Dendrogeomorphological investigations for assessing ecological and educational value of glacial geomorphosites. Two examples from the Italian Alps

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1. Introduction

One of the main goals of recent research carried out on geomorphosites is their valorisation in the frame of sustainable tourism and educational applications. Nowadays, many alpine geomorphosites are becoming the object of educational trips thanks to their educational values related to spectacular landscapes (Garavaglia & Pelfini, submitted). Among these, the glacial geomorphosites are becoming of great interest as representative of the mountain environment response to the global warming. Moreover, they highlight the interactions among the assessment values like rarity, representativeness and integrity (Grandgirard, 1999; Pelfini & Smiraglia, 2003; Reynard et al., 2007). Some glaciers are very meaningful as the most representative of the various typologies (e.g. valley glacier, debris covered glacier etc.) but others, without any integrity, are unique because they are the last glacial remains within a particular site. This is the case of the Calderone glacier in the Italian Apennines, the most southern European glacier and the only one still existing, even if debris covered and broken into two ice aprons (Pecci et al., 2008).

The glacier geomorphosites are highly representative for the study of climate history (Reynard & Panizza, 2005), responding in this way to educational goals. Moreover, their ecological value, represented among others by supraglacial and proglacial vegetation, is considered extremely useful for studies on glacier dynamics and reconstructions of glacial fluctuations, adding values for educational approaches once more.

Even if great attention is paid in assessing geomorphosite values, in order to promote and protect them, insufficient attention has been paid to “geomorphosite” topics in educational programs and only recently pedagogical trails for education in physical geography through geomorphosite observation have been proposed (Garavaglia & Pelfini, 2008).

This work tries to demonstrate the importance of the ecological value through the tree vegetation as a natural archive of data. Dendrochronology can be considered a very precious method not only to reconstruct geomorphological events, and so to increase the value of the scientific attribute (Grandgirard, 1999), but also to highlight the ecological valence of particular and sensible geomorphosites like glaciers. In fact living trees and stumps contribute to reconstructing glacier history and their present dynamics, and may represent also an important instrument for educational applications. The aim of this paper is also to discuss the meaning of ecological value assessed using tree vegetation.

The results obtained in two localities of the Italian Alps (Solda Valley in Ortles-Cevedale Group, Central Alps, and Veny Valley, in the Mont Blanc Massif, Western Alps) (Fig. 1) are summarised and used to discuss the ecological value and its related educational importance.
2. Glacial geomorphosites

The possibility of including glaciers and related morphologies in the geomorphosite framework, and consequently in natural and cultural heritage, was demonstrated by Pelfini & Smiraglia (2003). Glaciers can be defined as geomorphosites on the basis of scientific knowledge of natural assets, of natural laws that regulate their evolution...
and of their value relating to human perception. Glaciers represent beautiful landforms and frequently they are the goal of many hiking trails. Nevertheless, climatic changes in progress have led to profound changes of high-mountain environments, due to the rapid and intense shrinkage of the glacial masses (Oerlemans & Fortuin, 1992). The attributes and values that can be considered to identify these features as geomorphosites allow the glacier system to be considered not only as an assemblage of landscape elements but also as a sensible system and a significant example of geodiversity through their wide variety (Smiraglia, 2001).

The cultural attribute of glaciers begins with the evolution of the human species and its development, strictly related to glacier fluctuations, as Similaum man’s history, around 5000 yr B.P., suggests (Mohen & Eluère, 1997). Populations living in mountain environments were influenced by glaciers in their history, behaviour, art, legends, etc. Other examples in the Alps can be carried out from the relationship between glacier environments and the First World War events (Pelfini & Smiraglia, 2003). The economic attribute is represented mainly by hydroelectric energy and tourism. Glacier meltwater represents an important resource for hydroelectric power: many reservoirs in Aosta Valley and Valtellina were realised using hollows and glacier basins. In the Alps, glacial scenarios represent the natural support for tourism development: from few visitors about two centuries ago, to a hundred thousand each summer, at the present day, in areas like Mont Blanc and Monte Rosa. The increasing number of mountain huts and their enlargement (Smiraglia & Diolaiuti, 2002) underline a development of mountain frequentation. Moreover, some glaciers have been used for summer skiing even if only very few of them are still working today due to glacier shrinkage and other economic causes. The scenic attribute is obvious; the beauty of glacier sites remains one of the main aims of tourist frequentation. The scientific attribute is well documented by all the parameters suggested by Panizza (2001). Glaciers are well widespread; they are characterised by a wide variety of types (geodiversity) and by dynamics, the latter highlighting their role as climatic indicators. Glaciers are very sensitive indicators of climate changes (glacier as model of evolution), with short response time (except for polar glaciers). The exemplarity of a glacier is directly related to this valence: in fact if a glacier is a good model of evolution, it has also a great exemplarity.

