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Land Planning and Extreme Snow Events: The Case of Buthier Avalanche in Aosta Valley - IT

Andrea Debernardi[1], Simone Roveyaz[1], Enrico Borney and Barbara Frigo[2]*

[1]*Fondazione Montagna sicura – Montagne sûre, Italy*

[2]*Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Italy*

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***Corresponding author:** Frigo B, Associate Professor, Department of Structural, Geotechnical and Building Engineering (DiSEG), Politecnico di Torino, Corso Duca degli Abruzzi, 24 – 10129 Torino, Italy

Abstract

It is well known that climate change affects all sectors of human life also increasing the natural hazard. More sensitive to its effects, the Alpine regions are coped with unpredictable scenarios caused by unexpected weather conditions. The risk management is carried out by different defence methods - from the infrastructures to the management – and nowadays, it must take into account necessarily the variability of weather conditions caused by climate change.

The article reports the example of the indispensable update of hazard mapping used to reduce the snow avalanche danger with urban constraints in Cogne – Aosta Valley, in north-eastern of Italian Alps.

On 15th December 2008, an event induced by extreme weather and snow conditions occurred exceeding the known limits of the avalanche basin: the paper shows how the Avalanche Warning Service of Aosta Valley had to investigate in order to estimate the return period of the event and to update hazard maps. Due to the lack of information, the study was carried out coupling the historical and dendrochronological investigations of the woods embodied in avalanche basin and destroyed by the event.

Thanks to the lucky presence of forests with the same age and local tree-rings surveys, the return period of the avalanche of 15th December 2008 was estimated equal to a century.

Keywords: Snow avalanche; Return period; Tree-rings; Hazard maps

Introduction

The consequences of severe weather events involve all the aspects of the human lives, from natural systems and built environment to economic and social systems. Today, it is well known that the increase in the intensity and frequency of extreme weather events is one of the most visible consequences of global warming and that the Alpine Space is more severely affected than other European regions. From the point of view of the built environment, increasing the average temperature, changing precipitation patterns, and stronger weather extremes and variability induce important consequences for the Alpine Space, such as [1]:

a) Direct and indirect damage to buildings and infrastructures as a consequence of more frequent and more severe extreme weather events;

b) Increasing the risk due to natural hazards such as landslides, mudflows, snow avalanches, rock falls;

c) Modification of the permafrost area and consequent settlements of structures and plants;

d) Expansion of flood hazard zones and more frequent floods in existing hazard zones.

In the Alpine regions, the increasing scarcity of space for permanent settlement activities or additional land use (housing, tourism, transportation, etc...) is exacerbated by climate change. This is likely to cause an expansion of zones subjected to hazard, as well as additional demand for land protection measures.

Nowadays, urbanism and land planning is one of the main tools for the prevention and protection by snow avalanches. Permanent measures against avalanches directly indicate urban management and land use planning (zoning) of mountain areas. In Italy, the so-called *"Carte di Localizzazione Probabile delle Valanghe"* (C.L.P.V.) highlight the areas potentially affected by avalanche phenomena based on experiences and/or historical archives, as well as the analysis of the parameters that characterize a potential area of avalanche release (dynamics, morphology, inclination, exposition, vegetation, etc ...). The C.L.P.V. are coupled with "*Piani delle Zone Esposte al Pericolo Valanghe"* (P.Z.E.V.) which subdivide the recognised avalanche basin in three danger degrees (high, medium and low) plus the "presumed" no-risk area. Based on the different regional laws, in each of the identified avalanche areas, the planning instruments indicate well-defined requirements such as restrictions or impossibility to build houses or infrastructures [2].

An example of European excellence, it was the first code in Italy, Valle d'Aosta's Regional Law No. 11/98, which links regional spatial planning activities to natural hazard estimates. Landslides, snow avalanches and floods are taken into account. Regarding snow avalanches, in all regional territory each avalanche basin is subdivided according to the impact pressure induced by the maximum extreme avalanche event known or according to a statistically defined event considering a return period of 100 years [3]. The avalanche basin is governed by three avalanche hazard degrees (high in red, medium in yellow and low in green) based on a range of the estimated avalanche impact pressure (respectively higher than 3t/mq, between 0,5 and 3t/mq and less than 0,5t/mq) of the reference avalanche (Figure 1). For each degrees, the Regional Law indicates the restrictions to build and the related requirements trying to answer the following questions: is it possible to build? What can be built? How to build? At the present, the only existing guidelines are those given by De Biagi et al. [4].

