Vegetation outlines of two active rock glaciers with contrasting lithology

D. Tampucci$^1$, G. Boffa$^1$, F. Mangili$^1$, M. Gobbi$^2$, M. Caccianiga$^1$

$^1$Department of Biosciences, University of Milano, Via Celoria 26, I-20133 Milano, Italy.
$^2$Department of Invertebrate Zoology and Hydrobiology, MUSE - Museo delle Scienze, Corso del Lavoro e della Scienza 3, I-38123 Trento, Italy.

Abstract
Rock glaciers are periglacial landforms consisting of coarse debris with interstitial ice or ice core, characterized by creeping due to ice deformation. These landforms are drawing the attention of plant ecologist as harsh habitats and potential refugia in the global change context. Our aim was to describe the vegetation outlines of two active rock glaciers of the Ortles-Cevedale Massif (Central Italian Alps) on different substrates (silicate and carbonate) and compare them with the neighboring stable slopes and scree slopes. Two hypotheses were tested: 1) rock glaciers differ from the surrounding landforms for the presence of cold-adapted plant communities; 2) rock glacier plant communities indicate similar microclimatic conditions in spite of the contrasting lithology. Data were collected by phytosociological method performing 80 relevés of 25 m$^2$. Plant communities were compared by a cluster analysis based on the presence/absence species matrix and species relative frequencies for each landform were calculated. The cluster analysis separated first for all the two sites; afterwards, the landforms were differently discerned each other depending on the site. Despite the remarkable floristic differences due to the substrate, the vegetation of both rock glaciers suggest a general adjustment to cold-moist microclimate and long-lasting snow cover, differentiating more or less evidently from the adjacent scree slopes and enhancing the survival of nival entities at the elevation of alpine grasslands.

Key words: alpine flora, alpine vegetation, climate change, periglacial, permafrost, refugia, scree slope.

Introduction

Rock glaciers are periglacial landforms consisting of coarse debris with interstitial ice or ice core, characterized by creeping due to ice deformation (Barsch, 1996; Janke et al., 2013). These landforms are one of the most evident expressions of permafrost in mountain regions. They are theoretically located between the lower permafrost limit and the equilibrium line of the glaciers, an altitudinal belt well expressed in cold and dry climates that tends to shrink in response to temperature and precipitations increase (Barsch, 1996; Haeblerli, 1985). Consequently, rock glaciers gravitate towards continental ranges like the inner Alps, even though the relative contribution of debris and snow at topoclimatic scale seems to have a major role in driving their distribution rather than regional climate itself (Humlum, 1998). Ice deformation gives rock glaciers a creep movement similar to that of glaciers but slower (generally less than 1 m/y). There are three types of rock glaciers depending on dynamic and ice presence: active (with ice and creeping, located in contexts compatible with permafrost); inactive (with ice, but static for climatic or geomorphological reasons); relic (iceless and static, found in conditions no more compatible with permafrost and linked to past climate conditions) (Barsch, 1996; Haeblerli, 1985).

In the last decade, rock glaciers have drawn the attention of ecologists and botanists. Indeed, these landforms host communities adapted to harsh ecological conditions and are supposed to assume a biogeographical role in relation with climatic variations. In the matter of that, rock glaciers were proposed as potential refugia for high alpine plants and animals during the warm stages of the Holocene, as consequence of their microclimate and thermal inertia (Gentili et al., 2015; Gobbi et al., 2014; Millar & Westfall, 2010; Millar et al., 2013), a role similar to that already hypothesized for debris-covered glaciers (Caccianiga et al., 2011; Gentili et al., 2015; Gobbi et al., 2011).

Previous knowledge about the vegetation of alpine rock glaciers come from the studies of Cannone & Gerdol (2003) in the area of Livigno-Bormiese (Central Italian Alps) and Burga et al. (2004) in the area of Piz Corvatsch (Switzerland). These authors reported pioneer communities generally attributable to the order Androsaceta alpinae (associations Sieversio-Oxyrietum digynae and Androsacetum alpinae following Burga et al., 2004), with plants adapted to mechanical disturbance also recurring on scree slopes, glacier forelands and recent moraines. Vegetation cover and floristic composition depend mainly on substrate particle-size and movement intensity. Active rock glaciers are almost unvegetated, with sporadic glareicolous plants concentrated overall in the peripheral zones, where the surface movement is slower.
and fine-grained material is available. Instead, inactive and relict rock glaciers tend to be colonized by the typical species of alpine grasslands and snow-patches communities, or even by subalpine shrubs and trees at lower elevations. Rieg et al. (2012), analyzing four active rock glaciers in Stubai and Ortal Alps (Tyrol, Austria), found a threshold of 1.5 m/y for surface velocity: below this value plants cover depends on fine-grain availability, while over that limit the vegetation is heavily affected by ground instability. Coherently, Gobbi et al. (2014) identify grain-size as main driver of species distribution, highlighting the correlation with organic matter availability. In the same paper, the thermal regime of rock glacier was analyzed and evaluated as further limiting factor in plant colonization.

