Introduction

High mountain geomorphosites (*sensu* Panizza 2001) represent a very interesting subject for both geoheritage assessment and educational purposes (Reynard et al. 2007; Bollati et al. 2011). Their rapid evolution requires attention because, on the one hand, there is the possibility of geomorphosite degradation resulting from changes in the geomorphological processes acting on them (Diolaiuti and Smiraglia 2010; Pelfini et al. 2009), and on the other hand, active geomorphosites (*sensu* Reynard 2004) represent a useful tool for educational purposes (Reynard et al. 2007). In fact, they allow people to experience characteristic geomorphic features just from observing defined areas in the landscape (Reynard et al. 2007; Bollati et al. 2011). The importance of evolving geomorphosites is also associated with the hazards that may derive from geomorphic process changes and their intensification in response to climate change. This is significant, especially in tourist areas where the vulnerability component is present (Brandolini et al. 2006; Pelfini et al. 2009). Hence, the *educational exemplarity* (*sensu* Bollati et al. 2012) of these sites may be considered related to the aforementioned topics. Dissemination of concepts, that are fundamental to both risk scenarios and to the proper way to move through the natural environment, contributes to the educational importance of these types of sites of geomorphological interest (e.g., Bollati et al. 2013).

Moreover, active geomorphosites located in temperature- and precipitation-limited environments may be strongly influenced by climatic variations, because their characteristics are modified by variations in the frequency and intensity of climate-related geomorphological processes. This is in accord with the “narrow definition” of geosite proposed by Grandgirard (1997): “it can be any part of the Earth’s surface that is important for the knowledge of Earth, climate and life history.”

Glacial geomorphosites are among the most significant examples of active geomorphosites (i.e., changing in a “changing climate” (Diolaiuti and Smiraglia 2010)), whose quantitative evaluation should be periodically reassessed as a response to changes in their features (Pelfini 2009; Pelfini et al. 2009; Diolaiuti and Smiraglia 2010). After identifying their attributes during geomorphosite selection (Pelfini and Smiraglia 2003), many glacial geomorphosites were proposed as important because of their high scientific and cultural value (e.g., Pelfini and Gobbi 2005; Pelfini et al. 2005). Particular focus was placed on their ecological and educational attributes (Pelfini et al. 2010a; Garavaglia et al. 2010a).

A distinctive category of glacier geomorphosites is represented by the debris-covered glaciers (DCGs) which arise from a growth in supraglacial debris resulting from climate change-related processes (e.g., rock avalanches from the valley sides due to permafrost degradation and outcropping of endoglacial debris due to increasing ablation rates; Deline 2009). Debris coverage above a certain thickness threshold diminishes the glacial ablation rates (e.g., Mattson et al. 1993; Mihalcea et al. 2008; Brock et al. 2010), making the DCGs’ response to climate changes different to that of debris-free glaciers (DFGs). Hence, DCGs may be considered one of the features in the alpine landscape in which a distinctive response of the natural environment to climate change is evident.

Within the framework of geomorphological heritage assessment, there is agreement among scientists concerning the need for a census of geomorphosites based on objective evidence. However, more often discussed is the quantification of single (*simple*) values and global (*composite*) values (e.g., Reynard et al. 2007). Difficulties may arise in applying rigid evaluation schemes, considering the vast geomorphological differences in different morphoclimatic environments. Another problem is the subjectivity in assessing values (e.g., Bonachea et al. 2005; Bruschi et al. 2011). Considering all these conditions, some proposals were suggested using data base applications (e.g., Giardino et al. 2010; Ghiraldi et al. 2010). For instance, Bollati et al. (2012) proposed a method for assessing and selecting sites of geomorphological interest by employing either the function of the users (e.g., tourists, students of different levels, etc.) or the aim of the project (e.g., valorisation, education, or management). The same application was tested for selecting educational and cultural trails by obtaining global values for single itineraries which also considered natural hazards. Consideration of natural hazards was intended both negatively, to exclude unsuitable itineraries, and positively, as occasions for education about risk and safety conditions, as previously discussed (Bollati et al. 2013).

Many features are considered in geomorphosite selection (e.g., Bollati and Pelfini 2010), and in recent times, new attention has been directed towards their ecological attribute (i.e., the *ecological support role, ESR*; *sensu* Bollati et al. 2012), especially for glacial geomorphosites (e.g., Garavaglia et al. 2010a; Pelfini et al. 2010a). As presented in Table 1, the ecological value changes position and relative importance among groups of attributes depending on the author and the meaning that the author confers to it. Within this framework, the strategic role of vegetation may indeed be considered as influencing transversally the other attributes that are also taken into account when calculating *scientific value*, *additional values* and *potential for use* (Fig. 1). Vegetation's role is especially important in understanding DCGs: when the debris layer is thick enough (i.e., at least 40 cm at the sample site of Miage Glacier; Pelfini et al. 2007), the surface glacier velocity is low, and if the glacier tongue reaches altitudes below the tree line, not only herbaceous and shrub vegetation but also trees can germinate and grow (Pelfini 2009) providing a *rareness* value to these geomorphosites. Moreover, DCGs evolution and dynamics can be studied through the analysis of annual tree rings in supraglacial living trees (e.g., Pelfini et al. 2007; Leonelli and Pelfini 2013a).

The aim of this paper is to quantitatively assess the ecological attribute's contribution to glacier geomorphosites in relation to variation in the composite values (e.g., *global*, *scientific*, and *additional values* and *potential for use* (*sensu* Bollati et al. 2012)) during geomorphosite evaluation. First, the scientific literature concerning the study area was analysed and characterised chronologically. Next, the publications concerning the interaction between vegetation and glacial processes were selected as support for the quantitative re-evaluation of sites. The Miage Glacier, in the Mont Blanc Massif (Western Italian Alps), was selected as the study area because it is a highly representative debris-covered glacier in the Italian Alps for which the scientific literature is broad and varied in terms of the topics investigated.

Study Area

The Miage Glacier, located in the Veny Valley (Valle d'Aosta, Italy; Fig. 2a), drains the southwest slope of Mont Blanc. The glacier is approximately 13 km long and shows an ablation tongue, towards the terminus, characterised by two main lobes with a smaller one in between. The valley is included in the "Espace Mont Blanc" area, which is under consideration for inclusion on the UNESCO World Heritage List.

Certainly, the Miage Glacier represents a significant site from an educational viewpoint and due to its accessibility and notoriety (Pelfini et al. 2005; Bollati et al. 2013). Moreover, the entire area is considered a prime example of an open-air laboratory (Pelfini et al. 2009), suitable for research and education on the subject of differential ablation, as demonstrated for other sites by Pelfini et al. (2010b). According to Bollati et al. (2013), the Miage Glacier belongs to the category of "*complex active geomorphosite*" (Pelfini et al. 2009; *sensu* Reynard 2004 and Reynard and Panizza 2005) and its *simple* attributes and *composite* values (especially the scientific value) have been recently discussed (e.g., Pelfini et al. 2005) in terms of risk scenarios (Mortara and Sorzana 1987; Pelfini et al. 2009). Furthermore, the values of geomorphosites, distributed along three sample trails, were quantified for the first time by Bollati et al. (2013), demonstrating quantitatively the important value of the area in terms of geomorphological heritage.

More precisely, the geological, geomorphological and glaciological features enhance the scientific value of the area, as evidenced by extensive scientific research that began during the 18th century when the first papers describing this area were published (De Saussure 1774; Baretti 1880). The Miage Glacier represents the most significant place in the Italian Alps to study the dynamics of a DCG (e.g., Mihalcea et al. 2008; Brock et al. 2010) (i.e., for geomorphosite assessment: *model of geomorphological evolution*; *geohistorical importance*; *sensu* Bollati et al. 2012). There are many respects in which the *ESR* of this glacier and the associated processes are important to both vegetation (Fig. 3) (e.g., Pelfini et al. 2010a; Garavaglia et al. 2010a; Caccianiga et al. 2011) and arthropod communities (Gobbi et al. 2011).