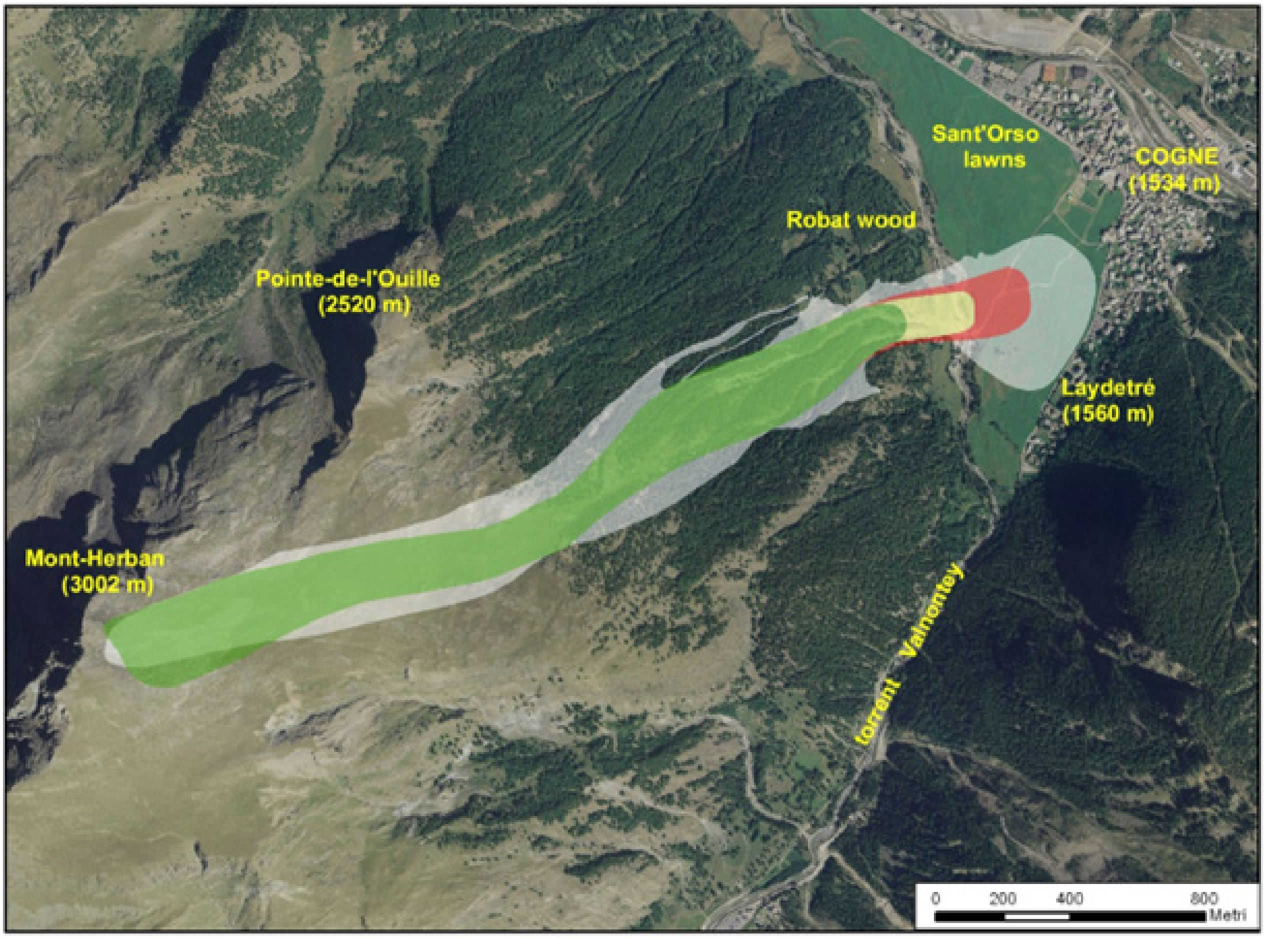

Figure 1: The avalanche hazard map (Carta Ambiti inedificabili Art. 37 LR 11/98) of the n. 52 – Buthier avalanche basin in Cogne – AO (IT) with the three avalanche danger degrees (high in red, medium in yellow and low in green) based on a range of avalanche impact pressure (respectively higher than 3t/mq, between 0,5 and 3t/mq and less than 0,5t/mq). In white the perimeter of the avalanche event of December 15th, 2008.