However, the vegetation features of alpine rock glaciers deserve further researches, since the few available studies concern only silicate substrates and the comparison with other high alpine landforms were not always in-depth analyzed. Our aim was to describe the vegetation of two active rock glaciers on different substrates (silicate and carbonate) and compare them with the neighboring stable slopes and scree slopes. Two hypothesis were tested: 1) rock glaciers differ from the surrounding landforms for the presence of cold-adapted plant communities; 2) rock glacier plant communities indicate similar microclimatic conditions in spite of the contrasting lithology.

Study area

The analyzed rock glaciers are located in two valleys belonging to the Ortles-Cevedale Massif (II/C-28.I-A in Marazzi, 2005), within the area of Stelvio National Park (Italy): Val d’Ultimo and Valle del Braulio. The sites are less than 32 km apart and no geographical barriers occurs between them, so they can be considered part of the same floristic context (Northeastern Alps subsection in Blasi et al., 2015).

Val d’Ultimo (South Tyrol) is a NE-SW oriented valley extended from the basin of Merano to the Giogo Nero pass. The examined rock glacier (“Lago Lungo”, 46° 27.435’ N, 10° 48.985’ E) (fig. 1a) is located in the Group of Gioveretto-Sternai (II/C-28.I-A.3.c in Marazzi, 2005). It is a multilobe tongue-shaped rock glacier fed by acid silicate debris (micaschist and ortogneiss of “Unità di Pejo”) that leans against a NW-facing glacial cirque, between 2500 and 2650 m a.s.l. The site is surrounded by imposing talus and until the first decades of 20th century was occupied by the namesake glacier, now reduced to a little mass of dead-ice completely debris-covered (Artoni, 1992; Bonardi et al., 2012; Montrasio et al., 2012).

Since the examined landforms stand at comparable elevation with similar values of aspect and slope, the main ecological difference between them lies in the bedrock. Temperatures and precipitations within the period 1983-2012 were analyzed using the records provided by Meteo Service of the Province of Bolzano for Val d’Ultimo (station of Fontana Bianca, 1900 m a.s.l.) (fig. 2a) and ARPA Lombardia for Valle del Braulio (station of Bormio, 1225 m a.s.l.) (fig. 2b). Calculating the Rivas-Martinez Index of thermal continentality (Rivas-Martinez & Rivas-Saenz, 1996-2009) and the Gams Index of hygric continentality (Oenzada, 1985), both areas results characterized by the typical continental climate of the inner Alps (respectively: 27.37 and 60.96° for Val d’Ultimo and 25.41 and 58.00° for Valle del Braulio).

Methods

Data were collected between July and August 2014. 80 vegetation relevés were performed by phytosociological method with the Braun-Blanquet scale as modified by Pignatti (1952) on three landforms for each area: stable slope (soil without ice), scree slope (debris without ice) and rock glacier (debris with ice). All the relevés were performed on 25 m² surfaces. Such value allows a homogeneous and representative sampling of the main object of our research, glareicolous vegetation of rock glaciers and scree slopes. On alpine grasslands, the micro-topographic pattern causes floristic variability at small (few centimeters) scale. Such variability, intrinsic of these communities, could be overlooked by our sampling strategy: for this reason, we performed a high-rank phytosociological outline of these communities. Relevés were compared by a cluster analysis based on the presence/absence species matrix, using the UPGMA method with Jaccard dissimilarity index. The conventional dissimilarity value of 0.75 was assumed as lower threshold for the admission of an association, according to Mueller-Dombois & Ellenberg (1974). Species relative frequencies for each landform, regardless the clustering, were calculated and gathered in 5 frequency classes with resolution of 20%. We also compared our data with that collected in the previous studies (Burga et al., 2004; Cannone & Gerdol, 2003; Gobbi et al., 2014; Rieg et al., 2012).
Vegetation of rock glaciers


