ASSESSMENT AND SELECTION OF GEOMORPHOSITES AND ITINERARIES IN THE MIAGE GLACIER AREA (WESTERN ITALIAN ALPS)

Bollati Irene [a, 1], Claudio Smiraglia [b], Pelfini Manuela [c]

[a, b, c] *Earth Sciences Department “Ardito Desio”*
Università degli Studi di Milano
Via Mangiagalli, 34
20133 Milan - Italy

Tel.: 00390250315514
Fax: 00390250315594

[a] corresponding Author: irene.bollati@unimi.it
[b] claudio.smiraglia@unimi.it
[c] manuela.pelfini@unimi.it

Introduction

Recently, the scientific community has been involved in the valorisation of the natural environment in the framework of cultural tourism and educational applications (e.g., Reynard et al. 2009; Garavaglia and Pelfini 2011), focusing on a variety of scientific topics, hazards, risks and the promotion of geological and geomorphological heritage (e.g., Bozzoni and Pelfini 2007; Pelfini et al. 2009).
In the framework of cultural tourism and natural resources, the concept of a geomorphosite (i.e., site of geomorphological interest, sensu Panizza 2001) has been accepted and commonly used. There are two main approaches for studying geomorphosites in this context: surveys of the sites for the promotion of tourism (e.g., Pralong 2005) and applications related to the dissemination of Earth sciences (e.g., proposal of educational trails, Garavaglia and Pelfini 2011; Bollati et al. 2011).
In recent years, the evaluation of geomorphosites using attributes and valences has been applied for scientific and educational purposes. Several approaches have been proposed for defining

strategies for quantitative analysis (e.g., Reynard et al. 2009; Bollati and Pelfini 2010) and for automation of the evaluation process (e.g., Ghiraldi et al. 2010). The application of a database may be useful for reducing subjectivity in geomorphosites evaluation and selection. Accordingly, one of the aims of this research, proposed recently (Bollati et al. 2012), is to attempt to decrease, as much as possible, the subjectivity that may affect this type of analysis. This methodology may be applied to different morphoclimatic and morphogenetic contexts to evaluate and compare both single geomorphosites and complex trails, as well as to describe risk scenarios.

Glacial environments represent sites of geomorphological interest in the framework of cultural tourism due to their rapid evolution (Bollati and Pelfini, 2010). Because of glacial activity, the concept of time may also be considered relevant and useful in the context of educational experiences (Reynard et al. 2007). In addition to the cultural, scenic and socio-economic attributes of glaciers, their scientific attributes are also important. The diffusion of glaciers, the various processes and landforms (geodiversity sensu Gray 2004) that characterise glacial areas, and the past and present rapid changes they record are some of the scientific attributes that have made glaciers a valuable cultural component of the environment (Pelfini and Smiraglia 2003).

To be more specific, glaciers are characterised by a variety of scientific and other values that can be considered in a quantitative assessment of geomorphosites (Pelfini and Smiraglia 2003). Glaciers are one of the most spectacular landscape elements in existence and are favoured by many people (Garavaglia et al. 2010b; Pelfini et al. 2010; Moreau 2010), especially mountaineers (Moreau 2010). They also represent an economic resource by providing hydroelectric energy, being a source of water and being a tourist attraction (Pelfini and Smiraglia 2003).

In wider glaciers, and particularly near the terminus region, there are ideal conditions for observing and understanding natural processes because of the dynamic behaviour of glacial masses and the greater quantities of melting water that are available for accelerating the processes (Smiraglia et al. 2008). Accordingly, these areas provide several spots definable as active geomorphosites (Reynard 2004) that have high educational value for the temporal scale of action of the geomorphic processes that is comparable to those of human cycles (Reynard et al. 2007; Bollati and Pelfini 2010; Bollati et al. 2011).

For all the above mentioned reasons, glaciers have been defined as an open air museum of deglaciation (Diolaiuti and Smiraglia 2010), underlining the educational value of these natural assets.

Knowledge about landscape elements (e.g., outbursts or debris flow deposits) provides opportunities not only to observe the results of geomorphological processes but also to introduce concepts regarding natural hazards, vulnerability and risk as a consequence of geomorphological process variation in relation to climate change (sensu Bell 1998; Pelfini et al. 2009; Bollati et al. 2012). This topic is meaningful particularly for a high mountainous environment, where the consequences of climate changes and the growing vulnerability due to an increase in the number of tourists are both evident (Pelfini et al. 2009; Bozzoni and Pelfini 2007).

Even the evident depletion of glacier volume (i.e., glaciers as “vanishing geomorphosites”, according to Diolaiuti and Smiraglia 2010) can be viewed positively because that glacial landscape variation is inducing the formation of new sites of geomorphological interest. For instance, in proglacial areas, this depletion is influencing the geodiversity and contributing to an increase in glacial geomorphosites with scientific value (Pelfini 2009a; Garavaglia et al. 2010b; Diolaiuti and Smiraglia 2010). For example, the glacial tongue retreat is accompanied by an enlargement of proglacial areas and consequent vegetation settlement (Pelfini et al. 2010), which represent a useful tool for investigating the evolution of high mountainous environments. This enhancement in proglacial vegetation also allows an analysis of the geomorphosite as a model of evolution (Garavaglia et al. 2010b).

Furthermore, glacial landform modifications are responsible for changes in geodiversity related to variations in glacier typology that must be considered for periodic geomorphosite re-evaluations, including the transformations from valley glaciers to cirque glaciers, from glaciers to glacierettes and from debris-free glaciers (DFGs) to debris-covered glaciers (DCGs). In fact, the intensification of crioclastic processes on the sides of the valley (Deline 2009; Diolaiuti and Smiraglia 2010), together with increasing glacier ablation that concentrates debris on the surface, leads to an increase in the number of DCGs. Moreover, this transformation represents a glacial strategy for self-preservation from the effects of global warming (Deline 2009; Benn and Evans 1998; Mihalcea et al. 2008) when the debris coverage reaches a critical thickness (e.g., 30-40 mm for glaciers in the Himalayans; Mattson and Gardner 1989; Mattson et al. 1993).

The development of debris strata contributes to the ecological support role of DCGs for both plants and animals (Caccianiga et al. 2011; Gobbi et al. 2011). The growth of supraglacial vegetation, including trees, increases both the ecological value of glacial geomorphosites (Pelfini et al. 2010) and their scientific value because research on supraglacial vegetation can lead to the detection of recent dynamics of DCGs (Richter et al. 2004; Pelfini et al. 2007; Caccianiga et al. 2011).

The main aims of this work are as follows: i) an assessment of the scientific value of a very interesting glacial area (Veny Valley in the Mount Blanc Massif, Western Italian Alps), characterised by the presence of the most representative Italian debris-covered glacier, Miage Glacier, to highlight the rich scientific data available both for thematic paths and for educational applications; and ii) quantification of the value of existing trails that link individual geomorphosites using a method (Bollati et al. 2012) that was previously applied in a fluvial environment (Bollati et al. 2011).

Methodology for sites and trails selection

Glaciological trails in alpine environments are usually created by different people (e.g., managers of natural protected areas, scientific researchers, tourism developers) with different aims (Cayla 2009), including environmental education, increased awareness with respect to a vanishing natural heritage, geomorphology, and diversification of the tourist options that are available to improve the economic valorisation of the area.

To minimise subjectivity related to geomorphosite selection, Bollati et al. (2012) proposed a database application as a methodology for selecting geomorphosites in relation to the aims of the sites (e. g. tourism, education) and their different potential targets (e.g., schools, academic students, tourists). The application assigns a numerical value to different attributes that characterise geomorphosites, minimising the subjectivity of the choice and allowing a direct comparison of geomorphosite values (for details, see Bollati et al. 2012). The quantitative criteria adopted are subdivided into three main categories: *scientific value, additional values*, and *potential for use* (Table 1). Finally, hazards are described, including information about the possible risk scenarios affecting trails (see also Cendrero and Panizza 1999; Ghiraldi et al. 2010) for supporting decision derived from interpretation of quantitative results and for education to risks in mountain environment In fact, hazards should be taken into consideration to select the best trail according to the user category (e.g., vulnerability) and to provide opportunities for education about risk through observation, from a distant, but strategically located point of view, of landforms modelled by hazardous processes.

The selection of geomorphosites (Panizza 2001) has been a topic of investigation for several years, and different approaches have been proposed to collect data (for details see Reynard et al. 2009 and Bollati and Pelfini 2010). For example, Giardino et al. (2010) proposed the use of a database directly in the field using mobile support for field data collection and mapping. This is an application that allows the collection of data, but not the evaluation and comparison of sites. Ghiraldi et al. (2010) proposed a similar automated methodology including the evaluation of sites basing mainly on the parameters of Reynard et al. (2007).

This methodology has already been used for selecting single geomorphosites along a fluvial valley (Bollati et al. 2012), and herein it is applied in the context of glaciers for the first time, using three main steps: i) an evaluation of single sites, ii) a quantitative evaluation of three touristic paths surrounding the glacial terminus, and iii) selection of the most suitable destination for each trail as a function of the goals, based on quantitative results and considering risk scenarios. In addition to strict glacial geomorphosites, other "satellite" sites, exemplar of the regional geological context and of geomorphic processes that characterise the alpine environment and are linked mainly to climate changes, are considered.

Data on geomorphosites were collected during the field survey using dedicated field forms, and then they were input into the database for quantification using Equations that calculate the parameters for each site (i.e., *scientific value, additional values*, *potential for use*, *scientific index* and *educational index*). The calculation of the potential for use differs depending on whether the trail is by foot.

An additional step was performed to combine the values of sites along each trail to calculate the value of each trail. The calculation takes into account that each trail is composed of a different number of sites by using the average value among site instead of the sum of values obtained by single geomorphosites along a given trail. Detailed Equations are provided in Table 2.

The application collects the information and calculates the values both for sites and for trails to perform a spatial analysis, which can be used to determine the most suitable areas to meet different goals based on the highest global values (sum of *scientific* and *additional values*), the educational index or individual attributes (e.g., *cultural value*).

Tourist access to Miage Glacier is facilitated by touristic trails. Currently, the Miage Glacier area does not have any interpretative glacier trails, but some educational panels are located along the three investigated touristic paths. The three official tourist trails, as well as the numbering system used in the Kompass cartography of the Mont Blanc area, are indicated in Table 3 (Map 85, 1:25,000; Kompass, Leimgruber ed.). The *spatial accessibility* is not the same for all three trails, and it varies along each individual trail (for example, consider trail 1). To determine the accessibility of each trail, the worst conditions for each trail are considered in the evaluation.

Miage Glacier geomorphosites

The Miage Glacier has already been recognised as a geomorphosite (e.g., Pelfini et al. 2005) and is considered a good example of an open air laboratory (Pelfini et al. 2009b) because it is well-known and valued as a tourist attraction. It is the main glacier on the Italian side of the Mount Blanc Massif (Fig. 1, a), the third largest glacier around the southern side of the Alps. The Miage Glacier drains the southwest slope of Mont Blanc, with a length of 13 km, an ablation tongue that terminates in two main lobes and a smaller intermediary tongue (Fig. 1c) that exhibits continuous debris coverage (Deline 2009).

