Research Symposium
“Alpine plants: evolution and challenges of life at high altitudes”

125th anniversary
of the Schachen Alpine Garden

Proceedings

Botanischer Garten München-Nymphenburg
5-8 July 2026

Programme

July 5, 2026

Botanisches Institut

6:00 pm – 8:00 pm
Eröffnungsabend / Welcome Evening

- Jörg Overmann (Staatliche Naturwissenschaftliche Sammlungen Bayerns)
  Gudrun Kadereit (Botanische Sammlungen München)
  Begrüßung
- Andreas Gröger (Botanischer Garten München-Nymphenburg):
  Hochgebirgsgarten der ersten Generation: 125 Jahre Alpengarten auf dem Schachen (auf Deutsch / in German)
- Christian Körner (Universität Basel, Departement Umweltwissenschaften):
  Die Welt der Alpen im Wandel (auf Deutsch / in German)

July 6, 2026

Botanisches Institut

9:00 am – 12:00 am
Conference Session 1: **Dynamics of alpine environments**

- Keynote by Jake Alexander (ETH Zurich):
  "Why are range shifts of mountain plants not keeping up with climate change?"
- Jörg Ewald (Hochschule Weihenstephan-Triesdorf):
  "The response of Bavarian mountain forests to climate change"
- Simon Pfanzelt (Botanischer Garten München-Nymphenburg):
  "Genetic structuring of the carnivorous plant *Pinguicula alpina* (Lentibulariaceae) in the Bavarian Alps"
- Petr Sklenár (Faculty of Science, Charles University, Prague) et al.:
  "Tropical alpine plant life: contrasting flowering phenology between tropical and temperate alpine communities"

1:30 pm – 2:30 pm
<u>Poster Presentations</u>:

- Sarah Bürli (Botanical Garden of the University of Graz):
  "Germinating against the odds"
- Andreas Gröger (Botanischer Garten München-Nymphenburg) et al.:
  "Phenological Monitoring Programme: climate change research at the Schachen Alpine Garden"
- Lucie Holzbachová (Faculty of Science, Charles University, Prague) et al.:
  "Flower economic spectrum: A key to understanding the floral diversity of alpine plants"
- Thomas Kudernatsch (Bayerische Landesanstalt für Wald und Forstwirtschaft, Freising) et al.:
  "Denser and more diverse: vegetation change in unmanaged forests of the Calcareous Alps since the mid-1980s"
- Michelangelo Olleck (Hochschule Weihenstephan-Triesdorf, Mountain Ecosystem Research Group, Freising) et al.:
  "*Pinus mugo* krummholz: a candidate for biome shift?"
- Loretta Giuseppina Pace (Alpine Garden of Campo Imperatore-Gran Sasso, University of L'Aquila):
  "High-Altitude Nature Conservation: An Alpine Botanical Garden in the Middle of the Mediterranean region"
- Anna Pasinato (Systematics, Biodiversity and Evolution of Plants, LMU München) et al.:
  "Quaternary Evolution of the Bavarian Flora and Beyond: Genetic and Ecological Adaptation to Changing Environments"
- Špela Pungaršek (Slovenian Museum of Natural History, Ljubljana):
  "Hundred years of the Juliana Alpine Botanical Garden – a hundred years of change"
- Mihai Pușcaș (Alexandru Borza Botanic Garden, Babes-Bolyai University, Cluj-Napoca) et al.:
  "Alpine vegetation dynamics under climate change: insights from over more than two decades of monitoring in the Eastern Carpathians"

- Petr Sklenár (Faculty of Science, Charles University, Prague) et al.: "Biogeography, niche shifts, and trait evolution across orobiomes in *Caltha* sect. *Psychrophila* plant lineage "

2:30 pm – 5:30 pm
Conference Session 2: **Evolutionary history and diversity patterns in alpine ecosystems**

- Keynote by Felix Gugerli Künzle (Swiss Federal Research Institute WSL, Birmensdorf):
  "Genomic signatures of adaptation in plants in response to environmental variation in space and time"
- Marcus Koch (Center for Organismal Studies (COS), Biodiversity and Plant Systematics, Heidelberg University) et al.:
  "Ghosts and bedrock shift – past, present and future of the extremely rare alpine *Cochlearia excelsa* in Austria"
- Teresa Zeni (Department of Botany, University of Innsbruck):
  "Patterns of polyploid frequency in the Eastern Alps based on extensive sampling across elevational gradients"
- Michał Ronikier (Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw):
  "Alpine plants in the Carpathians: a high-mountain comparative phylogeography"
- Alptekin Koc (Faculty of science, Department of Botany, Charles University, Prague):
  "Reproductive strategies of tropical and temperate alpine plants: a comparison between the Ecuadorian Andes and the Rocky Mountains"

July 7, 2026

Excursions

Tour 1: **Alpengarten auf dem Schachen**

Tour 2: **Murnauer Moos**

July 8, 2026

Botanisches Institut

9:00 am – 1:00 pm
Conference Session 3: **Nature conservation and case studies at high altitudes**

- Keynote by Pau Canicero Campmany (Universitat Autónoma de Barcelona):
  "Drivers of intraspecific diversity in high-elevation plants: insights from the Iberian Peninsula to the Alps"
- Patrik Mráz (Department of Botany, Charles University, Prague) et al.:
  A natural laboratory of polyploid evolution: alpine *Pilosella rhodopea* as the largest diploid–autopolyploid contact zone in angiosperms
- Valentin Heimer (University of Innsbruck):
  "Polyploidy and hybridisation shaped the evolutionary history of *Luzula* sect. *Luzula* in the Eastern Alps"
- Elvira Hörandl (Dept. Systematics, Biodiversity, Evolution of Plants, University of Göttingen) et al.:
  "Speciation and biogeographical history in the European Alpine System: the radiation of *Ranunculus* sect. *Euromontani* (Ranunculaceae)"

- Francesco Dal Grande (Padua Botanical Garden & Dept. of Biology, University of Padua) et al.:
  “Alpine Botanical Gardens and the Future of Ex Situ Plant Conservation”
- Stefano Azzolini (MUSE - Museo delle Scienze, Trento) et al.:
  “Conservation actions for *Saxifraga tombeanensis* in the Italian Alps”
- Anna Janiczek (W. Szafer Institute of Botany Polish Academy of Sciences, Cracow) et al.:
  “Between the mountains and the polar zone: biogeography and evolutionary history of *Dryas octopetala* L.”

Abstracts

(in alphabetic order by the presenting author)

Why are range shifts of mountain plants not keeping up with climate change?