The spatial and temporal distributions of the supraglacial tree coverage, that represents a rareness feature for the Miage Glacier as a geomorphosite, were characterised by Pelfini et al. (2007) and Leonelli and Pelfini (2013a). The supraglacial trees are primarily of the species *Larix decidua* Mill. and *Picea abies* Karst. (Pelfini et al. 2007). The investigations regarding the supraglacial trees, in conjunction with glaciological information, allowed the reconstruction of the recent dynamics of the lower portion of the glacier tongue (Fig. 3b) (Pelfini et al. 2007; Pelfini et al. 2012; Leonelli and Pelfini 2013a). In fact, tree rings may record both mechanical stress and climatic signals. For this reason, the trees growing on debris coverage, while being transported by the glacier flow in a manner comparable to a “tapis-roulant” (i.e., “treadmill”; Richter et al. 2004; Pelfini et al. 2005), are precious sources of geomorphological information. For example, the integration of glaciological data for surface velocity over time allowed the tracing of the tree’s paths and, subsequently, the determination of the position on the glacier where growth anomalies in the tree rings were recorded (Leonelli and Pelfini 2013a). Moreover, glaciological research indicates that, during the period 1975 - 1988 (Giardino et al. 2001), there was a passage of a kinematic wave which crossed the glacial tongue, modifying the glacier’s surface elevation (Thomson et al. 2000). The analysis of tree-ring anomalies, in the supraglacial trees growing on both lobes, allowed the reconstruction of past surface instability and the determination that there was a delay of a number of years in the wave traversing first the southern and then the northern lobe (Pelfini et al. 2007; Leonelli and Pelfini 2013a). An intensification of glacial activity, likely related to the kinematic wave, is also witnessed by trees colonising the proglacial area where the dendrochronological analysis allowed for the collection of information on glacial stream course changes over time (Fig. 3c) (Garavaglia et al. 2010b).

In regards to the portions of the glacier tongue presenting debris-free ice, as in the case of ice cliffs (Fig. 3a) where the ablation is more intense, the processes of down-wasting and back-wasting (*sensu* Benn and Evans 1998) are both present and may differently impact the supraglacial trees. For example, on the northern lobe, the debris cover displacement caused by the glacier flow moves the trees towards the glacier terminus, where they usually die from falling off the front edge of the glacier (Richter et al. 2004; Pelfini et al. 2005; Leonelli and Pelfini 2013a). However, when the trees move down valley along the edge of the ice cliff, they can be involved in the ice wall retreat (back-wasting), ending their life before they reach the glacier front. In contrast, when the ice cliff is buried because of an increase in the debris cover and subsequent lowering of the cliff inclination (as observed on the southern lobe), the trees may continue their movement and colonise the ice cliff slope, too (Pelfini et al. 2012).

Among the significant geomorphosites identified by Bollati et al. (2013) in the Miage Glacier apparatus, there is a well-developed morainic amphitheatre, recognised by different authors as one of the most significant in the European Alps (e.g., “The moraine of the Glacier de Miage is perhaps the most extraordinary in the whole Alps, and has given rise to the Lac de Combal”, Murray 1844; Forbes 1843; Baretti 1880) and is referred to in the literature as the Miage Morainic Amphitheatre (Deline and Orombelli 2005; Deline 2009) (Fig. 3f). This amphitheatre was generated by a diversion lobe of the Miage Glacier and colonised by arboreal vegetation. Dendrochronological analysis of the amphitheatre’s trees provided data for dating the maximum Holocene expansion in the Western Alps (Deline and Orombelli 2005) (i.e., for geomorphosite assessment: *model of paleogeomorphological evolution*; *geohistorical importance*; Bollati et al. 2012), including the estimated time of formation of Combal Lake (Deline and Orombelli 2005).

The *geodiversity* (i.e., *intrinsic geodiversity*; Panizza 2009) of the Miage Glacier area also benefits from the presence of different lake typologies (Jardin du Miage Lake, Miage Lake, Combal Lake, and Breuillard Lake). Among these lakes, the Jardin du Miage Lake (also known as Lac Vert) is surrounded by arboreal vegetation that is occasionally drowned along the lake edge and impacted by water level changes (Fig. 3d, e). As recently highlighted by Leonelli et al. (2013b), these trees may record these water lake changes by virtue of their growth rates and typical tree-ring isotope signatures related to the low $\delta^{18}O$ of glacier melt waters.

Within the Miage complex geomorphosite, there are several situations where the *ESR*, influenced by outcropping lithology and low drainage conditions deriving from the presence of particular landforms (Prinetti 2010), creates significant features: Breuillard Lake, Combal Lake and the area of Jardin du Miage near the homonymous lake. In particular, the progressive infilling with sediment of Breuillard Lake and Combal Lake allows gradual colonisation by endemic flora, thus increasing the biodiversity of the area (Fig. 3g, h, i) (e.g., Baretti 1880; Prinetti 2010). Concerning these features, some observations are already present on signage along naturalistic trails.

In addition to the glaciological and supporting botanical features, the geological features, that are relevant along the Veny Valley, contribute to *geodiversity*. In fact, the development of the valley along the Pennidic Front, one of the main structural lines of the Alps, lead to the outcrop of different lithologies on the two sides of the valley (Prinetti 2010). The Helvetic crystalline basement of the Mount Blanc Massif on the northern side and the sedimentary coverage of the UltraHelvetic and External Pennidic Domains on the southern side respond differently to gravity (prevailing rock falls on the northern side and debris flow and landslides on the southern side; e.g., Bollati et al. 2013) which generates different geological landscapes (*sensu* Gisotti 1993).

Moreover, the *rareness* attribute is represented not only by the tree coverage but also by a feature of Miage Lake, calving, which is a rarity at level of the Italian Alps (Diolaiuti et al. 2006; Pelfini et al. 2009). In addition, the complete drainage of the lake, which happened in 2004, permitted data collection that allowed for a detailed characterisation of the lake bottom and the hydrological paths (e.g., Deline et al. 2004; Diolaiuti et al. 2005; Masetti et al. 2010).

In general, all the described features contribute to the high *educational exemplarity*, *additional values* and *potential for use* attributes of the area. The quantitative evaluation of the trails and single sites (see details in Bollati et al. 2013) allowed the creation of a ranking system resulting in the trail 01 to Miage Lake being the most valued.

The Miage complex geomorphosite represents an ideal site to investigate how the vegetative component may transversally influence the composite attributes of *scientific value*, *additional values* and *potential for use* in geomorphosite value assessment.

Methods

The first step of the analysis was the collection and characterisation of the scientific research regarding the Miage Glacier and the Veny Valley area. The collection was focused on the classification of descriptive and scientific papers and on their topic, which has evolved over time. The bibliographic research was performed utilising international databases available online: *Google Scholar* and *Web of Knowledge* (both were consulted in early 2013 and took into account publications through the end of 2012). Information reported by local magazines was not considered. In order not to overemphasise any paper, the maximum value assigned to any single paper was 1. If the paper covered more than one topic, for each topic the value was calculated as follows: $V = \frac{1}{n}$ where n represents the number of topics. Then, for each year, the total number of papers for each topic was calculated.

Hence, starting from the results on the evolution of the scientific knowledge regarding the study area, the scientific research concerning the interaction between arboreal vegetation and glacial processes was used to reconsider the dataset of values (i.e., *scientific*, *additional*, *global*, *potential for use*, *educational index* and *scientific index*), calculated by Bollati et al. (2013), of the Miage geomorphosites and trails. New data had been acquired during 2012 and two sites have been added to the trail 03 to Breuillard Lake (i.e., Debris fan and Rock fall).

All the sites were re-evaluated to highlight the numerical contribution of the arboreal vegetation factor to the other attributes. Six sites were not involved in this re-evaluation (Miage Lake, Miage Stream alluvial fan, Freney Stream alluvial fan, Landslides and debris flows, Debris fan and Rock fall), because either the *ESR* was not meaningful or no scientific data to confirm the *ESR* were available. The assessment was made through the already applied methodology, tested initially along a fluvial valley (Bollati et al. 2012) and then tested in the Miage Glacier area for selecting geo-itineraries in a glacial environment (Bollati et al. 2013). The list of attributes (*single* values), the specific class of the *ESR* and the formula used for calculating the *composite* values are reported in Table 2. In the presented research, the application is used to recalculate the global value of Miage sites by considering the different typology of information available, focusing on the meaningful presence of arboreal vegetation and its transverse influence on the other attributes.