The entire area (Veny Valley) is part of the border area between Italy and France, termed Espace Mont Blanc, that is being evaluated by the UNESCO commission as a possible addition to the World Heritage List because of its unique nature. Moreover, the Veny Valley is a meaningful educational site because of its accessibility and the popularity of the sites (Pelfini et al. 2005). The Miage Glacier and the surrounding landscape can be considered a complex geomorphosite (sensu Reynard and Panizza 2005) within which different geomorphosites can be identified (Pelfini 2009a, 2009b). In addition, the Miage Glacier belongs to the category of complex active geomorphosites (sensu Reynard 2004), which exhibit processes that are easily understood by non-scientists (e.g., calving at Lac du Miage). This attribute is important even if the rates of glacial evolution as a debris-covered glacier is lower with respect to debris-free glaciers.

Before proceeding to the evaluation of the trails, an overview of the study area is provided to present the information used in the quantitative assessment of the site attributes (Table 1).

Scientific value

Baretti (1880) was the first author to consider the Miage Glacier a “model of glacier”. The role of the Miage Glacier as a glacial geomorphosite was analysed in detail by Pelfini et al. (2005), who highlighted that the site has high scientific value in terms of its *educational exemplarity* and that it is a *model for geomorphological* and *palaeogeomorphological evolution* (i.e., typical glacial and glacial-correlated processes and landforms; Baretti 1880).

The scientific value of the Miage area is undoubtedly significant and provides critical support in the quantitative evaluation, especially considering the geological and glaciological features of this area.

The geological setting not only contributes to the scientific value of this area in general but also enhances its *educational exemplarity*; this area is widely recognised as an ideal place to observe the convergent movement between the two lithospheric domains of Europe and Africa (Prinetti 2010). The Veny Valley runs NE-SW, parallel to the main regional structures dominated by the Europe-Africa plate convergence direction, and follows the SE margin of the crystalline basement of Mount Blanc Massif. The main structural units that outcrop along the Veny Valley include (from N to S): the Elvetic, Ultraelvetic and External Pennidic Domains (ISPRA 2012) (Fig. 1a). An important feature of this small area is the presence of meaningful geological elements and different outcropping lithologies that are modelled by glacier action and result in a diversified geological landscape (sensu Gisotti 1993). In fact, the geologic control of the relief is evident: the resistant Northern crystalline basement's susceptibility to erosion with respect to the weak Southern sedimentary coverage is reflected by the difference in altitude between the two sides of the Veny Valley and the typology of the slope processes that dominate the two sides of the valley. The Miage area has been explored since the 18th century, when De Saussure first observed it (De Saussure 1774). Many studies have been conducted strictly on its glaciological aspects, as detailed below; thus, the scientific importance of the glacier contributes to the *geohistorical importance* of the site.

From a geomorphological point of view, the Veny Valley shows evidence of modelling by glaciers, among which the most relevant include: Lex Blanche, Miage, Brouillard, and Brenva. Fluvial action and slope processes (Orombelli and Porter 1981), including rock avalanches (Deline 2009), contribute significantly to the formation of debris coverage in the Miage Glacier, mainly modelling areas that were left exposed by glaciers (site 1e, 2e, Table 2; Fig. 2a).

The Miage Glacier is the best example of a "Himalayan Glacier of the Alps" because of several key features (Pelfini et al. 2005), including the following: its accumulation zone; its steep cliffs characterised by avalanches; avalanches that indirectly feed the glacier; a notable difference in altitude between the accumulation area and the terminus; and variations in ice thickness in the frontal area at the passage of kinematic waves that are a consequence of the inversion of the ablation gradient, which is due to the differential ablation of abundant debris on the glacial tongue (Mihalcea et al. 2006).

A meaningful feature of the Miage Glacier is its supraglacial debris coverage (site 1e, 3e, Table 2; Fig. 2a). According to Deline (2005), the Miage Glacier was discontinuously covered during the last decades of the LIA. After the close of the LIA (1860-1880), the debris coverage began to expand, and during the period 1880-1930, the glacier was as covered as it is today (Sacco 1939; Deline 2005). The main causes of debris covering are surface melt-out of debris within the glacier, rock falls, rock avalanches, snow and debris avalanches and flows from the valley sides and the proximal side of lateral moraines that occurred during the 20th century on the Miage Glacier (Benn and Evans 1998; Deline 2009).

As mentioned previously, the debris coverage may influence the mass balance of the glacier when a critical value of debris thickness is reached (Mattson and Gardner 1989), reducing the magnitude and rate of glacier ice ablation. Similar to other DCGs, ice loss is concentrated where bare ice is exposed, as in the correspondence between supraglacial lakes, crevasses and ice cliffs, which cyclically open along the margin of the glacial tongue (Diolaiuti et al. 2006; Pelfini et al. 2012).

Supraglacial debris has a supporting role in ecosystems (*ecological support role*). For example, debris-coverage extent and depth have an important role in the spatial distribution of ground-dwelling arthropods (Gobbi et al. 2011). Moreover, debris thickness favours arthropod colonisation most likely acting as a refuge area for the cryophilic stenotherm species that live at higher altitudes and can be a channel for an expanded altitudinal range among high-altitude species (Gobbi et al. 2011). Moreover, plant distribution is controlled by physical factors such as the altitude/glacier velocity gradient, which influences debris stability. Caccianiga et al. (2011) proposed that glaciers such as the Miage may act as dispersal vectors for alpine plant species, fulfilling an important role during glacial periods and the warm stages of the Holocene. The Miage Glacier supports not only grass and shrubs but also young and well-developed trees, especially Larix deciduas Mill. and Picea abies (L.) Karst., although they tend to be characterised as having less than average growth compared with trees of the same age located on mountainsides or in the proglacial area (Pelfini et al. 2007). Supraglacial trees are continuously moved down-valley because of superficial glacial movements caused by surface velocity, differential ablation, the passage of cinematic waves, and debris instability, as recorded in tree rings and tree morphology (Pelfini et al. 2007). The trees continue to grow until they reach the glacier front. Moreover, trees may also die when involved in the retreat of ice cliffs due to backwasting (Pelfini et al. 2012). This two-way “tapis roulant” effect influences the trees’ life-span (approximately seventy years; Pelfini et al. 2007), which is not long enough to document a long record of events (Pelfini 2008). Additionally, proglacial vegetation in the Miage area (site 2a, Table 2) records information related to both glacier movements and the discharge of glacial melt-waters, allowing for the identification of areas affected by distinct glacial discharge (Garavaglia et al. 2010a) and enhancing the ecological support role of the Miage.

Another peculiar feature is the moraines, described by Forbes (1843) as “perhaps the most extraordinary of the whole Alps”. Detailed results from geomorphological investigations of Holocene glacial history (e.g., Deline and Orombelli 2005; Deline 2009) demonstrate the relevance of the glacier’s scientific attributes, especially in terms of its use as a palaeogeomorphological model. The Miage Morainic Amphitheatre (MMA; Deline 1999a; Deline and Orombelli 2005; site 1d, Table 2; Fig. 2d), located along the right lateral moraine where the glacier bends at 90° (Fig. 1c), is composed of three sub concentric sets of approximately 25 moraines whose formation is attributed to the Late Holocene, starting at least 5029–4648 cal. yr BP, while the base of the amphitheatre is believed to be older (System A, B, C; Deline and Orombelli 2005). These results allow researchers to replace the “LIA model” (Baretti 1880; Sacco 1919; Kinzl 1932; Porter and Orombelli 1982) explaining the formation of the MMA with a “Late Holocene Model” (Deline and Orombelli 2005), contributing to the study of these variations in the Western Alps area (geohistorical importance). Moreover, the transformation into a DCG at the end of the 19th century (Deline 2009) and the accretionary genetic process of the MMA resulted in the current position of the MMA (integrity) near the ice cliff (system C of Deline and Orombelli 2005).

Lakes in the Veny Valley represent another interesting element, not only for their scientific value but also for their educational value, because of the different typologies and many scenic features present in the Miage area. The most important lakes are supported by moraines or by the glacier ice cliff: Lac de Combal (site 1b), Lac du Miage (site 1c), Lac du Jardin du Miage (site 2b), and Lac du Breuillat (site 3d) (Table 2; Fig. 3).

Lac du Miage is a spectacular lake that is well-known for the calving events that can be observed there, especially during the ablation season. It is near and genetically connected to the MMA on the right side of the glacier (site 1c, Table 2; Fig. 2e, 3b). The lake is characterised by sudden water level fluctuations as well as several drainage events (Capello 1940; Cerutti 1951; Tinti et al. 1999; Deline et al. 2004; Diolaiuti et al. 2005; 2007; Masetti et al. 2010); the most recent event allowed for an investigation of the glacial lake bottom. The ice cliff of Lac du Miage is 200 m long, with an average height of 30 m, and represents the calving margin of the lake (Diolaiuti et al. 2006), which is located in an unusual lateral position (Smiraglia et al. 2008).

Lac de Combal (site 1b, Table 2; Fig. 2d) presently exhibits a bog landscape with few active channels that drain the Combal plain and it is located on the mountain side of the MMA (fig 3d). The glacier push towards the right side of the Veny Valley together with the construction of an artificial dam in 1742, which made the Dora di Veny stream increasingly narrow, producing a deposition of solid discharge from the glacial stream that led to sediment filling of the lake (Baretti 1880; Sacco 1917; Desio 1926).

Lac du Jardin du Miage (site 2a, Table 2; Fig. 2f, 3c) is located between the two main glacier lobes at an altitude of 1775 m a.s.l. in the forested area of the Jardin du Miage. It is a small lake with a surface area of less than 10,000 m2 and a depth of approximately 7 m. It is dammed by a lateral moraine, surrounded by tree vegetation that is partially submerged by glacial waters, and it has green-coloured waters, which explains why this lake is also known as Lac Vert (Deline 1999b). The lake has experienced different water level changes, as described by Lesca (1956); however, no immersed trees were described by the author. Current existing submerged and surrounding trees record the water level changes, and their isotopic trend of δ18O and δ 13C provides information about a period of increased ablation (Garavaglia et al. 2011).

The last lake examined in this work is the Lac du Breuillat (site 3d, Table 2; Fig. 2b, 3a) whose basin develops along the outer side of the left lateral moraine. Similar to the Lac de Combal, this lake is undergoing a filling phase that is practically complete. Its importance is also owed to its historical documentation by De Saussure (1774), who observed the variety of vegetation in the area (biodiversity or *ecological support role*), and to research conducted by Baretti (1880), who proposed a mean glacier retreat for that period by dating trees that colonise the lateral moraine deposit.

Additional values

The universally recognised feature of glaciers is their *aesthetic value*. The cultural value of glaciers is also recognised (e.g., Pelfini and Smiraglia 2003; Pelfini 2009a). The photographic heritage of glaciers, useful for reconstruction of their advance and retire stages, can be considered a cultural asset. Moreover, in the Veny Valley, a border crossing area between Italy and France, passage across the mountains used to be regulated by the presence of glaciers. In this historical context, the MMA was used before the end of the 17th century (Arnod 1968) to fortify the strategic morphology of the moraine complex, which looks like a natural trench.

Recent findings emerged during the 2010 ablation season: a pack of letters lost during a 1950 plane crash was discovered. The letters had been transported inside the glacier (La Stampa, 28 luglio, 2010; e.g., Boschis 2011). Evidence of cultural events related to human history, such as the plane crash remains, the letters dispersed within the glacier ice mass and debris coverage, could be used to raise both interest and questions regarding the dynamicity of glaciers, thereby increasing their *educational exemplarity*.

