Snow and avalanche: the influence of forest on snowpack stability

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ABSTRACT: Snow avalanches are among the most important disturbances that affect mountain ecosystems, influencing forest dynamics, establishment and mortality processes. At the same time, forests can affect the likelihood of avalanche release and can thus protect human settlements and infrastructures. The forest protective role is largely a function of forest stand structure, snow characteristics and topography.
Starting from winter 2003/2004 the snowpack evolution within forested areas of the Aosta Valley (Italy) has been monitored, in order to increase the present knowledge on complex relationship between forest and snowpack.
Since 2005, a specific research was carried out focused on detection and analysis of those avalanches that released within forested areas. First, an analysis of the Regional Avalanches Cadaster of the Aosta Valley was done to determine the number of avalanches, about 5 %, with a starting zone located into forested areas. Afterwards, 15 sites were chosen to compare forest characteristics with neighbouring areas located at same altitude, aspect and slope, where no avalanches occurred. The resulting data were used to evaluate the minimum requirement for selected parameters (e.g. tree density, basal area, canopy cover) that a forest must have in order to supply the protective function with respect to avalanche release and snowpack conditions derived from Avalanches Bulletin of Aosta Valley.
By increasing the current data-base, it might be possible to relate forest structural characteristics to the reduction of snowpack instability. As defense measure from avalanches, in some cases it should be preferable to use sustainable practices such as suitable silvicultural approach instead of traditional and permanent defence structures.

KEYWORDS: forest, snow, avalanches, protective function.

1 INTRODUCTION

The monitoring of the snowpack evolution by the Avalanche Warning Services is generally carried out outside forests to limit external influences on snowpack. Therefore, the knowledge of possible relationships between forest characteristics and snow evolution and stability is still scarce.

The complex relations between climatic, morphological and ecological factors suggest not to consider *a priori* forests as areas excluded from avalanche release. The necessity to evaluate snowpack characteristics within forest is becoming more frequent, as widely discussed at the European Geosciences Union General Assembly 2008: Fierz et al. (2008) showed the problems related to the classification of wet snow and crust, snow transported by wind and snow within forest areas.

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The knowledge about this topic is very limited (Brang et al., 2001), but the increasing interest on these themes determined a conspicuous input to research activities, such as some recent papers (e.g. Berretti et al., 2006).

Forest canopy influences the physical characteristics of the beneath snow: first of all the reduction of snow depth related to snowfall intensity (Pomeroy and Brun, 2001) and tree composition (Motta, 1995). Snow intercepted by crowns irregularly and gradually falls out and the amount of interception depends on snow humidity and air temperature; this process contributes to create a more heterogeneous snowpack than areas located outside forest (In der Gand, 1978) and prevents the formation of layers without cohesion, a process that represents one of the most important factors of snowpack instability (Brundl et al., 1999).

The presence of tree canopy induces air temperature mitigation and consequently a lower temperature gradient inside the snowpack, that becomes dominated by rounded grains and a lower percentage of faceted crystals and depth hoar compared to the snowpack in open areas (Freppaz et al., 2006; Letey et al., 2008). In forest, wind manipulation of snow is reduced, but within clearances wind can strongly accelerate and provoke considerable snow accumulations.

Within forest areas snow gliding is less evident, because ground roughness is higher than on bare soil; the presence of stump also contributes to increase snowpack stability; however, snow cover movements in forest have been reported (Höller, 2001 and Berretti et al., 2006) and the stems are often bended, especially in correspondence of steep areas with a consistent snowpack lasting for a long period.

Forests have not a mitigation role: in fact their effect along the avalanche track is limited to reduce lateral widespread and to slow down small events. The role of the forest is focused in the avalanche release zone where the forest cover has a stabilization function for the snow cover.

