Giulia Tomasi[1], Alessio Bertolli[1], Filippo Prosser[1], Costanza Geppert[2], Lorenzo Marini[2]

Alpine flora at the extremes: the distribution of plants vascular plants and bryophytes mountain peaks in Trentino, Italy

[1] Fondazione Museo Civico di Rovereto, Borgo Santa Caterina, 41, 38068, Rovereto, Trento, Italy
[2] DAFNAE, University of Padova, Viale dell'Università 16, 35020 Legnaro, Padova, Italy

Keywords: flora and bryophytes of Trentino, species migration, upper altitudinal limit, anthropogenic climate warming

Introduction

The Alps are among the European regions with the highest biodiversity; of the approximately 4,500 plant species (Aeschimann et al. 2004), 2,563 are spontaneous or naturalized species found in the province of Trento, and around 1,000 are alpine orophytes (Prosser et al. 2019). The numerous endemisms, 46 Italian exclusive endemisms that also concern Trentino (Bertolli et al. 2024), demonstrate the geological and climatic complexity that has caused isolation and adaptation phenomena to a diversified environment. In the Alps, the climate has warmed by about 1.8°C since 1880, almost double the global average (Zampieri et al. 2021). Climate models are particularly pessimistic for the southern Alps, where, in the worst-case scenario, an increase of more than 4°C is expected by the end of this century compared to the period 1981–2010 (Kotlarski et al. 2022). The evidence of a consequent enrichment of the summit vascular flora in the Alps has already been presented many years ago (Braun-Blanquet 1955). More recently, numerous medium- and long-term studies have confirmed that climate change is causing an altitudinal expansion of species, particularly in the summit areas of the Alps (Lamprecht et al. 2018). Prosser (et al. 2023) suggested that this phenomenon could be particularly evident in the south-eastern Alps.

Materials and Methods

The botanical section of the Fondazione Museo Civico di Rovereto, in collaboration with the DAFNAE Department of the University of Padua, began a study of summits above 2,700 meters above sea level in 2022–2023, sampling 27 representative peaks from different geographical areas and the main geological substrates of the province of Trento. The peaks are located between 2,745 and 3,757 meters in altitude in the Ortles-Cevedale Chain, Fassa and Gardena Dolomites, Adamello-Presanella Group, Pale di San Martino Group and Brenta Dolomites, all within protected areas and/or Nature Parks. The selection of the peaks to be studied took into account the following criteria: elevation (> 2700 m), location (as homogeneous as possible distribution across various mountain ranges), substrate (representative samples of various rock substrates), exposure (preferably south or east-facing ascent paths/tracks), and accessibility to the summit (peaks requiring high-level mountaineering skills were excluded from the study). Field data collection took place during the 2022 and 2023 growing seasons and resulted in the recording of 7,900 geo-referenced data points related to vascular plants and bryophytes. The survey followed a standardized protocol, divided into three sampling phases:

- Ascent sampling: In the last 200 meters below the summit, a transect was performed every 50 meters of elevation gain, recording the species list of both vascular plants and bryophytes visible along the main trail or access track (4 transects in total);

submitted: 29.04.2025
accepted: 30.06.2025

DOI: 10.5281/zenodo.17207780

- Summit area: A complete survey of the flora within a 20-meter radius from the summit cross (most of the summits had a cross or a marker; in the absence of one, the highest point was considered as the summit);
- Descent sampling: Along the main path, the first three populations of each species of vascular plants identified were mapped and geo-referenced up to 200 meters below the summit. For each population, information on size and reproductive status was collected.