Results

The first phase of the scientific publications analysis enhanced the considerable attention paid to the Miage Glacier and its surrounding area since the beginning of the frequentation of this glacial area in the 18th century. The analysis of the two databases brought to the collection a total of 100 scientific works, covering the period 1774-2012 and including the papers belonging to the 18th and 19th centuries, which contain more descriptive glaciological and naturalistic observations (i.e., naturalistic observations and trips, Fig. 4). The investigated subjects are various and the relative percentages are reported in Figure 4.

Figure 5 presents the distribution of the scientific works through time, separated according to the main subject. As evidenced by the data in Figure 5, glaciological and dendrochronological studies have been strongly increasing in recent years, as tools, to quantify the variations in the glacial environment in both space and time, have been developed. This increase may be considered a reflection of the rising interest in climate change.

Moreover, it is possible to see the advance of scientific research, especially in concurrence with the complete drainage event that happened at Miage Lake in 2004, which has allowed the collection of additional data on the hydrological paths and on the shape of the ice cliffs along which the lake develops, which are associated with the entire glacier dynamic (e.g., Diolaiuti et al. 2006).

The second part of the results involves the re-evaluation of thirteen sites, including two new sites not previously evaluated by Bollati et al. (2013). The removal of the *ESR* related to landforms and processes was based on data derived from scientific research developed during the last several years (Fig. 5). At this scope, among the collected papers, special attention was paid to those papers concerning the arboreal vegetation's response to glacier dynamics and those papers combining these results with attributes of the Miage Glacier as a geomorphosite. In Table 3, the scientific papers on which the re-evaluation of the *ESR* and transversal features were based are summarised and divided according to the circumstances in which the *ESR* is evident as described in the previous paragraphs.

In Figure 6, the re-evaluation results are illustrated for both sites and trails and the variation produced by the *ESR* is evident. The increase in the *scientific value* over time is determined not only by the *ESR* but, according to Figure 1, by all the attributes transversally linked with it. The two sets of values correspond to: i) new composite values (dark grey) obtained not considering the benefit given by the increasing scientific knowledge on the *ESR;* ii) effective composite values (light grey) considering all the data available in the scientific literature regarding these topics. The value increase is evident for most of the parameters. This increase does not involve all the sites, as mentioned above, but all those sites in which the study of vegetation confirms and provides a greater comprehension of the glacial processes and dynamics of this DCG (i.e., Miage Glacier, Miage Morainic Amphitheatre, Jardin du Miage Lake, Southern lobe proglacial area, Northern lobe ice cliff) or where the landforms, processes and outcropping lithology determine the colonisation by the endemic flora, increasing the biodiversity of the area (i.e., Breuillard Lake, Combal Lake; Prinetti 2010).

The trails enjoy the benefits of the value increases as well (Fig. 6). Trail 01 is invariably the most valued one. According to Bollati et al. (2013), if trail 02 reached the lowest position, the addition of two sites along trail 03 (i.e., Debris fan and Rock fall), not linked with the ecological component, generates an inversion in the ranking (light grey columns in Fig. 6). Alternatively, not considering the ESR (dark grey columns in Fig. 6) , trail 02, along which all the sites are affected by the *ESR* variation, undergoes a greater value loss with respect to trail 03 (Table 4).

Percentage variations in the composite attributes for each site and trail are reported in Figure 7, including only the 7 sites in which variations of the *ESR* are confirmed by scientific data. Concerning these sites, *scientific values* variation also reaches values greater than 20% at the Northern lobe ice cliff (i.e., back-wasting processes involving vegetation), the Miage Glacier (i.e., the vegetation response to the dynamics of the debris coverage), the Southern lobe proglacial area and the Miage Morainic Amphitheatre. The variations of *scientific value* at the level of the site are never lower than 12% (Fig. 7).

The *additional values* are responsive to the variation only at Breuillard Lake (16.67%). This is because the *scenic value*, that may be responsive to variation in the *ESR*, is enhanced by the presence of endemic flora that confers a more pleasing aesthetic to the site. The other sites are valuable scenically regardless of the vegetation. Generally, Breuillard Lake is the site which results in more homogeneous response to the variation and which obtained a high average of change (12%) (Fig. 7).

At Breuillard Lake, concerning *potential for use*, the possibility of using the already existing tourist trails, based mainly on the floristic component of the landscape, is promoted by the scientific recognition of the *ESR*. At this site, *potential for use* obtained the maximum percentage of variation (12.32%), whereas this parameter, in general, varies less than the others (2-12%).

The indexes for scientific and educational selection of sites ranged between 7.50 – 24.75% and 11.43-17.68%, respectively (Fig. 7). The Miage Morainic Amphitheatre and Northern lobe ice cliff are particularly favoured by the use of vegetation as an investigative tool for dating glacial advances and retreats in the first case (i.e., scientific index variation: 24.75%) and evolution of back-wasting processes in the second case (i.e., scientific index variation: 16.50%). The biggest variation in the *educational index* was obtained, once again, at Breuillard Lake (17.68%) where *scientific index* did not vary.

Trails present more homogeneous trends, and their value variations are reduced (Fig. 7). The *scientific value* continues as the most favoured one, as seen by the increase in the knowledge of the *ESR*, and its variations result to be significant along trail in which for all the sites the role of glaciers regarding vegetation is fundamental (i.e., 15,85% maximum at trail 02). Trail 03 presents more homogeneous percentage variations.

The percentage variations in the average composite values, not including the sites in which the *ESR* plays no role (see earlier discussion), and the changes in standard deviation are reported in Figure 8. In general, the most variable composite attribute is the *scientific value* (16.43%) (Fig. 8a), as previously discussed. The index used for selection of sites for scientific purposes also increases evidently (Fig. 8a). The standard deviation, which indicates the dispersion of values, especially for the scientific attribute, increases and the sites are more distinct from each other according to this parameter (fig. 8b).

Finally, considering the ranking among all the sites, all the *ESR* affected sites rose in the ranking. However, the only site that maintained its high position is Miage Lake, demonstrating that superb sites such as Miage Lake, in which it is possible to observe active processes such as calving, are highly valued and independent of variation in any other value. Table 4 presents the comparison among the site and trail rankings.

Discussion and Conclusions

The recognition of glaciers as sites of geomorphological interest is not recent (e.g., Baretti 1880). However, the determination and quantitative description of geomorphosite values for glaciers is a rather new research topic (Pelfini and Smiraglia 2003; Bollati et al. 2013). In particular, great attention has been recently paid to the role of *ESR* in certain settings, such as those of DCGs (Pelfini et al. 2005; Pelfini et al. 2010a; Garavaglia et al. 2010; Gobbi et al. 2011) such as the Miage Glacier, the most important DCG in the Italian Alps, proposed as geomorphosite by Pelfini et al. (2005). The collection of approximately 100 scientific papers, produced over a period of 250 years of scientific research, concerning the Miage Glacier apparatus, initially permitted the understanding of the evolution of scientific interest in this complex geomorphosite. The increasing number of scientific studies on the Miage Glacier, especially during the 21st century, is most likely related to the interest in DCGs as witnesses of climate change (Deline 2009). Additionally, the analysis of the Miage Glacier as a geomorphosite, beyond the first recognition in books of the 18th-19th centuries, received a significant boost that coincided with the growth of scientific interest in geoheritage. Among the papers collected, those concerning the use of vegetation as tool for detailing current and past glacial dynamics in different situations (i.e., supraglacial debris coverage, proglacial area, ice cliffs on the lobes, morainic amphitheatre, and glacial lakes with drowned vegetation) have been considered to quantify the contribution of the *ESR* to the composite values (i.e., *scientific*, *additional values* and *potential for use*) of sites and trails (*sensu* Bollati et al. 2012). With the additional data derived from scientific research on vegetation growing within the glacial environment of Miage Glacier, the increase in the *ESR* is evident. Furthermore, the *ESR* influences the other attributes that are closely connected with it in a cascade effect (as shown in Fig. 1): *scientific value* (i.e., *model of geomorphological evolution*, *model of paleogeomorphological evolution*, *educational exemplarity*, *geohistorical importance*, and *rareness*), *additional values* (i.e., *scenic value*) and *potential for use* (i.e., *use of other interests*). The composite attributes are responsive in different measure to this increase and surely the most involved attribute is the *scientific value*.

