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# HYDROLOGICAL EFFECTS OF NORWAY SPRUCE AND EUROPEAN BEECH ON SNOW COVER IN A MID-MOUNTAIN REGION OF THE POLANA MTS., SLOVAKIA

MATUS HRIBIK[1)], TOMAS VIDA[1)], JAROSLAV SKVARENINA[1)],
JANA SKVARENINOVA[1)], LUBOMIR IVAN[2)]

[1)]Technical Univerzity Zvolen, Masarykova 24, 960 53 Zvolen, Slovakia; Mailto: vrchar@gmail.com
[2)]The University Forest Enterprise, Študentská 20, 960 01 Zvolen, Slovakia.

The paper evaluates the results of a 6-year-monitoring of the eco-hydrological influence of Norway spruce (*Picea abies* (L.) Karst.) and European beech (*Fagus silvatica* L.) forest stands on the hydro-physical properties of snow cover. The experiment was carried out in the artificially regenerated 20–25-year-old forest stands approaching the pole timber stage in the middle mountain region of the Polana Mts. – Biosphere reserve situated at about 600 m a.s.l. during the period of maximum snow supply in winters of years 2004 – –2009. Forest canopy plays a decisive role at both the snow cover duration and spring snow melting and runoff generation. A spruce stand is the poorest of snow at the beginning of winter. High interception of spruce canopy hampers the throughfall of snow to soil. During the same period, the soil surface of a beech stand accumulates greater amount of snow. However, a spruce stand accumulates snow by creating snow heaps during the periods of maximum snow cumulation and stand´s microclimate slows down snow melting. These processes are in detail discussed in the paper. The forest stands of the whole biosphere reserve slow down to a significant extent both the snow cover melting and the spring runoff of the whole watershed.

KEY WORDS: Forest-Snow Interaction, Snow Water Content, Snow Density, Snow Depth, Snow Hydrological Efficiency, Beech and Spruce Forest.

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Práca hodnotí výsledky 6-ročného terénneho monitoringu eko-hydrologického vplyvu porastov smreka obyčajného (*Picea abies* (L.) Karst.) a buka lesného (*Fagus silvatica* L.) na hydrofyzikálne vlastnosti snehovej pokrývky. Experiment prebiehal v rokoch 2004 – 2009 počas obdobia s maximálnou zásobou snehu na výskumnej ploche v stredohorskej oblasti (nadmorská výška okolo 600 m n.m.) v Biosférickej rezervácii Poľana v 20- až 25- ročnom umelo obnovenom poraste vo fáze žrďoviny. Koruny porastu zohrávajú rozhodujúcu úlohu, ako pri topení snehu, tak aj pri formovácí odtoku. Začiatkom zimnej sezóny sa v smrekovom poraste nachádza menej snehu. Vysoká intercepcia smrekov bráni v prenikaní snehu k pôde. V rovnakom období sa na pôde v bukovom poraste akumuluje vačšie množstvo snehu. Smrekový porast však vďaka akumulovaniu snehu pri tvorbe snehových kôp počas obdobia s maximálnou kumuláciou snehu ako aj vďaka porastovej mikroklíme spomaľuje topenie snehu. V článku podrobne opisujeme tieto procesy. Porasty celej biosférickej rezervácie sa významne podieľajú na spomaľovaní ako topenia sa snehu, tak aj jarného odtoku z celého povodia.

KĽÚČOVÉ SLOVÁ: interakcia les-sneh, vodná hodnota snehu, hustota snehu, výška snehu, hydrologická účinnosť snehu, bukový a smrekový porast.

## Introduction

Mountain forests and generally afforested areas provide a number of valuable external environmental effects. Among others, they are able to keep the surface water outflow (runoff) at its minimum (*Midriak*, 1985; *Pobedinskij and Krecmer*, 1984; *Miller*, 1977; *Chang*, 2006). Moreover, forests play a very important role in the snow accumulation (potential water supply), and they also significantly influence the extent and type of runoff from watersheds. This perfectly hampers the occurrence of spring floods (*Hribik* et al., 2009; *Brechtel*, 1970; *Zauskova*, 2003; *Buchtele* et al., 2006) or, at least, mitigates their impacts (*Mindas* et al., 2001).

There is a mututal interaction between snow cover and forests, when snow cover significantly influences forest stands and their qualities, and forests affect the characteristics of snow cover. This interaction can have both positive effects (protection against low temperatures, inhibition of soil freezing), and negative impacts (snowthrows, snowbreakages, grinding and creation of flag-shaped crowns (*Plesnik*, 2004; *Pobedinskij* and *Krecmer*, 1984).

Snowbreakages cause severe damage to beech forests in Slovakia (*Holecy and Giertliova*, 2009). Moreover, as presented by *Holecy and Hanewinkel* (2006), spruce stands covered by snow are also much more vulnerable to wind.

Forest stands affect snow cover, snow storage and duration in at least two following ways:

– retention of snowfall on stand surface – interception of snow,
– tree-tops retain a deal of solar radiation, affecting in such a way the reduction of the snow pack by melting and sublimation.

Snow and snow cover play an important role in water balance of ecosystems in mid-mountain regions. In context of water balance of these ecosystems, a part of snow precipitation causes its reduction due to interception vapour and sublimation. Significantly negative impact of interception is especially known in spruce stands growing at lower altitudes. On the other hand, interception losses in mountain, ridge localities and wind-exposed slopes are partly compensated by so called ”positive” interception of occult precipitation, that means by capturing water deposited from wind-driven low clouds and fogs onto the forest canopy (*Kantor*, 1981; *Mindas* and *Skvarenina*, 2001; *Pobedinskij* and *Krecmer*, 1984). Solid precipitation that occurs in winter periods as snow is retained in the canopy of trees in greater amount than liquid precipitation and to a certain extent the whole process of interception is different. While rain drops are bound on the surface of vegetation by adhesive forces only temporarily, snow flakes get fixed on crown only in small amounts or they stay frozen on the surface of vegetation and are retained to a great extent and for a long time, all this in relation to air temperature and the speed of wind.

During warming, the snow in forest canopies melts, and the water drops either enter the ground snow cover or they fall from the branches and form irregularly spaced heaps (*Kantor*, 1981; *Kantor* and *Sach*, 2002; *Pecusova* and *Holko*, 2002; *Holko* et al., 2009).