Results

We identified 118 vascular plant species in total. 71 plant species were found both in Val d’Ultimo and Valle del Braulio (47 mutually exclusive and 24 shared). It was possible to describe five clusters with dissimilarity index > 0.75 (fig. 3). The main dichotomy detected by cluster analysis was the one between the two investigated sites, afterwards the landforms were differently discerned each other depending on the site. Concerning Val d’Ultimo, the dendrogram separated at first the stable slope from the remaining landforms, but inside the latter group another partition between rock glacier and scree slope was well recognizable. Concerning Valle del Braulio, the cluster analysis distinguished only stable slopes, without a clear split between rock glacier...
Cluster 1.1: stable slope on silicate substrate

The stable slope of Val d’Ultimo (fig. 4) is a seamless patchwork of humps and hollows covered by a continuous alpine grassland. Carex curvula and Anthoxanthum alpinum dominate the community, with a scarce shrubby layer of Loiseleuria procumbens, Vaccinium gaultherioides and Rhododendron ferrugineum. Locally, canopy overlapping may be quite high and species like Potentilla aurea, Leontodon helveticus, Ligusticum mutellina, Homogyne alpina and Soldanella alpica can reach remarkable cover values. The micro-topographic pattern at centimeter scale allows the coexistence of hummock species (e.g. Loiseleuria procumbens and Vaccinium gaultherioides) and snow-bed elements (e.g. Primula glutinosa and Gnaphalium supinum). Such situation made difficult a phytosociological outline at the association level, but the community could be ascribed to the alliance Caricion curvulae Br.-Bl. in Br.-Bl. et Jenny 1926.

Cluster 1.2: scree slope on silicate substrate

The scree slope of Val d’Ultimo (fig. 5) includes a wide range of particle size and hosts a scattered glaericolous vegetation rather rich in species. Among the preferential elements, Geum reptans, Oxyria digyna, Saxifraga seguieri, Saxifraga oppositifolia, Silene acaulis and Pritzelago brevicaulis are the most frequent. Luzula alpino-pilosa, Poa laxa, Saxifraga bryoides and Cerastium uniflorum are likewise widespread and abundant, but all shared with the cluster 1.3. Species assemblage is ascribable to the association Sieversio-Oxyrietum digynae Friedel 1956 em. Englisch et al. 1993 for the dominance and constancy of Geum reptans and Oxyria digyna. Some element of...
Vegetation of rock glaciers

Salicetea herbaceae Br.-Bl. in Br.-Bl. et Jenny 1926 like Soldanella alpica, Sedum alpestre and Veronica alpina are also present where fine-grained material is available.

Cluster 1.3: rock glacier on silicate substrate

On the rock glacier of Val d’Ultimo (fig. 6) vegetation changes notably depending on geomorphological situation, with few species occurring with high frequency: Luzula alpino-pilosa, Poa laxa, Saxifraga bryoides, Cerastium uniflorum and Doronicum clusii. Plant cover on the surface is mainly represented by sporadic individuals growing among coarse boulders, or patches of herbaceous vegetation on pockets of fine-grained substrate (relevés 131A, 131B, 131C, 132A, 132B, 134B, 134C, 135B). On the slopes and the edges, the vegetation is more rich and dense, probably in response to higher stability and presence of fine-grained material. In these zones, the above mentioned assemblage includes some typical element of the stable environments, as Carex curvula, Agrostis rupestris, Festuca halleri, Campanula scheuchzeri, Senecio carniolicus and Erigeron uniflorus, locally accompanied by Rhododendron ferrugineum and Salix serpyllifolia (relevés 132B, 133A, 133B, 133C). The community is roughly attributable to the alliance Androsacion alpinae Br.-Bl. in Br.-Bl. et Jenny 1926, with low frequency of species belonging to Caricetea curvulae Br.-Bl. 1948 and Salicetea herbaceae Br.-Bl. in Br.-Bl. et Jenny 1926, while the characteristic elements of Sieversio-Oxyrietum digynae are totally absent.