Jake Alexander

ETH Zürich, Switzerland

Climate warming is driving widespread shifts in species distributions, yet range expansions of many mountain plants lag behind the pace expected from changing temperatures. Understanding the mechanisms underlying range shift lags is essential both for predicting future range dynamics and for informing conservation management. I present work from our group that aims to develop a more mechanistic, demographic perspective on mountain plant range limits and range shifts. I focus on three classes of processes that may generate lags: dispersal limitation, establishment limitation, and extinction debt.

First, despite generally short dispersal distances and limited dispersal adaptations in many mountain species, observational data suggest that seeds are frequently transported substantial distances beyond current range edges by animals. However, transplant experiments indicate that while lowland species can establish on bare soil beyond their upper range limits, only around half can establish within intact vegetation, implying strong establishment limitation through competition and priority effects. These findings challenge classical expectations that biotic interactions weaken toward cold range margins.

Finally, warming-driven extinction lags in alpine plants may be prolonged by demographic inertia, although altered species interactions can also accelerate local population declines. Together, this work suggests that improved predictions of range shifts in mountain ecosystems require experimental tests of mechanisms, and integration of demographic processes into mechanistic models. Such understanding may also support proactive management approaches, including assisted migration for dispersal-constrained species whose persistence is threatened by climate change.

Conservation actions for *Saxifraga tombeanensis* in the Italian Alps.

Stefano Azzolini., Francesca Moret, Chiara Parisi, Sara Villa, Costantino Bonomi

Museo delle Scienze, Trento, Italy

Within the framework of the currently running LIFE Seedforce project (LIFE20/NAT/IT/001468 - Using SEED banks to restore and reinFORCE the endangered native plants of Italy), efforts are being made to improve the conservation status of *Saxifraga tombeanensis*, an Italian endemic species listed in Annex II of the Habitats Directive. This species is currently reported as Unfavorable - inadequate (U1=), as a matter of fact several populations have significantly declined in numbers and a few disappeared. Among the threats that affect this species the main one is the geographic isolation and the small size of the populations. In addition, the abandonment of coppicing practices, has led to the expansion of trees and shrubs that can partially shade the base of the rocky cliffs where this species grows, making it disappear in shaded part of the cliff.

Conservation actions include monitoring populations size, using modern techniques such as UAV, that allowed to survey cliff portions usually inaccessible with field surveys and returned significantly higher numbers with respect to traditional estimates. Plant propagation for restocking, mainly relied on cuttings that can reach significantly developed stages in two vegetative seasons. Propagation from seeds resulted particularly slow with at least 4 to 5 years to reach comparable results and with a very low survival rate after germination. Translocations required enlarging a crack in the cliff faces with a drill and placing in each drilled hole a small plant propagated in cell trays. So far initial translocations carried out in autumn reported very good survival rates.

Acknowledgements: Life Seedforce received funding by the Life Programme - The European Union funding instrument for the environment and climate action, under contract LIFE20/NAT/IT/001468.

Germinating against the odds

Sarah Bürli

Botanical Garden of the University of Graz, Austria

High elevation ecosystems are particularly sensitive to climate change. Recruitment from seeds is crucial for plant persistence in these ecosystems and their ability to shift towards higher elevations as global warming progresses. However, current understanding of recruitment dynamics under climate change is largely based on studies including common species solely, despite rare species contributing disproportionately to global plant diversity and potentially responding differently to environmental changes. This bias raises a key unresolved question: do predictions derived from common species adequately capture community-level responses to climate warming?

Addressing this gap requires integrating species rarity into both experimental and modeling frameworks. Here, we propose a research framework to investigate how climate change influences seedling recruitment across gradients of species rarity. The project combines an in-situ field experiment along a 1200 m elevation gradient, simulating global warming over the last and future decades, with Bayesian species distribution models to quantify shifts in recruitment niches of both rare and common alpine plant species. By explicitly comparing recruitment responses across plant rarity, this approach aims to test the generality of current predictions and refine forecasts of plant community shifts and extinction risk under climate change. This work provides a methodological foundation for incorporating underrepresented rare species into biodiversity projections, with implications for improving the accuracy of ecological forecasts in alpine systems.

Drivers of Intraspecific Diversity in High-Elevation Plants: Insights from the Iberian Peninsula to the Alps

Pau Carnicero Campmany

Universitat Autónoma de Barcelona, Spain

Climate is a determining factor in the distribution of species. Therefore, climatic oscillations cause changes in species distribution, leaving traces in the genomes of present-day populations that allow us to reconstruct their demographic history. The case of high mountain flora is paradigmatic, due to its marked response in the form of retreat to glacial refugia in heavily glaciated mountain regions as the European Alps. However, the dynamics of mountain flora in southern ranges are governed by different conditions, which challenges direct comparison with mountain systems in central and northern Europe. Taking the Iberian mountain ranges as a model and based on genomic data, I discuss the demographic dynamics of high mountain flora linked to the ice ages, the controversial concept of glacial refugia, and the response of species to current climate change.

Alpine Botanical Gardens and the Future of Ex Situ Plant Conservation

Francesco Dal Grande [1,2,3], Núria Beltran-Sanz [3], Marco Canella [1,2,3]

[1] Department of Biology, University of Padova, Padova, Italy
[2] National Biodiversity Future Center, Palermo, Italy
[3] Botanical Garden of Padova, University of Padova, Padova, Italy

This work was developed in collaboration with Alpine Botanical Gardens and conservation institutions across the European Alpine arc.

Alpine ecosystems host some of Europe's richest plant diversity, yet climate change and habitat degradation increasingly threaten their long-term persistence. Alpine Botanical Gardens (ABGs) represent a unique interface between ex situ and quasi in situ conservation, combining living collections, horticultural expertise, and ecological experimentation within mountain environments. Here, we present the first coordinated assessment of 14 ABGs across the European Alpine arc, evaluating their contribution to alpine plant conservation and germplasm preservation.

Our analyses show that ABGs collectively maintain approximately 32% of the vascular flora of the Alpine Geographical Region, including endemic, threatened, and policy-relevant taxa. Cross-referencing these collections with global germplasm repositories revealed substantial conservation gaps, with numerous alpine endemics absent or poorly represented in international seed banks. Many cultivated taxa also lack established germination or storage protocols, highlighting the role of ABGs as experimental platforms for propagation and restoration-oriented research.

Our results identify ABGs as strategic conservation infrastructures capable of linking horticultural practice, ecological knowledge, and germplasm banking. Strengthening collaborations between botanical gardens, seed banks, and conservation institutions will be essential to improve ex situ representation and develop adaptive conservation strategies for alpine flora under rapid environmental change.

Where acidic humus embraces calcareous rock: What makes subalpine spruce forests champions in plant diversity?