Forest canopy and the density of vegetation cover also significantly affect the temporal process of snow melting. In general, we can say that forest micro-climate decreases snow melting rate in comparison with an open area. This phenomenon, however, requires large snow storage; it is not observable in the areas with poor snow cover and during periods of higher temperatures. The melting of snow under the forest canopy during the periods of thaw is in general less intensive compared to open areas. The main causes of this phenomenon are: lower solar radiation due to its losses in canopy of the trees, and low intensity of heat exchange between atmosphere and snow in the stand – due to reduced air circulation. Melting of snow cover increases runoff of rivers, and it can cause serious damages (the losses of property and lives) (*Chroust*, 1997; *Miller*, 1977).

Both the duration and intensity of snow cover melting under tree canopy depend on tree species composition, canopy cover and the age of a stand. The determining factor of species composition is the proportion of conifers: e.g. spruce admixture in deciduous stands induces a retardation effect on the intensity and duration of snow melting (*Kantor*, 1981). The most distinct differences in snow melting duration and intensity between forests and open areas are observed in spruce and fir stands. For example, the intensity of melting is 2–9 times lower and the melting lasts 20–30 days longer compared to the open area (*Mracek* and *Krecmer*, 1975; *Pobedinskij* and *Krecmer*, 1984).

The influence of forests on the time of snow melting is smaller on north-facing slopes than on south-facing slopes. In forest stands of the same species composition, the snow melt accelerates with canopy cover reduction. Nevertheless, higher melting intensity e.g. in coniferous stands compared to deciduous ones does not mean that the snow cover will disappear sooner. Snow in a beech stand compared to a spruce one melted later despite its higher intensity of melting because of the greater water content in its snow cover (*Kantor*, 1979). In addition, the stand age is very important. In pole and maturing forest stands with characteristic high canopy cover, snow melting lasts longer than in young and mature forest stands. Also a silviculture pattern is a crucial factor influencing both the snow melting intensity and its duration. The shelter wood and selection silviculture pattern decrease melting intensity and slightly increase the melting period, while the snow cover melting intensity increases in clearcuts by 1.5–2 times.

Analysing the problems of snow cover, the attention is focused on the process of snow interception in the tree canopy – because it is substantially different from liquid precipitation. In this context, it would be necessary to distinguish between the instant interception, i.e. the interception concerning the agents acting during precipitation events, and the total interception concerned with the factors acting outside this period. The total interception is in general lower than the immediate one, only a part of snow retained in the tree canopy reaches the soil; either as wind blown snow or as water from melted snow (trickled from trees due to higher temperatures). The transfer from crowns to soil surface depends also on stand structure. Multi-storeyed stands and stands with heterogeneous age structure intercept more water than even-aged stands consisting of one storey (*Kantor* et al., 2009).

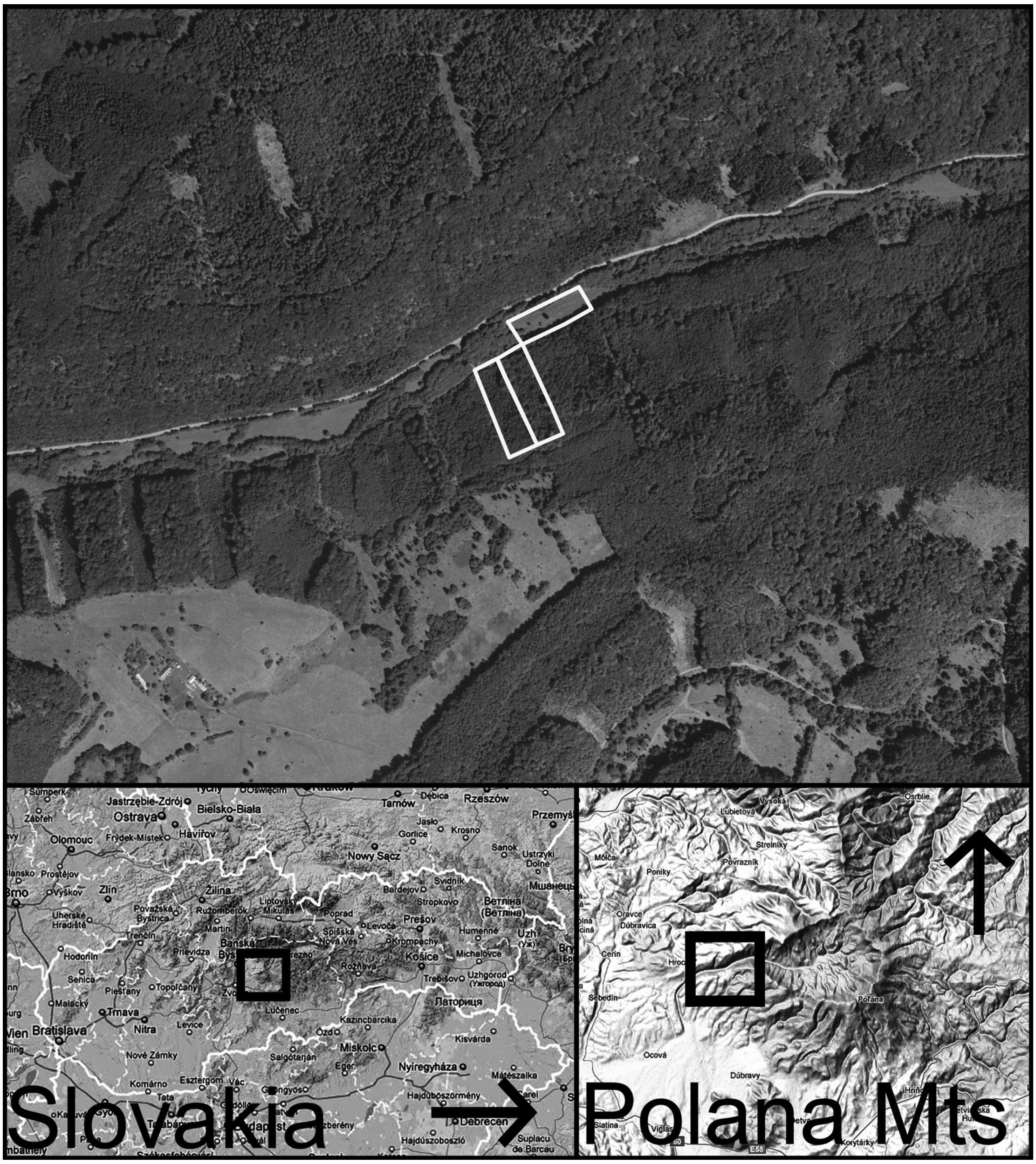


Fig. 1.The location of research site in the Biospherical Reserve Polana, Slovak Republic.