In some cases, such as that of Breuillard Lake, the *ESR* exclusively influences the attributes linked with educational purposes, while the attributes strictly used for the calculation of the *scientific index* remain unvaried. In other situations, the opposite occurs (e.g., the Miage Morainic Amphitheatre and Northern lobe ice cliff), and the benefit is obtained when geomorphosites are selected for trails with scientific purposes.

In addition, what emerges is the increase in standard deviation among the single values of sites, once again due to scientific factors. As a consequence, if we do not consider the ecological attribute as a criterion to evaluate sites, there will be less differentiation among the sites and trails which may impede the process of selection among sites for valorisation purposes.

Moreover, the relative importance among trails may change if we exclude the *ESR* attribute. For example, trail 02 is more connected with the biological component and largely benefits from the growth in available scientific data supporting the *ESR* of its sites, allowing it to overtake trail 03 in significance. Hence, the importance of the *ESR* attribute is evident in the selection of sites and trails during the geomorphosite evaluation procedure, especially for the selection of trails for scientific purposes.

In conclusion, the ecological component of the landscape, in relationship with landforms and geomorphic processes, may represent a discriminating factor in geomorphosite value assessment. The results of this study demonstrate that this observation is true, especially in the case of active geomorphosites but also in the case of passive geomorphosites that are currently affected by active processes.

The continuing growth in scientific interest towards this area is expected to result in new data in the future, which will support the necessary periodic revision of geomorphosite assessments.

Moreover vegetation dynamics, that are related to glaciers activity, represent a consequence of climate change to be enhanced within cultural and educational itineraries, as well as the glacier behaviour itself, since they are poorly known by common people (Garavaglia et al 2012).

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Figures and Tables captions

Table 1 The different approaches to and considerations of the ecological value (modified from Bollati and Pelfini 2010).

Table 2 Criteria for the evaluation of geomorphosites and the equations for calculating the parameters of sites and trails according to Bollati et al. (2012) (modified from Bollati et al. 2012; 2013).

Table 3 Summary of the scientific research concerning ecological interactions involving glacial landforms and vegetation in the Miage Glacier area.

Table 4 Variation of the ranking of sites according to variation of the ESR data.

Fig. 1 The transverse influence of the ESR on the other attributes used for geomorphosites evaluation (see criteria in Bollati et al. 2012).

Fig. 2 The Miage Glacier area and the thirteen evaluated sites. a) Geographic location of the Miage Glacier in Veny Valley (Valle d'Aosta); b) panoramic view of the Miage Glacier from La Visaille with the locations of the evaluated geomorphosites and trails; the location and partial extension of the Southern lobe ice cliff is also indicated. The Southern lobe ice cliff is italicised because it was not considered a valuable geomorphosite, because it cannot be reached from any tourist trail and is not completely visible from any tourist trail (Photo by D. Zannetti, 2012).

Fig. 3 Various significant features for the *ESR* in the Miage Glacier area. a) Supraglacial vegetation involved mainly in the back-wasting processes at the Northern lobe ice cliff (photo by D. Zannetti, 2012); b) Supraglacial vegetation on the Southern lobe, responding to the debris coverage dynamics (photo by D. Zannetti, 2012); c) Vegetation in the proglacial area of the Southern lobe involved mainly in the glacial stream activity (photo by D. Zannetti, 2011); d-e) Interannual water-level changes at Jardin du Miage Lake involving the drowned trees; the large boulder (white ellipse) allows a comparison between the two photos taken in July 2011 (d; photo by I. Bollati) and September 2011 (e; photo by L. Vezzola). The vegetation present inside the lake basin may be affected in terms of growth rates; f) The Miage Morainic Amphitheatre investigated through dendrochronological, pedological and carbon-14 analysis to determine the age of the different morainic ridges (photo by D. Zannetti, 2012); g-h-i) examples of flora present in the area of Jardin du Miage and Breuillard Lake and typical of the humid environment: *Dactylorhiza maculata* (L.), a protected species (g; photo by I. Bollati, 2011), *Eriophorum scheuchzeri* (h; photo by I. Bollati, 2011), *Caltha palustris L.* (i; photos by I. Bollati, 2011).

Fig. 4 Percentage of scientific papers according to topic.

Fig. 5 Scientific research on Miage Glacier. The distribution of scientific papers over time according to the scientific topic studied. The complete drainage of Miage Lake most likely gave a significant boost to scientific research in the area because of the possibility of collecting scientific data.

Fig. 6 Variations in the scientific value, scientific index and educational index for sites and trails in the Miage Glacier area. Not all the sites have undergone changes (i.e., Miage Lake, Miage Stream alluvial fan, Freney Stream alluvial fan and Landslides and debris flows, Debris fan and Rock fall). The dark grey columns are the values calculated not considering the data regarding the ecological value of the sites. The light grey columns are the effective values calculated considering all the data coming from the scientific literature regarding the ESR. The horizontal lines in the sites graphs are the respective average values that show the same increment. In the dashed ellipse, the inversion of the final scientific value between trail 02 and trail 03 is highlighted.

Fig. 7 Percentage variations in the composite attributes in sites and trails including only the sites in which the *ESR* has a meaning.

Fig. 8 Variations in the composite attributes: a) Percentage of variation in the composite attributes calculated considering the average in the composite attributes of sites but not considering those in which the ESR has no influence. b) Variation of the standard deviation in the composite attributes of all the sites derived from re-evaluation. The dark grey columns are the values calculated not considering the data on the ecological value of the sites. The light grey columns are the effective values calculated considering all the data coming from the scientific literature regarding the ESR.

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Figure 1
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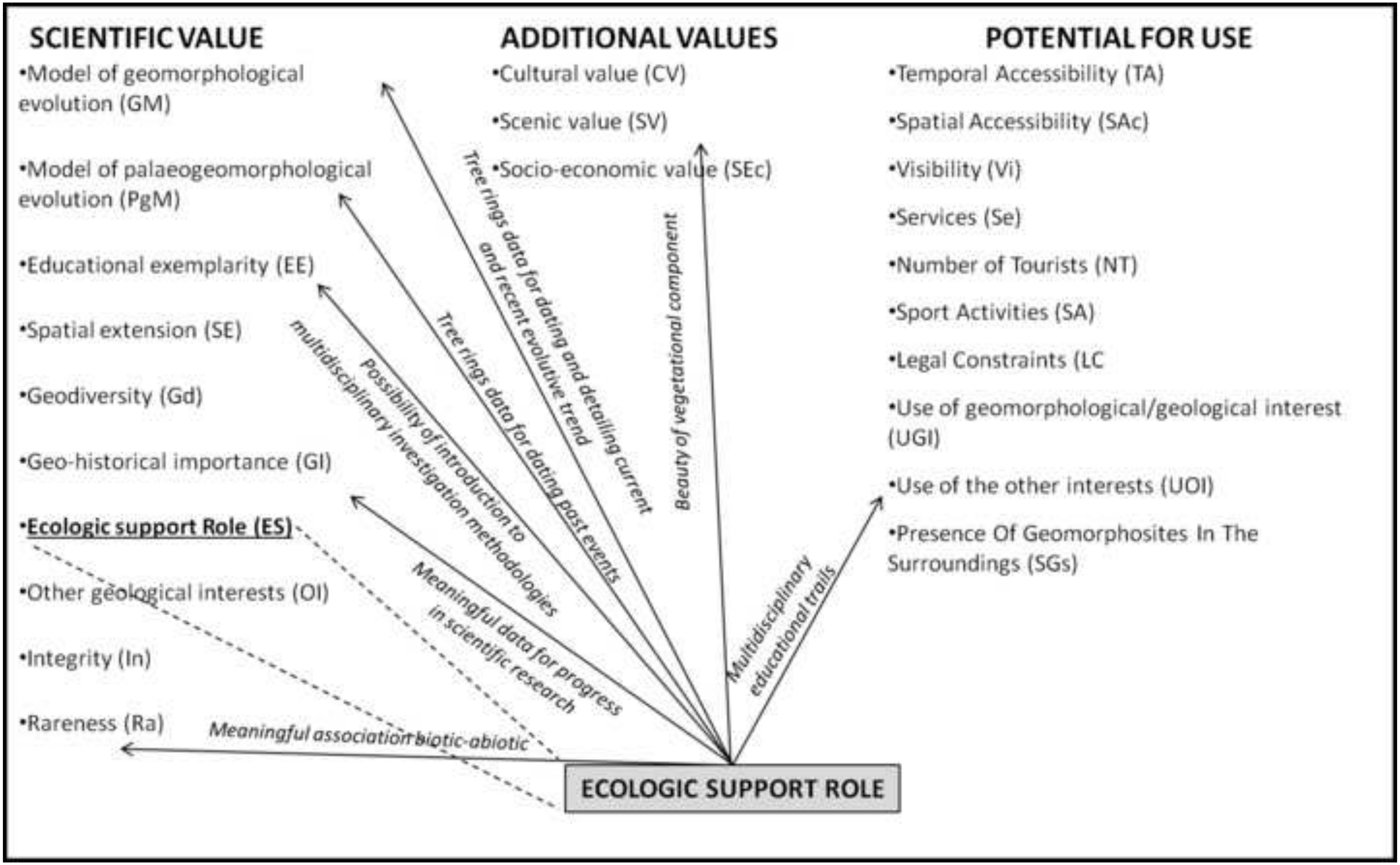

