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Tree rings as ecological indicator of geomorphic activity in geoheritage studies

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ABSTRACT

Mountain areas are characterized by geomorphic processes, especially mass wasting and snow avalanches, which may impact the landscape affecting also the biological component, trees included. If sites colonized by trees are characterized by geomorphic features with a high *Global* and *Scientific Value*, including *Representativeness of geomorphological processes*, *Educational Exemplarity*, and *Integrity*, they can be considered geomorphosites. In the framework of assessment of the *Scientific Value* of geomorphosites, *Ecological Support Role* is of great importance. Hence, tree rings derived information can be used as indicators to refine the *Scientific Value* of the sites and also to propose multidisciplinary approaches to understand landscape dynamics. In fact, trees colonizing sites of geomorphological interest are used for detecting past and present events and tree rings may be considered ecological indicators under different points of view. Arboreal vegetation can register growth disturbances in terms of morphological features, at macro- (particular morphologies of trunks) and micro-scale (annual growth rings, stress indicators like compression wood, traumatic resin ducts), becoming a powerful indicator of the geomorphic activity affecting the landscape. In some cases, combined with other techniques like climate data analysis, they may allow refining the often lacunose historical records of geomorphic events impacting different territories. The integrated analysis carried out in the Loana Valley (Sesia Val Grande UNESCO Geopark, Western Italian Alps), considering a selection of geomorphosites affected by mass wasting processes and snow avalanches and located along a touristic trail, allowed to detect which meteorological thresholds favour hydrogeological instability (i.e. overcome of Mean Annual Rainfall of 6–10%). Tree rings data coming from the investigated sites provided information on the recurrence of geomorphic activity, allowing filling gaps within the historical archives, by individuating years during which hydrogeological or snow-related events probably occurred and that were missed (i.e. 1986, 1989, 2001, 2007), and adding details on sites for which temporal constraints had not been found before (i.e. Pizzo Stagno Complex System). Finally, investigated sites demonstrated to differently record the history of instability affecting the area and this difference is mirrored in the sites values that are adopted in the framework of geoheritage analysis (*Scientific Value*, *Ecological Support Role* and *Educational Exemplarity*). The proposed multidisciplinary approach, including geomorphology, dendrogeomorphology and climatology, represents, hence, a useful tool in geoheritage valorisation and management strategies.

1. Introduction

Geomorphic processes, as well known, can represent hazard and risk for people, including both residents and users (e.g. tourism), and also for cultural and natural heritage (Cendrero and Panizza, 1999). According to Panizza and Piacente (2003), natural heritage includes geoheritage (sensu Osborne, 2000), which consists of ecosystem abiotic components at different spatial scale, from rocky outcrops to landscapes. Great attention is nowadays paid to landforms and geomorphological sites most representative of active geomorphic processes (Reynard et al., 2007; Pelfini and Bollati, 2014), which are responsible for hazards. When such geomorphological evidences are characterized by specific attributes (*Scientific, Additional*, *Global Values* and *Potential for Use*; see a review in Brilha, 2016), they can be considered *geomorphosites* (sensu Panizza, 2001), or more precisely *active geomorphosites* or *evolving passive geomorphosites* (sensu Pelfini and Bollati, 2014). In this sense, mountain geomorphosites, particularly sensitive to climate change, represent a key-category (Giardino and Mortara, 1999; Bollati et al., 2016; Reynard and Coratza, 2016; Bollati et al., 2017a,b).

The ecological meaning of geomorphosites is of a great interest both for the specificity of endemic flora associated to specific geologic bedrocks and for the meaning of geomorphosites in environmental

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reconstructions. In this framework, the classification of the ecological connotation is quite different: Panizza (2001) and other Authors (e.g. Pralong and Reynard, 2005; Garavaglia et al., 2010; Pelfini et al., 2010; Bollati et al., 2017a) include the "*Ecological Support Role" (ESR)* within the scientific values, while other Authors refer to it separately, as *Functional Value* (Gray, 2004) or *Ecological Impact Criterion* (Reynard et al., 2007; Pereira et al., 2008). Considering ESR among the *Scientific Values*, as discussed by Bollati et al. (2015) and reprised by Mocior and Kruse (2016), changes in vegetation (i.e. trees) colonizing a geomorphosite may affect other attributes of the geomorphosite itself, like *Representativeness of (paleo)geomorphological processes*. In fact, tree dynamics and tree rings features allow detecting and quantifying present and past landscape changes by means of multidisciplinary approaches (Bollati et al., 2012, 2016). Integrated approaches have also important implications in geo-education allowing the increasing of the *Educational Exemplarity* value of a site (Bollati et al., 2011; Garavaglia and Pelfini, 2011a).

Among the most powerful processes affecting mountain landscapes, there are mass wasting and snow avalanches processes (e.g. Luino, 2005; Kogelnig-Mayer et al., 2011), as documented by the high number of researches addressed to assess, estimate and model the related geomorphological hazard. Since mass wasting is strictly related to climatic conditions and trends, many researches concern the impact of climate change on this kind of geomorphological dynamics (e.g. Soldati et al., 2006; Keiler et al., 2010). More in detail, as mass transport also depends from the intensity and duration of rainfall events (Caine, 1980), the triggering meteorological conditions and thresholds for processes like landslides and debris flows are also deeply investigated (e.g. IRER, 2008; Brunetti et al., 2010). Luino (2005) for example describes precise sequences of geomorphic processes, active at different spatial scales (local or regional), following the overcoming of thresholds. Unfortunately, Global Climate Models can be difficulty downscaled at level of mountain areas because of the complex local relief and of the local climate and the meteorological variability that lead to local hydrogeological instabilities, for example localized in small catchments (Keiler et al., 2010). Also snow avalanches represent a hazard affecting mountain slopes according with abundance of snow, temperature gradient and slope morphology (Barbolini et al., 2011) but their relation with climate change is less clear (Bebi et al., 2009).