The socio-economic value of glaciers is usually high (hydroelectric energy, tourism, etc.), and it is especially high for the Miage Glacier area because it is often frequented by tourists during both the summer and the winter.

Potential for use

The morphological units chosen as sites suitable for educational purposes can be observed from different trails and roads. The main road to the Veny Valley provides access to several localities on the left side of the valley, from which the Miage Glacier is clearly visible. *Spatial accessibility* to the Miage Glacier is also facilitated by regularly used trails that start from local roads. The *temporal accessibility* is limited to the warmer months. The road along the valley is closed during the snowy season for due to the risk of avalanches, and the localities from which the foot trails start are only accessible by skis.

The area is characterised by the opportunity to practice different athletic activities (*other activities*) such as alpinism (e.g., alpinist ascent to Mont Blanc through the Miage Glacier) and free climbing because of the natural assets of the region (e.g., routes at Pyramides Calcaires). In fact, the Miage is highly frequented by alpinists from all over the world because of the standard Italian route to Mont Blanc, whose first ascent was performed in 1890 by Achille Ratti, the future Pope Pio XI, among others. These activities may increase tourists' interest in understanding the surrounding natural environment.

As mentioned above with regard to its socio-economic value, the area is well-equipped with public services and hotels (*services*). The only prohibitions in the area (*legal constraints*) are related to the collection of minerals, and some signs about this are located at the beginning of all the trails investigated herein.

The fauna and flora (*use of other naturalistic and cultural interests*) are illustrated using panels along trail 3, whereas panels strictly focused on the Miage Glacier (*use of geomorphological interest*) are located along trail 2, on the left lateral moraine of the Southern lobe and at Lac du Jardin du Miage, as well as along trail 1 at the Lac du Miage. These panels increase the potential for use because information that is provided as a result of geomorphological evaluations can be studied in the integration of existing paths.

Results

Quantitative evaluation of sites and trails

The features described previously were considered, and the results obtained using the database evaluation procedure confirmed the high value of the sites in the area, both from geological and geomorphologic points of view. The detailed evaluations illustrated in this paragraph are summarised in Table 4.

Generally, all sites exhibited high values for *integrity*, *educational exemplarity*, *geodiversity* and *socio-economic attributes*, which were among the scientific and additional values considered.

The most valuable site that obtained the maximum values for all of the scientific attributes was the Miage Glacier supraglacial debris (site 1/3e, Table 4; Fig. 2a). The glacier and its debris coverage are mainly important as a *model of geomorphological evolution* (1/1), in which the glacier represents the best example of a Himalayan glacier of the Alps (Pelfini et al. 2005). Some panels are located in the area to illustrate the increasing number of potential for use of the site. As a *model of geomorphological evolution*, the Northern lobe ice cliff (site 3b, Table 4; Fig. 2c) has equal importance (1/1) because it represents a bare glacial surface where, in the context of DCGs, the ice loss is concentrated. Hence, it is possible to observe different behaviour with respect to a debris-covered surface. These two sites share the maximum value (1/1) for their role as ecological support for supraglacial vegetation. The supraglacial debris is also characterised by the presence of interesting minerals (Prinetti 2010) and fossilised ferns in black metasediments that date to the Carboniferous period (Società Geologica Italiana 1992). For the glacial debris, these features contribute to the attribute category of *other geologic interests* (site 1/3e, Table 4; 1/1).

The MMA (Deline 1999a; Deline and Orombelli 2005) (site 1d, Table 4; Fig. 2e) is the second most important site from a scientific point of view, primarily because of its palaeoclimatic and educational attributes (1/1). The typology of this landform is a significant feature of integrity that confers high *geohistorical importance* to the site (1/1). The *cultural value* of the MMA was assigned the maximum value (1/1) because the 17th century fortification was correlated with the landform itself.

In general, the Miage Glacier supraglacial debris and the Miage Morainic Amphitheatre exhibit the greatest geohistorical importance among the features of this area (1/1).

Lac du Miage (site 1d, Table 4; Fig. 2d) is important for its *educational exemplarity* (1/1) and its *rareness* (0,5/1) because it is possible to observe the calving process from the touristic trail, mainly during the summer season. Moreover, the site is considered a good place to introduce the concepts of hazards and risks related to falling ice blocks and debris and the consequent anomalous waves that can affect tourists located too close to the shore (see details in the following subparagraph). The lake surroundings, which are described using illustrative panels, make it possible to enhance the potential for use of the site.

The other lakes, Lac de Combal (site 1b), Lac du Jardin du Miage (site 2b) and Lac de Breuillard (site 3d), are important for their ecological support role (0,67/1). The endemic flora that have been colonising the bog of Lac de Combal, the Jardin du Miage area and Lac de Breuillard is rare and interesting (ecological support role), not only because of the drainage condition of the plane but also because of the variety of rock outcroppings in the drainage basins (e.g., mainly granitic, calcareous and evaporitic lithotypes) (Prinetti 2010).

As expected, the “satellite” sites (Alluvial fan of the Torrent du Freney, Alluvial fan of the Torrent du Miage, Slope processes, Debris flows, landslides) obtain the lowest scientific (4,67-4,92/10) and additional values (1/3).

The cumulative parameters (*scientific value*, *additional values*, *global value*, *potential for use*, *educational index*, *scientific index*) were calculated by evaluating all the attributes for each site and comparing the geomorphosites and then the trails. Figures 5 and 6 provide a plot of the numerical results.

In Figure 5, the sites are graphed and ordered by global value (sum of scientific value and additional values). The *global value* trend is in agreement with the potential for use trend because some global value parameters were also used to calculate the potential for use.

In Figure 6, the high values (never equal to null) of all the sites are evident, and the average values are always greater than 0.5. The potential for use value is high, and it is characterised by the lowest variance among all the parameters investigated. The potential for use value is affected by some of the parameters, that concur to its definition (e.g., *services*, *temporal accessibility*, *legal constraints*, *other sites in the surroundings*), vary at a regional or at least a trail scale. In contrast, the additional values are less homogeneous and are characterised by the maximum variance among all the values calculated; this variance can be explained by the spot-like distribution of cultural elements, which tend to be associated with a single site (e.g., fortification at the MMA).

The educational index is calculated by considering the *educational exemplarity*, *spatial extension*, *aesthetic value* and *spatial accessibility* of each site (see Table 2), which are all important attributes to consider in educational proposals, as previously demonstrated by other authors (i.e., Reynard et al. 2007). In the specific case of the Miage area, where the heritage value is high, almost all the sites obtained high scores for *educational exemplarity*.

In Figure 7, the results of the trail evaluation, which were obtained by calculating the average of the values of all sites along each trail, are reported. The relative trail values follow a consistent pattern: trail 1 (Lac du Miage) always exhibits the highest values, and trail 2 (Lac du Jardin du Miage) always exhibits the lowest values.

The *potential for use* values, which are based on the trail, present a low variance. Along trails 2 and 3, for example, the sites are less spectacular and expanded than the sites along trail 1; these attributes (*aesthetic value* and *spatial extension*) are most likely more significant with respect to *educational exemplarity* and *accessibility*, as the geoheritage potential of this area has been generally recognised.

Finally, statistical analysis evaluating the parameters examined (in Figure 8a) at the site level did not reveal any statistically significant correlations (for example, scientific and educational index: R2 = 0.3793; Fig. 8a). The most interesting value was the correlation coefficient value at the trail level (R2 = 0.9998; Fig. 8b).

Hazards related to the trails

All mountain and alpine areas, as well as the Veny Valley, can be affected by different hazards (sensu Bell 1998) that influence the possible risk scenarios in each area (Pelfini et al. 2009a). The calving process, GLOF from epiglacial lakes (e.g., Yamada 1998), changes in the position of glacial streams, blocks and ice falling from ice cliffs and seracs, avalanches and rock falls from moraines are typical hazards in this type of environment. Some of these slope processes are increasing in frequency due to climate change. Evaluations are made at the trail level according to the information collected for the hazards of each site along carefully managed and monitored official trails. In addition, it is worth considering whether hiking trails should be utilised only during good weather conditions, which may diminish the inherent level of risk.

Debris falls are common wherever the touristic paths run close to the sides of moraines, especially during the growing phases of the glacier (Dutto and Mortara 1992). In the particular case of trail 1, the debris falls may occur from the right lateral moraine. Along the same trail, on the right side of the valley, along the Pennidic Front, unconsolidated debris, detached from weak gypsum and black schist layers,) is subjected to debris flows and locally to rock falls and landslides at less weathered gypsum outcroppings. These events are commonly triggered by undercutting fluvial actions and the most meaningful of which occurred in 1986 (Fig. 4a), when the composite movement reached the road without affecting people, and most likely temporarily damming the Dora di Veny (Prinetti 2010). With respect to trail 3, on the opposite side of the Veny Valley, in the trail section from Lac du Breuillat (site 3d, Table 2 and 4) to the lateral moraine of the left side of Miage Glacier supraglacial debris (3e, Table 2 and 4), there is also a high hazard of rock falls from the more resistant crystalline basement of the Mount Blanc Massif.

Hiking trails often cross glacial streams (e.g., proglacial area of the Southern lobe, site 2a, or Torrent du Freney, site 3a, Fig. 4b; Table 2 and 4) that are characterised by changes in streambed position and a great discharge variability, especially in relation to increasing ablation during the warmer hours and sometimes due to extreme events, which increase the risk for tourists due to lack of awareness. Often, structures such as bridges on glacier streams must be replaced or moved because of drainage fluctuations and the changing positions of the glacier stream (Fig. 4b) (Bozzoni and Pelfini 2007; Pelfini et al. 2009).

Calving represents a typical hazard for the Miage Glacier areas close to Lac du Miage (site 1c, Table 2 and 4), where the vulnerability factor may increase if observers stop along the shoreline in front of the ice cliff to appreciate the aesthetic value of the natural process. For example, a devastating incident happened on August 9th, 1996, when a large ice block fell into the Lac du Miage after detaching from the northern ice wall of the glacier, which experiences heavy rainfall events at high altitudes. An anomalous wave injured tourists who were watching the natural show (Tinti et al. 1999). However, from the higher moraines bordering the lake, ice blocks and debris fall may be observed under safer conditions.

Discussions and conclusions

Debris-free and debris-covered glaciers represent one of the most important and well-known typologies of geomorphosites (sensu Panizza, 2001) (Pelfini and Smiraglia 2003). The importance of active geomorphosites (sensu Reynard, 2004), such as those characterising the Miage Glacier, has been demonstrated within the framework of cultural multidisciplinary trails and educational applications (e.g., Bollati et al. 2011).

The results show that the main objectives of this research were achieved; in particular, the richness of knowledge provided by open air laboratories Miage Glacier undoubtedly increases the *educational exemplarity* and *scientific value* of a complex geomorphosite (sensu Reynard and Panizza 2005) such as the Miage Glacier. The Miage Glacier is easily accessible, and the richness of its scientific attributes is evident. The features of *scientific value*, in particular, are especially notable; the most evident qualities observed in this area include its applicability as a *model of geomorphological* and *palaeogeomorphological evolution*, its *educational exemplarity*, and its *ecological support role*. Additionally, the geological characteristics influencing geomorphological modelling of the Veny Valley, categorised as *other geologic interests*, increase the *scientific value* of this area.