Results

The 7,900 geo-referenced data points documented the presence of 295 vascular plant taxa and 161 species of bryophytes. Among these, 138 vascular plant and 72 bryophyte species were recorded above 3,000 meters. The comparison of the vascular plants recorded in this study with the whole flora of Trentino published by Prosser et al. (2019) showed that the summit flora has more orophytes and boreal species and less Eurasian and Mediterranean species. Regarding the life form spectrum, compared to the overall provincial flora, the summit flora shows more hemicryptophytes and chamaephytes, while geophytes and therophytes are less frequent (Figure 1).
With increasing elevation, the number of species decreased for both substrate types. The total number of species associated with sedimentary rocks was lower than the number of species associated with silicate (Figure 1). Interestingly, there were no limestone peaks without plant species even at the highest elevations, indicating that for several species there is no space for further upward expansions.
The study also established the maximum altitudinal record in the province of Trento for vascular plants at 3,607 meters above sea level (*Poa laxa* Haenke subsp. *laxa* on Punta Taviela) and for bryophytes at 3,757 meters (*Grimmia triformis* Carestia & De Not. on Zufallspitze/Cevedale). Compared to the known maximum limits for species in Trentino (Prosser et al. 2019), 229 taxa showed a higher altitude limit. In some cases, the elevation increase was over 500 m, such as for *Gymnocarpium dryopteris* (L.) Newman on Forcola, recorded at 3,295 meters (+625 m). We also observed a single individual of *Larix decidua* Mill. at 3,152 m on Lobbia Alta, which represents the maximum elevation for the entire species' range (Prosser et al. 2023). These records are partly related to climate change but also to incomplete records in the past. An analysis of the maximum elevation recorded for each species helped highlighting the preferred ascent paths of the species through morphological analysis in GIS. For the highest records, we observed an average exposure of the slope of c. 178°, and an average slope of c. 34°.

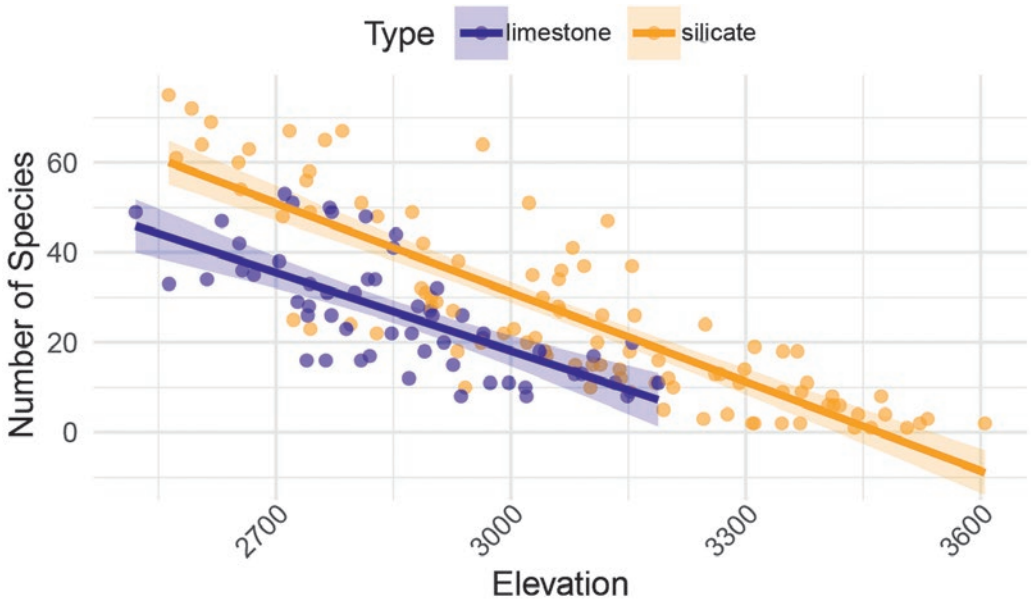

Figure 1: Effect of bedrock and elevation on plant species richness observed in the different elevation bands.