Jörg Ewald

Hochschule Weihenstephan-Triesdorf, Mountain Ecosystems, Institute of Ecology and Landscape, Freising, Germany

Despite their superficial apperance as coniferous “monocultures” subalpine *Picea abies*-forests of the Calcareous Alps harbour remarkable fine-scale plant species richness. In fact, a meta-analysis has shown that their vascular understorey figures among the richest in Europe. Thus, subalpine spruce forests on calcareous (Adenostylo glabrae-Piceetum) and mixed bedrocks (Homogyno-Piceetum) harboured 45-50 or 40-50 vascular plant, and 15-23 or 20-25 soil dwelling bryophyte species per 12 x 12 m plot. The large calciphytic species pool, relatively open tree canopies and microsite diversity of forest floor thickness, morphology and chemistry have been proposed as explanations.

Based on regional studies in the Bavarian Alps I discuss forest pasture (Ewald, 2000), forest continuity and high stand age, macronutrient (NPK) limitation (Reger et al., 2014), succession (Ewald, 1999), deadwood legacies, forest floor heterogeneity and bimodal frequency distributions of acidophytes and calciphytes as concurrent drivers of plant species richness. While these forest types enjoy legal protection as annex I habitat type 9410 in the European Natura 2000 system, climate change is likely to promote the meltdown of forest floors and the advance of deciduous, shade-tolerant European beech to higher elevations. While highly specialised habitats for threatened bird species like capercaillie (*Tetrao urogallus*) and three-toed woodpecker (*Picoides tridactylus*) decline, lack of soil development and alpine pastures limit the potential for upward migration of subalpine spruce ecosystems.

References:

Ewald J (2000) Long-term impact of forest pasture on the understorey of mountain forests in the Tegernsee Alps (Bavaria). Z. Ökologie und Naturschutz, 9, 161–171.

Ewald J (1999) Relationships between floristic and microsite variability in coniferous forests of the Bavarian Alps. Phytocoenologia, 29, 327–344.

Reger B, Mellert K-H, Ewald J (2014) Indikatorarten für nährstoffarme Standorte in den Bergwäldern der Bayerischen Alpen. Tuexenia, 34, 39–51.

The response of Bavarian mountain forests to climate change

Jörg Ewald

Hochschule Weihenstephan-Triesdorf, Mountain Ecosystem Research Group, Institute for Ecology and Landscape, Freising, Germany

As the exposed forefront of the Calcareous Alps, the Bavarian Alps exhibit a moderate lapse rate of 0,48°C/100 m elevation and annual preciptation of 1000-3000 mm. The region hosts the world's oldest mountain forest meteorologial station at Peissenberg, where a warming of 2,38°C has been measured since 1850, while precipitaion remained unchanged.

Forest productivity, as measured by site index of the main tree species *Picea abies*, declines with elevation, but is even more strongly constrained by the prevalence of nutrient deficiences on shallow calcareous soils. Radial growth of the same tree species shows a complex correlation with temperature and precipitation: Warm and dry years limit growth up to an elevation of ca. 1000 m, while they boost radial growth above that line. Thus, high elevation forests are expected to respond to climate change with increased growth, while lower elevation forests may suffer from heat and drought periods.

Upper limits of many plant species had been recorded at the end of the Little Ice Age by Otto Sendtner (1854). Resurveys by alpine biotope mapping and a citizen science project demonstrate that forest understorey and tree species have extended their upper limits, but are lagging behind the warming trend and are constrained by lack of soil development and alpine pasturing above the treeline.

Long-term monitoring of forest soils has revealed substantial losses of organic floors during the last decades even under closed forest, which is likely triggered by warming.

Under the scenario of continued high CO_2-emissions (RCP 8.5), warming by another 3-4°C must be expected until 2100, which would shift elevational belts by another 600-800 m and render lower and middle elevations unsuitable for *Picea abies*. Adaptation of forests is faced with goal conflicts between salvage logging of bark beetle- (*Yps typographus*) infested spruces and proactive management of dead wood and humus as as between between the maintenance of open habitats and protection against natural hazards and carbon storage.

Phenological Monitoring Programme: 15 years of climate change research at the Schachen Alpine Garden

Andreas Gröger, Jenny Wainwright-Klein

Botanischer Garten München-Nymphenburg, München, Germany

Phenology timing is a highly sensitive bioindicator for changing environmental conditions. In 2011, Munich Botanic Garden decided to actively contribute to climate change research in high altitudes. It started a long-term phenological monitoring programme at the Schachen Alpine Garden, its satellite in the Bavarian Alps at 1850 m asl. 10 indicator species were selected, and 35 phenological characters defined. Monitoring was carried out three times per week on the same indicator plant individuals. After 15 years of observations, following preliminary results can be summarized:

(1) The phenological plasticity of (sub)alpine plant species can be very high. The point in time of a phenological character in spring can vary up to 10 days, in late summer even up to 50 days.

(2) Correlation of phenology to soil temperature (measured in a depth of 5 cm) is more pronounced than to air temperature and day lengths.

(3) To understand the effect of temperature change on phenology, the 35 characters were grouped by seasons: 13 characters in early summer (DOY (Day of Year) 145-185), 12 in midsummer (DOY 185-210), and 10 in late summer (DOY 211-250). The days of entry of the characters of these groups were correlated to the variation of the Degree Days (DD), which is the summation of mean daily temperature higher than +1°C. It revealed, that with a soil temperature increase of 2 K, early summer phenology advances by 7 days, midsummer phenology by 12 days, and late summer phenology by 14 days.

Obviously, high altitude plants feature an enormous phenological plasticity, indicating their resilience to temporary climate variations. But with long term temperature increase, they will have to compete with other species from lower altitudes or migrate into higher elevations. Competition will be the crucial factor in the change of the vegetation belts.

Genomic signatures of adaptation in alpine plants as a response to environmental variation in space and time

Felix Gugerli

Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

Organisms may respond to spatio-temporal environmental variation in various ways: (i) individuals adjust through phenotypic plasticity without genetic changes, (ii) gene flow moves beneficial gene variants among populations, (iii) rare mutations may introduce new advantageous alleles, (iv) adaptation induces a change in allele frequencies if conferring a fitness increase, while (v) local extinctions can occur if all above strategies fail.

Here, I focus on adaptation via divergent selection, which relies on standing genetic variation as the basis for evolutionary processes. Genomic approaches enable us to study these processes, which is particularly promising in species living in heterogeneous habitats subjected to rapidly changing conditions. Hence, plants that grow in topographically complex alpine habitats and experience above-average climate warming are highly suited for such genomic studies, while they are also vulnerable to the changes anticipated.

