

PHOTOPLANT

TECHNICAL DISSEMINATION FACT SHEET

By:

**Dr. Martina Tarascio
Professor Thomas Abeli
Professor Lisa Brancaleoni
Professor Renato Gerdol
Dr. Anna Cazzavillan**

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By Martina Tarascio and Thomas Abeli

Dipartimento di Scienze della Terra e dell'Ambiente – Università degli Studi di Pavia

Lisa Brancaleoni, Anna Cazzavillan e Renato Gerdol

Dipartimento di Scienze dell'Ambiente e della Prevenzione – Università degli Studi di Ferrara

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1. EXECUTIVE SUMMARY

The PHOTOPANT project investigated the role of photoperiod in modulating the response of Arctic–alpine plant communities to climate change, with particular reference to implications for ecological restoration.

Through a common garden experiment conducted in an alpine environment, snowbed vegetation swards from the Arctic and the Alps were subjected to an experimental design combining two photic regimes (natural 16-hour photoperiod and extended 24-hour photoperiod) and two thermal conditions (ambient and passive warming using Open-Top Chambers).

Community response was assessed through measurements of biomass, vegetation cover, gas exchange, and leaf carbon allocation.

The results highlight a strong dependence on geographic origin: alpine swards showed a better response than Arctic ones under all treatments. Vegetation cover was particularly high in alpine swards compared to Arctic ones, with secondary effects of both photoperiod and simulated warming.

Overall, the findings indicate that local adaptation is a key factor in plant community responses to new climatic conditions, while photoperiod, although influencing specific physiological processes, plays a secondary role compared to provenance.

These findings support the importance of considering the origin of plant material in restoration strategies and suggest the potential application of alpine ecotypes in environments subject to warming and prolonged light regimes.

2. ABSTRACT

The PHOTOPANT project investigated the role of photoperiod in modulating the response of Arctic-Alpine plant communities to climate change, with particular attention to the implications for ecological restoration. Through a common garden experiment conducted in an alpine environment, swards of snow valley vegetation from the Arctic and the Alps were subjected to an experimental design that combined two photic regimes (natural 16-h photoperiod and extended 24-h photoperiod) and two thermal conditions (environmental and passive heating via Open-Top Chambers). Community response was assessed through biomass and vegetation cover measurements. The results highlight a strong dependence on geographic origin: Alpine swards showed a better response than Arctic patches in all treatments. Vegetation cover was particularly high in Alpine swards compared to Arctic patches, with secondary effects of both photoperiod and simulated warming. Overall, the results indicate that local adaptation is a key factor in plant communities' response to new climate conditions, while photoperiod, while influencing specific physiological processes, plays a secondary role compared to provenance. This evidence supports the importance of considering the origin of plant material in restoration strategies and suggests a possible application of alpine ecotypes in contexts subject to warming and prolonged light regimes.

3. INTRODUCTION

3.1 The role of photoperiod

Photoperiod is an important ecological factor regulating plant physiological and phenological processes, but it has so far received limited attention in studies on the effects of climate change on flora and vegetation, as well as in habitat restoration.

It is particularly relevant when comparing Arctic and alpine ecosystems, which share similar climates but differ greatly in photoperiod: during summer, the Arctic receives 24 hours of light for variable periods depending on latitude, whereas at mid-latitudes day length is approximately 16 hours. This difference affects the duration of the growing season and selective pressures.

Climate warming is expected to promote northward plant migration; however, photoperiod—being a fixed signal independent of climate—may limit this shift, as many species regulate flowering, growth, and senescence based on day length.

Some species may survive at new latitudes but fail to reproduce or complete their life cycle. Moreover, interactions among photoperiod, temperature, and water availability will differentially influence species responses in Arctic and alpine environments: long photoperiods favor shoot development, while shorter ones promote root growth, also affecting drought tolerance.

Since about half of Arctic–alpine species are photoperiod-sensitive, differences in light response can alter species competition, plant community productivity, and associated ecosystem services such as carbon sequestration, water retention, grazing, and tourism.

As a result, carbon sequestration models and restoration practices remain incomplete if photoperiod is not considered, highlighting the need for further research on this factor.

3.2 Alpine ecosystems

Among alpine ecosystems of particular relevance to the project, alpine grasslands and snowbeds are of special interest.

Alpine grasslands are natural herbaceous ecosystems located above the tree line in high mountain areas, characterized by continuous or extensive cover of graminoids (Poaceae, Cyperaceae, Juncaceae, etc.) and other herbaceous plants adapted to harsh climatic conditions (low temperatures, strong winds, short growing season).

