	96.8	39.0	99.2
21. 3. 2008	38.4	●∗	26.4	71.6	27.1	61.6	43.7	116.4
28. 3. 2008	12.1	∗	26.1	93.2	31.1	120.8	39.7	140.4
4. 4. 2008	36.2	∗	21.8	122.8	28.7	140.0	47.3	192.0
11. 4. 2008	12.0	∗●	22.9	98.0	20.7	82.4	35.7	110.0
18. 4. 2008	23.5	●∗	16.4	73.2	18.7	84.8	40.9	160.0
25. 4. 2008	17.0	●	15.1	51.8	0.0	0.0	19.8	73.2
29. 4. 2008	0.0		0.0	0.0	0.0	0.0	0.0	0.0

● rain; ∗ snow; ●∗ rain with snow; ∗● snow with rain

Statistical significance of differences in the snow water equivalent in the spruce and beech stands in the period of snow accumulation (6. 11. 2007 to 4. 4. 2008). Paired *t*-test at the level of significance 0.05

Stand	Mean	Standard deviation of sample	Difference	Standard deviation of differences	t	p	Significance
Spruce	74.60	52.53					
Beech	79.30	55.78	–4.70	14.71	–1.50	0.15	no

1986/1987 (see Table 2) – in the spruce and beech stands only 80 days, in the open area 85 days.

Throughout the winter season, the snow depth as well as the snow water equivalent was generally highest in the open area followed by the beech stand. The smallest parameters of snow were mostly found in the spruce stand. Nevertheless, differences in both parameters of the snowpack both between the stands

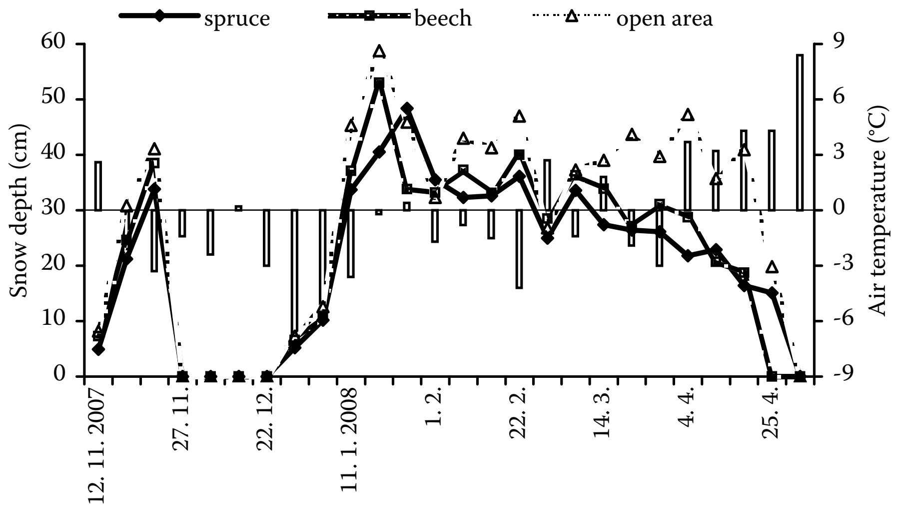

Fig. 7. The depth of snow at the field research station Deštné in winter 2007/2008

and as compared with the open area were not substantial being at the level of statistical significance.

The period of snow accumulation (12. 2. 2006 to 5. 3. 2007)

The first snow was recorded in the experimental stands as well as in the open area at the beginning of the second decade of December 2006 (snow depth 4.7 to 5.9 cm, snow water equivalent 10.2 to 12.9 mm). The snow depth as well as water storage in snow gradually increased until the beginning of January (snow water equivalent in spruce 31.2 mm, in beech 56.4 mm, in the open area 48.0 mm). Nevertheless, as early as after three weeks in the period from 2. 1. to 9. 1. 2007, all snow melted. In the course of further measurements, only rainfall occurred in January.

Thus, new snow was not recorded at the Deštné station until 1. 2. 2007 (snow depth in spruce 32.5 cm, in beech 48.6 cm, in the open area 51.5 cm; snow water equivalent in spruce 86.0 mm, in beech 107.8 mm and in the open area 112.4 mm). In the following weeks, both basic parameters of the snowpack increased till 5. 3. 2007 when they reached their maximum values. The snow depth was practically the same in both stands and in the open area (from 44.2 to 48.9 cm). The snow water equivalent was slightly smaller in spruce (168.0 mm) than in beech and in the open area (181.6 mm).