Assessing adaptive genetic responses to changing environments has become feasible in recent years due to progress in sequencing technologies and increasingly established high-resolution environmental descriptors, e.g., through remote sensing or climate modelling. Likewise, conceptual and analytical advances nowadays allow for identifying genomic patterns indicative of selective processes and determining their underlying environmental drivers.

Here, I will elaborate on the principles of detecting signatures of selection in genomic data, linking these patterns to environmental gradients, and how one may infer the potential of populations to adapt to future environmental changes. Examples from alpine plant species will showcase the prospects, but also limitations of studying local adaptation with genomic approaches and how this knowledge may inform conservation management.

Polyploidy and hybridisation shaped the evolutionary history of *Luzula* sect. *Luzula* in the Eastern Alps

Valentin Heimer

University of Innsbruck, Austria

Whole-genome duplication and hybridisation are major drivers of flowering plant diversification.In holocentric species, concerted chromosome fission (agmatoploidy) can further increase karyotypic diversity, and together, these processes often produce reticulate evolutionary histories that complicate phylogenetic inference and generate complex phenotypic variation.

We investigated the evolution of *Luzula* sect. *Luzula* (Juncaceae), a holocentric lineage characterised by polyploidy, extensive karyotypic variation, and high morphological similarity among species. Using phylogenomics, population genomics, cytogenetics, morphometrics, and ecological analyses, we examined how whole-genome duplication, agmatoploidy, hybridisation,and ecological differentiation contributed to its diversification, focusing on the European Eastern Alps.

Phylogenomic analyses identified *Luzula* sect. *Luzula* as one of the youngest lineages in the genus, originating in the mid-Pliocene and diversifying during the Pleistocene. High coancestry and blurred species boundaries suggest ongoing speciation, with some recently described taxa shown to be paraphyletic. Both agmatoploidy and polyploidy evolved repeatedly across independent lineages and genomic analyses revealed widespread hybridisation within and across ploidy levels. In several cases, hybridisation was accompanied by whole-genome duplication, producing multiple allopolyploid species. The partially agmatoploid species *Luzula alpina* emerged as a notable example of cross-ploidy hybridisation. Ecological niche analyses showed strong overlap among alpine species, consistent with their frequent co-occurrence.

Overall, our study highlights the value of integrative approaches for resolving complex evolutionary histories and highlights *Luzula* sect. *Luzula* as as an exciting system for studying the many mechanisms that shape plant diversity on earth.

Speciation and biogeographical history in the European Alpine System: the radiation of *Ranunculus* sect. *Euromontani* (Ranunculaceae)

Eleonora Manzo [1], Ellen Sigourney Lorberg [1], Leana Bremer [1], Salvatore Tomasello [1], Peter Schönswetter [2], Elvira Hörandl [1*]

[1] Dept. of Systematics, Biodiversity and Evolution of Plants (with herbarium), Albrecht-von-Haller Institute for Plant Sciences, University of Göttingen, Germany
[2] Institute for Botany, University of Innsbruck, Austria
[*] presenting author

High mountain systems provide manifold preconditions for allopatric and sympatric speciation. We hypothesize that allopatric speciation due to geographical isolation of mountain chains, and sympatric speciation via allopolyploidy played major roles for a radiation within *Ranunculus* within the European Alpine System (EAS).

We used target enrichment of 1,249 nuclear gene loci on 81 samples for phylogenomics, biogeographical analysis, coalescent species delimitation analysis, SNPs for genetic structure and NeighborNet analysis, flow cytometry for ploidy determination, and morphometrics for selected species pairs. Inclusion of type material supported new classifications. Results suggest that the core *R.* sect. *Euromontani* comprises 12 monophyletic species, most of them (sub)endemic to one mountain system. *R.* sect. *Euromontani* originated from a South-Mediterranean lineage and diversified 1.39 Mya from two main ancestral areas, the Carpathians and the Alps. Subsequent dispersals southwards to the Pyrenees, Apennines, to Corsica and the Balkan peninsula resulted in new species. Founder-event speciation was the most common mechanism, only one species (*R. montanus*) originated likely in situ via allopolyploidy in the Alps. In the West Carpathians, *R. tatrimontanus* spec. nov. was recognized as different from *R. gruinalis* (= *R. pseudomontanus*) in the South Carpathians. In the Pyrenees, clinal variation suggested inclusion of *R. ruscinonensis* into *R. gouanii*. *R. apenninus* and *R. pollinensis* are sympatric in the Apennines and might be conspecific. We conclude that peripatric speciation during the Pleistocene is the predominant mechanism for this geographical/climatic radiation in the EAS, whereas sympatric speciation via allopolyploidy happened only in the Alps. Our results highlight the need for taxonomic revisions in the European mountain systems.

Flower economic spectrum: A key to understanding the floral diversity of alpine plants

Lucie Holzbachová [1], Petr Sklenář [1], Jakub Štenc [1,2]

[1] Faculty of Science, Charles University, Prague, Czech Republic
[2] CREAF, Spain

Flowers of zoogamous plant species are subject to combined selection pressures from abiotic and biotic factors, yet their impact on floral diversity has mostly been studied separately. The concept of the Flower Economic Spectrum (FES) has been recently proposed to understand the evolutionary phenotypic variation and diversity of functional traits in flowers that evolved under multiple selection factors.

The world's mountainous regions are home to a large part of global biodiversity and mountain environments impose strong pressures on flowering, such as extreme climatic conditions and low abundance and diversity of pollinators. However, not all alpine regions share the same conditions. Tropical and temperate mountains differ in many important ecological factors that strongly influence generative plant reproduction. We studied more than 50 herbaceous and woody species from two mountain regions (Ecuador and the USA). The study examines the phenotypic variability of alpine flowers through the lens of the FES, i.e. relationship between flower longevity and investment into flower biomass (cost of flower production). Our preliminary results show a positive association between flower biomass investment and flower longevity, with differences in longevity patterns between the two alpine regions. Together, these findings provide empirical support for the proposed Flower Economic Spectrum.

Between the mountains and the polar zone: biogeography and evolutionary history of *Dryas octopetala* L.