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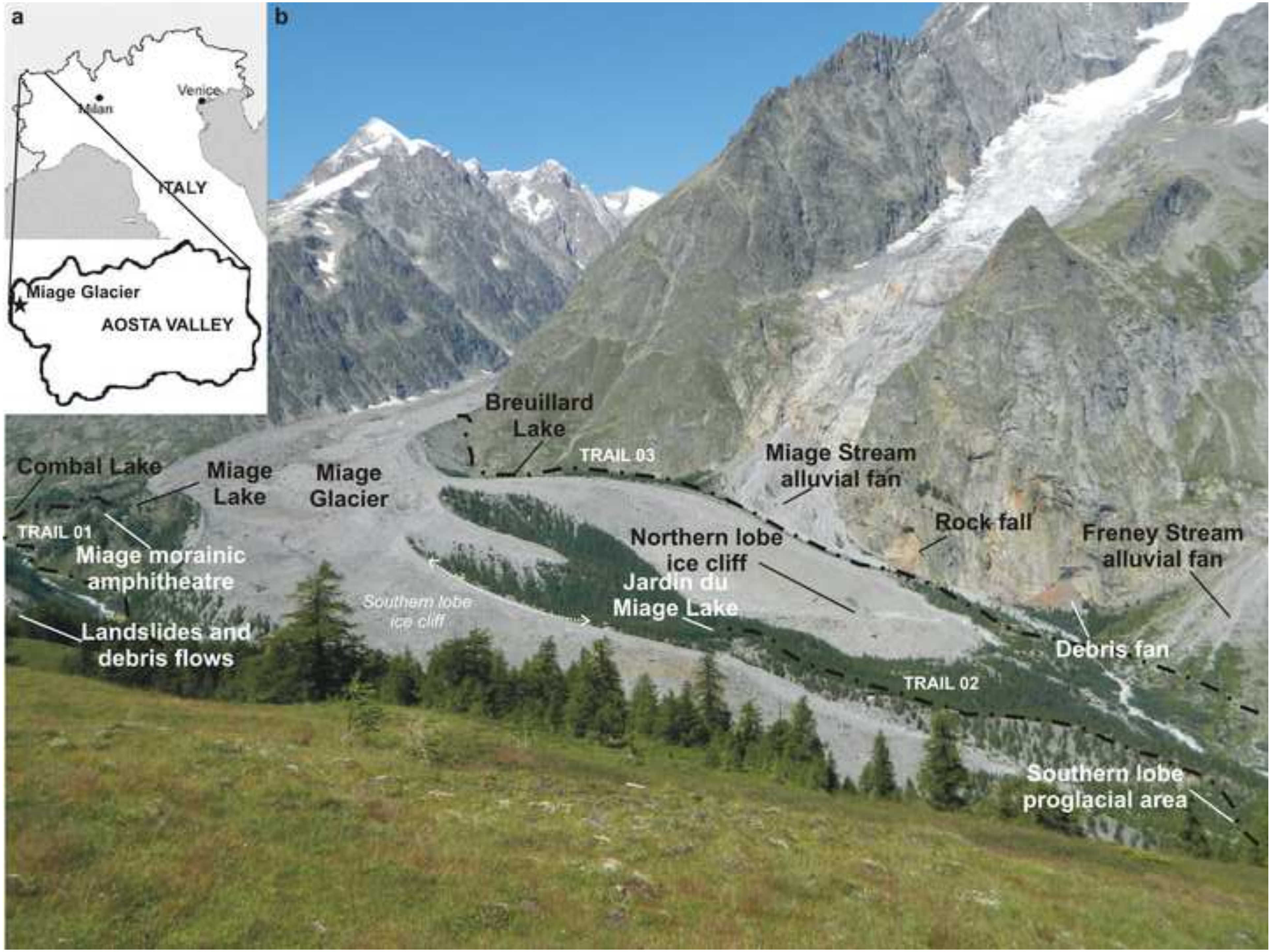

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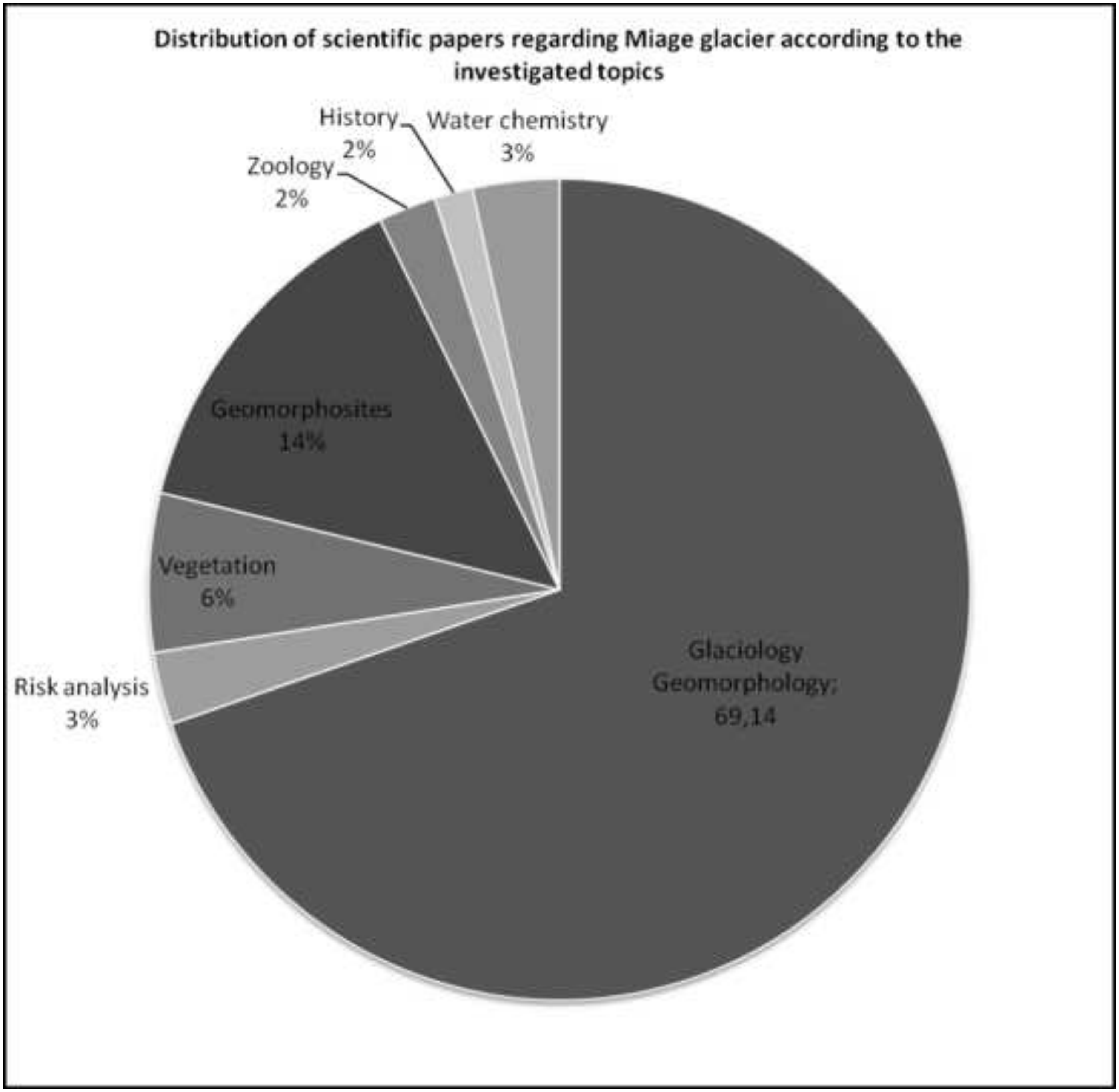