The facts above point out that the influence of snow cover on forest stands is multiple: either positive or negative. In like manner, the forest and its species composition influence snow cover and its properties to a certain extent. Therefore, it is important to understand how particular types of forest stands perform within this context. Numerous research results (*Brooks* and *Vivoni*, 2008; *Lyon* et al., 2008; *Mindas*, 2003; *Molotch* et al., 2009; *Pobedinskij* and *Krecmer*, 1984; *Rinehart* et al., 2008; *Veatch* et al., 2009) point out that the accumulation and melting of snow depends on a large number of factors (geographic area, size of mountains, elevation, slope, exposition, stand age and canopy cover, oceanic/continental climate etc.), hence, the obtained knowledge is not easy to interpret and generalize.

The aim of this paper is to discuss the influence of young forests with different tree species composition on the accumulation and melting process of snow cover on the forest ground. The monitored values of snow water content, snow efficiency, snow depth and snow density in beech and spruce forest stands in pole timber phase are compared with the measured values at open area. This research is motivated by our effort to assess the flood risk in small mountain watersheds. Our assessment is therefore focused on the period of maximum snow supply in the catchment that occurs in the area of the Polana Mts. at the end of winter (*Koncek* and *Briedon*, 1964).

## Methodology of field monitoring and description of study area

The measurements of snow cover parameters were carried out in sample points of the Batovsky Balvan area, situated in the Polana Biosphere Reserve – Hucava stream watershed in Slovakia. The water content of snow cover was measured by a mass method, with a snow sampling tube (model VS-43). The snow cover depth was measured with portable and stable laths for snow measurements.

Basic physical parameters (snow depth, snow water content, snow density) were monitored at the time of the highest snow supply in mountain locations. The measurements were performed at intervals of three weeks, in winters 2004 – 2009.

The monitoring was held in two forest stands situated in the Biosphere Reserve (BR) Polana at same elevation, with the same slope gradient and exposition, similar in age, but differing in species composition (Fig. 1). This area is a volcanic mountain system consisting mostly of andesites and tuffs. The dominant soils are andosols. More details about the landscape and the research transects can be found in *Kunca* (2003) and *Vilcek* et al., (2007). Snow cover starts to occur in the last third of October and lasts up to the end of April. The average snow cover depth in the central part is 50 cm, at the borders of the Biospherical Reserve Polana only about 30 cm. Maximum depths recorded were 100 – 120 cm (in March 1970 up to 170 cm). Fig. 2 shows that, in long-term context, snow occurs from November to April. Snow occurrence in May and October is sporadic.

Snow cover lasts about 130 to 190 days per year in the Polana Mts. The average annual precipitation total ranges from 900 to 1000 mm.

The monitored plot belongs to the 4-th altitudinal forest zone. It is situated at 600 m a.s.l., on a north-facing slope having an inclination of 10°. The details concerning the investigated plot are given in Tab. 1. The performances of two different forest types were compared: a beech stand with hornbeam admixture, 20–25 years old, and a homogeneous spruce forest of the same age. The two forests had the same exposition, elevation and slope inclination. Both commercial forest stands have been artificially regenerated. In order to understand all the explored phenomena better, a control plot was established in a clearcut, at the same elevation, a similar inclination (5°) and a north-facing exposition (*Hribik*, 2007).

The observed annual mean of wind velocity in the peak parts of the Polana Mts. aproaches 2.1 m $s^{-1}$ (*Lapin* and *Tekusova*, 2002). Forest stands situated in the base parts of the Polana Mts. caldera, especially young forests, are protected from direct strong winds with the specific orography (*Mahel*, 1986). Therefore snow redistribution is not significantly affected by wind in these forests.

Snow cover depth in both forest stands is a very variable parameter because of variable interception and variable canopy cover. Taking these facts into account, five measurements of snow water content and snow density were carried out in both investigated forest stands. In the case of the research plot in a clearcut, three measurements were sufficient, because this plot had not been attacked by snow drift. In addition, 20 measurements of snow depth were performed with snow-measuring laths. The measurements comply with the methodological standards used by the Slovak Hydrometeorological

Institute (*Turcan*, 1973) that follow the Slovak technical regulation for measurement of snow supply (*DTR*, 2002). In the following, all figures and tables present the average values of measurements measured with above mentioned methodology.

T a b l e 1. The characteristics of the research site "Batovsky Balvan" in the Polana Mts.

| | | |
|---|---|---|
| Location of site | Pod Batovskym Balvanom | |
| Geographical coordinates | N48°41‘ E19°23‘ | |
| Date of establishing | 10. 10. 2004 | |
| Elevation | 600 m a.s.l. | |
| Exposition | northern | |
| Slope | clearcut 5°, forest stands 10˚ | |
| Mean annual air temperature | 5.8 °C | |
| Mean January air temperature | –5.0 °C | |
| Mean July air temperature | 16.1 °C | |
| The number of days with mean air temperature >10 °C | 148 days | |
| Mean annual precipitation totals | 727 mm (Observatory Hrochot) | |
| Number of days with snow cover | 140–145 days | |
| Soil type | cambisols | |
| Altitudinal forest zone | IV. typical beech wood | |
| Forest type | (Fagetum pauper – Fp) | |
| Woody species | beech 90%, hornbeam 10% | spruce 100% |
| Forest cover to drainage basin area ratio | 90 % | 100 % |
| Age<br>Averaged thickness<br>Averaged height | 20–25 years<br>15–19 cm<br>12–15 m | 20 years<br>12–19 cm<br>10–12 m |
| Growing phase | Pole timber phase | |

The physical properties of snow cover were investigated by a mass method, using a snow gauge VS-43 or a gauging tube with a digital balance (Fig. 3). Snow samples were taken in the following way: The measuring cylinder was pressed into the snow cover down to the soil surface. Snow cover depth was read out on the scale on the outer side of the cylinder. The snow inside the cylinder was pressed with the piston, to prevent the sampled snow from getting out while pulling the cylinder out from snow cover. The open bottom of the cylinder was closed by a security lid. Then the content of the pit was weighed. The obtained data on snow cover depth and weight were used for the calculation of the following hydrometeorological characteristics:

Snow density:

$$\varsigma = m/k.h, \tag{1}$$

where $\varsigma$ – snow density [g cm$^{-3}$], $m$ – snow sample weight [g], $k$ – cross section area of 50 [cm$^2$] (snow-meter constant), $h$ – snow depth [cm], $H$ – snow water content [mm].