These plant communities develop on slopes, basins, or wide inclines where trees cannot grow and are a typical component of high-elevation alpine environments.

Characteristic flora includes species from genera such as *Poa*, *Carex*, *Juncus*, *Dryas*, *Gentiana*, *Alchemilla*, *Anthyllis*, *Draba*, *Helianthemum*, *Pulsatilla*, and many others.

Within alpine grasslands, snowbeds are habitats characterized by long-lasting snow cover, resulting in very short growing seasons and more extreme environmental conditions.

They host highly specialized plant communities dominated by herbaceous and dwarf shrub species adapted to low temperatures, delayed phenology, and often water-saturated soils.

Depending on soil morphology and snow persistence, different vegetation types can be identified, all belonging to the *Salicetea herbaceae* class, widespread across southern mountain ranges such as the Alps, Pyrenees, Carpathians, Balkans, and Apennines.

From a conservation perspective, snowbeds are of high importance because they host numerous Arctic–alpine microthermal species and taxa with fragmented distributions. They are particularly vulnerable to climate change, which alters snow cover duration.

Reduced snow cover leads to changes in floristic composition and potential loss of specialized species, making these habitats sensitive indicators of climate change and priorities for monitoring, conservation, and restoration strategies.

3.3 Pressures and ecosystem services

Mountain grasslands are habitats of high ecological and socio-economic value, hosting rich plant biodiversity and providing key ecosystem functions such as hydrological regulation, soil protection, and support for traditional agro-pastoral activities.

For example, species-rich *Nardus stricta* grasslands are a priority habitat (H6230) under the EU Habitats Directive, combining high plant diversity with a long history of extensive pastoral management.

These systems are closely linked to ecosystem services and high-quality traditional products, such as Protected Designation of Origin mountain cheeses, whose economic value depends directly on maintaining traditional practices and floristic composition.

Major pressures include abandonment of grazing, leading to shrub encroachment and biodiversity loss and agricultural intensification, reducing species diversity and altering vegetation structure.

Snowbeds, while sharing some of these pressures, are even more vulnerable to climate change, which affects snow duration, temperature regimes, and soil water availability, directly influencing species composition and phenology.

Additional anthropogenic pressures include ski infrastructure and lifts, artificial snowmaking reservoirs, stampling and unmanaged grazing

These factors cause soil compaction, microclimatic alterations, and habitat fragmentation.

The interaction between climate change and local disturbances may accelerate species replacement by more competitive taxa, reducing the role of snowbeds as refugia for Arctic–alpine species and lowering their conservation value.

For these reasons, these habitats are considered priorities in conservation strategies and require integrated management approaches that address both global climate pressures and local human impacts.

4. CARRIED OUT ACTIVITIES

4.1 Experimental set-up

The experimental activities of the PRIN2022 PHOTOPANT project were designed to understand the implications of the combined effects of photoperiod and temperature for the conservation and management of snowbed vegetation. The experiment was conducted at the Bruno Peyronel Alpine Botanical Garden (2290 m a.s.l.)(Figures 1,2), selected as the study site due to its high climatic similarity to the natural environments of origin of the swards, being the highest alpine botanical garden in Europe.

A common garden experiment was established using a fully factorial design combining two photoperiod regimes:

- natural (~16 hours of light)
- extended (24 hours, achieved using lamps powered by photovoltaic panels to simulate Arctic light conditions)(Figure 3)

and two thermal regimes:

- ambient conditions
- passive warming using Open-Top Chambers (OTCs)

Studying this system at mid-latitudes made it possible to simulate future Arctic-like scenarios under controlled yet ecologically realistic conditions.

The Bruno Peyronel Alpine Botanical Garden provides temperature regimes, growing season duration, and snow cover patterns comparable to Arctic–alpine ecosystems, making it particularly suitable for hosting transplanted snowbed communities.



Figure 1 - Overview of the experimental site at the Bruno Peyronel Alpine Botanical Garden



Figure 2 - Entrance to the Bruno Peyronel Alpine Botanical Garden



Figure 3 - Experimental group of swards in the extended photoperiod treatment using twilight-activated lamps

In 2024, snowbed vegetation swards were collected from:

- Arctic region: Ny-Ålesund (Svalbard)
- Alpine region: Pale di San Martino (Dolomites)

Communities were selected to include comparable Arctic–alpine species (notably *Salix* spp., *Bistorta vivipara*, *Silene acaulis*, and *Saxifraga oppositifolia*).

Swards were transported and transplanted into the common garden within containment frames to limit lateral expansion and facilitate installation and later removal.