Here, a geomorphosites evaluation procedure (Bollati et al. 2012) that was previously tested on a fluvial landscape (Bollati et al. 2012) was applied to a glacial environment. This procedure facilitated a quantitative assessment of not only the features of *scientific value* but also the *additional values*, *potential for use*, and e*ducational* and *scientific indexes* of the Miage glacial area. Using this quantification methodology, the calculated values of both individual geomorphosites and several trails confirmed the positive qualities that are attributed to the area. Using the global value, the differences among sites based on their scientific and additional values were not detectable; therefore, individual parameters needed to be examined and assessed. The categories of *educational index* and *potential for use* exhibited the highest values among those calculated, demonstrating that they are crucial parameters for tourism and educational purposes and indicating that the Miage area is well equipped in these categories. The “satellite sites” were found to be less valuable than the glacial sites, but they are still considered useful in providing a complete overview of the geomorphic processes, related to the geological setting that characterise the area.

The final analysis of the results for the overall existing touristic trails, and not just for the individual geomorphosites, can be used to suggest the most suitable trails for the creation of educational and geo-tourism applications while taking into consideration the potential hazards that affect each trail.

The greater correlation among parameters at the trail level provided stronger selection factors than those that were evaluated based on individual sites and highlighted the most valuable trails among those assessed.

The analysed trails are official touristic trails; new trails or trails are not proposed herein. Our analysis focused on optimising the options for educational purposes. Further, hazards were considered as follows: If the *global value* of two trails was equal, but one of the trails could be affected under certain conditions (even under extreme conditions) by any kind of hazard, then the choice shifts to the less hazardous trail. If the global value is equal between trails, but some points along the trail are enriched by the possibility of observing active geomorphological processes under safe conditions (for example, from the opposite valley side), then the trail provides optimal conditions for education on geomorphological risks.

More specifically, the results highlight the presence of sites of great value all around the glacier, particularly along trail 1 to Lac du Miage. Moreover, trail 1 provides the greatest number of sites of interest. However, the evaluation results were normalised with respect to the number of sites along each trail, and site abundance appeared to influence the results, most likely mirroring the *geodiversity* of the trail. Moreover, trail 1 is characterised by slope processes, but even considering the climatic conditions that trigger these processes and the safety rules that must be observed, the trail is still suitable for educational and geo-tourism activities in general. The same considerations may be applied to the calving process at Lac du Miage: if tourists may learn about its characteristics (e.g., triggering factor, frequency and dimension of the calving process and, as a consequence, the safe distance that must be maintained), then observations from a safe distance should be allowed. To observe supraglacial debris, the path to the right lateral moraine along trail 1 (site 1e, Table 2) is safer than the path to the left lateral moraine along trail 3 (site 3e, Table 2). Moreover, trail 1 is the only trail that provides services (i.e., a refreshments hut) to welcome people.

In contrast, the processes that usually characterise proglacial areas, such as the sudden release of water from the glacier, are common on trail 2 (Lac du Jardin du Miage). As trail 2 obtained the lowest values among the trails analysed, its trail is less suitable for educational purposes.

Hence, even though all the trails are well-managed and frequented by tourists, each one is suitable for different purposes based on the goals of the users. In general, when it is difficult to access sites along the trails (see details on *accessibility* in Bollati et al. 2012), such difficulties make the trails unsuitable for groups, especially those with children (i.e., trails 2 and 3). Good accessibility that makes it possible to observe and discuss active glacial processes makes the trails suitable for groups with a higher level of education (i.e., trail 1).

In conclusion, the proposed method for selecting geomorphosites and trails makes it possible to quantify their values and thereby reduce subjectivity. Moreover, the information collected in the database can be easily updated and improved in response to environmental modifications, allowing the creation of a dataset that may be useful for comparing sites on both local and regional scales. *Scientific* and *additional values*, as well as *accessibility* and *potential for use*, facilitate the determination of the most interesting trail in relation to the objective of a given project (e.g., educational or tourism, as in in this specific case). Information about hazards provides a rationale for excluding proposals due to the presence of risk scenarios, allowing for the selection of the best trails that provide educational benefits without geomorphological risk and increasing the *educational exemplarity* of the site itself.

Even though it was tested in a local but internationally relevant context, this method may represent a starting point for evaluating geomorphosites and cultural trails.

Acknowledgements. The authors are grateful to anonymous reviewers for suggestions that allow to improve the manuscript. The Authors are also grateful to Dr. Valentina Garavaglia and Dr. Giovanni Leonelli for the scientific support.

Funding. The research was performed in the framework of the PRIN 2008 project (led by Prof. C Smiraglia).

References

Arnod PA (1968) Relation des passages de tout le circuit du Duche d'Aoste venant des provinces circonvoisines avec un sommaire description des montagnes, 1691 et 1694. Dresses par Philibert-Amedee Arnod des Conseillers commis, juge au baillat d'Aoste pour S.A.R., commissaire et intendant deputè par le Conseil des Commis. Manuscript Archivio di Stato, Torino, Archivum Augustanum 1: 11-72.

Baretti M (1880) II ghiacciaio del Miage. Versante italiano del gruppo del Monte Bianco. Memorie della Regia Accademia delle Scienze di Torino II (34): 3-36.
Bell FJ (1998) Environmental geology. Principles and Practice. Blackwell Scientific Publisher, Oxford.

Benn DI, Evans DJA (1998) Glaciers and glaciations. Hodder Arnold Publication, London.

Bollati I, Pelfini M (2010) Il paesaggio fisico italiano: una varietà di una varietà di geomorfositi di rilevante valenza per la ricerca scientifica e didattica. Boll Soc Geogr It XIII (III): 169-202.

Bollati I, Pelfini M, Pellegrini L, Bazzi A, Duci G (2011) Active geomorphosite and educational application: a didactical itinerary along Trebbia River (Northern Apennines, Italy). In: Reynard E, Laigre L, Kramar N (eds) Les géosciences au service de la société. Actes du colloque en l'honneur du Professeur Michel Marthaler, 24-26 juin 2010. Lausanne, Institut de Géographie de l'Université de Lausanne, Géovisions 37, pp.219-234.

Bollati I, Pelfini M, Pellegrini L (2012) A geomorphosites selection method for educational purposes: a case study in Trebbia Valley (Emilia Romagna, Italy). Geogr Fis Din Quat, 35 (2012): 23-35.

Boschis G (2011) Il B-17 scomparso sul Monte Bianco. La Rivista del CAI 5 (2011): 28-30.

Bozzoni M, Pelfini M (2007) Pericolosità geomorfologiche e vulnerabilità lungo i sentieri turistici in ambiente alpino: proposta metodologica per le loro individuazione e rappresentazione. In: Piccazzo M, Brandolini P, Pelfini M (eds) Clima e rischio geomorfologico in aree turistiche. Patron Editore, Bologna, pp. 29-45.

Caccianiga M, Andreis C, Diolaiuti G, D'Agata C, Mihalcea C, Smiraglia C (2011) Alpine debris covered glaciers as a habitat for plant life. Hol 21: 1011-1020.

Capello CF (1940) I laghi glaciali del Miage. L'Universo 21 (10): 685-705.

Cayla N (2009) Le patrimoine géologique de l'arc alpin. De la médiation scientifique à la valorisation géotouristique. Unpublished PhD Thèse, Université de Savoie.

Cendrero A, Panizza M (1999) Geomorphology and Environmental Impact Assessment: An Introduction. Suppl Geogr Fis Din Quat II (3): 167-172.

Cerutti AV (1951) Le vicende del Lago del Miage. Augusta Praetoria IV (1): 26-35.

De Saussure HB (1774) Voyage autour du Mont Blanc en 1774 lOe Juil. Brouillard en crayon. Manuscript (Ms. Saussure, 14/1), BPU Geneve.

Deline P (1999a) La mise en place de l'amphithéâtre morainique du Miage (Val Vény, Val d'Aoste)/The setting up of the Miage morainic amphitheatre (Val Vény, Valley of Aosta). Géomorphologie 5 (1): 59 – 72.

Deline P (1999b) Les variations Holocènes récentes du Glacier du Miage (Val Veny, Val d'Aoste). Quat 10: 5-13.

Deline P (2005). Change in surface debris cover on Mont Blanc massif glaciers after the 'Little Ice Age' termination. Hol 15: 302- 309.

Deline P (2009) Interactions between rock avalanches and glaciers in the Mont Blanc Massif during the late Holocene. Quat Sci Rev 28: 1070–1083.

Deline P, Orombelli G (2005) Glacier fluctuations in the Western Alps during the Neoglacial, as indicated by the morainic amphitheatre (Mont Blanc Massif, Italy). Boreas 34: 456-467.

Deline P, Diolaiuti G, Kirkbride MP, Mortara G, Pavan M, Smiraglia C, Tamburini A (2004) Drainage of ice-contact Miage Lake (Mont Blanc Massif, Italy) in September 2004. Geogr Fis Din Quat 27: 113-119.

Desio A (1926) Appunti morfologici sui dintorni di Courmayeur, Natura 17: 50-63.

Diolaiuti G, Kirkbride MP, Smiraglia C, Benn DI, D'Agata C, Nicholson L. (2005) Calving processes and lake evolution at Miage glacier, Mont Blanc, Italian Alps. Ann Glac 40 (1): 207-214.

Diolaiuti G, Citterio M, Carnielli T, D'Agata C, Kirkbride M, Smiraglia C (2006) Rates, processes and morphology of freshwater calving at Miage Glacier (Italian Alps). Hydr proc 20: 2233–2244.

Diolaiuti G, Carnielli T, Citterio M, D'Agata C, Rosazza S, Riccardi A, Smiraglia C (2007) Il calving sulle Alpi Italiane. Processi in atto e rischi connessi ad un fenomeno in rapida diffusione. L'esempio del Ghiacciaio del Miage (Monte Bianco). In: Piccazzo M, Brandolini P, Pelfini M (eds) Clima e rischio geomorfologico in aree turistiche. Patron Editore, Bologna, pp. 117-144.

Diolaiuti G, Smiraglia C (2010) Changing glaciers in a changing climate: how vanishing geomorphosites have been driving deep changes in mountain landscapes and environments Géomorphologie 2: 131-152.

Dutto F, Mortara G (1992) Rischi connessi con la dinamica glaciale nelle alpi italiane. Geogr fis din quat 15: 85-99.

Forbes JD (1843) Travels through the Alps of Savoy and other parts of the Pennine Chain. Adams & Black Editor, Edimburgh.

Garavaglia V, Pelfini M, Motta E (2010a) Glacier stream activity in the proglacial area of debris covered glacier in Aosta Valley, Italy: an application of dendroglaciology. Geogr fis din quat 33: 15-24.

Garavaglia V, Pelfini M, Bollati I (2010b) Influence of climate change on geodiversity in the alpine environment: the case of two Italian glacier investigated through dendrochronology, Géomorphologie 2: 153-164.

Garavaglia V, Leonelli G, Pelfini M, Vezzola LC (2011) Tree-ring responses to climate and to seasonal changes in water levels of an ice-contact lake in the Western Italian Alps. EGU 2011, Wien, Geoph Res Abs 13, -9192-2.

Garavaglia V, Pelfini M (2011) Glacial geomorphosites and related landforms: a proposal for a dendrogeomorphological approach and educational trails. Geoheritage 3, pp. 15–25.