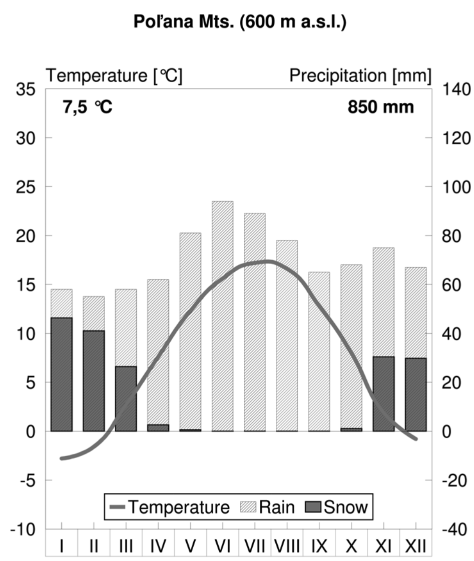


Fig. 2. The climate diagram of the experimental plot Polana Mts. (600 m a.s.l.).

Snow water content (SWC):

$$H = 10.m/k. \tag{2}$$

After replacement the cross-section area of 50 cm$^2$:

$$H = m/5 \tag{3}$$

$$\text{or } H = 10.k.h.\varsigma/k \tag{4}$$

$$\text{and finally arranged: } H = 10.h.\varsigma. \tag{5}$$

The coefficient of snow hydrological efficiency (*SHE*)

We calculated this coefficient as the square root of snow water content (*SWC*) multiplied by the density of snow cover ($\varsigma$).

$$SHE = \sqrt{SWC \cdot \varsigma}. \tag{6}$$

The field measurements were carried out from January to April each year in order to record the period of maximum snow supply in the catchment. Although in the assessed area snow precipitation was also observed in November and December, permanent and long-term snow cover is in this period scarce due to the frequent thaw events and unsettled weather. Hence, snow water content is sufficient and interesting for water management

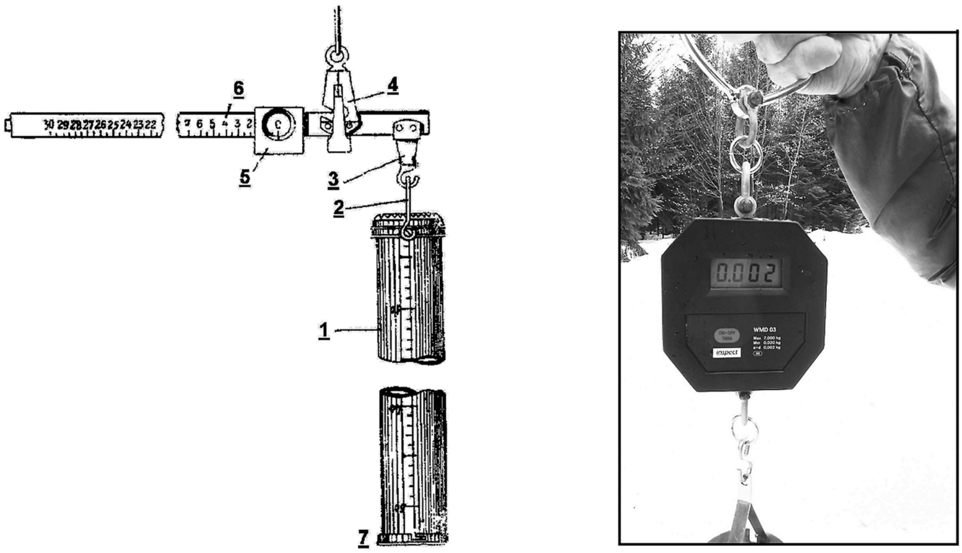


Fig. 3. On the left side: Snow gauge VS-43 (1 – sampling cylinder, 2 – grip, 3 – hook, 4 – hanging balance, 5 – balancing , 6 – arm of the unequal-armed balance, 7 – classic security lid); On the right side: Up-dated snow gauge with a digital balance.

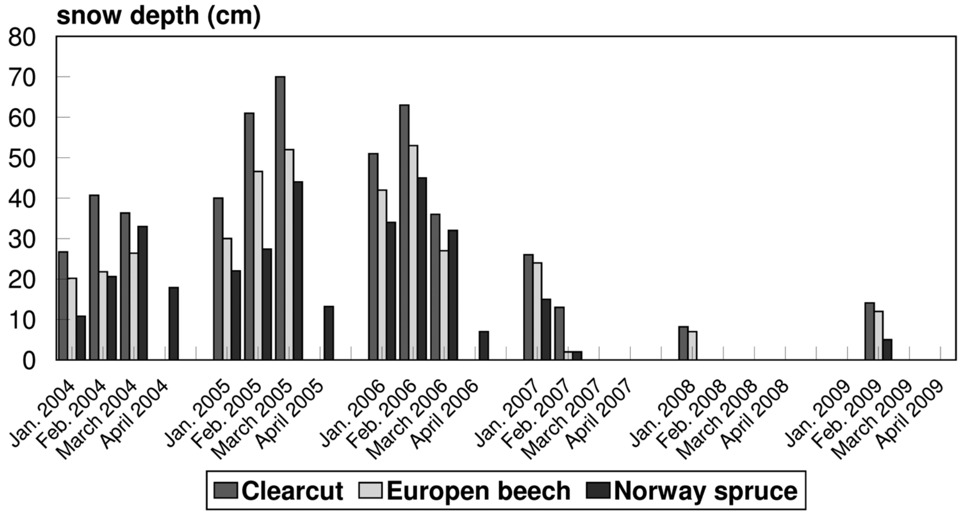


Fig. 4. Depth of snow cover and its seasonal dynamics in winter seasons 2004 – 2009 in the both observed beech and spruce pole-timber stands and in the clearcut.

only after ample snow amount is accumulated. At the studied sites, such conditions occur in the period from January to April (*Koncek* and *Briedon*, 1964).