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These hazard maps represent the result of an important analysis of the territory, from the morphological, geological and forestry points of view, linked to the study of the local climatic conditions and to historical avalanche investigations. Obviously, the dynamic analysis of most catastrophic avalanche phenomena is based on extreme snow conditions and the subsequent choice of the best dynamic model (analytical, statistical or continuous) essential to identify the maximum run-out area of an avalanche.

Therefore, due to climate change, hazard maps in Alpine regions have to be 'dynamic': they have to be updated over the years with the integration of information obtained from the study of new extreme events and their increase in frequency, magnitude and spatial impact [1].

The paper is focused on the snow avalanche hazard. On the middle of December 2008, a series of catastrophic avalanches in the North-West of Italy was caused by extreme snowfall [5], for example, in Valsavarenche – AO [6,7] and Ceresole Reale – TO, municipality in Alta Valle Orco (Piedmont) [8]. We report the case of Buthier avalanche in Cogne – AO (Italy). As other cited events, the Buthier avalanche exceed the limits of hazard map bringing the Avalanche Warning Service of Aosta Valley to investigate on the return period of the avalanche and update the hazard cartography. In the absence of historical data, the analysis was carried out by means of a dendrochronological investigation of the forest on the avalanche basin. The tree-ring dating proved to be the only scientific method supporting the back-analysis with the following peculiarities: simplicity of execution, low cost and potentially executable in any season.

Data and Results

The snow avalanche event

The middle of December 2008 was characterized by heavy snowfalls throughout all the Italian Western Alps causing numerous avalanches [5-8] and severe damages to forests, buildings and mobility: 8 municipalities and 4000 people were isolated. In this paper, we focus our attention on one of these events occurred in Cogne - Aosta Valley (North-West of Italy): the avalanche basin n. 052 – *Buthier*, called according to the small village at the end of the basin. The avalanche basin (Figure 2) extends from the top of *Mont Herban* (almost 3000m a.s.l.) until the meadows of *Sant'Orso* (1540m a.s.l.) closed to the "Veulla" (that means "city center" in the local language). Due to their rarity at high altitude, these wide areas of lawn were awarded "Wonder of Italy" in 2012 for their scenic sites and cultural heritage. Since 1939, the meadows of Sant'Orso have been preserved as "natural beauty" and, according to the municipal statute, building is forbidden in this area.

Figure 2: Aerial view of the Buthier avalanche released on December 15th, 2008. At the same time, the closer Pointe de l'Ouille avalanche released too (to the right in the picture): it also causes extensive damage to the forest (photo: forestry station of Aymavilles – Aosta Valley).

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Snow and meteorological conditions

During Winter 2008/09, 1.731 avalanche phenomena occurred in Aosta Valley affecting about 15% of total regional surface. 1.274 of them are spontaneous events released from 866 avalanche basins, 313 of which never reported before in regional Avalanche Cadastre of Aosta Valley [5].

Analyzing the number and the monthly distribution of avalanches in Aosta Valley, we notice that in the north-western and central sectors of region, the month with the highest number of events (90%) is December followed by April, while in the south-eastern one the relation is reversed: the month with the highest avalanche frequency is April followed by December. From these data, it is clear that the highest number of spontaneous avalanches is related to the most abundant snowfall (recorded during December 2008 and April 2009) and with the increase of temperatures (during spring time in April). This is in agreement with the observations on climate change: larger quantities of snow, concentrated in fewer days. Extreme snowfalls matched with rapid temperature gradients lead to the increase (in number) of extreme mixed avalanches and to more frequent wet avalanches also in winter [9]. And this is what happened from 15th to 17th December, 2008. Characterized by frequent snowfall before mid-December, the early winter 2008/09 carried a thick snow cover between 100 and 170cm at 2000-2500m a.s.l.. During the night between 13th and 14th December, it started to snow throughout the Aosta Valley with increasing intensity (from 3cm/h to 15cm/h) and moderate winds. After 24 hours (on 15th December 2008 at 1 p.m.), the height of the fresh snow in Champorcher, Cogne, Valsavarenche and Rhêmes valleys was varying from 60cm to 130cm, leading the snowpack to exceed the 300cm of thickness. After a slight decrease on the 15th December afternoon, the snowfall stopped during the night of 17th December.

During this extreme snowfall, the snow level rose from 1000-1200m a.s.l. to 2.000m on 16th December weighting the snowpack below this altitude. The triple effect of heavy snowfall, the sharp rise of the freezing level and the wind activity created the perfect conditions to release several avalanches over wide areas of the Aosta Valley.