Ghiraldi L, Coratza P, Marchetti M, Giardino M (2010) GIS and geomatics application for the evaluation and exploitation of Piemonte geomorphosites. In: Regolini-Bissig G. and E. Reynard, eds., Mapping Geoheritage. Lausanne, Institut de Géographie, Géovisions 35, pp. 97-113.

Giardino M, Perotti L, Carletti R, Russo S (2010) Creation and test of a mobile GIS application to support field data collection and mapping activities on geomorphosites. In: Regolini-Bissig G. and

E. Reynard, eds., Mapping Geoheritage. Lausanne, Institut de Géographie, Géovisions 35, pp. 115-127.

Gisotti G (1993) Rapporti tra formazioni geologiche e paesaggio: il paesaggio. Boll Serv Geol It 59: 137-152.

Gobbi M, Isaia M, De Bernardi F (2011) Arthropod colonisation of a debris-covered glacier. Hol 21(2): 343 –349.

Gray M (2004) Geodiversity: Valuing and Conserving Abiotic Nature. John Wiley & Sons Ltd, Chichester.

Kinzl, H. (1932) : Die grössten nacheiszeitlichen Gletschervorstösse in den Schweizer Alpen und in der Mont Blanc Gruppe. Zeitschrift für Gletscherkunde 20, 269-397.

ISPRA (2012) Foglio 89, Courmayeur, 1:50000, Progetto CARG.

Lesca C (1956) Osservazioni sui laghi del Ghiacciaio del Miage. Boll Com Glac It 2, 29 – 56.

Masetti M, Diolaiuti G, D’Agata C, Smiraglia C (2010) Hydrological Characterization of an Ice-Contact Lake: Miage Lake (Monte Bianco, Italy). W Res Man 24: 1677–1696.

Mattson LE, Gardner JS, Young GJ (1993) Ablation on debris covered glaciers: an example from the Rakhiot Glacier, Punjab, Himalaya. Proceedings of the workshop Snow and Glacier Hydrology, IAHS Publishing, Washington, USA 218: 289–296.

Mattson LE, Gardner JS (1989) Energy exchange and ablation rates on the debris-covered Rakhiot Glacier, Pakistan. Z Glets Glaz 25(1): 17 – 32.

Mihalcea C, Mayer C, Diolaiuti G, Lambrecht A, Smiraglia C, Tartari G (2006) Ice ablation and meteorological conditions on the debris covered area of Baltoro Glacier (Karakoram, Pakistan). Ann Glac 43: 292-300.

Mihalcea C, Brock BW, Diolaiuti G, D'Agata C, Citterio M, Kirkbride MP, Cutler MEJ, Smiraglia C (2008) Using ASTER satellite and ground-based surface temperature measurements to derive supraglacial debris cover and thickness patterns on Miage Glacier (Mont Blanc Massif, Italy). Cold Reg Sci Tech 52: 341–354.

Moreau M (2010) Visual perception of changes in a High mountain landscape: the case of the retreat of the Evettes Glacier (Haute-Maurienne, northern French Alps). Géomorphologie 2: 165-174.

Orombelli G, Porter SC (1981) Il rischio di frane nelle Alpi. Le Scienze 156: 68–79.

Panizza M (2001) Geomorphosites: concepts, methods and examples of geomorphological survey. Chi Sci Bull 46: 4-6.

Pelfini M (2007) Geografia Fisica, Geomorfologia e Itinerari Didattici in Ambiente Alpino. Ambiente Società, Territorio 4: 24-26.

Pelfini M (2009a) La rapida evoluzione dei geomorfositi glaciali e la relativa influenza sulle valenze dell'attributo scientifico: il caso del Ghiacciaio del Miage 131-143. In V. Agnesi, ed., Ambiente geomorfologico e attività dell'uomo. Risorse, Rischi, Impatti, Mem Soc Geogr It LXXXVII: 131-143.

Pelfini M (2009b) Geomorfositi glaciali: il caso del ghiacciaio del Miage, un debris covered Glacier dalle caratteristiche particolari. Geoitalia 28: 59-61.

Pelfini M, Smiraglia C (2003) I ghiacciai, un bene geomorfologico in rapida evoluzione. Boll della Soc Geogr It XI (VIII): 521-544.

Pelfini M, Bozzoni M, Santilli M (2005) Il ghiacciaio del Miage: un geosito dalla peculiare valenza ecologica. SLM 23: 8-15.

Pelfini M, Santilli M, Leonelli G, Bozzoni M (2007) Investigating surface movements of debris-covered Miage glacier, Western Italian Alps, using dendroglaciological analysis. J Glac 53: 141 – 152.

Pelfini M, Diolaiuti G, Smiraglia C (2009) Geomorfositi glaciali e turismo: evoluzione,pericolosità e rischi. Il caso del Ghiacciaio del Miage (Monte Bianco), Valle D’Aosta. In: Coratza P, Panizza M (eds) Il patrimonio geomorfologico come risorsa per un turismo sostenibile, S.A.P. Editore, Mantova, pp. 105-124.

Pelfini M, Garavaglia V, Bollati I (2010) Dendrogeomorphological investigations for assessing ecological and educational value of glacial geomorphosites. Two examples from the Italian Alps. In: Regolini-Bissig G. and E. Reynard, eds., Mapping Geoheritage. Lausanne, Institut de Géographie, Géovisions 35, pp. 81-96.

Pelfini M, Diolaiuti G, Leonelli G, Bozzoni M, Bressan N, Brioschi D, Riccardi A (2012) The influence of glacier surface processes on the short-term evolution of supraglacial tree vegetation: A case study of the Miage Glacier, Italian Alps. Hol 2: 1-10.

Porter SC, Orombelli G (1982) Late-glacial ice advances in the western Italian Alps. Boreas 11: 125-140.

Prinetti F. (2010) Andar per sassi. Le rocce alpine fra natura e cultura. Musumeci Editore, Quart, Aosta, pp. 251.

Pralong JP (2005) A method for assessing tourist potential and use of geomorphological sites. Géomorphologie 3: 189-196.

Reynard E (2004) Géotopes, géo(morpho)sites et paysages géomorphologiques. In: Reynard E Pralong JP (eds) Paysages géomorphologiques, Lausanne, Instute de Géographie de l'Universitè de Lausanne, Travaux et Recherches 27, pp. 124-136.

Reynard E, Panizza M (2005) Geomorphosites: definition, assessment and mapping. An introduction. Géomorphologie 3: 177-180.

Reynard E, Fontana G, Kozlik L, Scapozza C (2007) A method for assessing scientific and additional value of geomorphosites. Geogr Elv 62 (3): 148-158.

Reynard E, Coratza P, Regolini-Bissig G (2009) Geomorphosites. Pfeil Verlag, Munchen, pp 240.
Richter M, Fickert T, Grüninger F (2004) Pflanzen auf schuttbedeckten Gletschern-Wandernde Kuriositäten. Geoöko 25: 225–256.

Sacco F (1917) L'apparato morenico del ghiacciaio del Miage. Boll Soc Geol It 36: 323-354.

Sacco F (1919) I ghiacciai Italiani del Gruppo del Monte Bianco. Boll Com Glac It 3: 21-102.

Sacco F (1939) Il quaternario nella catena del Monte Bianco (versante italiano). Accademia delle Scienze, Tipografia Vincenzo Bona, Torino.

Smiraglia C, Diolaiuti G, Pelfini M, Belò M, Citterio M, Carnielli T, D'Agata C (2008) Glacier changes and their impacts on mountain tourism: two case studies from the Italian Alps. In: Orlove B, Wiegandt E, Luckman B (eds) Darkening peaks. Glacier retreat, Science and Society, University of California Press, Los Angeles, pp. 206-215.

Società Geologica Italiana (1992) Le Alpi dal Monte Bianco al Lago Maggiore. BE-MA Editore, Milano, pp. 304.

Tinti S, Maramai A, Cerutti AV (1999) The Miage Glacier in the Valley of Aosta (Western Italian Alps, Italy) and the extraordinary detachment which occurred on August 9, 1996. Phys Chem Earth Sci 24 (2): 157-161.

Yamada T (1998) Glacier lake and its outburst flood in the Nepal Himalaya. Japanese Society of Snow and Ice. Data Centre for Glacier Research, Tokyo, pp. 96.

Fig.1 *Miage glacier and touristic trails investigated*. a) Geographical location of the Miage glacier, Western Alps, Aosta Valley, Italy; b) Structural setting of Val Veny (modified from Prinetti, 2010); c) the three main trails around the Miage glacier front (dashed lines 1,2,3) . 1: Lac du Miage; 2: Lac du Jardin du Miage; 3: Lac du Breuillat. Along the paper the reference sites names are those used on local topography.

Fig.2 *Geomorphosites proposed in the Miage Glacier surroundings.* a. Miage Glacier debris coverage and epiglacial morphologies; b. Lac du Breuillat; c. Ice cliff of the Northern lobe d. Lac de Combal and MMA (white dashed line); e. Lac du Miage; f. Lac du Jardin du Miage. All photos were taken in summer, 2010 by I. Bollati.

Fig. 3 *Lakes in the Miage glacial apparatus*. a) Lac du Breuillat; b) Lac du Miage and the MMA sketch modified after Deline (1999); c) Lac de Combal. The photo were taken by I. Bollati during summer 2010 and the topographic sketches were taken from Lesca (1956).