Discussion

The results show a clear decrease in species richness as one moves toward the summits, confirming the strong relationship between species distribution and temperature in mountain ecosystems (Vittoz et al. 2010). However, the rate of colonization of these areas by species characteristic of lower elevation belts has accelerated (Steinbauer et al. 2018), and similar trends were also evident in our case study. The rise in temperatures and the reduction of snow cover are favoring the altitudinal migration of generalist species. In contrast, specialist species at higher elevations are increasingly close to their physiological limits. The differences observed between limestone and siliceous substrates indicate that the availability of potential habitats for species migration is not uniform, with siliceous peaks still offering available empty niches compared to the limestone peaks. The chorological analysis revealed a predominance of orophytes, alpine and arctic-alpine endemics, with a clear differentiation between peaks on siliceous and limestone substrates. Limestone species showed greater altitudinal limitation compared to species from silicate bedrock, with a tendency for habitat saturation at higher elevations. Species with higher thermophilic and nitrophilic indices and a lower moisture index are expected to benefit from the predicted decrease in water availability, favoring their upward migration. Since the study was conducted systematically using a standardized protocol, it provides a solid foundation for advancing our knowledge of alpine flora dynamics in Italy. These semi-permanent plots will be essential for future monitoring aimed at investigating species range dynamics in response to climate warming. High-mountain ecosystems, and summits in particular, represent natural study sites that are easy to relocate, allowing for the collection of reliable time series data.

References

Aeschimann D., Lauber K., Moser D. M. & Theurillat J. P., 2004: Flora Alpina, 3 vol. Haupt, Bern/Zanichelli, Bologna.

Bertolli A. (ed.), Adorni M., Alessandrini A., Andreatta S., Ardenghi N. M. G., Argenti C., Bona E., Bovio M., Dellavedova R., Gallino B., Kleih M., Mainetti M., Martini F., Peccenini S., Prosser F., Scortegagna S., Selvaggi A., Tomasi G. & Wilhalm T., 2024: Flora endemica nel nord Italia. Athesia, Bolzano, 542 pp.

Braun-Blanquet J., 1955: Die Vegetation des Piz Languard, ein Massstab für Klimaänderungen. Svensk Botanisk Tidskrift, 49(1–2): 1–8.

Kotlarski S., Gobiet A., Morin S., Olefs M., Rajczak J. & Samacoïts R., 2022: 21st Century alpine climate change. Climate Dynamics. https://doi.org/10.1007/s00382-022-06303-3

Lamprecht A., Semenchuk P. R., Steinbauer K., Winkler M. & Pauli H., 2018: Climate change leads to accelerated transformation of high-elevation vegetation in the central Alps. New Phytologist, 220(2): 447–459. https://doi.org/10.1111/nph.15290

Prosser F., Bertolli A., Festi F. & Perazza G., 2019: Flora del Trentino. Ed. Osiride/Fondazione Museo Civico, Rovereto, 1211 pp.

Prosser F., Bertolli A. & Tomasi G., 2023: Changes in the flora of Lobbia Alta, a peak of the Adamello-Presanella Alps (Trento, Italy) between 1935 and 2021. Italian Botanist, 15: 9–20. https://doi.org/10.3897/italianbotanist.15.97630

Steinbauer M. J., Grytnes J., Jurasinski G., Kulonen A., Lenoir J., Pauli H., Rixen C., Winkler M., Bardy-Durchhalter M., Barni E., Bjorkman A. D., Breiner F. T., Burg S., Czortek P., Dawes M. A., Delimat A., Dullinger S., Erschbamer B., Felde V. A., Fernández-Arberas O., Fossheim K. F., Gómez-García D., Georges D., Grindrud E. T., Haider S., Haugum S. V., Henriksen H., Herreros M. J., Jaroszewicz B., Jaroszynska F., Kanka R., Kapfer J., Klanderud K., Kühn I., Lamprecht A., Matteodo M., Morra di Cella U., Normand S., Odland A., Olsen S. L., Palacio S., Petey M., Piscová V, Sedlakova B., Steinbauer K., Stöckli V., Svenning J. C., Teppa G., Theurillat J. P., Vittoz P., Woodin S. J., Zimmermann N. E .& Wipf S., 2018: Accelerated increase in plant species richness on mountain summits is linked to warming. Nature, 556: 231–234. doi:10.1038/s41586-018-0005-6

Vittoz P., Camenisch M., Mayor R., Miserere L., Vust M. & Theurillat J. P., 2010: Subalpine-nival gradient of species richness for vascular plants, bryophytes and lichens in the Swiss Inner Alps. Botanica Helvetica, 120(2): 139–149.

Zampieri M., Lionello P., & Matiu M., 2021: Recent warming trends in the Alps: A review. Climate Research, 83: 1–14. DOI: 10.3354/cr01652