## Results

*Snow depth*

Snow depth is the universal measure of snow cover. Fig. 4 illustrates the influence of tree-species composition on the snow cover depth in the observed years 2004–2009. It is obvious that significant differences among the all observed winters were detected. The snow cover during winter 2004 did not exhibit a significant deviation from the long-term normal; snow depth was uniformly distributed with mean values culminating at 41 cm outside the stands. During winter 2005, the snow cover depth approached its maximum (70 cm in a clearcut), the same value during winter 2006 was slightly lower, but the observed snow cover duration was the longest (four months) from the whole time series. On the contrary, in winters 2007 and 2009 the snow cover depths were smaller and the winter periods were shorter than the corresponding long-term average values. In 2007, the greatest snow depth observed in the clearcut approached 30 cm. The corresponding values recorded in the spruce stand approached only 15 cm. The values observed in February approached only one-third of the values recorded in January, and in the spruce stand even occurred snowless spots. A similar situation appeared during the last two observed years. The highest value in 2008 was recorded in January in a clearcut, and it approached only 8 cm. During this winter no snow occurred in the spruce stand. During winter 2009, snow was observed only in February: on average 14 cm in the clearcut and 5 cm in the spruce stand. It is evident that these snow cover depth values were the lowest and the snow periods were the shortest from the whole evaluated time series.

A more detailed view reveals the following order of the observed snow cover depth: clearcut > beech stand > spruce stand. The only exceptions represent the ends of winter periods in the years when snow cover occurred only for a short time. During snow culmination, dense coniferous crowns of spruce trees protected the created snow heaps, what resulted in a 2–4 week delay of snow extinction in comparison with both the beech stand and the clearcut.

*Snow density*

This physical property represents the ratio between the volume of the current water content and the original volume of the snow. It varies considerably over the whole season because of air temperature changes and both the ageing and the repeated freezing of snow. The maximum recorded mean values of snow density were from 0.2 g $cm^{-3}$ at the beginning to 0.5 g $cm^{-3}$ at the end of winter. The highest snow density was recorded in the spruce stand at the end of all winter seasons (0.5 g $cm^{-3}$).

The observed data of snow density are evaluated in Tab. 2. In most cases, the highest values were detected in the clearcut. Such a situation could occur at a certain time after new snowfall when different influences of climate manifested themselves in the different degree of the metamorphosis of snow cover (*Pecusova and Holko*, 2002). The densities of freshly fallen snow in the spruce stand, in the beech stand, and in the clearcut approached in general very similar values (January 2004, 2005, 2006). However, snow density rapidly increases in forest stands, especially during longer periods of warming, thaw or snow melting. At the end of the snow cover season, snow density in the forests exceeded the values recorded in the clearcut several times due to the snow heaps created in forest stands. The snow cover density considerably increased after the wet snow and water had fallen from canopy of the trees. After a thaw and a new snowing we observed some cases when both the old and fresh snow and sometimes also ice crust occurred in the stands at the same time. At that time, fresh snow with low density was detected only in the clearcut. The density of snow cover in mountain areas of the Polana Mts, especially in spruce stands, is often higher due to the creation of granular rime generated from frequently occurring fogs and low clouds. Fig. 5 desribes the dependence of snow density on the duration of snow cover during winters 2004 – 2007 in the observed beech and spruce pole-timber stands and in the clearcut. Similar results are published by *Kantor* et al., (2007).

The data about snow cover density in years 2004–2007 revealed the dependence between snow cover duration and snow density. The snow density was generally the lowest in the beech forest over the whole snow period. The density of snow cover

T a b l e 2. Average density of snow cover during winters 2004 – 2009 in the investigated beech and spruce pole-timber stands and in a clearcut.

| Year | 2004 | 2004 | 2004 | 2004 | 2005 | 2005 | 2005 | 2005 | 2006 | 2006 | 2006 | 2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | I. | II. | III. | IV. | I. | II. | III. | IV. | I. | II. | III. | IV. |
| Clearcut | 0.2733 | 0.3002 | 0.4324 | – | 0.1928 | 0.217 | 0.2438 | 0.3957 | 0.2882 | 0.2675 | 0.3818 | – |
| Beech | 0.2156 | 0.2124 | 0.3236 | – | 0.1867 | 0.2035 | 0.2265 | – | 0.2718 | 0.245 | 0.3296 | – |
| Spruce | 0.2577 | 0.3086 | 0.3814 | 0.5042 | 0.204 | 0.2428 | 0.2629 | 0.3889 | 0.3315 | 0.2143 | 0.3094 | 0.3226 |
| Year | 2007 | 2007 | 2007 | 2007 | 2008 | 2008 | 2008 | 2008 | 2009 | 2009 | 2009 | 2009 |
| Month | I. | II. | III. | IV. | I. | II. | III. | IV. | I. | II. | III. | IV. |
| Clearcut | 0.2125 | 0.3357 | – | – | 0.1889 | – | – | – | – | 0.22 | – | – |
| Beech | 0.1817 | 0.369 | – | – | 0.1881 | – | – | – | – | 0.2413 | – | – |
| Spruce | 0.339 | 0.3434 | – | – | – | – | – | – | – | 0.2106 | – | – |

in the clearcut was lower than in the spruce stand, except the periods of stronger snow melting. The highest snow cover density values detected till the culmination of winter might result from the fact that the spruce stand, by its interception, hampered snow flakes to enter the stand, and, at the same time, the snow cover was enriched by the fragments of rime fallen from tree crowns as well as because of ice layers formed probably by frozen wet snow and water fallen from forest canopy.

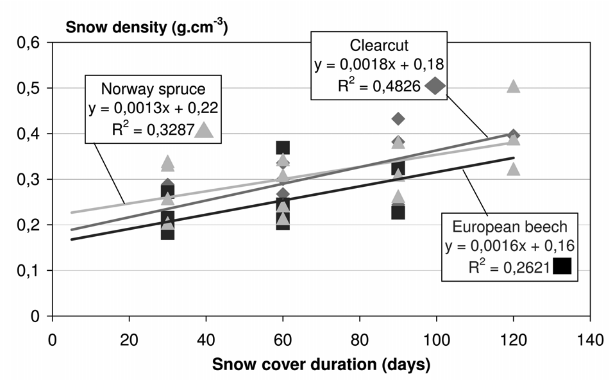


Fig. 5. The dependence of snow density on the duration of snow cover during winters 2004 – 2007 in the observed beech and spruce pole-timber stands and in a clearcut.

*Snow water content*

From the viewpoint of forest hydrology, water content is the most important hydro-physical parameter. It is defined as the height of water level resulting from snow melting on the spot, and it depends on both the snow cover depth and its density. We can see that in the years rich in precipitation, the water stored in snow represented about one quarter of the annual total for the observed area.

In the last three years, however, the snow water content in these areas approached low values, and the snow-cover periods were short.

In the years rich for snow, vegetation effects on the retention of water stored in the snow are significant. There is a potential for the floods to occur, which can be eliminated by the type of vegetation, its quality and ability to effectively bind water in the snow.