Anna Janiczek [1,2], Tomasz Suchan [3], Dawson M. White [4], Michał Ronikier [3]

[1] W. Szafer Institute of Botany Polish Academy of Sciences, Lubicz 46, 31-512 Cracow, Poland
[2] Doctoral School of Natural and Agricultural Sciences, Lubicz 46, 31-512 Cracow, Poland
[3] Stanisław Leszczycki Institute of Geography and Spatial Organization Polish Academy of Sciences, Twarda 51, 00-818 Warsaw, Poland
[4] Harvard University Herbaria, 22 Divinity Ave., Cambridge, Massachusetts, USA

Dryas octopetala L. (Rosaceae) is a key component of the arctic-alpine flora and, in the temperate mountains of Europe, represents one of the most characteristic links between alpine and polar floras. Despite its biogeographic significance, the evolutionary history and genetic structure of this species remain insufficiently understood. In our project we examined this emblematic species using molecular biogeographic approaches to address the following questions: (i) what is the taxonomic and biogeographic status of *Dryas octopetala* in relation to the circumpolar distribution of the genus *Dryas*; (ii) what is the genetic structure of *D. octopetala* across Europe, and (iii) what do genetic studies of Western Carpathian populations indicate about the history of their high-mountain flora?

Phylogenetic analyses covering the circumpolar range of the genus *Dryas* revealed several evolutionarily and biogeographically distinct genetic groups connected by, in some regions, extensive contact zones. Our results indicate that, contrary to the traditional view, *Dryas octopetala* is not a truly circumpolar species. According to the preliminary taxonomic interpretation, its principal distribution is restricted to Europe. Detailed phylogeographic analyses identified two major genetic lineages across Europe with distinct geographic distributions and biogeographic histories. The western lineage includes populations from the mountains of Western Europe and much of Scandinavia, whereas the eastern lineage encompasses populations from the Carpathians and the Balkan Peninsula. In addition, populations from northern Scandinavia and the European Arctic (Svalbard) show affinities with a third, West Siberian biogeographic lineage. Studies of the Western Carpathians indicate that this region is an important center of biodiversity for this species.

Reproductive strategies of tropical and temperate alpine plants: a comparison between the Ecuadorian Andes and the Rocky Mountains

Alptekin Koc

Department of Botany, Faculty of Science, Charles University, Prague, Czech Republic

When it comes to generative reproduction, one of the challenges that plants face in alpine habitats is successful pollination. Due to high elevation and the associated cooler climate, invertebrate pollinators are generally scarcer and, in some cases, less active in alpine biomes than in lower-elevation habitats. However, the density and diversity of pollinators can also be vastly different between alpine habitat types. Such is the case when comparing the pollinator communities between the temperate alpine and the tropical high elevation Páramo. Literature as well as our preliminary data show that pollinator density, diversity and flower visitation rates are significantly lower in tropical Páramos compared to temperate alpine equivalents. We therefore hypothesized that tropical alpine flowering species face a higher degree of pollen limitation than temperate alpine ones. One way they might have adapted to these extreme conditions could be a shift toward more autonomous breeding strategies such as autonomous selfing or even apomixis to assure generative reproduction. To test this assumption, we compared the breeding systems of representative plant species from a super Páramo (Guagua Pichincha, Andes, Ecuador) with those of a temperate alpine grassland (Niwot ridge, Rocky Mountains, USA). The breeding systems were determined using seed set assessments that resulted from pollination treatments applied on 25 species in each study area. Here, we present preliminary results of the breeding system analyses as well as results on the pollinator communities

Acknowledgements: Research project "Temporal dynamics and stochasticity of plant pollination in alpine ecosystems", MŠMT, Inter-Action Project Number: 252-234029, PI: Petr Sklenář).

Ghosts and bedrock shift – past, present and future of the extremely rare alpine *Cochlearia excelsa* in Austria

Marcus A. Koch, Nora Walden

Heidelberg University, Center for Organismal Studies (COS), Biodiversity and Plant Systematics, Germany

The genus *Cochlearia* comprises several cold-adapted species distributed from the Arctic to the European alpine regions. It is characterized by interspecific and interploidal gene flow, fostered by range shifts during glacial and interglacial cycles. Today, Central European species are highly endangered by global climate change and landscape degradation, irrespective of whether they occur in lowland, montane, or alpine habitats. Three diploid species occur in Central Europe.
Cochlearia pyrenaica has the broadest distribution, with scattered populations ranging from the Pyrenees to Slovakia and from Austria to the United Kingdom. The other two species are narrow endemics in Austria: *Cochlearia macrorrhiza* near Vienna and *Cochlearia excelsa* in the Seckauer Tauern and Gurktaler Alpen. Here, we used ddRAD data mapped against a *Cochlearia excelsa* pangenome to show that the high-alpine *Cochlearia excelsa* evolved postglacially from the calcicolous montane *C. pyrenaica* in the Central Alps.
The best-fitting evolutionary model suggests that an extinct ghost lineage contributed to the origin of *Cochlearia excelsa*, which subsequently split into two relict populations as high-alpine remnants during postglacial warming. These evolutionary models are further supported by plastome data, which indicate additional connectivity to diploid *C. pyrenaica* populations in France's Massif Central, where they occur on volcanic bedrock. A historical and population survey and 25 years of monitoring of *C. excelsa* provide further evidence of a rapid decline and the eventual extinction of subpopulations between 1850 and 2150 m a.s.l. Accordingly, this alpine species should be considered extremely vulnerable, and ex situ cultivation and management strategies should be established urgently.

Denser and more diverse: Vegetation change in unmanaged mountain forests of the Calcareous Alps since the mid-1980s

Thomas Kudernatsch [1], Markus Blaschke [1], Jörg Ewald [2]

[1] Bayerische Landesanstalt für Wald und Forstwirtschaft, Freising, Germany
[2] Hochschule Weihenstephan-Triesdorf, Fakultät Wald und Forstwissenschaft, Freising, Germany

Unmanaged natural forest reserves are important reference ecosystems for detecting environmental change. We resurveyed permanent vegetation plots in the strict forest reserves Schrofen and Wettersteinwald (Bavarian Alps) to detect changes in the vegetation structure and composition of these mountain forests since the mid-1980s.

The gradient covered by the investigations ranges from mixed mountain forests of the montane zone to natural spruce forests of the lower subalpine zone and larch-pine forests of the upper subalpine zone. Particularly noticeable changes were an increase in the canopy closure of the stands and the establishment of a shrub layer. In addition, an increase in frequency was observed for many species of the herb layer (including woody regeneration), resulting in an increase in alpha diversity. The species with a positive reaction in the study period ("winners") were predominantly competitive and vigorous forest species with comparatively higher nutrient and lower light requirements. In many cases, the increase in the frequency of species was accompanied by an expansion of their altitudinal ranges. As a result, the relevés of the subalpine coniferous forests and the mixed mountain forests today show an overall higher floristic similarity than in the 1980s, which can be interpreted as a homogenization of the species composition of the understorey vegetation.