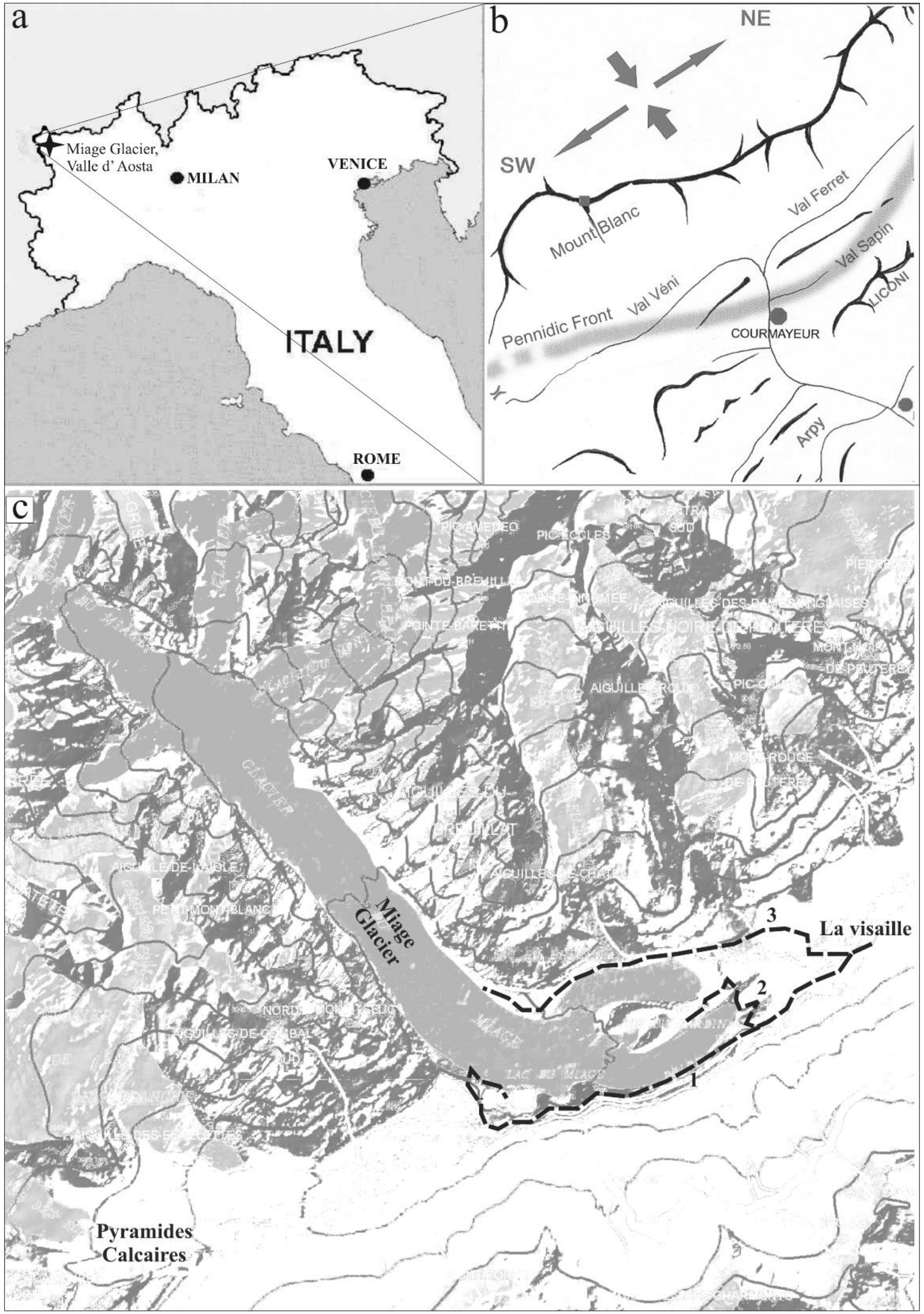
Fig. 4 *Example of risk scenarios*. a) The trail 1 to the Lac du Miage the road is characterized by debris flows on weak lithotypes (schists and calceschists) and landslide in general on fragile litotypes outcropping on the Southern side of Val Veny, exposed also to dissolution (gypsum levels). In 1986 the road interrupted was interrupted by a landslide. The hypothesized thickness of the event occurred in 1986 is indicated respect to the actual trail level; b) Trail 3 to Lac du Breuillat: wooden boards and iron mobile bridges as infrastructures to reduce vulnerability at Torrent du Freney.

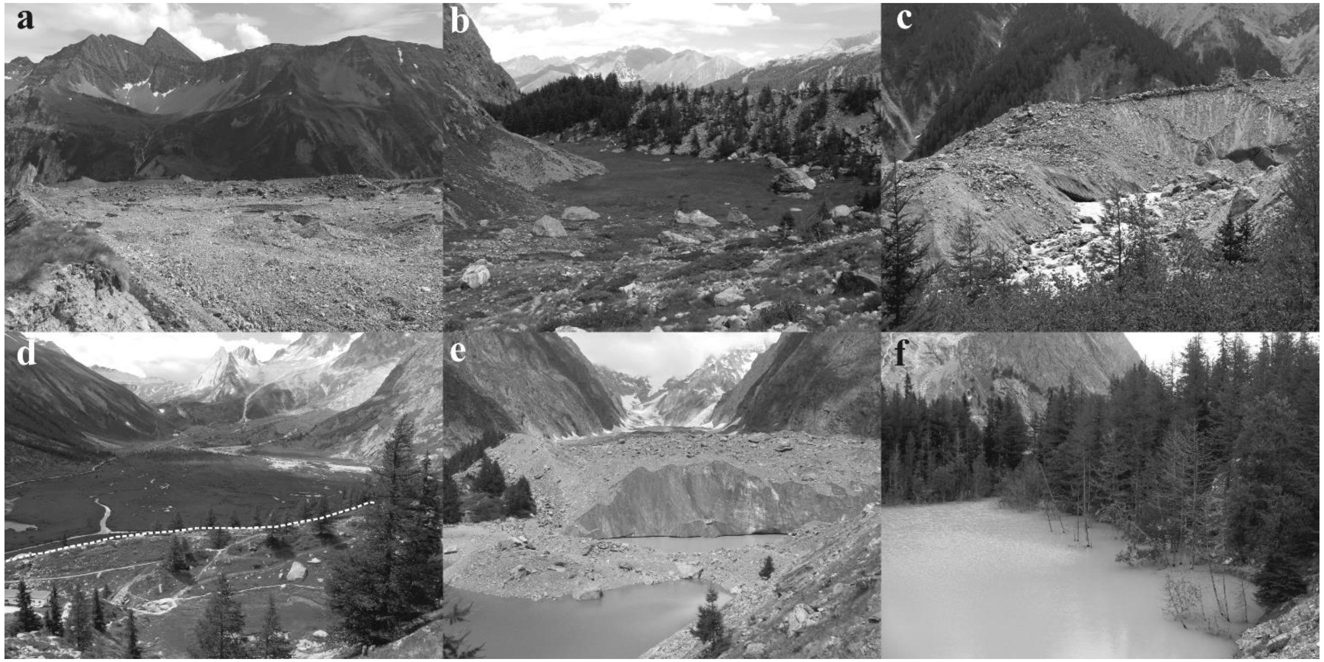
Fig. 5 *Graph of the sites ordered by global value*. The trends of the derived parameters (scientific value, additional values, global value, potential for use, educational index, scientific index) increase quite similarly even if not high value of the coefficient of correlation among them have been calculated (see details in Fig. 8).

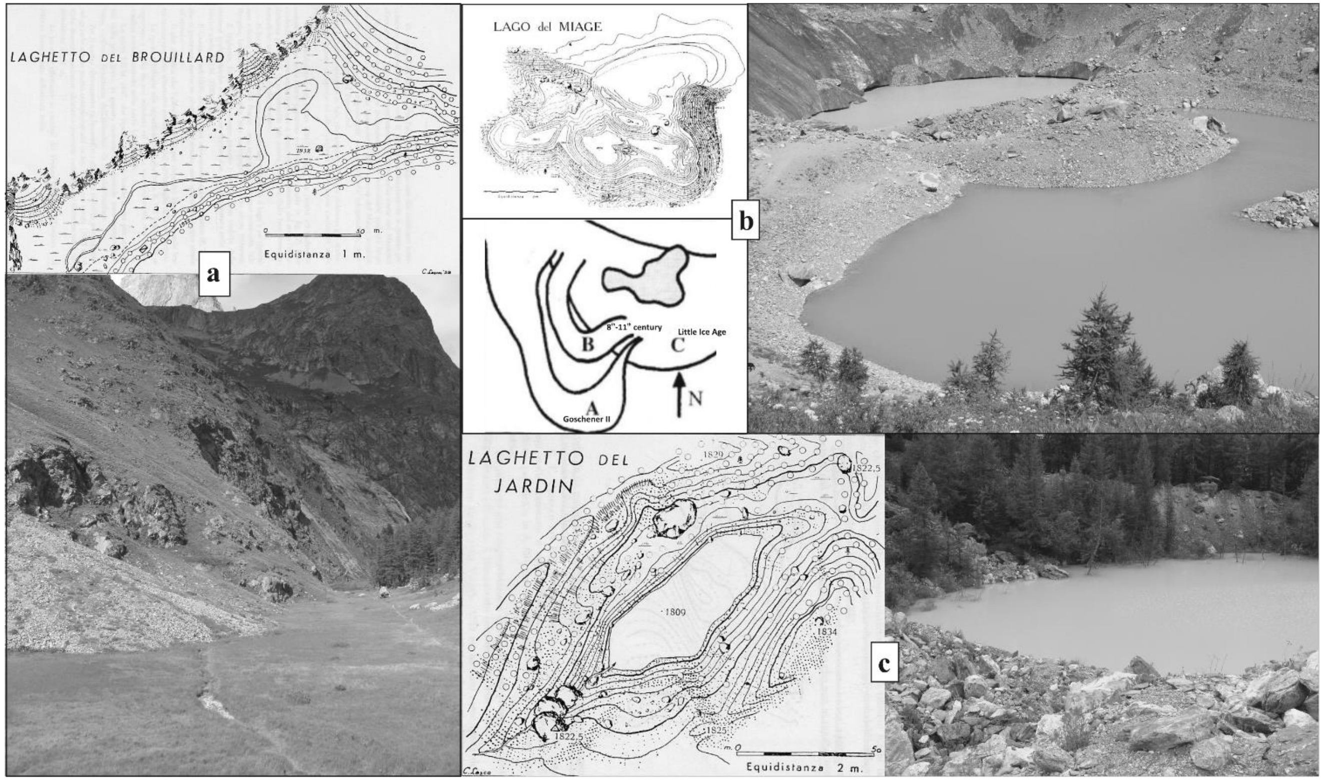
Fig. 6 *Numerical assessments of geomorphosites (grey points) and average values (black lines)*. The reported parameters are scientific value, additional values, global value, potential for use, educational index, scientific index and they have been normalized to the corresponding maximum value to obtain values comprised between 0-1.

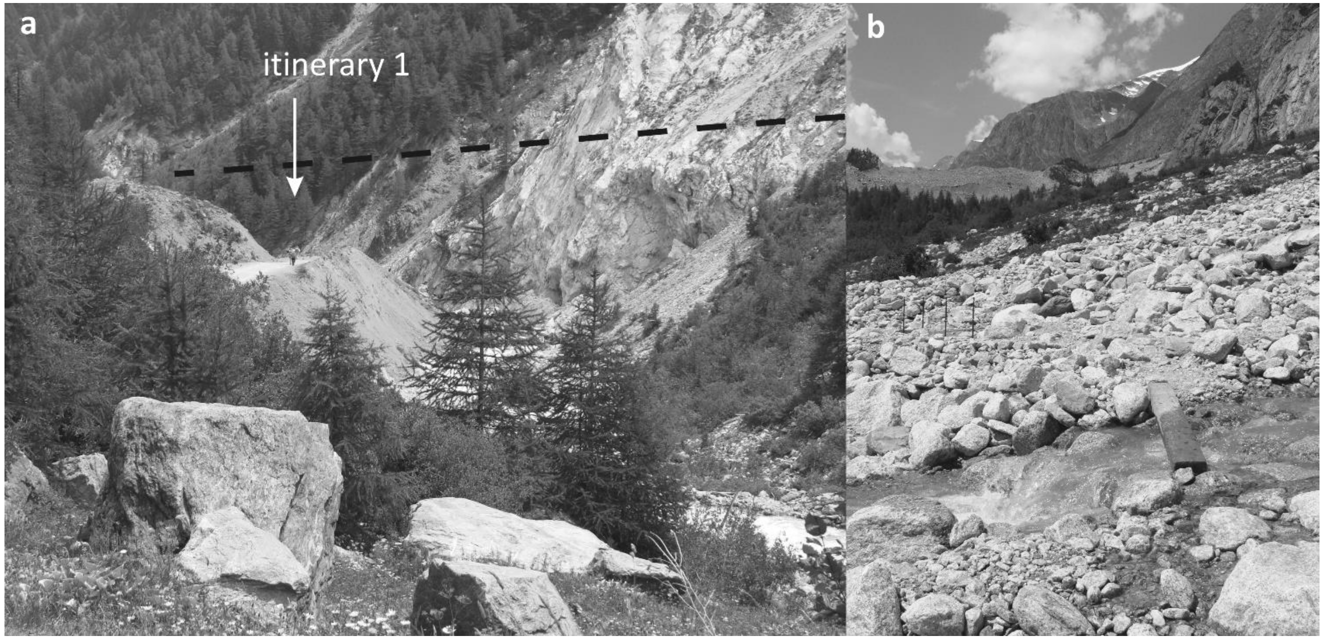
Fig. 7 *Results of the comparison among itineraries*. The results obtained for each itinerary derived by the sum of each site normalized to the number of sites (average values) to avoid the influence of this parameter.