Within forests, avalanche release areas are localized on slope greater than 30° (Schneebeli and Bebi, 2004). Past research (Saeki and Matsuoka, 1969) has shown that the average height of a tree necessary to stabilize the snowpack must be about twice the snow depth. In British Columbia 76 avalanche sites localized on Coast Mountains and Columbia Mountains were analyzed to investigate the main parameters of the release zones of destructive avalanches (McClung, 2001). Soil roughness, in a forest with trees higher than 2 m, is the most important factor that reduces avalanche frequency: 90% of avalanches start within forests characterized by a tree height of less than 2 m. Meyer-Grass (1987) showed that forests can exercise a protective function only with a stem density larger than 250 trees/ha and a height greater than 3 m. These forest parameters must be related with average seasonal snowfall and snow accumulation data.

Concerning forest canopy cover, values greater than 46% reduce the avalanche frequency. If the slope angle and the snow depth increase, only the largest stem diameters guarantee an effective stabilization, because of their resistance to strong static pressure by snow cover: Meyer-Grass (1987) considered only diameter at breast height (*dbh*) greater than 16 cm. Trees with *dbh* minor than 6-10 cm show a great flexibility of stems so they can only marginally contribute to snowpack stabilization (Johnson, 1987).

An empirical principle was developed for evergreen forest: canopy cover necessary to hinder middle-size and big avalanche release is about 50-60% if trees are high enough and have a regular distribution (without big gaps). If canopy cover is less than 50-60%, the protection effect depends only on the forest population density (stem/ha), also considering dead trees (Perzl, 2007).

The presence and the size of gaps inside forest is also a fundamental parameter for protective function: with a canopy cover of about 50%, slope about 35° and width of gaps about 15 m, avalanche release is less probable. Instead, gaps larger than 30 m along a slope cannot hinder avalanche release (Imbeck, 1983; Schonenberger et al. 2005) because snowpack stabilization is localized only 2-3 m around the stem of adult trees (In der Gand 1978).

A systematic approach that analyzes forest parameters with respect to snowpack stability and avalanche release is still lacking; therefore, the aim of this work is to define the main features that a forest must have to ensure a direct protective function against avalanche release.

2 METHODOLOGY

2.1 Aosta Valley Regional Avalanches Cadaster

Through an agreement between the Aosta Valley (NW Italy) and the University of Turin, a research into the Regional Avalanches Cadaster was conducted with the purpose of analyzing the characteristics of the starting zone of the historical avalanches that occurred in the past. Features as land cover, altitude, slope and aspect of the release zone were considered.

This preliminary step allowed to detect avalanches that released within forests. Events occurring in forested areas but very close to steep cliffs and watersheds (with slope > 60°) were excluded, because in this case the forest cover effect can be considered negligible.

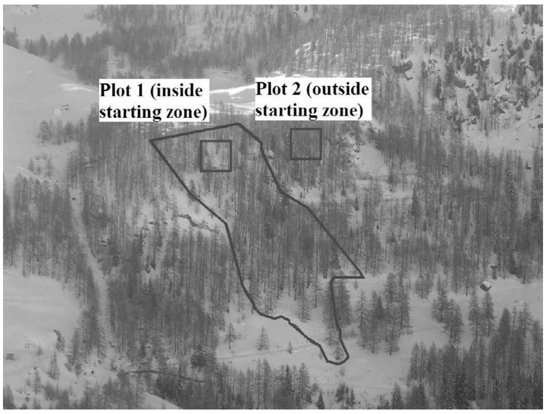
2.2 Choose of significant study-sites

In order to describe the characteristics of the forest where past avalanches occurred, only the avalanche events that happened in the last 10 years were considered. This time lag is considered short enough to assume the current forest conditions are similar to those occurring at the time of the historical events. Fifteen avalanche sites were chosen to provide comprehensive coverage of the Aosta Valley (Fig.1).

Figure 1. Distribution of the study sites in the Aosta Valley. Numbers denote n of avalanches analyzed within a site.

2.3 Measurement procedures and data analysis

For each investigated avalanche site, two 25x25 m plots were chosen: one inside to the release zone of the past event and another outside the starting zone. Each external plot was chosen at the same altitude, aspect and slope of the neighbouring internal test area, but with a different structure supposed to be able to avoid the avalanche release.