In a Central European context, the combination of canopy closure and increased understory diversity is unusual. In our opinion, the main driving forces behind these changes are increasing temperatures due to climate change and changes in land use practices (cessation of timber harvesting, reduced browsing by grazing livestock and wild ungulates) and continued high atmospheric nitrogen inputs.

A natural laboratory of polyploid evolution: alpine *Pilosella rhodopea* as the largest diploid–autopolyploid contact zone in angiosperms

Patrik Mráz [1,2], Jana Duchoslavová [1,3], Daniel Papež [1], Núria Beltrán-Sanz [1], Aleš Soukup [4], Judita Zozomová-Lihová [5], Yann Betrand [1,6], Kristína Pulišová [5], Barbora Šingliarová [1,5]

[1] Department of Botany, Charles University, Prague, Czech Republic
[2] Herbarium collections, Charles University, Prague, Czech Republic
[3] Leibniz Centre for Agricultural Landscape Research, Müncheberg, Germany
[4] Dep. of Experimental Plant Biology, Charles University, Prague, Czech Republic
[5] Institute of Botany, Plant Science and Biodiversity Centre, Slovak Academy of Sciences, Bratislava, Slovakia
[6] Institute of Botany, Czech Academy of Sciences, Průhonice, Czech Republic

Polyploidy is widespread in angiosperms, yet the formation and establishment of new polyploid lineages in nature remain poorly understood. These processes are expected to occur in primary contact zones, where polyploids originate from sympatric diploid or lower-ploidy ancestors, typically via fusion of reduced and unreduced gametes. However, most known contact zones are of secondary origin, whereas primary zones are paradoxically rare.

Here, we present diploid–polyploid *Pilosella rhodopea* as a model system for studying polyploid evolution in action. This species is restricted to the alpine belt of the mountain ranges of the Balkans and occurs exclusively in mixed-cytotype populations, with diploids, triploids, and tetraploids as major cytotypes. Our integrative analyses show that polyploids arise recurrently through fusion of varying-ploidy gametes across cytotypes, including unreduced gametes produced by diploids. All polyploids are of autopolyploid origin and produce substantially fewer seeds than diploids, likely due to meiotic irregularities. Despite this apparent fitness disadvantage, autotri- and autotetraploids dominate many populations. Their success is likely driven by enhanced clonal growth, mediated by (i) increased production of axillary rosettes and (ii) formation of adventitious rosettes from root buds, a trait absent in diploids. We further discuss mechanism how whole-genome multiplication can generate novel traits.

Increased clonality, together with intercytotype gene flow, facilitates the establishment and persistence of newly formed autopolyploids, maintaining the largest known diploid–autopolyploid primary contact zones in angiosperms.

***Pinus mugo* krummholz: A candidate for biome shift?**

Michelangelo Olleck [1], Mathias Mayer [2], Jörg Ewald [1]

[1] Hochschule Weihenstephan-Triesdorf, Mountain Ecosystem Research Group, Institute for Ecology and Landscape, Freising, Germany
[2] Universität für Bodenkultur, Institute of Forest Ecology, Wien, Austria

Temperatures in mountain regions are rising significantly faster than in lowlands, with the European Alps warming at more than twice the global average. This accelerated warming at high elevations is driving fundamental shifts in vegetation composition, particularly at the treeline, where *Pinus mugo* shrub vegetation (dwarf pine krummholz) encroaches on alpine grasslands extending its upper limit, and is infiltrated by tall forest trees at its lower limit. The concurrent ecosystem transformationdoes not only reshape plant communities and aboveground biomass but can also have profound effects belowground. Besides providing nutrients for plant growth, moutain soils and mycorrhiza play a critical role forecosystem carbon balance.

Encroachment of *Pinus mugo* into herbaceous alpine areas has been widely reported, driven both by climate warming and by land-use changes such as the abandonment of mountain grasslands. On the shallow bedrocks of the Calcareous Alps, carbon accumulation under *Pinus mugo* leads to organic soils (Folic Histosols), creating a hotspot of Ericaceous diversity. The recent upward shift of competitive treeline species (e.g., *Picea abies*, *Larix decidua*) replacing *P. mugo* and pushing its zone of dominance further upslope, is less studied.

Our research project (currently under review) aims to investigate both above- and belowground components of the *Pinus mugo* ecotone as an important yet understudied mountain ecosystem to assess climate change–induced shifts in vegetation, soil processes, biodiversity, and carbon dynamics.

High-Altitude Nature Conservation: An Alpine Botanical Garden in the Middle of the Mediterranean region

Loretta Pace [1], F. Tarquini [2], A. Riti [2], C. Castiglione [1], F. Attorre [2]

[1] Department of Life, Health and Environmental Sciences, University of L'Aquila, Italy
[2] Department of Environmental Biology, Sapienza University of Rome, Italy

Located within the Gran Sasso and Monti della Laga National Park, the “V. Rivera” Alpine Botanical Garden (2,130 m asl) lies above the tree line, serving as a vital sanctuary for biodiversity. The Central Apennines represent a unique biological crossroads, bringing together diverse flora shaped by the climatic cycles of the Pleistocene. This region boasts diverse vegetation types, influenced by complex topography, variable rock types and historical human activity.

This rich biodiversity is increasingly threatened by climate change, which is forcing significant shifts in species distribution. The ability of species to respond to climate change will depend largely on their capacity to colonise new territories. Although these plants have evolved to withstand daily weather variations, they lack the rapid adaptability needed to survive the current pace of global climate change. Preserving this biological heritage presents a complex challenge, requiring the protection of genes, populations and entire habitats amidst increasing anthropogenic pressure. In order to develop appropriate conservation strategies, it is necessary to integrate a wide range of disciplines that enable us to understand plants not only from a taxonomic perspective, but also in terms of their environmental relationships and the functional traits that arise from them.

The Alpine Garden addresses these threats through a dual mission: to conduct essential scientific research on high-altitude species and to actively propagate endangered flora. The role of a university Alpine Garden such as the ‘V. Rivera’ is therefore not only to preserve, but also to innovate its strategic functions within the field of conservation.

Quaternary Evolution of the Bavarian Flora and Beyond: Genetic and Ecological Adaptation to Changing Environments

Anna Pasinato [1], Sebastian Mortimer [1], Klara Korb [1], Vinicius Daguano-Gastaldi [1], Jessica Berasategui [1], Lilia Galvez [2], Agnes Scheunert [2], Simon Pfanzelt [3], Andreas Fleischmann [3], Gudrun Kadereit [1,3]

[1] Prinzessin Therese von Bayern Lehrstuhl für Systematik, Biodiversität und Evolution der Pflanzen, Ludwig-Maximilians-Universität München, Germany
[2] Genomics Core Facility der Staatlichen Naturwissenschaftlichen Sammlungen Bayerns, Germany
[3] Botanische Staatssammlungen und Botanischer Garten München-Nymphenburg, Staatliche Naturwissenschaftliche Sammlungen Bayerns, Germany

Genetic variation in modern plant populations arises from interacting ecological and evolutionary processes operating across timescales, from rapid adaptation to long-term diversification. Quaternary climatic oscillations have been key drivers, shaping biodiversity through range shifts, speciation, hybridization, adaptation, and extinction. These processes have left spatial patterns of genetic diversity within and among populations, influencing their future evolutionary potential.