Cluster 2.1: stable slope on carbonate substrate

The stable slope of Valle del Braulio (fig. 7) is colonized by a fragmented alpine grassland alternated with outcrops and debris, locally interrupted by ample hollows. The community is dominated by Carex firma, Sesleria caerulea and Dryas octopetala, with a conspicuous group of low-covering exclusive species: Saxifraga caesia, Agrostis alpina, Carex ornithopoda, Minuartia verna, Helianthemum alpestre, Anthyllis vulneraria, Draba aizoides, Sedum atratum, Polygonum viviparum, Aster bellidiastrum, Bartsia alpina, ecc. Such plant assemblage is ascribable to the alliance Caricion firmae Gams 1936 (relevés 211A, 211B, 212A, 212B, 212C, 213A, 213B, 213C). In the depressions, the above mentioned species sharply decrease and are replaced by high cover of Silene acaulis, Ranunculus alpestris and Soldanella alpina, with Gnaphalium hoppeanum and other sporadic species of Arabidion caeruleae Br.-Bl. in Br.-Bl. et Jenny 1926 (relevés 214A, 214B, 215A, 215B, 215C and to a lesser extent 211C, 214C).

Cluster 2.2: scree slope and rock glacier on carbonate substrate

On the unstable substrates of Valle del Braulio, plant cover is scarce or absent, with isolated individuals even where fine-grained material is available. Even
though two clusters are recognizable, their dissimilarity index is < 0.75 and the lack of a clear distinction between scree slope and rock glacier brings us to attribute the whole community to the same association: *Papaveretum rhaetici* Wikus 1959. The two landform are joined by the constant presence of *Poa minor*, *Arabis alpina* and *Arabis pumila*, but the relative frequency of other species shows some difference. The scree slope (fig. 8) is colonized by a well-expressed *Papaveretum rhaetici*, where *Papaver aurantiacum*, *Saxifraga aphylla*, *Pritzelago alpina* and *Moehringia ciliata* are widespread (relevés 221A, 221B, 221C, 222A, 222B, 222C, 223A, 223B, 224A, 224B, 224C). The rock glacier (fig. 9) shows a lower frequency and abundance of these elements and is better characterized by the exclusive coexistence of *Arabis caerulea* and *Saxifraga oppositifolia*, both rare on stable slope and scree slope respectively (relevés 232A, 232B, 232C, 233A, 233B, 233C, 234B, 234C, 235B). Species richness reaches the highest values on the peripheral zones of the rock glacier, where the elements of both aspects equally coexist (relevés 231A, 231B, 231C and to a lesser extent 234A).

**Discussion**

The nature of the bedrock appears to be the main factor influencing floristic composition of the studied landforms. Cluster analysis clearly grouped relevés as a function of the study site rather than of the different landforms. Being our study sites very close to each other, without geographical barrier between them and located at similar elevation, aspect and slope, the different floristic composition can be attributed to the different substrate. The landforms could be discriminated only within each site, with stable slopes always clearly different from scree slopes and rock glaciers.

Particularly interesting is the comparison between scree slopes and rock glaciers, environments similar to each other but except for the occurrence of ice. In Val d’Ultimo the difference between these two landforms emerges at the community level, with *Sieversio-Oxyrietum digynae* on the scree slope and an *Androsacion alpinae* community on the rock glacier. The latter looks like a transition toward the association *Luzuletum spadiceae* Rübel 1911 (class *Salicetea herbaceae*) for the dominance of *Luzula alpino-pilosa* and the elective presence of *Doronicum clusii*, even though the scarcity of characteristic species of the class make this collocation uncertain. *Luzuletum spadiceae* is strictly linked to silicate coarse substrates at high elevation, and is considered as an indicator of low temperatures during the whole year and snow permanence up to 8-9 months (Giacomini & Pignatti, 1955; Grabherr & Mucina, 1993; Oberdorfer, 1977). In summary, the community detected on the rock glacier could be interpreted either as an *Androsacion alpinae* conditioned by cold-moist microclimate and long-lasting snow cover or as a species-poor aspect of *Luzuletum spadiceae* where the elements of *Salicetea herbaceae* are limited by the unavailability of fine-grained substrate. However, both cases implicate the crucial role of microclimate in determining this plant assemblage. This result contrasts with the previous studies on silicate rock glaciers (Burga *et al.*, 2004; Cannone & Gerdol, 2003; Gobbi *et al.*, 2014; Rieg *et al.*, 2012), where the high frequencies of *Oxyria digyna* and *Geum reptans* and the lack of *Luzula alpino-pilosa* and *Doronicum clusii* allow the attribution of the vegetation cover to *Oxyrietum digyna*. A better knowledge of the whole vegetation contest of these rock glaciers, including the surrounding landforms, is necessary for an ecological interpretation of such difference.