Preventive measures were adopted to avoid genetic contamination (e.g., removal of flowers and fruits).

Measurements of multiple variables (see Section 4.2) were carried out during the 2025 growing season, allowing direct comparison of responses from swards of different geographic origins under identical environmental conditions, isolating the effects of photoperiod and temperature.



Figure 4 – Removal of experimental swards

At the end of the experiment, the site was restored to its original conditions by:

- removing all equipment (lamps and OTCs)
- removing experimental swards (Figure 4)
- replanting native *Carex foetida* swards previously removed and maintained ex situ during the experiment (Figure 5)



Figure 5 - Restoration of the natural conditions of the experimental site with local swards

4.2 Collected data

During the 2025 experimental season, the following data were collected:

Phenological data

- Vegetation cover of swards, assessed through standardized image acquisition and subsequent analysis using image-processing software (ImageJ)(Figure 6).
- Leaf count in *Bistorta vivipara* and graminoids.
- Assessment of presence/absence and reproductive stage of *Salix* spp. (male and female inflorescences) and *Bistorta vivipara*.
- Presence of target species within the Swards.

Biomass data

- Measurement of fresh and dry aboveground biomass at the end of the experiment
- Determination of total carbon (%) allocated in leaf biomass

Ecophysiological data

- Gas exchange measurements (photosynthetic assimilation and transpiration)

Microclimatic data

- Continuous recording of environmental variables using dataloggers:
 - temperature
 - soil osmotic potential



Figure 6 - Acquisition of Figures of the experimental swards

5. RESULTS

To investigate plant community and species response, the following indicators were analysed:

- aboveground biomass
- total and partial vegetation cover
- gas exchange

These variables were used as performance indicators under different treatments.

5.2 Total cover

Vegetation cover showed marked differences depending on the geographical origin of the swards, with significantly higher values in swards of Alpine origin compared to those of Arctic origin throughout the observation period (Figure. 7). In Alpine swards, the presence of OTCs resulted in a reduction in cover compared to conditions without OTCs, highlighting a negative effect of simulated warming on the ability to maintain high cover, especially in conjunction with a prolonged photoperiod. While in the local phototopic regime, in fact, plants maintained a typical growth pattern, with a summer increase and peak, followed by a decline towards the end of the season, under the constant light regime, the same plant communities showed a decrease in green cover during the experimental season, exacerbated by the thermal stress induced by OTCs. Conversely, in swards of Arctic origin, cover remained at very low values in all treatments, showing limited variations in response to both photoperiod and the presence of OTCs, thus making a significant comparison between treatments difficult.

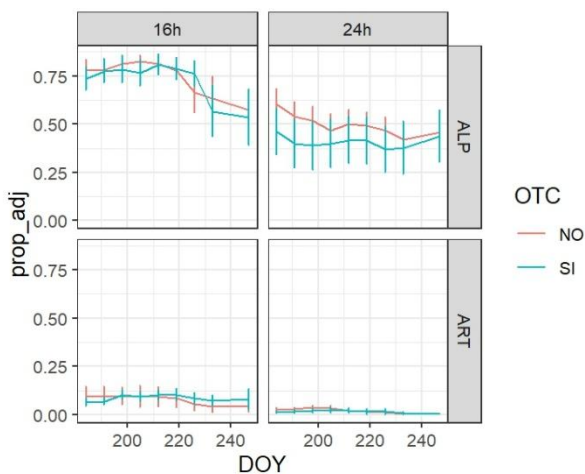


Figure 7 - results of the analysis of total cover in the experimental swards

5.3 Biomass

Biomass response to photoperiod was found to be strongly dependent on the geographical origin of the swards. In swards of Arctic origin, the extended photoperiod caused a reduction in both fresh biomass and dry biomass compared to natural photoperiod conditions. Conversely,

in swards of Alpine origin, the extended photoperiod did not produce significant variations in dry biomass, while it induced an increase in fresh biomass (Figures 8, 9).