The results from 2004–2007 show that the water content values decreased in the following order: clearcut > beech stand > spruce stand. This sequence changed at the end of winter when, due to a different microclimate, the recorded water stock in the spruce stand was higher. Fig. 6 illustrates how interception in forest canopy layers influenced the water contents of snow cover in the investigated beech and spruce stands. Beech stands store more water than spruce stands. Spruce stands protect, to some extent, water content of snow and lengthen snow melting in some cases even by one month.

The maximum water content values were recorded in the clearcut in March 2005 and in February 2006 (both 170 mm). The highest value in 2004 (157 mm) was observed in March – also in the clearcut. The beech forest manifested the highest value in February 2006 (130 mm). The highest values in the spruce forest (115 mm) were recorded in March 2005, and in January and February 2006.

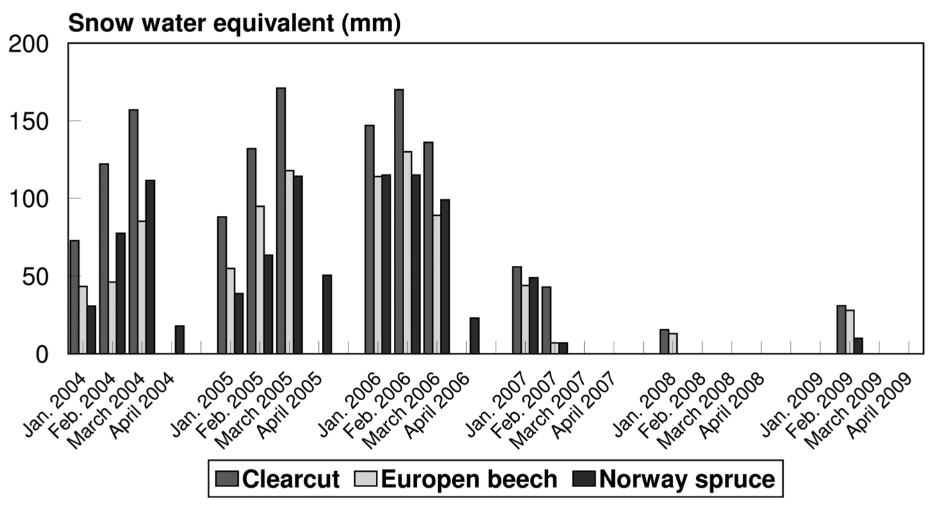


Fig. 6. Water equivalent of snow cover and its seasonal dynamics during winters 2004 – 2009 in the observed beech and spruce pole-timber stands and in a clearcut.

*Coefficient of snow hydrological efficiency*

The coefficient of snow hydrological efficiency (SHE) informs about the overall influence of snow water content and the density of snow on the hydrological properties of snow cover. The coefficient was calculated according to *Mracek* and *Krecmer* (1975) as the square root of product of snow water content and snow density. The SHE values were calculated only for winters with heavier snow cover i.e. 2004, 2005, 2006 according to Fig. 7. The data from winter 2004 (Fig. 7a) demonstrate both the conservation and accumulation effects of the clearcut on snow cover in comparison with the beech stand. In terms of SHE, the beech stand was even less efficient than the spruce stand. Similarly, as at the above discussed parameters, the hydrological efficiency of the spruce stand was very high during snow melting periods. The heaps of accumulated heavy snow fallen from spruce canopy manifested high hydrological efficiency even in April (SHE = 1.73 in April 2005, Fig. 7b). Comparing SHE values between the beech and spruce stands we can see that they also depend on the snow consistency (powdery/heavy). From January 5 till February 28 of 2005, the calculated SHE values were higher in the beech stand, because a certain portion of snow had been captured in dense spruce canopy. Later in winter, the situation switched: the heavy snow could not be kept by dense spruce canopy any longer; so it gradually moved to the ground where it created massive heaps that increased the observed hydrological efficiency of the spruce stand. Similar changes in SHE values were recorded during winter 2006, but the sequence was opposite. Fig. 7 documents the varying accumulation of water supply in the explored beech and spruce stands.

*Snow melting*

The course of snow cover melting in the explored spruce stand, beech stand and the clearcut is presented in Tab. 3.

The melting was evaluated only for winters with sufficient snow cover by calculating the mean daily decrement of snow cover water content in mm day$^{-1}$. We primarily focussed on spring periods during the snow cover extinction. Tab. 3 informs that the most intensive snow melting was observed in the beech stand where the mean daily decrement of snow calculated for the four snowy seasons fluctuated between 14.8 and 19.6 mm day$^{-1}$. The less intense melting was observed in the clearcut approaching 13.6–17.1 mm day$^{-1}$. The absolutely lowest rate of snow melting was recorded in the micro-climate of the spruce pole-timber stand, approaching only 0.7–6.8 mm day$^{-1}$. The finding of the fastest snow melting rate in the beech stand was a surprise, but analysing it more thoroughly it has a logical background. Beech trees let the considerable doses of direct solar radiation to pass through their leafless canopy and at the same time, they effectively act as a filter against the long-wave radiation of the accumulated heat, especially during night. The active surface of beech stands constrains ventilation by air circulation and also by advection of cold air occurring at mountain-valley circulation. In such a way, beech stands provide a typical spring warm microclimate (by botanists defined as the microclimate of spring heliophytes). This state outlasts until the tree leaves will have been fully developed. Then the spring insolation micro-climate changes to a shadow-tolerating (skyophillous) cold stand microclimate that lasts till the autumnal leaf-fall. Snow melting in forest stands also accelerates the decomposition of organic litter that reduces the albedo of snow cover. The fastest decrement of snow in beech forests occurs around tree stems, by forming typical so called snow „funnels“. It is generally supposed that these “funnels” are created by heat conduction at forest edges, and by the exposition of tree stems to direct solar radiation, and also by long-wave radiation of the surfaces of stems in the presence of several other factors (stemflow). Remarkable is also the observed decrement of snow water content for 24 days (March 1–24, 2006). However, the Slovak Hydrometeorological Institute (SHMI) did not record any increased flow of Hucava creek at the same time. Based on this information, it can be supposed, that the recorded decrement of snow water content occurred mainly because of the sublimation of certain volumes of snow into the atmosphere.