This project investigates the evolutionary history of Bavarian flora during the Quaternary by combining herbarium records, fieldwork, common garden experiments, and genomic and computational methods. It focuses on species-specific histories as components of a broader regional mosaic, with particular attention to endangered \`dealpine´ taxa and the environmental factors behind their decline. \`Dealpine´ species, occurring from Alpine to lowland regions, have shown marked population reductions, especially in lowland Bavaria. Some persist along major rivers such as the Lech, Isar, and Inn, while others may represent relict populations in nearby habitats.

The study aims to (i) determine how the Last Glacial Maximum has structured genetic variation, particularly in the Alpine foreland, and (ii) assess how past evolutionary trajectories shape future responses to climate change. To address this, we will identify genetic clusters within species, estimate genomic offset to assess vulnerability, and model distributions under future climate scenarios. Ultimately, the project will evaluate whether climate change primarily drives lowland population declines or whether alternative factors, such as land-use change, offer better explanations.

Genetic structuring of the carnivorous plant *Pinguicula alpina* (Lentibulariaceae) in the Bavarian Alps

Simon Pfanzelt [1], Andreas Fleischmann [1], Om Kulkarni [2], Agnes Scheunert [2]

[1] Staatliche Naturwissenschaftliche Sammlungen Bayerns, Botanische Staatssammlung und Botanischer Garten München (SNSB-BSuBGM), Munich, Germany
[2] Staatliche Naturwissenschaftliche Sammlungen Bayerns, Genomics Core Facility (SNSB-GCF), Munich, Germany

In the floristic literature of Central Europe, the term ‘dealpine’ in its wide sense is used for species that grow mainly above treeline in the Alps but can also be found in the lowlands of the prealpine region. Dealpine elements are mostly cold-adapted species, whose lowland occurrences have often been explained as remnants of their more widespread distribution ranges during the glacials. One of these dealpine species is the carnivorous butterwort *Pinguicula alpina* (Lentibulariaceae). It is still frequent in the Bavarian Alps. In contrast, the remaining scattered populations in calcareous fens and seepages of the Bavarian prealpine area are in strong recent decline. In the present work, we tested the hypothesis whether *P. alpina* from the Bavarian Alps constitutes a single population or if there is genetic structuring. Genotyping was based on double-digest restriction site-associated DNA sequencing and included a total of 41 ingroup individuals (excluding replicates) of *P. alpina* from the entire Bavarian Alpine range. Clustering methods, F-statistics and principal components analysis provided no evidence for clearly distinct genetic groups. Instead, genetic structure could best be characterized through an isolation-by-distance pattern, as genetic and geographic distances between samples were correlated. However, the integration of spatial information into the assessment of genetic variation showed that the Inn River Valley may impede gene flow and consequently acts as a biogeographic barrier that disrupts genetic continuity.

Hundred years of the Juliana Alpine Botanical Garden – a hundred years of change

Špela Pungaršek

Slovenian Museum of Natural History, Ljubljana, Slovenia

The Juliana Alpine Botanical Garden is the oldest alpine botanical garden in Slovenia. Established in 1926 by the mountaineer, botanist and timber merchant Albert Bois de Chesne, it has been managed by the Slovenian Museum of Natural History since 1962. Situated in the centre of the Julian Alps in the Trenta Valley at an altitude of 800 metres, the garden is home to around 700 plant species native to the Slovenian Alps and their foothills, as well as dry karst meadows. Among them are also several endemic, rare and protected species. Information about the plant species grown in the garden around 90 years ago enables us to compare them with recent data. There were several alpine species, as *Eritrichium nanum*, *Favratia zoysii*, *Leontopodium nivale* subsp. *alpinum*, *Potentilla nitida*, *Saxifraga exarata* subsp. *carniolica*, etc. grown in the garden since its foundation, but don't prosper well in the last decade.

We discuss the possible reasons why certain plant species have failed to thrive in the garden. Climatic data show that the annual temperature in the valley has risen by 1°C over the past 60 years, while the number of days with snow cover has halved. Therefore, we indicate that climate change is an important factor also for managing a botanical garden collection and has to be taken into account. Although the garden's plant collection is artificially maintained, it also reflects changes in the surrounding climate.

Alpine vegetation dynamics under climate change: insights from over more than two decades of monitoring

Mihai Pușcaș [1,2], Tudor-Mihai Ursu [3], Pavel Dan Turtureanu [1], Zoltan Robert Balázs [2]

[1] A. Borza Botanic Garden, Babeș-Bolyai University, Republicii 42, Cluj-Napoca, Romania
[2] Faculty of Biology and Geology, Babeș-Bolyai University, Republicii 44, Cluj-Napoca, Romania
[3] Institute of Biological Research, NIRDBS Bucureşti branch, Cluj-Napoca, Romania

Alpine ecosystems are highly sensitive to climate warming, and recent studies identify thermophilization and shrub expansion as key components of vegetation change on alpine summits (Yue et al., 2026; Vanneste et al., 2026). Within this context, we analyse the alpine vegetation dynamics from the GLORIA site in the Rodna Mountains (Eastern Carpathians, Romania), based on repeated surveys conducted in 2001, 2008, 2015 and 2022. Previous analyses have already documented shifts in species composition and diversity, including increasing species richness and clear thermophilization signals (Puşcaş et al., 2013; 2017).

Focusing on the most recent monitoring cycle, we assess vegetation change across the four alpine summits included in the study. Over the last decade, vascular plant cover increased overall, while exposed non-vegetated surfaces showed a partial decline, mainly reflecting a reduction in scree cover. The strongest increases in vascular cover were recorded on north-facing slopes of higher-elevation summits, reaching +18–21 %. Within the vascular component, shrub expansion was most pronounced at lower-elevation summits, where total shrub cover increased by up to +20–28 %, especially on warmer slope exposures. Shrub expansion is largely driven by Ericaceous dwarf shrubs, with *Rhododendron kotschyi* contributing approximately 70% of the total shrub increase. This pattern is consistent with landscape-scale evidence from the Carpathians, where shrub encroachment (particularly of Ericaceous species) drives vegetation greening (Turtureanu et al., 2025).