For example, the Forni glacier was proposed as a representative glacial geomorphosite (Pelfini & Gobbi, 2005) and the glaciological trail “Sentiero Glaciologico del Centenario al Ghiacciaio dei Forni”, on the Lombardy side of Ortles-Cevedale Group, was opened in order to visit a geomorphosite of naturalistic, cultural and historical interest (Smiraglia, 1995). Nevertheless, as a consequence of the glacier tongue rapid shrinkage and of the instability phenomena, a new route was recently imposed, evidencing possible risk increase for users. Paleogeomorphological evidences in glacial systems are also paleoclimatic sources of information. Moraine ridges allow the positions reached during glacier advances to be identified, to calculate volumes, past glacial thickness, equilibrium line altitude
fluctuations etc., and consequently they consent to obtain paleoclimatic information. Glaciers are important also as ecological support: life outposts like algae and insects (glacial flea) (Michler, 1980; Panizza, 2001) are strictly dependent on the glacier tongue conservation. This was also recognised by Barthlott et al. (1996), to be one of the incentives to geodiversity assessment. On the Forni glacier, the increasing debris coverage on the snout allows species of arthropods to live on ice, becoming biological indicators of climate changes (Pelfini & Gobbi 2005). Where debris layers become thicker, vegetation can colonise the glacial surface and also more stable trees can grow, as on the Miage glacier (Pelfini et al., 2007).

As mentioned before, the ecological value is included among the additional values (and not in the scientific one), when related to geotourism or integrated cultural landscapes contexts. Several case studies propose different approaches to ecological value assessment in relation to different geomorphological situations: Pereira et al. (2008) include the ecological value among the additional ones, quantifying it on the basis of the relationship between geomorphosites and biological features (Tab. 1); Zouros (2007) proposes to assess the aesthetic and the ecological values contemporarily (case studies from Greece). For the karst environment, the ecological value has been linked to the economic, touristic and heritage status by Héritier (2006); in this case the “heritage value” concept synthesises the recognised values basing on a mathematic evaluation or a synthetic analysis. González Trueba & Serrano Cañadas (2008) suggest two different approaches: i) to determine the scientific or intrinsic value, based on geomorphic topics and allowing a more objective and systematic knowledge of the site, and ii) to define the “cultural or added value”, based on the consideration of cultural and environmental elements affecting and enriching the intrinsic value. They use the ecological criteria as the starting point for the geomorphosite assessment.

In the present work, the ecological value is underlined as a component of both the scientific (glacier fluctuation reconstruction) and additional (promotion and education) values.

<table>
<thead>
<tr>
<th>Ecological value</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>Without relation to biological features</td>
</tr>
<tr>
<td>0,38</td>
<td>Occurrence of interesting fauna and/or flora</td>
</tr>
<tr>
<td>0,75</td>
<td>One of the best places to observe interesting fauna and/or flora</td>
</tr>
<tr>
<td>1,12</td>
<td>Geomorphological features are important for ecosystem(s)</td>
</tr>
<tr>
<td>1,50</td>
<td>Geomorphological features are crucial for the ecosystem(s)</td>
</tr>
</tbody>
</table>

Table 1  Numerical assessment of the geomorphosite indicator of ecological value (from Pereira et al., 2008).
3. Case studies: the Marlet glaciers and the Miage glacier

Two examples are presented in order to underline the importance of the ecological value for the Earth and climate history and for an educational approach.

The first case is represented by the Marlet glaciers (Ortles Cevedale Group). The “Ghiacciaio Alto del Marlet” is a debris-covered glacier fed mainly by avalanches from the Ortles peak (3905 m a.s.l.) and shows a very steep and uneven topography. The “Ghiacciaio Basso del Marlet” moves down-valley from the Ortles northern crest and presents a half debris-covered tongue. The two Marlet glaciers deposited huge moraines ridges, principally built during the Little Ice Age and characterised by vegetation coverage. Among them, a small moraine system is present; it is colonised by well developed vegetation consisting of grasses, shrubs, living trees and stumps (principally Larix decidua Mill. and Pinus cembra L.) (Fig. 2). A dendrochronological analysis was carried out on living trees and stumps, using maximum tree cambial ages to obtain a minimum age for the surfaces and to reconstruct recent glacier evolution. It is a simple situation, appositely selected for educational applications.