Complex reciprocal interactions between geomorphic processes and ecosystems have been frequently debated (e.g. Swanson et al., 1988; Pelfini et al., 2007; Viles et al., 2008). Swanson et al. (1988) categorized 4 classes of possible consequences of landforms presence and morphogenetic processes action on ecosystems in term of environmental modifications gradient and regulation of patterns and frequency of geomorphic and non-geomorphic disturbances. Considering the case of snow avalanches, Bebi et al. (2009) underlined how, for landscape management purposes, the comprehension of the ways in which avalanche disturbances affect ecosystem processes is important and how forest conditions may alter avalanche impact. In the first case the severity and return time interval of snow avalanches may more or less inhibit the colonization by some arboreal species, potentially threatening biodiversity; in the second case, instead, forest may slow down snow avalanches speed or prevent their formation by stabilizing snow in starting zones (e.g. larch forest; Albert et al., 2008). The potential hazard mitigation role of trees vegetation may be considered a form of ecosystem service as suggested by Viles et al. (2008).

Besides the mitigation role of vegetation under certain conditions, trees affected by geomorphological dynamics, in the specific, are considered powerful tool for investigating spatial and temporal distribution of geomorphic events (e.g. slope instability, snow avalanches; Pelfini et al., 2006; Soldati et al., 2006; Stoffel and Bollschweiler, 2010) and the relative rates (e.g. Viles et al., 2008; Bollati et al., 2016). Besides the macro-indicators related to vegetation (its presence or absence and its growth disturbance rates), more specific studies on the micro-features in tree rings, used in the framework of dendrogeomorphology (Alestalo, 1971), may help in detecting and dating past and present geomorphic processes affecting trees, as far as a seasonal resolution (Stoffel et al., 2005). Tree rings morphological features, generally called disturbance indicators (e.g. compression wood, traumatic resin ducts, growth anomalies), allow to date past events confirming or completing the record of events where lacunose (Pelfini and Santilli, 2008; Stoffel and Bollschweiler, 2008; Luckman, 2010; Kogelnig-Mayer et al., 2011; Pop et al., 2016), a problem occurring especially where human settlements are rare (Jakob, 2005; Barbolini et al., 2011; Văidean et al., 2015). Hence, trees, through dendrogeomorphological investigations, may become a tool not only for environmental reconstructions (e.g. Pelfini et al., 2014) but also for calibrating, at a more precise spatial scale, the models related to debris flows and avalanches, which are based on the events recurrence time (Kogelnig-Mayer et al., 2011).

In the present research, through a research carried out on a key area in the Western Italian Alps, we aimed at: i) reconstructing spatio-temporal changes in geomorphic hazardous processes (mainly landslides, debris flows and snow avalanches), affecting a selection of geomorphosites, by applying dendrogeomorphological techniques; ii) investigating the key role of meteorological conditions triggering the investigated geomorphic events; iii) analysing the importance of arboreal vegetation as ecological indicator of environmental changes, affecting geomorphosites features (*Ecologic Support Role*) in sensitive areas as mountain regions; iv) determining how these derived information may be gathered each other and used for enhancing the *Scientific* and *Global Value* of mountain geomorphosites in the perspective of a further educational and geotouristic enhancement.

The selected area corresponds to the upper portion of the Loana Valley, located in the Ossola region (Western Italian Alps). This valley represents one of the most popular accesses to the Val Grande National Park and it was recognized as an ecological corridor due to its morphological features (PNVG, 2001; Bionda et al., 2011). The Loana Valley is included within the Sesia-Val Grande Geopark, ratified in 2013 within the UNESCO European Geopark Network. The valley has been selected since different touristic and excursionist trails are present and the representativeness of landforms located along the trails has been recently pointed out and quantified in literature in order to propose some geotrails (Bollati et al., 2017a).

2. Study area

The study area is represented by the upper portion of the Loana hydrographic basin (red polygon in Fig. 1). It is located in the Verbano-Cusio-Ossola Province and it covers an area of about 27 km^2. The Loana hydrographic basin is placed at the boundary between the Ticino hydrographic basin, partially located in Switzerland, and the Toce hydrographic basin, in the Ossola Valley. The Loana stream, flowing from South towards North, is a tributary of the Eastern Melezzo draining the Vigezzo Valley and flowing, toward East, into the Swiss portion of the Maggiore Lake. The reach of the Loana stream, within which the investigated sites are located, spans between 1250 and 1300 m a.s.l.

2.1. Geological and geomorphological setting

The Upper Loana Valley is part of a geological and geomorphological relevant zone because the head of the valley is interested by the presence of the Insubric Line (locally named Canavese Line) separating the Southern Alps (on the SE) from the axial part of the Alpine chain, here represented by the Austroalpine Domain (on the NW) (Bigioggero et al., 2006). The main lithologies outcropping in the area are schists, paragneiss, gneiss and locally marbles, and along the southern part of the water divide, mafic rocks like amphibolites are abundantly represented. The region is characterized by a wide deformation belt related to the presence of the Insubric Line, conferring weakness to rocks and favouring their weathering and degradation, as already reported in other areas of the Alpine region by Soldati et al. (2006). Hence, the