These results emphasize spatially structured vegetation change, with shrub expansion and cover increases occurring unevenly across alpine environments, reflecting the combined influence of elevation and local microclimatic conditions.

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Comparative phylogeography of the Carpathians: alpine plants in a temperate mid-elevation mountain system

Michał Ronikier, Tomasz Suchan, Intrabiodiv Consortium

Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw, Poland

The Alps and the Carpathians are two major parts of the European Alpine System. While roughly comparable in length and surface, they significantly differ in current and past structure of habitats for alpine organisms. We will present a comparative phylogeographical analysis of the alpine plants in the Carpathians to (i) identify main genetic groups and lines of genetic divergence (phylogeographical breaks), and (ii) compare it with well-known patterns available for the Alps and discuss how major physiographical characteristics of high- and mid-elevation mountain systems influence the high-mountain plant phylogeography.

Our analysis is based on 22 high-mountain species studied in a coherent and methodologically standardised framework. The multispecies phylogeographical synthesis (based on MAPI - *Mapping Averaged Pairwise Information*; Piry et al., Methods Ecol. Evol. 2016) revealed emerging main phylogeographical features at the scale of the range, despite differences among single-species structures. Major, consistent phylogeographical centres are shown in the Western Carpathians, northern part of the Eastern Carpathians and Southern Carpathians (with internal diversification in several species), confirming this main physiographically-driven outline in the comparative framework. The most coherent group characterizes the Western Carpathians. As phylogeographical structure of the Carpathian alpine plants is characterized by presence of several divergent allopatric groups, this main feature is similar to that observed in the Alps although the environmental isolation barriers are essentially different. Here, lower-elevation areas act as long-term barriers and possible glacial-period extension of habitats for cold-adapted species did not outweigh combined effect of these long-term settings of the chain and of isolation by distance.

Biogeography, niche shifts, and trait evolution across orobiomes in *Caltha* sect. *Psychrophila* plant lineage

Petr Sklenář [1], Gabriela Šrámková [1], Patrik Mráz [1], Eliška Záveská [2]

[1] Department of Botany, Faculty of Science, Charles University, Prague, Czech Republic
[2] Institute of Botany, Czech Academy of Science, Průhonice, Czech Republic

Evolutionary drivers of species diversification in Southern Hemisphere orobiomes remain poorly understood, largely due to unresolved phylogenies and insufficient population-level sampling. *Caltha* sect. *Psychrophila* (Ranunculaceae) is a monophyletic lineage of approximately 16 species, comprising three North American taxa of the *Caltha leptosepala* group and about 13 species distributed across South America, Australia (including Tasmania), and New Zealand.

In the Southern Hemisphere, species are primarily restricted to moist alpine habitats, with some extending to lowland environments in southern South America. Its disjunct, Gondwanan distribution across multiple orobiomes, together with pronounced morphological diversity, makes this lineage an exceptional model for studying alpine plant evolution. We employ high-resolution genomic data (RADseq, HybSeq) from densely sampled populations across the full distributional range to reconstruct phylogenetic relationships and infer biogeographic history. These data are integrated with morphometric analyses and climatic niche modelling to investigate patterns of trait evolution. By combining genomic, morphological, and ecological approaches, this study provides new insights into the evolutionary processes shaping Southern Hemisphere alpine floras.

Tropical alpine plant life: contrasting flowering phenology between tropical and temperate alpine communities

Petr Sklenář [1], Antonella Bernardi [2], Nyika Campbell [3], Jakub Štenc [1], Alvaro Barragán [2], Lucie Holzbachová [1], Sisimac Duchicela [3]

[1] Department of Botany, Faculty of Science, Charles University, Prague, Czech Republic
[2] Facultad de Ciencias Exactas Naturales y Ambientales, Centro de investigaciones de la Biodiversidad, Museo QCAZ, Pontificia Universidad Católica del Ecuador, Quito, Ecuador
[3] Department of Geography and Institute of Arctic and Alpine Research, University of Colorado, Boulder, USA

Flowering phenology is a key component of alpine plant community dynamics, reflecting interactions between climatic constraints and biotic processes. While temperate alpine systems are characterized by short growing seasons and strong environmental filtering, tropical alpine environments experience weaker seasonality and potentially more diffuse phenological patterns. Here, we compare flowering phenology between temperate (Colorado, USA) and tropical (Ecuador) alpine plant communities using temporal, plot-level data collected across entire growing seasons. We quantified community-level phenological structure using multiple complementary metrics (community synchrony, pairwise flowering overlap, and temporal species turnover) and assessed community flower density dynamics.

The temperate alpine community exhibited strong temporal aggregation, characterized by high synchrony, elevated flowering overlap, and tightly clustered peak flowering dates. Consistent with these patterns, temporal turnover in species composition was significantly lower than expected under null models, indicating increased temporal stability. In contrast, the tropical alpine community showed weaker synchrony, greater dispersion of flowering peaks, and turnover patterns that did not differ from random expectations, despite substantial overlap in flowering periods. These results demonstrate that alpine plant communities across latitudes differ not only in the timing but also in the temporal structure of flowering. Our findings indicate that strong seasonal constraints in temperate systems promote synchronized and persistent flowering, whereas tropical alpine communities exhibit more diffuse and less constrained phenological dynamics.

Patterns of polyploid frequency in the Eastern Alps based on extensive sampling across elevational gradients

Teresa Zeni

Department of Botany, University of Innsbruck, Austria

Polyploidy, the presence of more than two chromosome sets in somatic cells, is widely recognized as an important feature of plant biodiversity. At global scales, an increase in polyploid frequency with latitude suggests a role of temperature in shaping the distribution of polyploid plants. However, patterns at finer, regional scales remain unclear. Here, we investigate how polyploid frequency varies along elevational gradients in the Eastern Alps.

We analyzed a flora-wide dataset of approximately 42,000 georeferenced angiosperm samples collected along 101 elevational transects. Ploidy levels were determined using flow cytometry, resulting in a comprehensive cytogeographic dataset for the region. Contrary to expectations based on global patterns, polyploid frequency decreased with increasing elevation. Below the timberline, it increased with distance from glacial refugia, particularly among species with limited dispersal ability, suggesting an influence of postglacial colonization dynamics. Within species exhibiting multiple ploidy levels, cytotypes did not show consistent elevational segregation. Broad-scale niche differentiation was variable across species and often not statistically supported, with climatic variables generally more important than soil factors. Overall, these results highlight the role of regional historical and ecological processes, particularly dispersal and postglacial history, in shaping polyploid distributions.