The second case is represented by the Miage glacier in the Mont Blanc Massif (Fig. 3), the most representative debris covered glacier in the Italian Alps with a forest vegetation growing on its debris layer (Pelfini et al., 2007) (Fig. 4). Here the relationship between glacier activity and tree dynamics is complex and represents an important support to glaciological investigations.
Fig. 3  A sketch of the Miage glacier front. The dashed circles show the sampling areas chosen for the dendrogeomorphological survey. Letters A, B, C indicate the three groups, sampled to date glacier movements; letters G, S and T are the groups of undisturbed trees used to build the reference chronologies.

Fig. 4  Supraglacial tree cover on the Miage glacier. European larches colonise debris coverage and react to the glacier movements producing growth anomalies in annual rings permitting a precise dating of surface movements. Photos by M. Bozzoni.
3.1 Dendrochronological sampling and analysis

All the samples were collected and prepared according to the traditional methods (for details see Schweingruber, 1988). For the analysis, the cambial age of each sample was determined by counting the number of annual rings. Missing rings, in samples without pith, were estimated according to Jozsa (1988) and Villalba & Veblen (1997). Tree-ring width was measured precise to 0.01 mm, using the LINTAB system and TSAP software (Rinn, 1996) and through image analysis technique, with the WinDENDRO software (Regent Instrument Inc., 2001). The crossdating of the dendrochronological series was performed using COFECHA (statistical analysis) and TSAP software (visual analysis).

All the dendrochronological curves were averaged in an indexed chronology. The standardisation was realised through the ARTSAN software (Holmes, 1994). A double process of standardisation was chosen to eliminate the growth trend (Cook & Kairiukstis, 1990): as the first step, a negative exponential or a linear regression was applied, then a cubic smoothing spline, with a wave length of 100 yr and a variance conservation of 50 %, was performed.

Near the Marlet glaciers, 29 European larches were sampled to establish the minimum age of older and well-vegetated ones. A mean tree-ring chronology was created from 12 living trees and, successively, 13 samples from stumps were crossdated using local references and other chronologies available at the International Tree-Ring Data Bank (ITRDB; Grissino-Mayer & Fritts, 1997).

On the Miage glacier, 52 European larches were sampled on the lower part of the tongue. Three reference chronologies, based on undisturbed larches growing outside the glacier, were constructed for a comparison with the tree-ring data from the supraglacial trees. They were used to identify growth anomalies induced in the supraglacial trees by the glacier surface movements. In order to identify the temporal distribution of the growth disturbances in the supraglacial trees, two main approaches were adopted: i) a tree-ring growth series analysis performed on ring-width measurements (looking for pointer years and abrupt growth changes) and ii) skeleton plots made by a visual assessment of the samples (event years) (for a complete description of the methods, see Pelfini et al., 2007).

3.2 Dendrogeomorphological results on the Marlet glaciers

Dendrochronological results evidence how tree rings allow different ages to be attributed to the moraine systems (relative dating) and, indirectly, to identify an ancient glacier advancing phase drawing a glacier shape completely different to the Little Ice Age one. Moreover, the difficulties in absolute dating reveal a not unique advancing phase. In fact moraine disposition suggests an age progressively increasing down-valley (from A to D in Fig. 2). The cambial age and the reconstructed real tree ages represent a minimum age because errors might have affected dating procedure
(Heikkinen, 1994). The mean larch chronology, that covers the period 1396-2004, was used for crossdating samples from dead trees, alive between 1411 and 1947. The germination period was certainly older, also because some samples from stumps were decayed in their inner part. So, on the basis of the added rings, we estimated that on moraines B, C and D (Fig. 5) some tree germinations could be dated almost to the 14th century: about 1430 on moraine A, 1320 on moraine B, 1370 on the C one and 1300 on the D one (Fig. 5). The obtained ages do not follow an age increase trend down-valley. The moraines’ minimum ages are probably underestimated; in any case moraine depositions seem to be attributable to a period before 1300, for the most external one (D), and before 1430, for the inner one (A) (unpublished data). This could be a moraine system built during advancing phases before the Little Ice Age or in its earlier phases, as observed in other areas (Grove, 1988; Pelfini et al., 2002), even if it is not possible to establish how many years before. In any case, the colonisation seems to have taken place in a small time interval (about 130 yr); the advancing phases were probably quite close in time.