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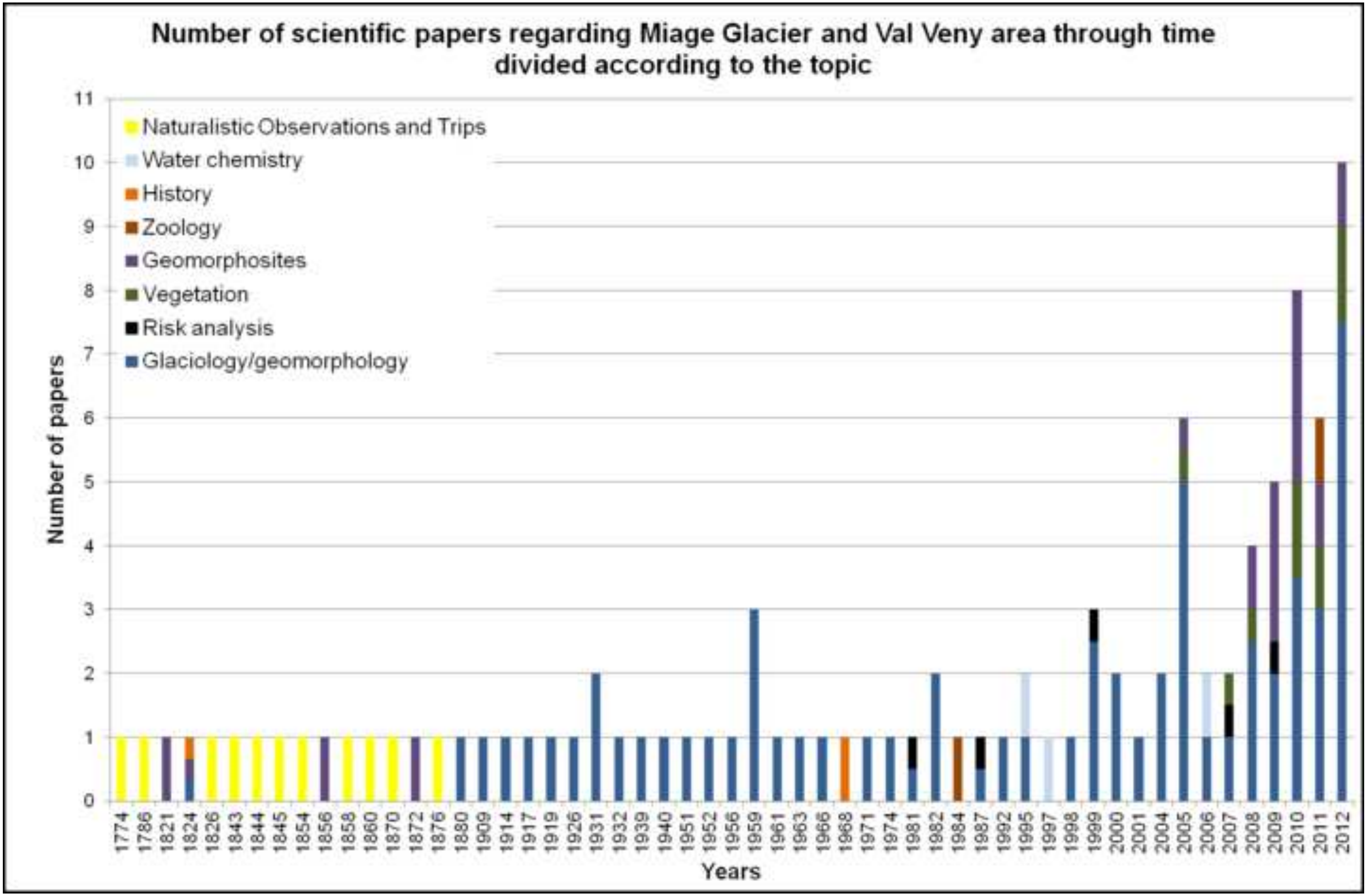

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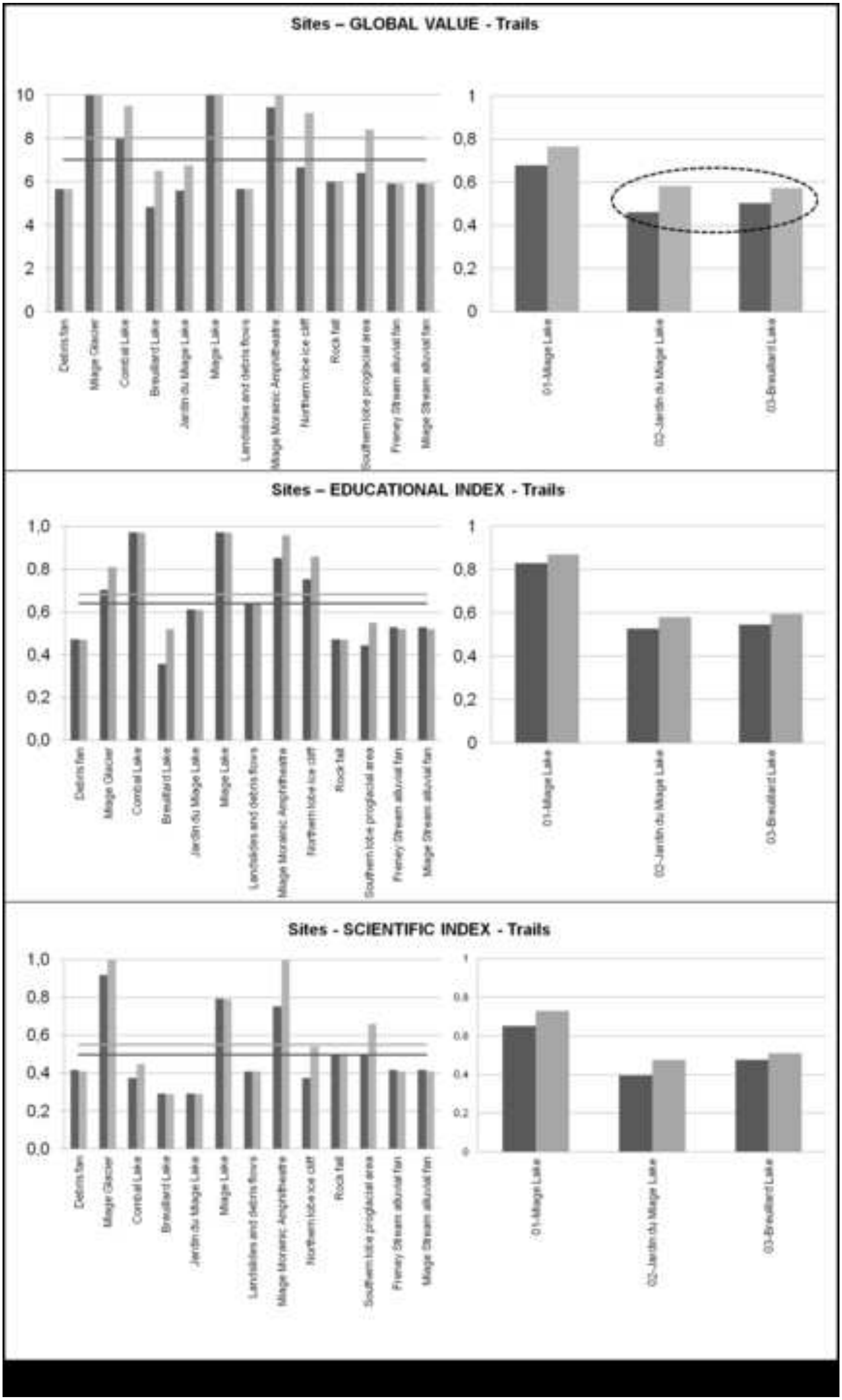