The period of snow melting (5. 3. 2007 to 5. 4. 2007)

Snow began to melt on the experimental plots in the assessed winter on 5. 3. 2007. In the first ten days, the rate of snow melting was very low – in spruce on average only 2.3 mm/day, in beech 3.1 mm/day and in the open area 2.9 mm/day. Also in next days, snow melted rather slowly, in a period from 15. 3. to 28. 3. in spruce and beech on average 6.6 to 6.8 mm/day, in the open area only 5.2 mm/day. All snow melted in both stands on 30. 3. 2007 at the mean rate of melting 30 mm/day at the most. In the open area, snow

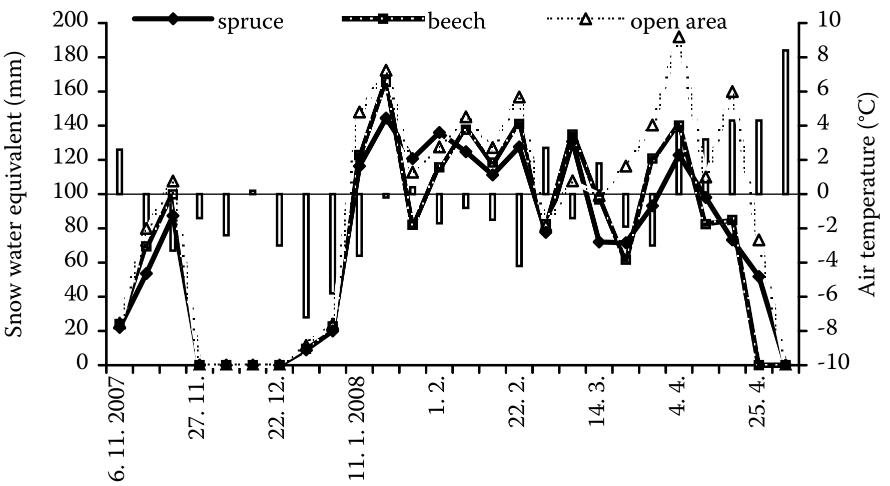

Fig. 8. The snow water equivalent at the field research station Deštné in winter 2007/2008

melted out 6 days later 5. 4. 2007 again at the mean rate about 30 mm/day.

Winter season 2007/2008

Similarly like in previous seasons, basic parameters of the snowpack during winter 2007/2008 are given in Table 5 and in two diagrams (Figs. 7 and 8).

Generally, it is possible to evaluate the winter season 2007/2008 as the season with above-average precipitation, nevertheless, the snowpack depth in both stands did not exceed 30 to 40 cm during the snow accumulation and the snow water equivalent was only exceptionally higher than 140 mm. The predominating type of weather was cyclonal with the frequent fluctuation of temperatures above and below the freezing point and numerous temporary periods of thawing. The total number of days with the cover of snow was, however, relatively high – in spruce and in the open in total 140 days, in beech 134 days.

Figs. 7 and 8 show that the snow depth as well as the snow water equivalent was highest in the open area throughout the winter season but with some exceptions. No substantial and significant differences in the snowpack parameters were found between the spruce and beech stands in the majority of measurements.

The period of snow accumulation (6. 11. 2007 to 4. 4. 2008)

The first snow was noted at the Deštné field research station in the assessed winter season unusually early 6. 11. 2007. At the turnover of the 2nd and the 3rd period of November, the snow water equivalent in both stands amounted to 88 to 100 mm, in the open area even to 108 mm. Nevertheless, within next three days, all snow melted and the cyclonal type of weather predominated practically exclusively with rainfall until 22. 12. 2007.

New snow was noted as late as at measurements carried out on 28 December 2007. At rich snow but also with rain mixed precipitation in the course of January, the snow depth as well as the snow water equivalent gradually increased till they reached its maximum in both stands and in the open area on 18 or 25 January 2008: spruce – depth 48.4 cm, snow water equivalent 144.4 mm; beech – depth 53.0 cm, snow water equivalent 165.6 mm; open space – depth 58.8 cm, snow water equivalent 172.4 mm.

Rich precipitation in February but particularly in March was of mixed character at the cyclonal type of weather. Thus, the snow depth in spruce and beech ranged from 26.1 to 36.1 cm and from 27.1 to 40.0 cm, respectively. Only in the open area, it was generally deeper, from 26.8 to 47.0 cm. The snow water equivalent fluctuated similarly in this period: in spruce from 71.6 to136.0 mm, in beech from 61.6 to 141.0 mm and in the open area from 81.6 to 156.8 mm.

The period of spring melting (from 4. 4. 2008 to 27. 4. 2008)

The 4th of April can be considered to be the beginning of spring melting at the Deštné field research station in winter 2007/2008. At measurements carried out in the course of this day the snow water equivalent in spruce amounted to 122.8 mm, in beech 140.0 mm and in the open area 192.0 mm.

During the following week, the snow melting intensity was favourable. In spruce, it was only 3.5 mm per day, in beech 8.3 mm/day and in the open area 11.7 mm/day. In the next week from 11. 4. to 18. 4., the snow melting was reduced at very low air temperatures or quite interrupted in the open area.

In the final stage of melting in the last decade of April, the snow melting rate in spruce reached about 26 mm/day, in beech about 28 mm/day and in the open area maximally 37 mm/day. All snow melted in spruce and in the open area on 27 April, in beech 6 days earlier, namely on 21 April 2008.

Similarly like in previous winters the fact that quite a predominating part of water infiltrates to the underlying rock and then drains away without any damage can be considered to be the most important finding.