Fig. 8 *Correlation between scientific and educational index for sites and itineraries*. The correlation coefficient is greater considering the itineraries values (0,9998) rather than the single geomorphosites (0,3793).

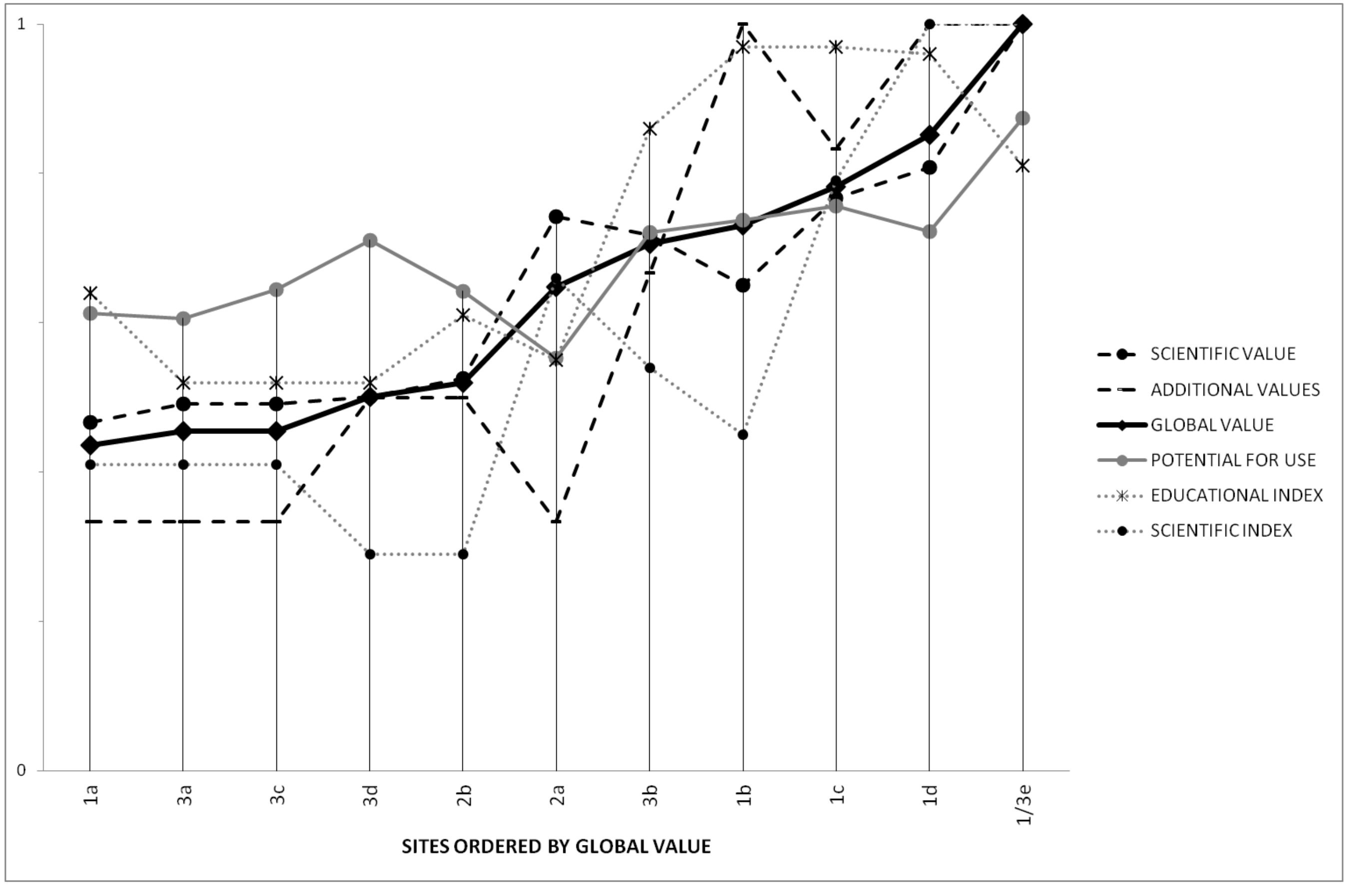

a
Miage Glacier,
Valle d'Aosta
MILAN
VENICE
ITALY
ROME
b
NE
SW
Mount Blanc
Val Ferret
Val Sapin
LICONI
Pennidic Front
Val Véni
COURMAYEUR
Arpy
c
PIC AMEDEO
PIC ECCLES
MONT-DU-BREUILLAT
POINTE-BARETTI
AIGUILLES-DES-DAMES-ANGLAISES
AIGUILLES-NOIRE-DE-PEUTEREY
AIGUILLE-ROUGE
MONT-ROUGE
DE-PEUTEREY
AIGUILLE-DE-L'AIGLE
LAC DU MIAGE
Miage
Glacier
3
La visaille
2
1
Pyramides
Calcaires

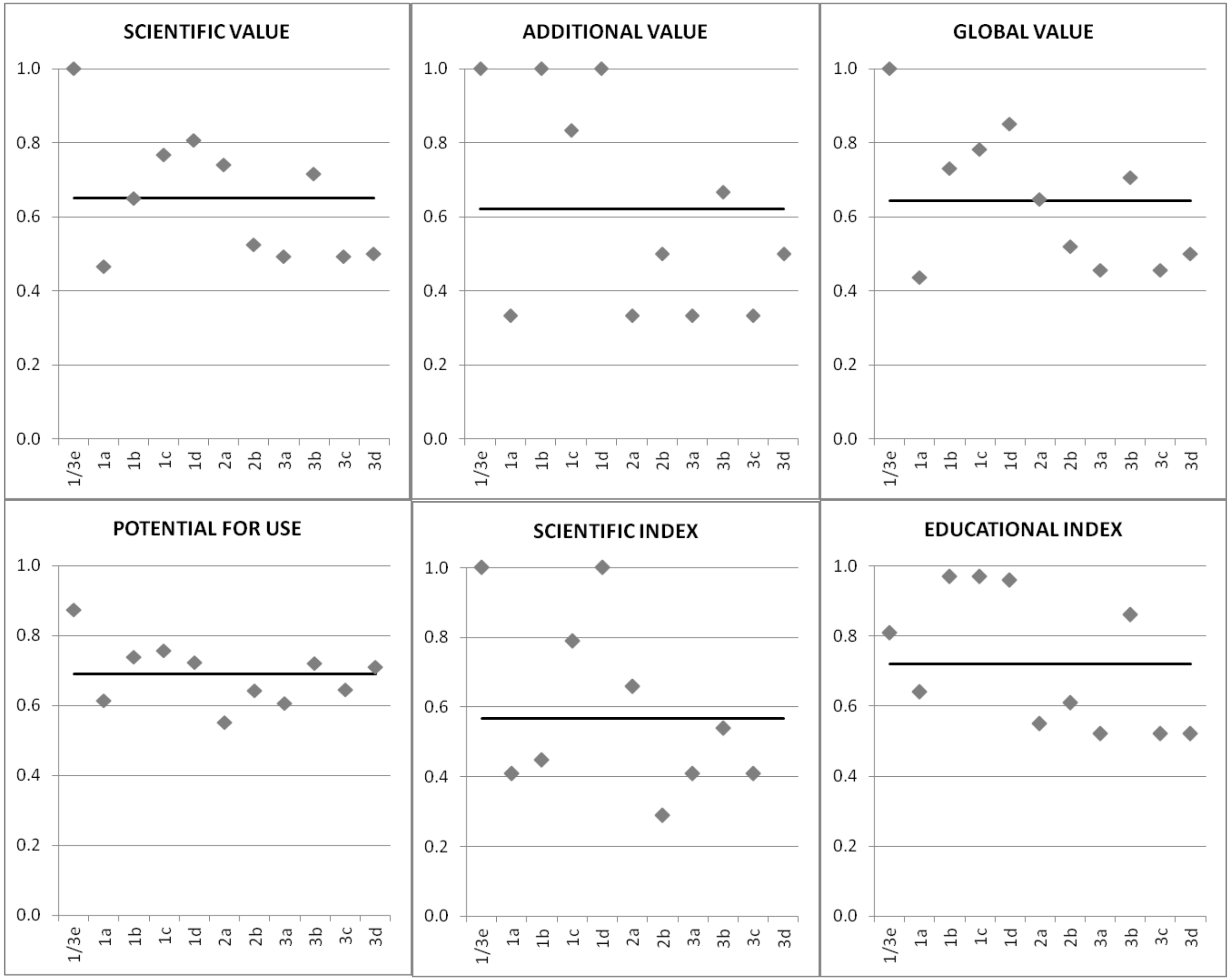

a
b
c
d
e
f

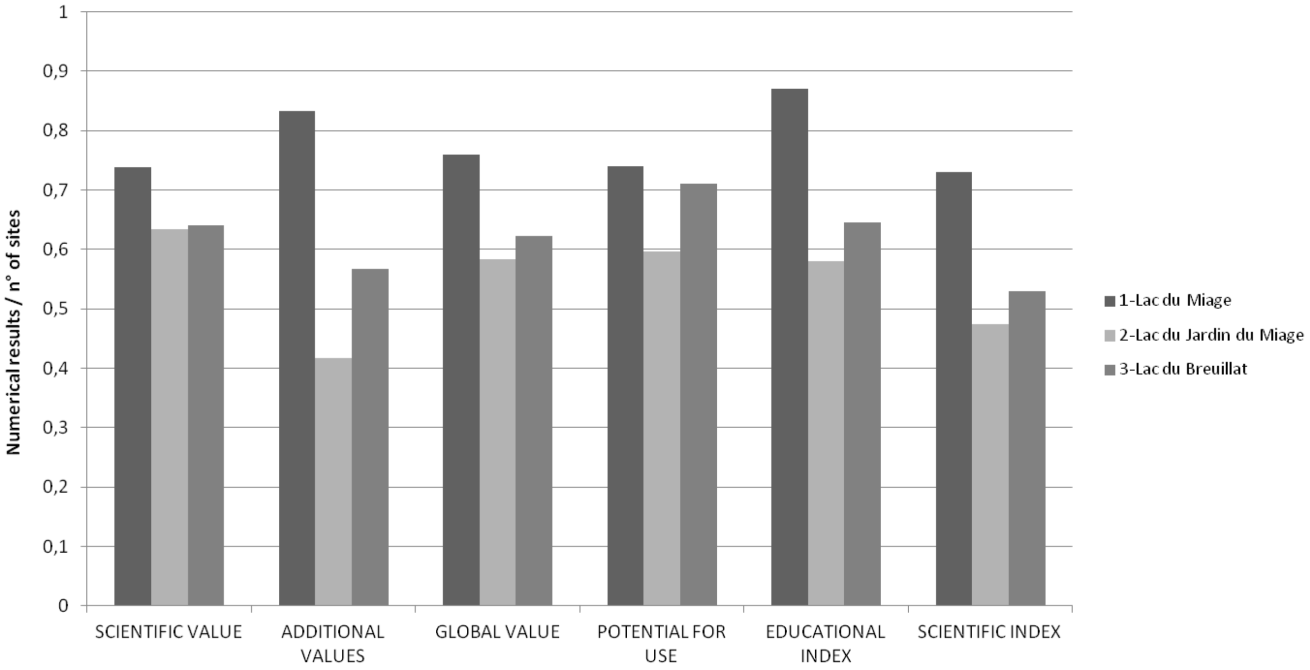

LAGHETTO DEL BROUILLARD
2938
0 50 m.
Equidistanza 1 m.
C. Lesca '38
a
LAGO del MIAGE
b
8th-11th century
Little Ice Age
B
C
A
Goschener II
N
LAGHETTO DEL JARDIN
1829
1822,5
1809
1834
1825
m. 0 50
Equidistanza 2 m.
C. Lesca
c



a
itinerary 1
b


1
0
1a
3a
3c
3d
2b
2a
3b
1b
1c
1d
1/3e
SITES ORDERED BY GLOBAL VALUE
SCIENTIFIC VALUE
ADDITIONAL VALUES
GLOBAL VALUE
POTENTIAL FOR USE
EDUCATIONAL INDEX
SCIENTIFIC INDEX