The thresholds for trees were 8 cm for *dbh* and 2 m for the height: lower heights could be raised by the snowpack according to the literature (Meyer-Grass, 1987). The field protocol included both the site description (altitude, aspect, shrub, herb and stone cover) and the forest structure analisys (species, tree density, *dbh*, crown size, height). Each trees was mapped using a GPS. The *Stand Visualization System* (SVS) software (USDA Forest Service), was used to calculate the forest crown cover.

2.4 Nivo-meteorological data

The snow and meteorological data and some weather reports were acquired by the Aosta Valley to describe the nivo-meteorological conditions of the period when the analyzed avalanche events happened.

3 RESULTS

3.1 Avalanche Cadaster analysis

The research conducted into the Aosta Valley Regional Avalanche Cadaster involved 1010 known avalanche paths. Among these, about 45% show a release zone with a slope angle greater than 30°. The most of them (38% of the total) have a release area in-between 2000 and 2500 m a.s.l., therefore into a forested altitudinal vegetation zone. Considering the release zone land cover, we classified ten types of substrata with two different morphologies (channelled and open slope): the greatest number of events happened in correspondence of rock slopes (28%) or rock slopes with grass and shrubs (21%). Moreover, a not negligible amount of avalanches (5%) released within forested areas. 3 cases of channelled avalanches and 50 cases of open slope avalanches.

Considering the damages caused by those avalanches, most of them damaged first of all forests (35%), then infrastructures (25%), mountain pastures (13%) and ski runs (5.5%). Anyway, in a large number of cases (21%), avalanches did not cause any damages.

3.2 Avalanches released in forest

The following analysis considers the avalanches that released within forest in the last 10 years. Most of them occurred when the avalanche danger was equal to 3-considerable. The prevalent aspect is North (60%) and, concerning the slope, all the investigated avalanches released between 33 and 48°, but most of the events (40%) was registered on slope of between 35 and 40° at an altitude ranging from 1900 and 2000 m a.s.l. (47%).

Considering the detachment period, the avalanches in-depth examined were detached mainly during March and April (67%).

3.3 Forest surveys

3.3.1 Test areas internal to the release zone

About 87% of the avalanches released below larch (*Larix decidua* Miller), and into this percentage the largest number of avalanches (54%) occurred during spring. Considering the slope of the forested avalanche release areas, it appears that a density of 327 trees/ha with *dbh*> 8 cm (252 trees/ha with *d* larger than 16 cm), did not guarantee a protective function on slopes between 30 and 35°. Considering slopes between 35 and 40°, avalanche events were registered within forest with 360 trees/ha with *dbh* > 8 cm (236 trees/ha with *dbh* > 16 cm) and, for slopes of 40-45°, the density was 495 trees/ha with *dbh* > 8 cm (273 trees/ha with *dbh* >16 cm). Only one avalanche occurred on a 48° slope (slope class 45-50°) in a forest with 300 trees/ha with *dbh* > 8 cm (225 trees/ha with *d* > 16 cm).

The forested areas where avalanche release occurred showed a crown cover equal to 68% (n=3), with a slope angle ranging from 30 to 35°; 53% (n=6), with slopes of 35-40°; 40% (n=4), with slope angles of 40-45°, and 53% (n=1), with slopes of 45-50°.

Relating to the shrubs cover, most of the avalanches (67%) released in areas with high shrubs cover, with a cover ranging from 40 to 80%.

3.3.2 Test areas external to release zone

Focusing on forests where avalanches did not occur, it was possible to observe that density of 680 trees/ha (n=2) with *dbh* > 8 cm (267 trees/ha with *dbh* > 16 cm) fulfilled the protective function against avalanche release on slope with an inclination of 30-35°.