The Marlet glacier site is easily accessible for users and attributes and valences are easily observable in a restricted area. The presence of clean and debris covered glaciers in the valley reveals the changes happening in glacial environments, while the moraine systems and the relative forest vegetation allow the paleoenvironmental and paleoclimatic values to be assessed. In this case, the vegetation role in assessing the ecological value and the dendrochronological investigations’ role in improving the scientific value are highlighted, confirming the possibility of a didactic application.

Fig. 5  The Marlet moraine amphitheatre. The letters indicate the four moraine ridges; the black numbers represent the maximum age of the oldest sampled trees obtained by tree rings counting; the grey numbers show the maximum age of the oldest sampled trees, estimated on the basis of the sampling height and distance to the pith. Photo by V. Garavaglia.
3.3 Dendroglaciological results on the Miage glacier

On the Miage glacier, an evaluation of tree coverage represented the first step to assessing the ecological value related to the uniqueness of this supraglacial vegetation; nevertheless dendroglaciological analysis highlights the importance of growth anomalies to analyse glacier geomorphosite evolution and their present dynamics. The tree colonisation depends on the debris thickness and on the glacier stability; in fact only the main lobes are colonised by trees, especially the southern one (*Larix decidua* Mill. and *Picea abies* Karst.). Morphological situations such as hollows, depressions or niches, facilitate the tree growth. Trees and tree ring morphologies (e.g. respectively deformed, twisted trunks, eccentric rings and compression wood) document in detail the vertical and lateral tilting, the ice sliding down-valley, the transmission of kinematic waves, glacio-karst phenomena, and debris cover instability. The growth disturbances are well recorded in tree-ring width, characteristics, morphology and other indicators. The latter were identified and dated, confirming the passage of a kinematic wave (also documented through aerial photographs and glaciological investigations) and adding a great detail about the kinematic wave arrival and its different intensity in the two lobes. The growth disturbance signals mainly occurred since the middle of 1980s on the southern lobe and during the beginning of 1990s on the northern one, with a delay of about five years (Fig. 6) (for details, see Pelfini et al. 2007).

The tree ability to record glacier movements is controlled by the glacier surface velocity and by the evolution of ice cliffs (backwasting and downwasting) that lead to the roots’ exposure, near the ice cliff edges, and the final fall of trees towards the escarpment.

The dendrochronological investigations on the Miage glacier highlight the wide scientific value of the most important Italian debris-covered glacier, a geomorphosite with a vegetational component improving its ecological value. The dating of the tree reactions to the glacier movements highlights the link between biological and glacial components and its importance in studies both on glacier dynamics and on valorisation of glacier geomorphosites.
4. Conclusions

Generally the ecological value is represented by the element of rarity like the presence of exclusive animals or vegetation components.

As mentioned before, recently the rigor and objectivity that characterise the scientific value assessment, compared to the more intuitiveness of the cultural and added ones, have been highlighted. On the placement of the ecological value as a fourth scientific valence or among the additional values depends on the meaning given to it (e.g. Panizza, 2001; Pralong, 2005). In the specific case of this paper, if dendroglaciological analyses are considered as precise technical methodologies, the ecological value that they represent should be assessed among the scientific valences.

In the case of the Marlet glaciers (as in many other study cases in the Alpine environment, e.g. McCarthy & Luckmann, 1993; Luckmann, 1998), the dendrochronological dating of small moraine amphitheatres allowed us to assess the importance of tree vegetation in reconstructing glacier history and, as a consequence, to improve the geomorphosite scientific attribute. The simplicity of the morphological situations better relates to the didactical applications. Images of cores can be proposed to students in order to help them to reconstruct landscape changes and to
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approach dating methods without the necessity of dedicated instruments. The different morphologic characteristics of moraines and their dating allowed us to introduce the concept of glacier fluctuation in the educational applications.

In the Miage debris covered glacier, the presence of widespread supraglacial vegetation reinforces the rarity concept and improves the glacier ecological value. The dendroglaciological analysis allows the assessment of the importance of trees in analysing the present glacier dynamics and, as a consequence, to contribute to the scientific evaluation of a geomorphosite. Moreover, in this case, trees represent a precious instrument to investigate glacier dynamics and contribute also to improving the geomorphosite valence. At the same time, the good accessibility to the Miage and Marlet glaciers represents a possibility of spreading the glacial geomorphosite knowledge to a wide public, from hikers to scholar users. In both the studied areas, the use of dendrochronology allowed us to increase the knowledge on the ecological and educational values. By inserting these applications in educational trails, it may be possible to popularise scientific results generally discussed only in academic environments, transmitting the notions of climate change impact, valorisation and conservation of geomorphosites.

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References