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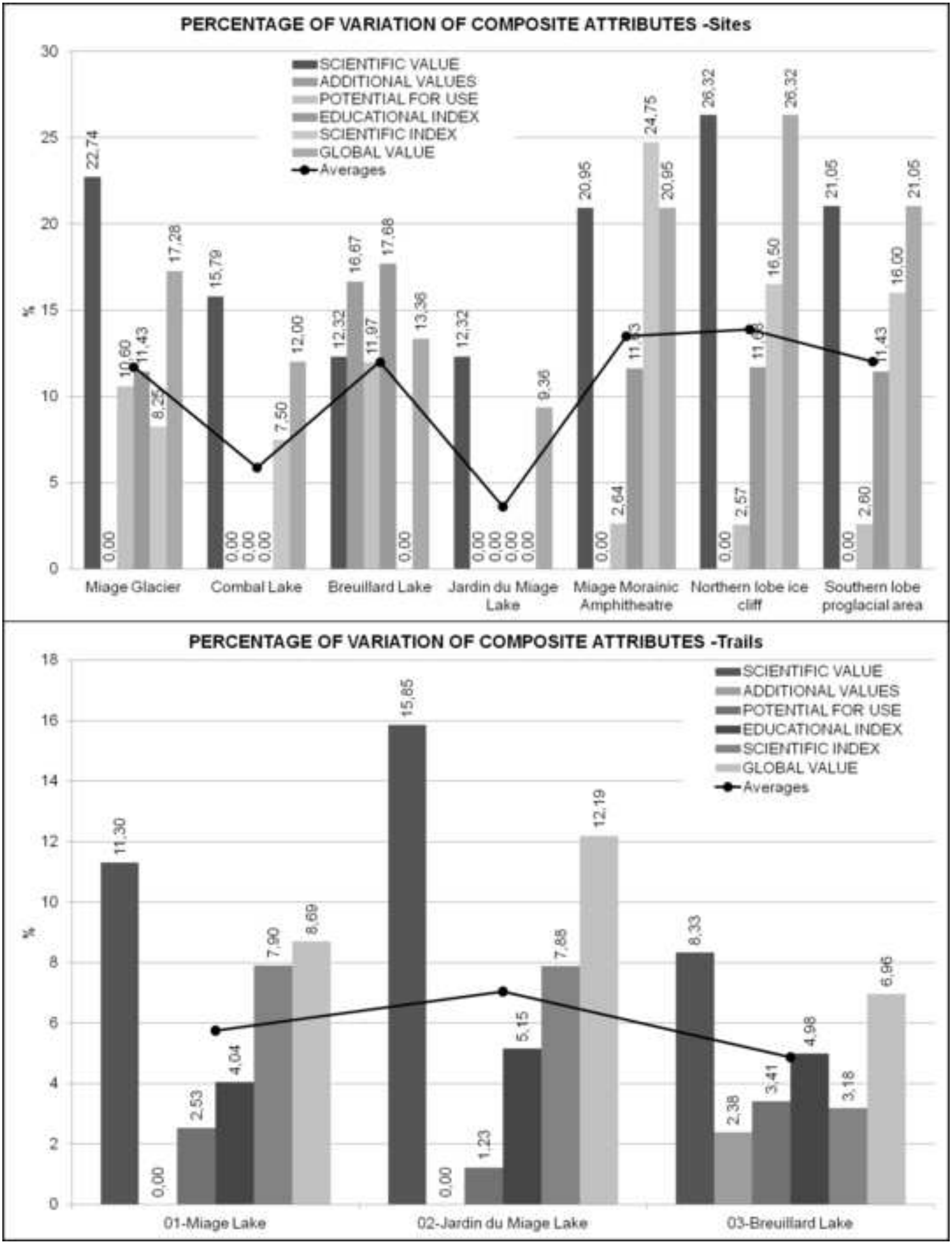

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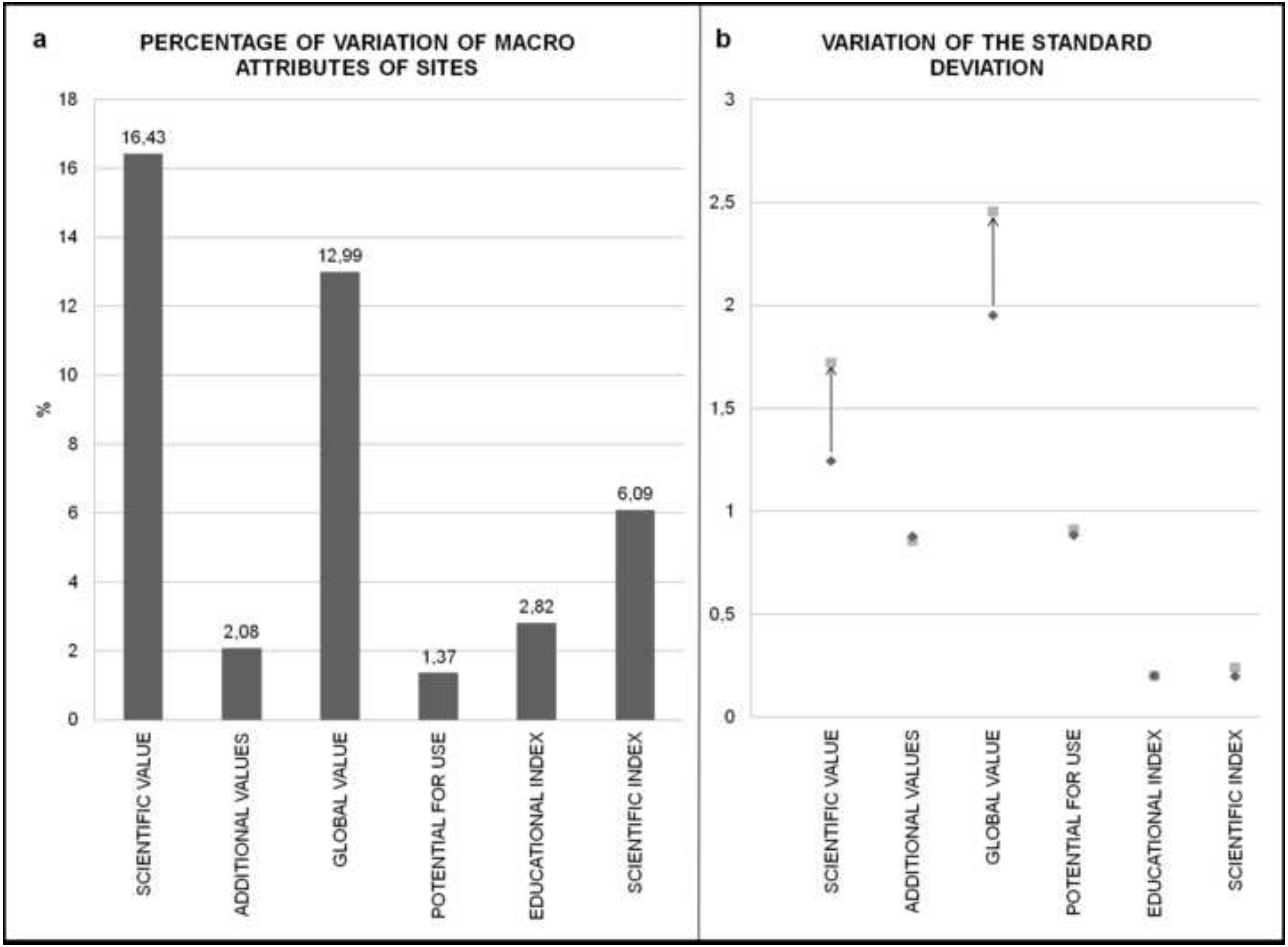

Table 1

SCIENTIFIC VALUE	*ADDITIONAL VALUE*
Ecological value as support for living nature: (Panizza 2001; Bollati et al. 2012), especially in sensitive contexts (Quaranta 1992; Carton et al. 1994; Rivas et al. 1997; Panizza 2001; Panizza and Piacente 2003; Gray 2004; Pralong 2005; Pralong and Reynard 2005; Pelfini et al. 2010a; Garavaglia et al. 2010a). For some Authors the whole landscape may be considered as living organism (Romani 1994). <u>Other terms</u>: Functional value (Gray 2004) Naturalistic value: (Brancucci et al. 1999)	Barca and Di Gregorio (1991); Hooke (1994); Coratza and Giusti (2005); Specific category: *Ecological Impact Criterion* **-** EcI (Reynard et al. 2007; Pereira et al. 2008).