Over 90% of the 1.274 spontaneous and extreme avalanches detected in Winter 2008/09 occurred on December 15th, mainly in the morning, when the snowfall reached its maximum intensity. From December 15th to 17th, 419 spontaneous avalanche events had been detected: 69 of them exceeding the registered limits, and even 68 events not known before. They released above 2300m a.s.l. and presented a dynamics typical of dry snow mixed avalanches. One of the valleys where the largest number of events was the valley of Cogne.

Event description

On the morning of Monday 15th December, Cogne was shrouded by fog and heavy snowfall. Nobody could see the snow avalanche, but a terrifying roar was heard, followed by a strong smell of resin filling the countryside. The cause of the sound was revealed only when the fog was cleared, uncovering the Mont Herban with a large wound of the forest at its northeastern side (Figure 2).

The avalanche released just below the Mont-Herban peak – east/north-east face, at 2970m a.s.l. and 35° of inclination - and flowed on the grassy slopes up to 2300m meeting the edge of the coniferous forest. From here, the mixed avalanche continued breaking down and uprooting many pines and coniferous trees. The presence of two watersheds in the forest affected the avalanche partially limiting the lateral expansion. The snow flow was splitted allowing trees grown between the two watersheds to remain intact: a strip of wood, as a wedge-shape with 350m length and a range of 10m-40m width was saved from the avalanche destruction. The two main avalanche streams re-joined closed to the meadows of Buthier, at about 1570m, where the inclination of the slope decreases and the avalanche velocity slowed down leaving snow deposition with most of the uprooted trees. During its descent, the avalanche passed very close to the buildings of the Buhier village at 1560m, crossed the Valnontey creek and, finally, stopped in the meadows of Sant'Orso.

The powder part of avalanche continued until the first houses of Laydetré (1560m) where a thin layer of snow mixed with spruce needles and twigs of conifers was deposited. Globally, the snow avalanche broke more than 5,000 specimens of spruce and larch, dragging them to the end of the slope. A specific survey of the debris position showed that the dragged material differs according to the size during the deposition: the larger trunks of uprooted trees stopped at the end of the slope, just beyond the Valnontey creek (Figure 3), while branches and needles were deposited farther, near the meadows of Sant'Orso.

The avalanche caused extensive damage also to buildings (a pasture and a chalet at 1737m and 1554m a.s.l., respectively) and minor damage to the tennis courts (Figure 4).

Damage to wood and forest

The data related to the wood area within the limits of the n. 052 avalanche in the Cogne valley had been achieved from the regional Piano Economico dei Beni silvo-pastorali [10] related to the public forest area (particles n. 22 - Loc. Sentiero Robat, 23 - Loc. Sopra Buthier e 24 - Loc. Crestone di Buthier, in Figure 5 & Table 1).

Thanks to the data for the two censuses carried out in 1990 and 2010, with the method of sample plots, it was possible to estimate the wood broken by the avalanche of 15th December 2008, in terms of number of plants and volume of wood (Table 2). In particular, the forest area corresponding to n. 22 particle was largely destroyed while the area corresponding to n. 23 was completely torn apart for 300m length. Just a small core of larch (LC51E) of 1120mq survived. The n. 24 particle was just lapped by avalanche on its northern limit (Figure 6).

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Figure 3: At the end of the slope, the snow flow hit two buildings in Buthier village on the south of deposition zone (on the left of picture). However, the snow flow was partially deflected by a little deflecting dam built to protect the buildings from the debris flows from the slopes of Mont-Herban. At 1554m a.s.l. (on the right of the picture), the chalet was hit by the avalanche damaging the roof, the chimney and the western side. Fortunately, the main stream of avalanche passed south of the deposition zone where most of larger size wood debris were deposited.