In the slope class 35-40°, it appears that a density of 615 trees/ha (n=6), with *dbh* >8 cm (370 trees/ha with *dbh* > 16 cm) have prevented the avalanche detachment, while, considering the slope ranging from 40 and 45°, the mean density threshold was 622 trees/ha (n=3), *dbh* > 8 cm (358 trees/ha with *dbh* > 16 cm).

Where the avalanches did not occur, the shrubs cover was lower than in the internal plots, ranging from 20 to 40% in most of the cases (47%).

4 DISCUSSION

At the time when most of avalanches started within forest the avalanche danger level was greater than 3 (87%), i.e. in occasion of high snowpack instability especially on steep slopes (greater than 35°).

The avalanche released mostly between the end of the winter and the spring period, when the average air temperature increase and consequently the liquid water content of the snow cover increases.

Half of the analyzed cases were characterized by shrubs coverage higher in the avalanche release zone than in the external areas; in 55% of the study cases shrubs presence could have had a determinant role in reducing snowpack stability, accelerating the kinetic metamorphism within the snow.

The average crown cover external to the avalanche release zones was 55% for slope steeper than 35°, instead for the internal areas it was about 45%. Nevertheless, the crown cover of the external areas exceeded the value of the release zones only in 60% of cases (even if minimal differences were observed): this result support the hypotheses that crown cover is not the only factor that determines the protective rule of a forest.

The stem density (stems/ha) seems to be the most important factor for snowpack stabilization: all the analyzed study cases showed lower stem densities in the release area than in the external one, with an average difference of about 280 stems/ha considering *dbh* > 8 cm and 160 stems/ha considering *dbh* > 16 cm. Two diameter thresholds were taken into account in order to compare collected data with both Meyer-Grass (1987) that used densities for *dbh*>16 cm and Berretti et al (2006) that used *dbh* > 8 cm.

In the release zones, higher density are observed where the slope increases. However, a density of 340 stems/ha with *dbh* > 8 cm (of which 245 stems/ha with *dbh* > 16 cm) has not assured the forest protective function where the slope > 40°. Even 490 stems/ha are not enough with slope > 40°.

Visible traces and information about past releases are not observed in external avalanche areas, therefore it is possible to infer that a forest with these structural characteristics has been able to prevent avalanches release (Tab.1).

	Basal diameter > 8 cm			Basal diameter > 16 cm		
	Slope <35°	Slope 35°-40°	Slope >40°	Slope <35°	Slope 35°-40°	Slope >40°
Deciduous conifers	1104	572	395	326	365	328
Deciduous +evergreen conifers	825	256	/	525	208	/
Evergreen conifers	/	/	1075	/	/	416

Tab.1 Values of stem density and trees composition of the external avalanche areas.

The observed characteristics of the forest outside the historical release zones are confirmed by literature values only in 60% of our cases, probably because literature data are more cautious than what observed in the present work.

5 CONCLUSION AND FURTHER WORKS

Considering the non negligible number of avalanches characterized by a starting zone located within forested areas, future studies are necessary in order to analyze the complex relation that might exist between forest and ground cover with the site morphology and snowpack characteristics.

It is evident that a single factor (such as tree composition, crown cover, density) is not able to describe the protective role of a forest by itself.

Only a continuous research finalized to build a database of avalanches that released within forests, can increase the knowledge related to the forest stabilization effect on snowpack. Such research would provide basis for applying a correct and sustainable silvicultural management, if possible and with due caution, in substitution of permanent defense structures..

6 REFERENCES

Berretti R., Caffo L., Camerano P., De Ferrari F., Domaine A., Dotta A., Gottero F., Haudemand J.C., Letey C., Meloni F., Motta, R., Terzuolo P. (2006) *Selvicoltura nelle foreste di protezione. Esperienze ed indirizzi gestionali in Piemonte e Valle d'Aosta* Compagnia delle foreste, Arezzo.

Brang, P., Schonenberger, W., Ott, E., Gardner, B. (2001). Forests as protection from natural hazards. The Forests Handbook, vol. 2. Blackwell Science, Oxford, pp. 53–81.