SCIENTIFIC VALUE
ADDITIONAL VALUE
GLOBAL VALUE
POTENTIAL FOR USE
SCIENTIFIC INDEX
EDUCATIONAL INDEX
1.0
0.8
0.6
0.4
0.2
0.0
1/3e
1a
1b
1c
1d
2a
2b
3a
3b
3c
3d


Numerical results / n° of sites
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
SCIENTIFIC VALUE
ADDITIONAL VALUES
GLOBAL VALUE
POTENTIAL FOR USE
EDUCATIONAL INDEX
SCIENTIFIC INDEX
■ 1-Lac du Miage
■ 2-Lac du Jardin du Miage
■ 3-Lac du Breuillat

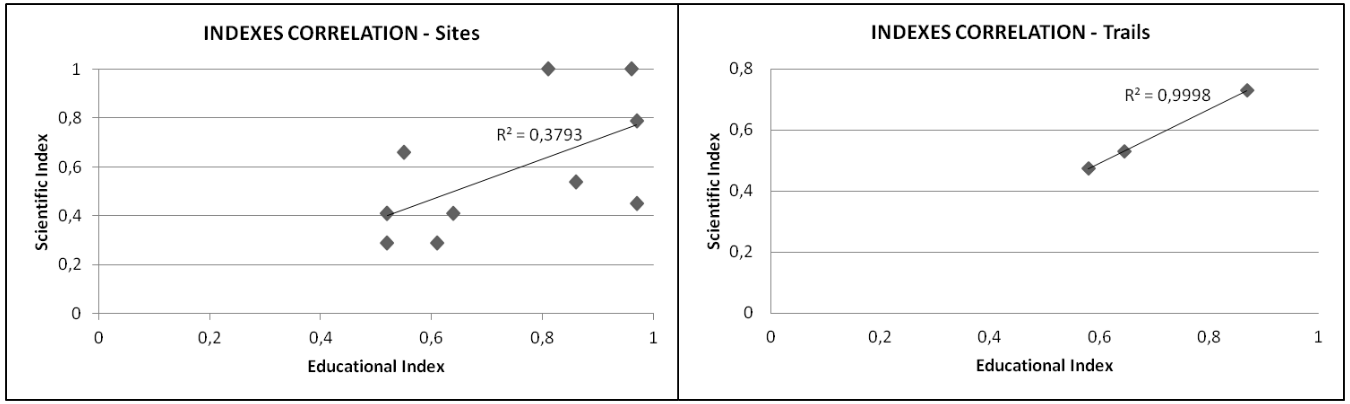

INDEXES CORRELATION - Sites
Scientific Index
Educational Index
R² = 0,3793
1
0,8
0,6
0,4
0,2
0
0,2
0,4
0,6
0,8
1
INDEXES CORRELATION - Trails
Scientific Index
Educational Index
R² = 0,9998
0,8
0,6
0,4
0,2
0
0,2
0,4
0,6
0,8
1

Table 1 *Criteria for evaluation of geomorphosites*. For more details see Bollati et al. (2012).

Scientific value (SV)	**Potential for use (PU)**	
Model of geomorphological evolution (representativeness)-GM	Temporal accessibility TA	
	Services-Se	
Model of palaeogeomorphological evolution-PgM	Visibility-Vi	
Educational exemplarity-EE	Number of tourists-NT	
Spatial extension-SE	Sport activities-OA	
Geodiversity-Gd	Legal constraints-LC	
Geo-historical importance-GI	Use of geomorphological/geological interest UGI	
Ecologic support role-ES	Use of the additional interest UAI	
Integrity-In	Presence of geomorphosites in the surroundings SGs	
Rareness-Ra	Spatial accessibility-SA	Calculated Accessibility-CA
Other geological interests-OI		*only for on-foot trails*
		Typology-Ti
		Trend
Additional values (AV)		Steepness-St
Cultural-Cu		Sloping-Sl
Aesthetic-Ae		Width-Wi
Socio-economic-Ec		Ground material-GM
		Vegetation on the slope
		Water/Snow along the path-WSP
		Slope Material-SM
		Slope Inclination-SI
		Degree Of Conservation Of The Path-DC
		Human Interventions-HI
		Tourist Information-TI

Table 2 *Equations for calculating parameters of trails*. Modified from Bollati et al. (2012). The abbreviation used in the equations are indicated in Table 1.

CALCULATED VALUES	EQUATION	Conditions
SV	SV = (GM + PgM + EE + SE + Gd + GI + EI + OI + In + Ra)	
AV	AV = (C + Ae + SE)	
GV	GV = (SV + AV)	
Index of use	IU = EE + SE + Ae	
PU s.s.	PUss = (TA + Vi + Se + NT + SA + LC + UGI + UAI + SGs)	
PPU	PPU = (PUss + IU)	
CA	CA = (Ti + St + Sl + Wi + GM + WSP + SI + SM + DC+ HI + TI)	
A_Factor_c	AFc = ((CA/11)+(SAc/0.4))/2	SAc ≤ 0,4
A_Factor_s	AFs = (1+(SAc/1))/2	SAc ≥ 0,6
PU (for on-foot itineraries)	PUc = PPU + AFc	
PU	PUs = PPU + AFs	
Scientific Index	SIn= (GM + PgM + GI + OI)/4	
Educational Index	EIn= [EE + Ae + (A_Factor_c/s)]/3	
	ITINERARY	
	(Σ SCIENTIFICs / n° sites)*MAX	
	(Σ ADDITIONALs / n° sites)*MAX	
	(Σ GLOBALs / n° sites)*MAX	
	(Σ POTENTIAL FOR USEs / n° sites)*MAX	
	(Σ SCIENTIFIC INDEX / n° sites)*MAX	
	(Σ EDUCATIONAL INDEX / n° sites)*MAX	

Table 3 *Trails and geomorphosites*. The three touristic trails, in the Miage Glacier area, that have been evaluated and the included assessed geomorphosites. (Reference cartography: Kompass Mont Blanc area; 1:25,000).

TRAIL		CARTOGRAPHY	GEOMORPHOSITES
1	Lac du Miage	11	1a-Slope processes (Debris flows, landslides) 1b-Lac de Combal 1c-Lac du Miage 1d-Miage Morainic Amphithéâtre (MMA) 1e- Miage Glacier - Supraglacial debris
2	Lac du Jardin du Miage	17	2a-Proglacial area of the Southern lobe 2b-Lac du Jardin du Miage
3	Lac du Breuillat	18	3a-Alluvial fan of the Torrent du Freney 3b-Ice cliff of the Northern lobe 3c-Alluvial fan of the Torrent du Miage 3d-Lac du Breuillat 3e- Miage Glacier supraglacial debris

Table 4 . *Values of attributes for each geomorphosites*. The abbreviations are those included in Table 1 and 2.

Site	SCIENTIFIC VALUE PARAMETERS										ADDITIONAL VALUE PARAMETERS		
	GM (0-1)	PgM (0-1)	EE (0-1)	SE (0-1)	Gd (0-1)	GI (0-1)	ES (0-1)	OI (0-1)	In (0-1)	Ra (0-1)	Cu (0-1)	Ae (0-1)	Ec (0-1)
1a	0,67	0	1	0,5	0,5	0	0	1	1	0	0	0	1
1b	0,67	0,33	1	0,75	0,75	0,33	0,67	0,5	1	0,5	1	1	1
1c	1	1	1	0,5	1	0,67	0	0,5	1	1	0,5	1	1
1d	1	1	1	0,75	0,5	1	0,33	1	1	0,5	1	1	1
1/3e	1	1	1	1	1	1	1	1	1	1	1	1	1
2a	0,67	0,33	1	0,5	0,75	0,67	1	1	1	0,5	0	0	1
2b	0,67	0	0,67	0,5	0,75	0	0,67	0,5	1	0,5	0	0,5	1
3a	0,67	0	1	0,75	0,5	0	0	1	1	0	0	0	1
3b	1	0	1	0,75	0,75	0,67	1	0,5	1	0,5	0	1	1
3c	0,67	0	1	0,75	0,5	0	0	1	1	0	0	0	1
3d	0,67	0	0,67	0,75	0,75	0	0,67	0,5	0,5	0,5	0	0,5	1

Site	POTENTIAL FOR USE s.s. PARAMETERS											FINAL PARAMETERS					
	TA (0,25-1)	SA (0,2-1)	Vi (0-1)	Se (0-1)	NT (0-1)	OA (0-1)	LC (0-1)	UGI (0-1)	UAI (0-1)	SGS (0-1)	**CA** (0-11)	**SV** (0,5-10)	**AV** (0-3)	**GV** (0,5-13)	**PU** (0,5-13)	**EIn** (0-1)	**SIn** (0-1)
1a	0,25	0,4	0,8	1	1	0,5	1	0	0	1	9,3	4,67	1	5,67	7,97	0,64	0,41
1b	0,25	0,4	1	1	1	0,5	0,67	0,5	0	1	9,3	6,5	3	9,5	9,59	0,97	0,45
1c	0,25	0,4	1	1	1	0,5	0,67	1	0	1	9,3	7,67	2,5	10,17	9,84	0,97	0,79
1d	0,25	0,4	1	1	1	0,5	1	0	0	1	8,58	8,08	3	11,08	9,39	0,96	1
1/3e	0,25	0,2	1	1	1	1	0,67	1	1	1	4,3	10	3	13	11,36	0,81	1
2a	0,25	0,4	0,6	1	1	0,5	0,67	0	0	1	3,64	7,42	1	8,42	7,18	0,55	0,66
2b	0,25	0,4	0,6	1	1	0,5	0,67	1	0	1	3,64	5,26	1,5	6,76	8,35	0,61	0,29
3a	0,25	0,2	0,8	1	1	0,5	1	0	0	1	7,45	4,92	1	5,92	7,88	0,52	0,41
3b	0,25	0,2	0,8	1	1	0,5	1	0,5	0	1	7,45	7,17	2	9,17	9,38	0,86	0,54
3c	0,25	0,2	0,8	1	1	0,5	1	0,5	0	1	7,45	4,92	1	5,92	8,38	0,52	0,41
3d	0,25	0,2	1	1	1	0,5	0,67	0,5	1	1	3,38	5,01	1,5	6,51	9,24	0,52	0,29