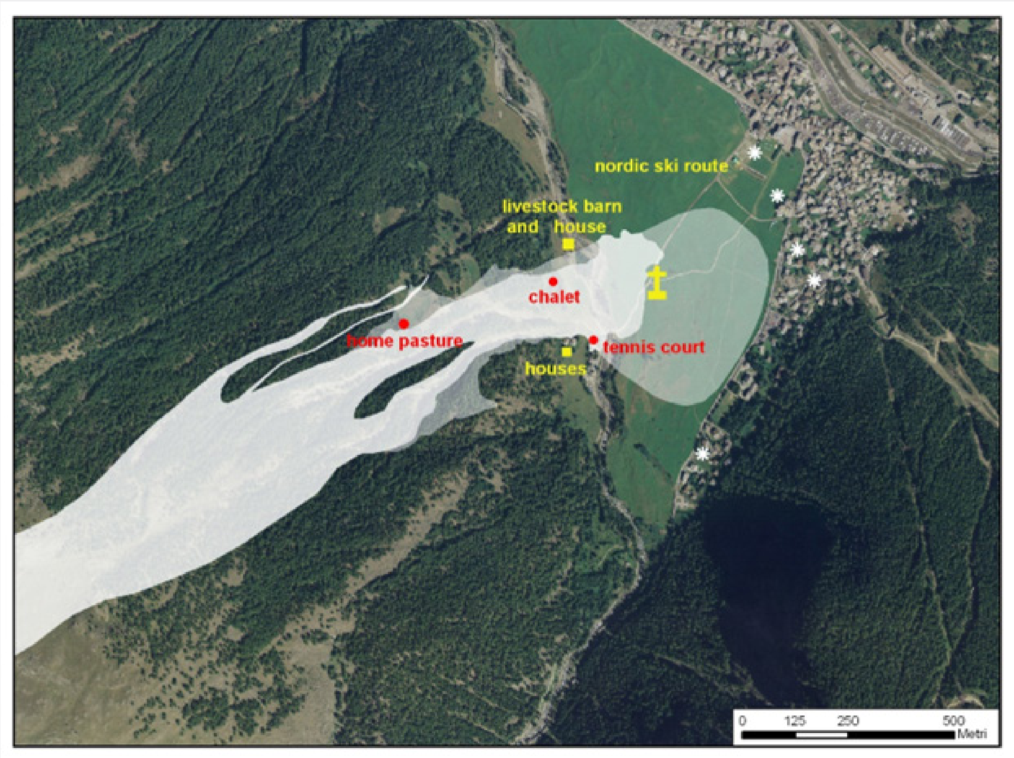

Figure 4: The size of avalanche track at the end of the slope and deposition zone (December 2008): in white (limits of dense part of avalanche) the areas with severe damage of vegetation and in transparent white (limits of powder part of avalanche) the areas with milder damage to forest. Highlighted in red are the damaged buildings.

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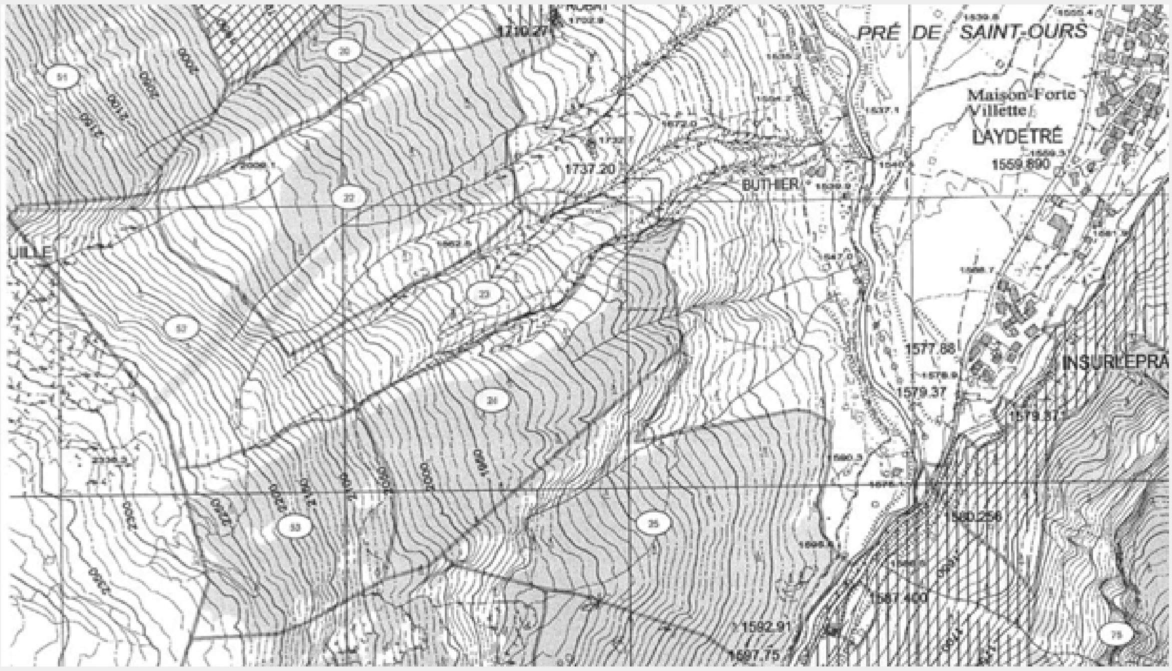

Figure 5: The map of the forest owned by the municipality of the Buthier avalanche basin (particles n. 22 - Loc. Sentiero Robat, 23 - Loc. Sopra Buthier e 24 - Loc. Crestone di Buthier). The peculiarities of the tree population are reported in Table 1.