**Discussion**

In general, the obtained results from the period 2004–2009 are fully comparable with the observations made by *Koncek* and *Briedon* (1964). The long-term (reference period of 30 years) average values for open area in a similar study reported by these authors approached 20 cm in January, 25 cm in February and 10 cm in March. For the average maximum of snow cover depth, they reported a value of 40 cm observed in the first days of February. The variability of our data about snow cover depth seems to be relatively high, because the snow supply varied considerably during all six evaluated winters. In January, our observed average values in the clearcut approached 30 cm in 2004 and 2007, 45 cm in 2005, and even 53 cm in 2006. In consistence with *Koncek* and *Briedon* (1964), we recorded the deepest snow cover in the first days of February (2004 – 44 cm, 2006 – 67 cm) – except for the year 2005, with extraordinary strong winter when the highest value of snow cover was observed at the beginning of March (75 cm). This value represents also the maximum recorded over the whole 6-year lasting study period. The average snow cover depth in February of this year approached 65 cm. Average snow cover depths in March of the years 2004 and 2006 varied around 40 cm. We can see that the winters 2004 – 2006 were abundant in snow – the average snow cover depth was several times higher than the long-term value. The values in years 2007–2009 (except for January 2007) were below the average also in comparison with the data reported by *Fasko* et al., (2002). *Kantor* et al., (2009) pursued almost the identical research in the Orlicke Hory Mts (Czech Republic) in winter 2006. In mid-March, they recorded a value of 164 cm in a beech stand and 157 cm in a spruce stand. These values are two times higher than our results – reflecting the fact that the climate in the Czech Republic is closer to the oceanic one than the climate of Slovakia.

Due to their interception, the snow cover depth values were lower and less variable in forest stands compared to a clearcut. The same fact was observed by *Pecusova* and *Holko* (2002). However, the situation changes after the culmination of winter when snow melting starts. The depth of snow approached a slightly higher value than in a clearcut also due to the forest micro-climate that hampered solar radiation to penetrate to the surface of snow cover and so slowed down the process of its melting. A similar situation was also reported by *Mracek* and *Krecmer* (1975) from the Northern Bohemia, and *Mayer* et al., (1997) from the Schwarzwald Mts (Germany).

*Brechtel* (1972) found out in mid-mountain beech forests of Hessen (Germany) that the highest stock of snow water had been accumulated in beech stands, and that the stock of snow in spruce stands had been smaller than in clearcuts. These different results can be explained by the fact that the author carried out his research in about 100-year-old stands, while our monitoring was performed in 20–25-year-old pole-timber beech and spruce stands. Another work of *Brechtel* (1984) informs about small SWC values in clearcuts (snow drift), and maximum SWC values in both young spruce and beech stands (about 150 mm) observed in the first days of March. *Kantor* et al., (2009) report about 819 mm and 832 mm measured in a spruce and a beech stand in the Orlicke Hory Mts (Czech Republic) in mid-March. In comparison with our results, these values are several times higher. However, they were obtained at an altitude of 900 m during the winter much richer in snow than as usual. The SWC in both stands was 2 and 6 times higher than throughout the 30-year series of measurements (*Kantor* et al., 2009).

T a b l e 3. Intensity of snow melting (sublimation) in the explored beech and spruce pole-timber stands and in the clearcut during spring periods 2004 – 2006.

| Date | Place | Melting intensity/sublimation [mm day$^{-1}$] |
|---|---|---|
| 12. – 26. 03. 2004 | clearcut | 15.7 |
| | beech | 17.0 |
| | spruce | 6.8 |
| 17. 03. – 4. 04. 2005 | clearcut | 17.1 |
| | beech | 19.6 |
| | spruce | 3.9 |
| *1. 03. – 24. 03. 2006 | clearcut | 1.5 |
| | beech | 1.8 |
| | spruce | 0.7 |
| 24. 03. – 11.04. 2006 | clearcut | 13.6 |
| | beech | 14.8 |
| | spruce | 4.2 |

*Because the fact, that in study time 1. 03. – 24. 03. 2006 by monitoring SHMI did not confirm increasing water discharge in creeks of BR Polana, we supposed, that decrease of SWE by sublimation was affected.

The results of our monitoring of snow cover density are comparable with the results obtained by several other authors. *Kantor* et al. (2009) report about values of snow cover density in a young spruce stand starting from 0.098 g cm$^{-3}$ and approaching 0.475 g cm$^{-3}$ in winter 2005/2006. In a young spruce stand, they observed values from 0.105 up to 0.488 g cm$^{-3}$, which are very similar to the results of our study. *Chroust* (1997) monitored the changes of snow cover density in spruce stands in relation to snow cover duration. Also *Bartos* et al. (2009) inform that the snow density increases at the end of winter. They explain this fact by the changes of snow cover structure resulting from