These conclusions agree with findings given in studies of Krečmer et al. (1971), Kubin and Poikolainen (1982), Schwarz (1984), Hribík and Škvarenina (2007) and other authors. The surface runoff with possibilities of erosion and subsequent danger due to stormflows is not serious when the overland flow did not exceed 3 to 4 mm either in spruce or beech in April 2008.

SUMMARY AND CONCLUSION

As for winter seasons assessed in this study, depth/weight measurements of snow carried out in winter 2005/2006 show quite an exceptional informative value. At the Deštné long-term field research station in the Orlické hory Mts., these seasons were characterized by the extreme duration of the continuous snow cover (beech 157 days, spruce 160 days). From the aspect of precipitation they were markedly above-average (total precipitation from 1. 11. 2005 to 30. 4. 2006 1,203.7 mm).

The period of snow accumulation culminated on 13. 3. 2006 when the following maximum values were recorded – spruce: snow depth 157.2 cm, snow water equivalent 819.0 mm; beech: snow depth 164.1 cm, snow water equivalent 832.7 mm. The snow water equivalent in both stands was 2 to 6 times higher than throughout the 30-year series of measurements.

In conclusion, it is necessary to stress once more that the process of snow accumulation and melting was markedly affected (winter seasons 2005/2006, 2006/2007 and 2007/2008) or even disturbed in assessed seasons by practically total damage to the spruce stand by top breakages in February and March due to the extreme load of wet snow.

Snowstorms (e.g. in the first decade of February 158 mm, in a week from 6. 3. to do 13. 3. even 182 mm) damaged up to 98% spruce trees. In some cases, it referred only to top breakages but about in 50% of trees only 2 to 3 living whorls of branches remained. The beech stand was damaged markedly less. About 10% of subdominant trees with the unfavourable slenderness ratio were irreversibly bent or broken due to the load of snow.

With respect to the marked reduction of the biomass of spruce crowns after snow breakages no marked differences were noted in snow depth or snow water equivalent in the spruce and beech stands in the winter season 2005/2006 nor in the following two winters in the period of snow accumulation.

Snowpack investigation and calculation of daily changes of water stored in snow enabled to estimate also the rate of snow melting. It was not generally markedly different in the spruce and beech stands. Only at the end of the winter season 2005/2006, the snow melting rate was higher, on some days markedly higher in the leafless beech stand (e.g. 21 to 23 April, 2006 in beech more than 40 mm/day, in spruce less than 20 mm/day). However, the maximum daily totals from melting snow in the spruce and beech stands never exceeded 50 mm.

The finding that the decisive part of water from melting snow infiltrated through unfrozen soil to the underlying rock was also of exceptional importance. In the spruce and beech stands, overland flow including the lateral flow of water through soil (interflow) ranged at a level of ± 4% of winter precipitation in 2005/2006. In the following two winter seasons it was even lower – maximally ± 2% of winter precipitation.

Generally, it is possible to state very favourable hydrologic effectiveness of both types of stands in the period of spring snow melting. It is necessary to remind extremely high precipitation including above-average snowpack parameters in the winter period 2005/2006. If the spring final stage of snow melting is not accompanied by intensive rainfall or rainstorm, mountain coniferous and broadleaved forest ecosystems sufficiently reduce the danger of stormflows and floods.

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Analýza akumulace a tání sněhu v mladém horském smrkovém a bukovém porostu v Orlických horách, Česká republika

ABSTRAKT: Ve studii je hodnocena akumulace sněhu a intenzita tání sněhu v mladém smrkovém a bukovém porostu. Šetření se uskutečnila na Výzkumném stacionáru Deštné v Orlických horách (900 m n. m, ZJZ expozice) v zimních obdobích 2005/2006, 2006/2007 a 2007/2008. Proces akumulace i tání sněhu byl v posuzovaném období výrazně ovlivněn, resp. narušen prakticky totálním poškozením smrkového porostu vrcholovými zlomy v důsledku extrémního zatížení mokrým sněhem. Zima 2005/2006 byla charakteristická extrémně vysokými parametry sněhové pokrývky (maximální výška sněhu ve smrku 157 cm, v buku 164 cm, maximální vodní hodnota sněhu ve smrku 819 mm, v buku 833 mm). Zima 2006/2007 byla z pohledu sněhových srážek podprůměrná, zima 2007/2008 průměrná. S ohledem na významnou redukci biomasy korun smrků po sněhových polomech v zimě 2005/2006 tak nebyly v hodnocených obdobích zaznamenány průkazné rozdíly jak u výšky, tak i u vodní hodnoty sněhu ve smrkovém a bukovém porostu. Intenzita tání sněhu ve smrkovém a bukovém porostu nebyla nikdy vyšší než 50 mm za den. Pokud není jarní závěrečná fáze tání sněhu doprovázena intenzivními přívalovými srážkami, tlumí horské jehličnaté i listnaté lesní ekosystémy nebezpečí velkých vod a povodní v požadované míře.

Klíčová slova: akumulace sněhu; intenzita tání sněhu; smrk; buk; horské polohy

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