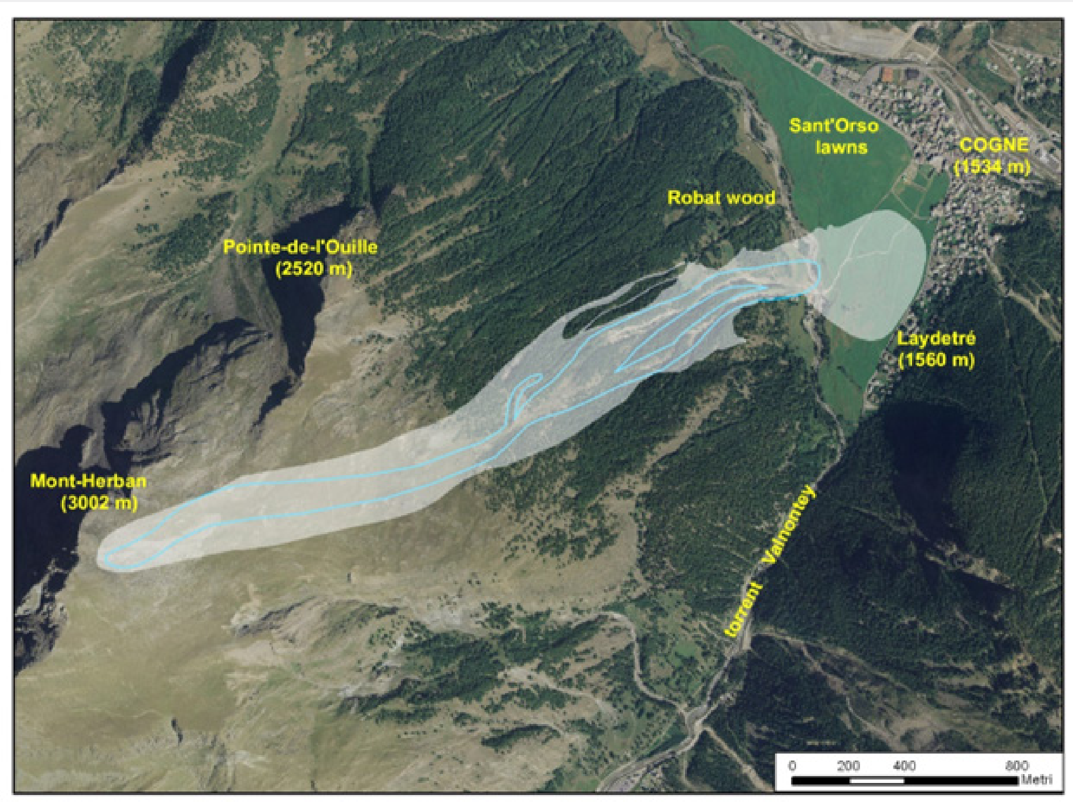

Figure 6: The avalanche of 15th December 2008 (in white) compared with the historical limits assigned by the regional Avalanche Cadastre of Aosta Valley (in blue). Note the clear interference of the avalanche with the forest and the location of the small survived core of LC51E larch (1120mq) enclosed in the historic perimeter.

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Table 1: Peculiarities of the tree population of particles n. 22, 23, 24 enclosed in the Buthier avalanche basin in Cogne – AO

Particle	n. 22	n. 23	n. 24
Total area [ha]	202,467	78,593	152,919
Production area ha]	111,561	0,1120	124,171
Avalanche area [ha]	75,000	77,473	28,600
Forest type	High forest	High forest	High forest
Populating	Mixed Conifer	Larch	Mixed Conifer
Structure	Irregular	Contemporary	Irregular
Forestry vocation	Moderate	Moderate	Moderate
Natural regeneration	Poor	Poor	Poor
Prevailing destination	Production/protection	Naturalistic	Naturalistic
Dominant species	PE40A: Picea abies, Larix decidua LC51X e LC52B: Larix decidua	Larix decidua	LC51B: Larix decidua, Picea abies PE40A: Picea abies, Larix decidua

Table 2: Estimation of the tree (in number and volume) broken by avalanche event occurred on 15th December 2008 in Cogne – AO.