Concerning Valle del Braulio, the communities of scree slope and rock glacier are very similar and both attributable to *Papaveretum rhaetici*, but some floristic difference emerges analyzing the distribution of single species. Particularly interesting is the exclusive coexistence of *Arabis caerulea* and *Saxifraga oppositifolia* on the rock glacier, a plant assemblage to our
Tab. 2 - Synoptic table of mean relevés values and species frequency classes for each landform (I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%).

<table>
<thead>
<tr>
<th>Shrub cover (%)</th>
<th>Herbaceous cover (%)</th>
<th>Bryophytes and lichens cover (%)</th>
<th>Outcrop cover (%)</th>
<th>Debris cover (%)</th>
<th>Soil cover (%)</th>
<th>Species richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>65</td>
<td>60</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shrub cover (%)</th>
<th>Herbaceous cover (%)</th>
<th>Bryophytes and lichens cover (%)</th>
<th>Outcrop cover (%)</th>
<th>Debris cover (%)</th>
<th>Soil cover (%)</th>
<th>Species richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>65</td>
<td>60</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vegetation of rock glaciers</th>
<th>Val d’Ultimo</th>
<th>Valle del Braulio</th>
<th>Total species richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total species richness</td>
<td>45 43 30</td>
<td>60 20 24</td>
<td></td>
</tr>
</tbody>
</table>
knowledge never evaluated before within Thlaspietalia rotundifolii. Arabis caerulea is the characteristic species of Arabidetum caeruleae Br.-Bl. 1918, typical of snowbeds on carbonate substrates (Giacomini & Pignatti, 1955; Grabherr & Mucina, 1993; Oberdorfer, 1977). Saxifraga oppositifolia is a glareicolous plant widespread on many different substrates, provided the suitable elevation (Aeschimann et al., 2004; Landolt et al., 2010; Pignatti, 1982; Webb & Gornall, 1989). Although the syntaxonomical interpretation of these species could be unclear, their ecological information appears evident, since both find their optimum in cold and moist habitats typical of the nival belt. In our case the presence of Arabis caerulea and Saxifraga oppositifolia was not sufficient to discriminate a well-defined community, but collecting data from further carbonate sites, it would be probably possible to formalize a new variant of the association Papaveretum rhaetici Wikus 1959 differentiated by these species as plausible indicators of cold and moist microclimates.

Therefore, in spite of the remarkable floristic differences due to the substrate, the vegetation of both rock glaciers suggest a general adjustment to cold-moist microclimate and long-lasting snow cover, differentiating more or less evidently from the adjacent scree slopes and enhancing the survival of nival entities at the elevation of alpine grasslands. The role of microclimatic heterogeneity in matter of refugia is more and more acknowledged (Ashcroft et al., 2012; Birks & Willis, 2008; Dobrowski 2011; Rull, 2009; Stewart et al., 2010). Active rock glaciers seem to increase the environmental variability between alpine and nival belts at the landscape level, providing potential warm-stage refugia for cold-adapted species. Our observations may thus establish a basis for further researches about rock glaciers plant communities, focused on the ecological and biogeographical significance of these landforms in the global change context.

Acknowledgements

We thank Valeria Lencioni of MUSE - Museo delle Scienze, Trento, Luca Pedrotti of Stelvio National Park, Roberto Seppi, Claudio Smiraglia, Alfredo Bini and Manuela Pelfini for their geomorphological expert advices, Chiara Compostella, Guido Stefano Mariangeli, Gianalberto Losapio, Maddalena Raffaela Althea Angeleri, Clara Citterio, Chiara Maffioletti and Ilaria Alice Muzzolon for their collaboration in sampling sessions and data analysis. The research is part of the PhD project of the first author “DT” and it was co-financed by Stelvio National Park and MUSE - Museo delle Scienze.
References


<table>
<thead>
<tr>
<th>Sample</th>
<th>Time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>05.08.2014</td>
<td>N46 27.553</td>
<td>E10 48.868</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>06.08.2014</td>
<td>N46 30.019</td>
<td>E10 24.072</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>07.08.2014</td>
<td>N46 30.019</td>
<td>E10 24.072</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>08.08.2014</td>
<td>N46 30.019</td>
<td>E10 24.072</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: The table above lists sample locations and their respective dates, latitudes, and longitudes.*