Brundl, M. Schweizerisches Landesforstinventar (1993-1995). Ergebnisse der Zweitaufnahame. p 442

Fierz C., Armstrong R., Durand Y., Etchevers P., Greene E., McClung D.M., Nishimura K., SatyawaliP.K., Sokratov S. (2008). The international Classification of seasonal snow on ground. European Geoscience Union Conference, Vienna 2008. Geophysical Research Abstracts Vol. 10 EGU2008-A-10525

Freppaz m., Marchelli M., ViglittiD., Bruno E., Zanini E. (2006). Suoli più freddi in un mondo più caldo? Rivista Neve e Valanghe n. 58 pp.74-81

Imbeck, H. (1983): Die Lawinenschutzwirkung des Waldes. Mitteilungen des Eidgenossischen Instituts fur Schnee- und Lawinenforschung Davos, 43 pp. 57–67.

In der Gand, H. (1978): Verteilung und Struktur der Schneedecke unter Waldbaumen und im Hochwald. International Seminar on Mountain Forests and Avalanches. IUFRO Working Party on Snow and Avalanches. Davos: Swiss Federal Institute for Snow and Avalanche Research pp. 98–119.

Johnson, E. A., (1987): The relative importance of snow avalanche disturbance and thinning on canopy plant populations. Ecology, 68 pp. 43–53.

Letey S., Viglietti D., Freppaz M., Motta R., Zischg A. (2008) Neve, valanghe e foreste: una realtà tutta da scoprire. Neve e Valanghe 64: 26-35.

Mayer A., Stockli V. (2005). Long-term impact of cattle grazing on subalpine forest development and efficiency of snow avalanche protection Arctic, Antarctic, and Alpine Research, Vol. 37, No. 4 pp. 521–526

Mayer H. (1982) Waldbauliche Zukunftsperpektiven fur den Gebirgswald. Schweiz. Z. Forestwes. 133 (9) pp.759-780.

McCLUNG D. M. (2001) Characteristics of terrain, snow supply and forest cover for avalanche initiation caused by logging. *Annals of Glaciology 32*

Meloni F., Lingua E., Motta R. (2006). Analisi della funzione protettiva delle foreste: l'esempio della "Carta delle foreste di protezione diretta della Valle d'Aosta. Atti 5° Congresso SISEF: Foreste e Società - Cambiamenti, Conflitti, Sinergie

Meloni F., Lingua E., Motta R. (2006). Analisi della funzione protettiva delle foreste: l'esempio della "Carta delle foreste di protezione diretta della Valle d'Aosta". *Forest@ 3 (3): 420-425, 2006.*

Meyer-Grass, M. (1987): Waldlawinen: Gefahrdete Bestande, Massnahmen, Pflege des Gebirgswaldes. In Bischoff, N. (ed.), Pflege des Gebirgswaldes: Leitfaden fur die Begrundung und forstliche Nutzung von Gebirgswaldern. Berne, Switzerland: EDMZ, 379.

Motta, R. (1995) I lariceti delle Alpi occidentali: un problema ecologico selvicolturale. SILVAE pedemontis. 1 pp. 7-16

Motta, R., Haudemand, J. (1999). Selvicoltura nelle foreste di protezione diretta delle Alpi. Il bosco "Ban de Ville" di Courmayeur. Monti e Boschi n.ro 3-4

Ott, E. (1996): Leitbilder zur Schutzwirkung des Waldes vor Lawinenbildung. Forstwissenschaftliches Centralblatt, 115: 223–230 e Salm, B., 1978: Snow forces on forest plants. In In der Gand, H., Kronfeller, G., Ott, E., and Salm, B. (eds.), International Seminar on Mountain Forests and Avalanches. IUFRO Working Party on Snow and Avalanches. Davos, Switzerland: Swiss Federal Institute for Snow and Avalanche Research pp. 156–181.

Schonenberger W., Noack A., Thee P. (2005). Effect of timber removal from windthrow slopes on the risk of snow avalanches and rockfall. Forest Ecology and Management 213 pp.197–208.