Particle n. 22		Tree		Volume		Total		Estimation of Broken Trees	
Year	Species	n.	%	[mc]	%	Tree	Volume [mc]	Tree	Volume [mc]
1990	Spruce	6260	58	2708.82	52.45	10735	5164.53	9870	2780
	Larch	4407	41	2404.05	46.55				
	Scots Pine	10	0	7.68	0.15				
	Pine	58	1	43.98	0.85				
2010	Spruce	385	45	812.27	34.07	859	2384.30		
	Larch	444	52	1544.80	64.79				
	Scots Pine	---	---	---	---				
	Pine	30	3	27.1	1.14				

Particle n. 23		Tree		Volume		Total		Estimation of Broken Trees	
Year	Species	n.	%	[mc]	%	Tree	Volume [mc]	Tree	Volume [mc]
1990	Spruce	1571	55	723.85	64.16	2853	1128.19	2850	1110
	Larch	1207	42	369.45	32.75				
	Pine	75	3	34.89	3.09				
2010	Spruce	---	---	---	70	---	---		
	Larch	---	---	---	25				
	Pino cembro	---	---	---	5				

Particle n. 24		Tree		Volume		Total		Estimation of Broken Trees	
Year	Species	n.	%	[mc]	%	Tree	Volume [mc]	Tree	Volume [mc]
1990	Spruce	7321	62	3580.79	60.69	11771	5900.59	5810	6750
	Larch	4244	36	2245.90	38.06				
	Pine	206	2	73.90	1.25				
2010	Spruce	2592	43	1172.78	38.56	5961	3041.43		
	Larch	3369	57	1868.65	61.44				
	Pine	---	---	---	---				

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The final estimation of the broken trees reported 18.530 plants per 6750mc of wood in the public area and 2.000 plants per 800mc of wood in private land, for a total amount of about 20.500 plants destroyed corresponding to 7550mc of wood.

The estimation of the return period

Despite the historical research conducted at public and private archives, documents relating to past events of Buthier avalanche were not found. It is an exception a brief note of César Emmanuel Grappein written after the flood on October 16th, 1846 that lists a series of natural disasters that affected the territory of Cogne: "*Un très petit hameau qui* était *à Buttier et qui s'appelait Favro a* été *tout emporté en entier par une avalanche".*

However, an historical analysis of photographic documents with Cogne, the meadows of Sant'Orso, the Gran Paradiso and Mont-Herban as a subjects, shows that it is possible to identify at least two events quite similar than the event of December 15th, 2008 during the last 100 years. The photographs of nineteenth/twentieth centuries put into evidence that the Buthier slope was uniformly wooded, while in those dated between 1925 and 1935, the forest looks damaged by an avalanche event probably occurred in those years. In the following forty years, the avalanche basin was re-colonized by wood forest, as evidenced by some pictures dating in the sixties. The photographs of the seventies show again the forest damaged, which should witness another big avalanche event.

From '70s until the winter 2007-2008, the Avalanche Regional Cadastre of Aosta Valley recorded only two events: the first in April 1972 and the second in the winter of 1982-1983 with severe damages to the forest. From this date, tall trees species were able to occupy homogeneously the northeastern slope of Mont Herban.

Thanks to the following six images (Figure 7), the frequency and the size of the avalanche phenomenon starting from the beginning of the twentieth century has been reconstruct by analyzing the width of the forest cover.

Figure 7: The six images to evaluate the frequency and size of the avalanche phenomenon starting from the beginning of the twentieth century analyzing the width of the forest cover.
(a) 1915 (photo: BREL Archive - Fonds Fisanotti);
(b) 1925-1935 (photo: BREL Archive - Fonds Domaine);
(c) 1963 (photo: BREL Archive - Fonds Willien);
(d) 1970-1975 (photo: private collection A. Roveyaz);
(e) 2008 (photo: E. Borney) and
(f) 2009 (photo: E. Borney).

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By observing the sequence of the six photographs, we note that central strip of forest saved from the event of December 2008 appears also in historical photos of 1925-1935 (Figure 7b) and 1970-1975 (Figure 7d), but is larger than the event of December 15th, 2008 witnessing how past events were less destructive. This is also confirmed by the observation of the lateral limits of the forest affected by the historic avalanches which appear to be less extensive than those achieved by the last 2008 event. Focusing on the images where the forest is damaged (Figure 7b, 7d & 7f) and on the left edge of the intact forest, it is easy to conclude that the event of December 15th, 2008 was clearly larger than the previous ones. In order to verify this conjecture, during the spring, an extensive dendrometric survey [11-13] was carried by using the Pressler auger, sampling various plants survived in the small core of larch (LC51E) and in staked ones at in the damaged forest (Figure 8). The samples were suitably processed to make the growth rings more visible and thus facilitate age counting on each plant.