Table 2

A. ATTRIBUTES (SINGLE VALUES)		
Scientific value (SV)	**Potential for use (PU)**	
Model of geomorphological evolution (representativeness)-GM	Temporal accessibility TA	
Model of palaeogeomorphological evolution-PgM	Services-Se	
Educational exemplarity-EE	Visibility-Vi	
Spatial extension-SE	Number of tourists-NT	
Geodiversity-Gd	Sport activities-OA	
Geo-historical importance-GI	Legal constraints-LC	
Ecologic support role-ESR	Use of geomorphological/geological interest UGI	
Other geological interests-OI	Use of the additional interest UAI	
Integrity-In	Presence of geomorphosites in the surroundings SGs	
Rareness-Ra	Spatial accessibility-SA	Calculated Accessibility-CA
		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

B. QUANTITATIVE CRITERIA FOR EVALUATION OF ECOLOGIC SUPPORT ROLE	
0	Without any connection with the biologic element
0,33	Presence of interesting flora and fauna
0,67	The geomorphological features condition/favour the ecosystems
1	The geomorphological features determine the ecosystems

C. FORMULA FOR CALCULATING COMPOSITE VALUES

CALCULATED VALUES	EQUATION	Conditions	Ranges
SV	SV = (GM + PgM + EE + SE + Gd + GI + ESR+ OI + In + Ra)		0,5-10
AV	AV = (C + Ae + SE)		0-3
GV	GV = (SV + AV)		0,5-13
Index of use	IU = EE + SE + Ae		0-3
PU s.s.	PUss = (TA + Vi + Se + NT + SA + LC + UGI + UAI + SGs)		0,25-9
PPU	PPU = (PUss + IU)		0,25-12
CA	CA = (Ti + St + Sl + Wi + GM + WSP + SI + SM + DC+ HI + TI)	SAc ≤ 0,4	0-11
A_Factor_c	AFc = ((CA/11)+(SAc/0.4))/2	SAc ≥ 0,6	0,25-1
A_Factor_s	AFs = (1+(SAc/1))/2		0,8-1
PU (on-foot trails)	PUc = PPU + AFc		0,5-13
PU	PUs = PPU + AFs		1,05-13
Scientific Index	SIn= (GM + PgM + GI + OI)/4		0-1
Educational Index	EIn= [EE + Ae + (A_Factor_c/s)]/3		0,083-1
ITINERARY			
	(Σ SCIENTIFICs / n° sites)*MAX		0-1
	(Σ ADDITIONALs / n° sites)*MAX		0-1
	(Σ GLOBALs / n° sites)*MAX		0-1
	(Σ POTENTIAL FOR USEs / n° sites)*MAX		0-1
	(Σ SCIENTIFIC INDEX / n° sites)*MAX		0-1
	(Σ EDUCATIONAL INDEX / n° sites)*MAX		0-1

Table 3

SCIENTIFIC PRODUCTION DERIVING FROM INTEGRATION OF BIOLOGICAL AND ABIOLOGICAL DATA		
FRAMEWORK	REFERENCES	HIGHLIGHTS
Supraglacial vegetation and glaciological data	Pelfini et al. 2007	Identification and dating of different growth anomalies (e.g. pointer years, compression wood, abrupt growth changes) allowed the individuation of simultaneous presence of different disturbance indicators but not contemporarily on the two glacier lobes. The results fit with glaciological data documenting volume and surface-level variations in the same period.
	Leonelli & Pelfini 2012	The temporal analysis of abrupt growth changes (AGCs) confirmed a period of higher glacier surface instability, reaching a maximum in the years 1988 (on lobe S) and 1989 (on lobe N), probably related to the passage of a kinematic wave within the glacier tongue. AGCs >+70% and >+40% are suggested as a proxy for substrate instability in spatio-temporal reconstructions in the Alpine environment.
	Caccianiga et al. 2011	Biodiversity on the debris coverage were quantified through observing species assemblages that are comparable with those of subalpine glacier forelands, but with the addition of high-altitude species.
Trees at the ice cliffs and glaciological data	Pelfini et al. 2012	Analysis of tree age and tree distribution patterns on the glacier tongue, especially near at the ice cliffs of northern and southern lobes, suggested that a large number of trees die under conditions of dominating back-wasting on the northern lobe, instead, in the case of prevalence of down-wasting, as on the southern lobe, trees more easily survive and flow downvalley transported by the glacier flux.
Proglacial vegetation and glaciological data	Garavaglia et al. 2010b	Dating scars, compression wood and rings width variations allowed the individuation of areas directly affected by glacial discharge or by boulders falling from the glacier front. The concentration in specific years indicated an intensification of glacial activity influencing the forest vegetation.
Miage Morainic amphitheatre dating and geomorphological data	Deline 1999	Morainic geometry analysis with dating methods (dendrochronology, lichenometry, radio dating, soil analysis) allowed the individuation of a succession of glacier overflowing phases over the right lateral moraine and of heightening phases of the moraines (by superposition) during the Late Holocene, except for the older base of the morainic amphitheatre. The Litte Ice Age contribution was précised.
	Deline & Orombelli 2005	Integration of data presented by Deline (1999), with digging and coring in intermorainic depressions of the MMA and through a deep core drilling in a dammed-lake infill (Combal), allowed the proposal of The 'Neoglacial model'. It considers the MMA as formed during the whole Neoglacial by a succession of glacier advances and during the LIA, separated by raising phases of the right-lateral moraine by active dumping because of the Miage debris coverage.
Drowned vegetation at Lac du Jardin du Miage and glaciological data	Astrade et al. 2012	Abrupt growth decrease was individuated into the tree rings of the drowned trees at Lac du Jardin du Miage as a response to water level changes.
SCIENTIFIC PRODUCTION LINKING VEGETATION DATA WITH GEOMORPHOSITES CONCEPTS		
FRAMEWORK	REFERENCES	HIGHLIGHTS
Supraglacial vegetation and geomorphosite evaluation	Pelfini et al. 2005	Dendrochronology analysis on supraglacial vegetation allowed the determination of link with debris coverage that increment the ecological value of Miage as geomorphosite.
Supraglacial and proglacial vegetation influencing geomorphosite evaluation	Garavaglia et al. 2010a	Investigating trees which colonize the glacial forefield of debris free glaciers and the debris coverage of DCG allowed to quantify the effects of climate change on tree colonization and to assess the creation of new geomorphosites increasing geodiversity in proglacial areas.
Supraglacial vegetation and dating of morainic ridges influencing geomorphosite evaluation	Pelfini et al. 2010a	The dendroglaciological analysis allowed the assessment of the importance of trees in analyzing the present glacier dynamics and, as a consequence, to contribute to the scientific evaluation of a geomorphosite in term of rarity, ecological and educational attributes.

Table 4

Sites rank – Global value	*Not considering data on ESR*	*Considering data on ESR*
01	Miage Glacier	Miage Glacier
02	Miage Lake	Miage Morainic Amphitheatre
03	Miage Morainic Amphitheatre	Miage Lake
04	Combal Lake	Combal Lake
05	Northern lobe ice cliff	Northern lobe ice cliff
06	Southern lobe proglacial area	Southern lobe proglacial area
07	Rock fall	Jardin du Miage Lake
08	Freney Stream alluvial fan	Breuillard Lake
09	Miage Stream alluvial fan	Rock fall
10	Debris fan	Freney Stream alluvial fan
11	Landslides and debris flows	Miage Stream alluvial fan
12	Jardin du Miage Lake	Debris fan
13	Breuillard Lake	Landslides and debris flows
Trails rank – Global value	*Not considering data on ESR*	*Considering data on ESR*
01	01-Miage Lake	01-Miage Lake
02	03- Breuillard Lake	02- Jardin du Miage Lake
03	02- Jardin du Miage Lake	03- Breuillard Lake