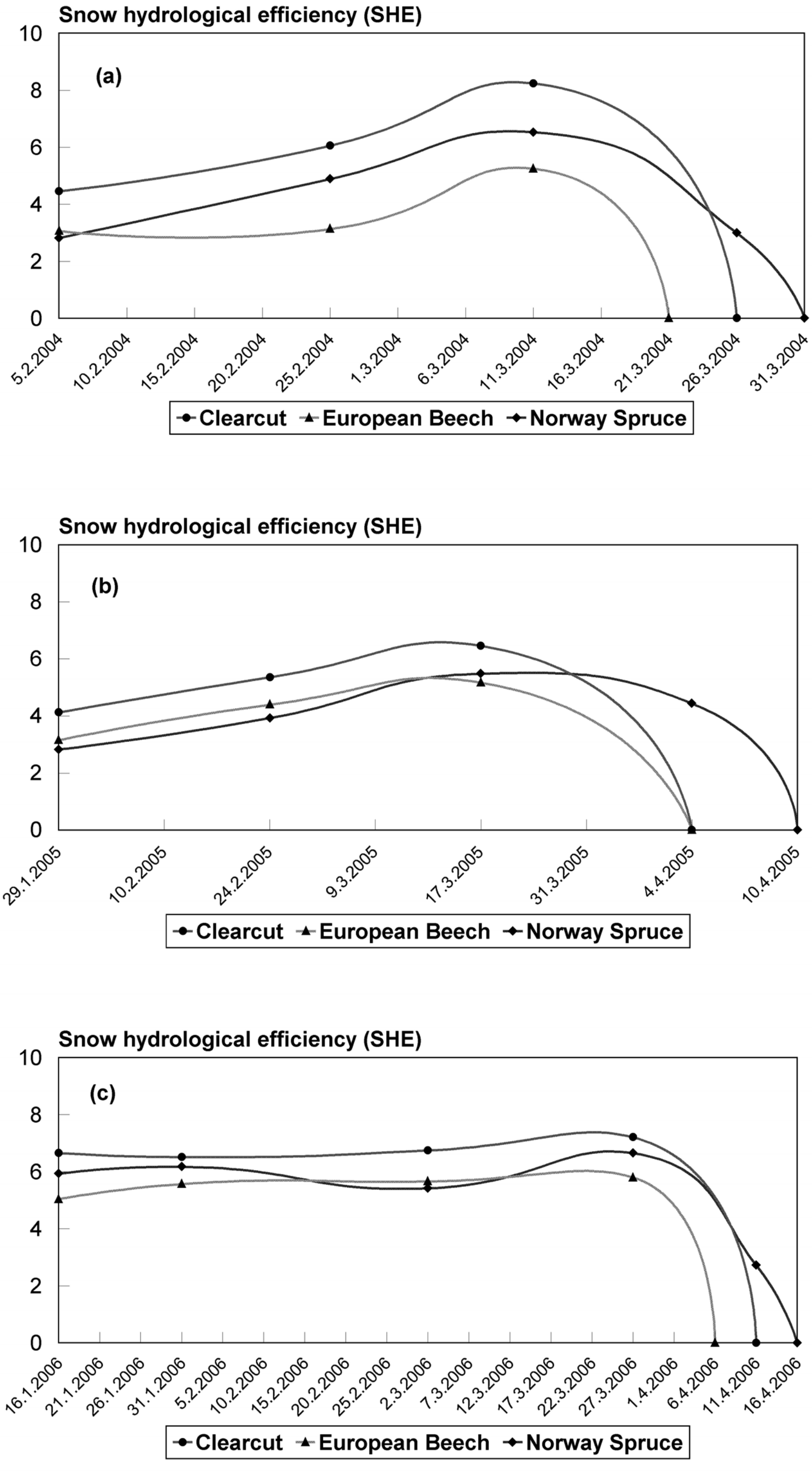


Fig. 7. Average coefficient of hydrological efficiency of snow cover during winter 2004 (a), winter 2005 (b) and winter 2006 (c) in the explored beech and spruce pole-timber stands and in a clearcut.

increasing air temperature. They also found that in the forest stand the density of bottom snow layers is influenced by soil temperature.

*Vajda* et al. (2006) at analyses of spruce (*Picea abies*) growing in arctic-boreal climate at timber-line in Lapland found out that the density and the water content of snow cover may also depend on the type of vegetation. However, according to our results, the snow density does not vary significantly between the two vegetation types; the observed mean snow density value approached 2.6 g $cm^{-3}$, that is similar to the mean values detected in the two forests and in the open area.

Snow depth and density were also investigated in 33 stands of western hemlock-Sitka spruce near Juneau, Alaska, USA (*Hanley* and *Rose*, 1987). The average snow densities in the open area ranged from 0.09 to 0.18 g $cm^{-3}$. Snow depth in the forest stands approached, on its average, only 62% of the value observed in the open area, but the values of its density were very similar to our results.

Surveys made in the Nordic Swedish Mountains (*Zakrisson*, 1987) inform that till April, the snow density was the same in clearcuts as the values in the surrounding forests. In April 1984, however, the snow density value in forests was 4–6 % lower than in clearcuts. The corresponding values for 1985 were 4–5 %. This difference occurs at the end of snow season, probably due to the higher quantity of solar radiation entering a forest stand.

This discussion points out again that the differences in snow deposition observed in a forest stand and in a clearcut result mainly from the occurence of winter thaw (that only rarely occurs in northern boreal forests) and the effects of forest microclimate that reduces the amount of solar radiation entering forest stands.

The values of snow hydrological efficiency coefficients (SHE) in beech and spruce stands observed in the Beskydy Mts were also reported by *Mracek* and *Krecmer* (1975) and *Zeleny* (1975). Similarly, as in our study, the accumulation effect followed this sequence: clearcut > spruce forest > beech forest. The authors also point out at the eco-hydrological accumulation effect of a forest gap.

Both the duration and the intensity of snow melting under the forest canopy depend on tree-species composition, canopy cover and the stand age. *Pobedinskij* and *Krecmer* (1984) report an average value of 4.1 mm $day^{-1}$ for snow melting intensity in spruce stands. The values observed by *Kantor* et al. (2009) during winter 2006, which was extraordinary rich in snow, were higher, sometimes significantly higher in a leafless beech stand than in a spruce stand (e.g. in April 21–23, 2006 when the melting intensity in a beech stand exceeded 40 mm $day^{-1}$, the value in a spruce stand did not approach 20 mm $day^{-1}$). However, the maximum daily totals of snow melted in a spruce stand and a beech stand never exceeded 50 mm $day^{-1}$.

## Conclusions

Forests play an important role at snow accumulation (or creation of potential water supply creation) and their influence is important on both the manner of water retention and runoff from a watershed. Collected data in both the beech and spruce forest stands during their small pole stages in the locality of Batovsky Balvan situated in the Biospherical Reserve of Polana (600 m a.s.l.) were used for the calculation of snow hydrological efficiency coefficient. In this paper several hydrophysical features of snow cover observed in sites of 25-year-old beech and spruce forest stands including a clearcut situated in the same area are compared.

The results point out the influence of a clearcut on both the conservation and accumulation of the snow pack related to the same observed measures in small pole staged beech and spruce forest stands. The lowest snow hydrological efficiency was detected in the observed beech forest stand. These measures observed in a spruce stand were remarkably higher during the snowmelting time. The six years of monitoring snow cover development pointed out that:

- the depth of snow cover decreased in the following order: open site > beech forest > spruce forest,
- the deepest snow cover (70 cm) was observed in winter 2005,
- the water content of snow cover approached its highest value (170 mm) at the open site during winter 2006,
- the winters in the period of 2007 – 2009 were very poor in snowfall at the observed elevations of the central Slovakia and it resulted in the absence of snow cover during this period,
- the smallest snow depth at the climax of winter was generally observed in the spruce forest stand, but at the end of winter the spruce forest stand was keeping snow cover longer and retarded snow melting strongly,
- the duration of snow cover decreased in the following order: spruce forest > beech forest > open site.

Other result of our paper is that snow density in different forest stands is not dependent on species composition of the stands. Our measurements from the plots in monitored years show nonsignificant differences in snow density.

This paper widens a mosaic of knowledge about the effect of different forest stands on snow properties at the time of snow cover culmination in a mid-mountain region of the Polana Mts – Biosphere Reserve, that is evident and plays an important role in snow melting and spring surface runoff formation from a watershed. The obtained resuls allow us to evaluate spring flood risk from melted snow in the future.

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