Figure 8: The larch (Larix decidua Miller) crushed by the avalanche on December 15th, 2008 (sample n. 5). It was located closed to the Buthier village. The age of the plant is about 140 years old.

In conclusions (Figure 9), the dendrometric survey on Buthier wood confirmed that the n. 52 – Buthier extreme avalanche (such as released on December 15th, 2008) presents a return time slightly larger than a century. Its highest intensity can be considered that of the 2008 event.

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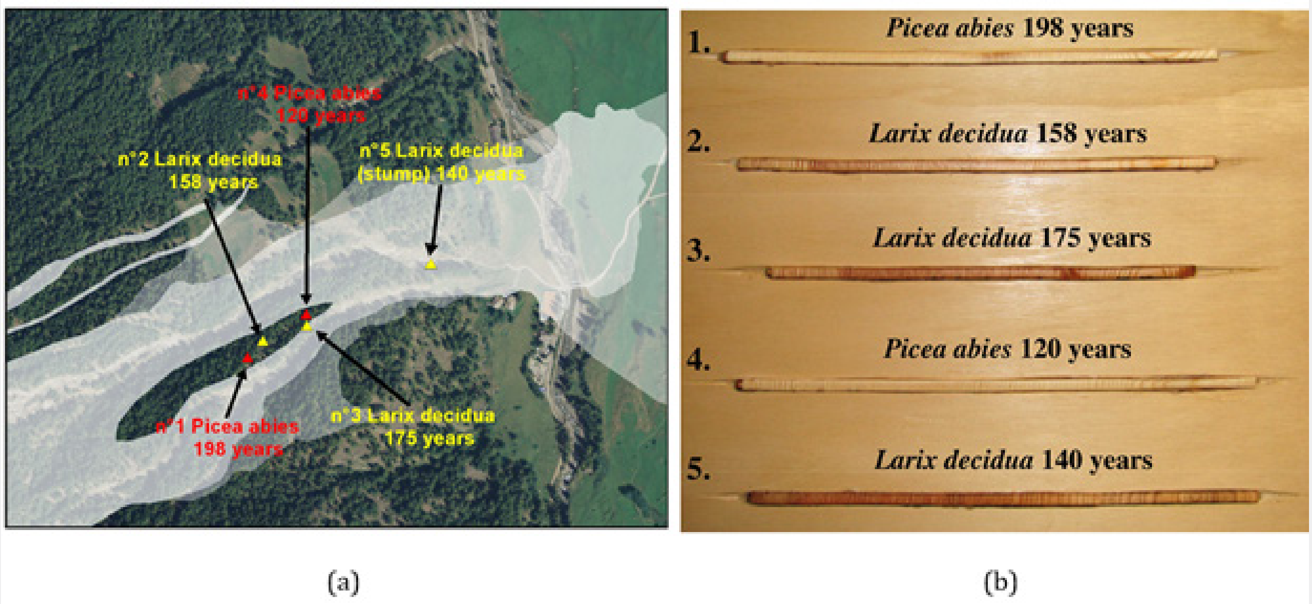

Figure 9: (a) The map reports the most significant points of sampling with the information on plant species and the age: spruce (Picea abies (L.) Karsten) in red and larch (Larix decidua Miller) in yellow.
(b) The largest and the lowest number of tree-rings were found in carrot n. 1 and n. 4 pulled out from spruces of about 198 and 120 years old, respectively. This information leads us to assume that any avalanche did not affect the small area saved by the event of December 15th, 2008 for more than 150 years confirming the conjecture made by analysing the historical photographs.

Conclusion

Due to unforeseen weather and snow conditions, extreme avalanches occurred in the north-western Italian Alps in mid-December 2008 that exceeded the known perimeters recorded and reported by the regional avalanche registries. To define the involved area and the magnitude of occurred extreme events, regional administrations endeavored to estimate the return periods of these events with rapid and inexpensive methods.

The paper presents the survey carried out for the estimation of the return period of the avalanche released on 15th, December 2008 in Cogne - Aosta Valley (IT). The analysis combines the historical investigation and dendrometric survey of forests with the same age damaged or spared from the fury of the avalanche.

The method has proved quick and easy to apply even in winter conditions appearing a eligible indispensable aid for the updating of hazard maps defined by the return period of maximum expected or occurred avalanche event.

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