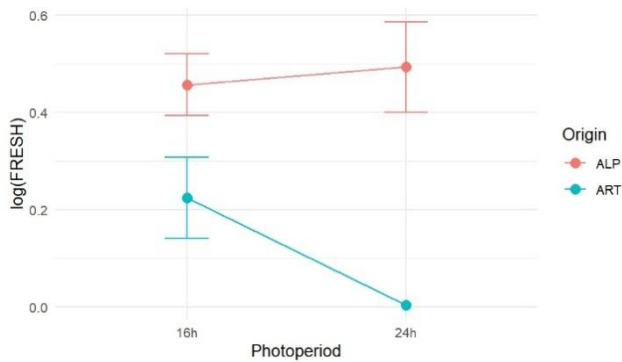


Figure 8 - results of the analysis of the fresh biomass of the experimental swards in the different treatments

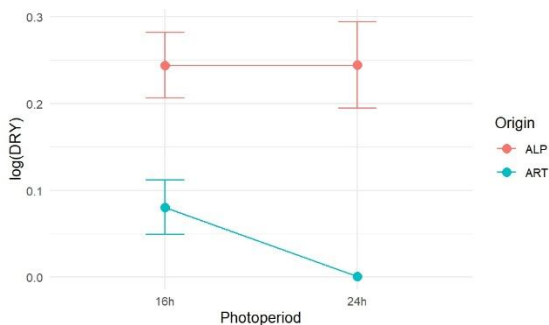


Figure 9 results of the analysis of the dry biomass of the experimental clods in the different treatments

5.4 Gas Exchange

Season-averaged CO₂ exchanges ($\mu\text{mol m}^{-2} \text{s}^{-1}$) were significantly different between arctic and alpine swards ($p < 0.0001$), between swards in the lamp and no-lamp treatments ($p < 0.0001$), between swards in the OTC and no-lamp treatments ($p < 0.01$), and between swards in the combined lamp and OTC treatment compared to the other treatments ($p < 0.01$). Significant differences were recorded among treatment covariates, (1) PAR ($p < 0.01$), (2) soil temperature ($p < 0.0001$), and (3) percent leaf cover ($p < 0.0001$).

5.5 Total leaf carbon

At the end of the season, the available leaf biomass for arctic swards was significantly lower than for alpine swards and consisted exclusively of graminoids. Furthermore, the leaf biomass of *Bistorta vivipara* at the end of the season was insufficient to make a comparison between treatments. Total leaf carbon allocation (%) did not show significant differences between treatments for either graminoids ($p = 0.22$) or *Salix retusa* ($p = 0.34$) but did show significant differences between taxa ($p < 0.0001$). In particular, carbon allocation was significantly higher for *Salix retusa*, intermediate for *Bistorta vivipara* and graminoids, and relatively low for the other species present in the swards.

6. CONSEQUENCES ON MANAGEMENT

According to the most recent projections, the effects of climate change will affect both mid- and high-latitudes and cannot be mitigated at the local scale. Consequently, the management of alpine meadows and snowbeds must necessarily take into account a factor that is not fully controllable.

However, the results obtained indicate that local adaptation is a key element in the response of plant communities and must be considered in environmental impact assessments, management strategies, ecological restoration interventions, including floristic regeneration, and, in the most extreme cases, in the assisted migration of species of conservation and/or economic interest.

The results on vegetation cover indicate a strong control by the origin of the swards, while the effects of photoperiod and OTC are secondary, confirming a differential response between Alpine and Arctic populations to the experimental conditions. Alpine populations performed better than Arctic populations, strengthening the hypothesis of adaptation to local conditions.

Similarly, the results on biomass suggest the possible use of Alpine ecotypes in restoration efforts even at high latitudes.

Overall, these results highlight a contrasting response between Arctic and Alpine populations to prolonged light conditions, confirming the importance of origin in modulating the effect of photoperiod on biomass production.

6.1 Management

The management of alpine meadows and snowbeds should aim to reduce local pressures that can amplify the vulnerability of these ecosystems to climate change. In particular, it is necessary to limit the impacts of the construction of tourism and service infrastructure, such as ski slopes, ski lifts, roads, and artificial snow reservoirs, which lead to soil alterations, microclimate changes, and habitat fragmentation.

Another management aspect concerns grazing regulation, which is an important ecological factor for maintaining the biodiversity of mountain meadows but must be carefully calibrated: excessive levels of grazing pressure can lead to soil compaction and the loss of sensitive species, while the abandonment of grazing practices can favor the progressive colonization of competitive or shrubby species, resulting in a reduction in plant diversity.

Finally, it is essential to maintain adequate hydrological conditions, avoiding overexploitation of water resources and artificial changes to drainage that could compromise soil moisture, a key factor in the persistence of snowbeds communities. Effective management interventions should therefore integrate the reduction of local anthropogenic pressures with monitoring the effects of climate change, which in Alpine and Arctic ecosystems manifests itself through variations in snow cover duration, temperature, and soil water availability.

6.2 Recovery

The insights from the PHOTOPANT project are particularly relevant for the restoration of snowbeds, where plant enrichment is an important tool, especially in environments degraded by anthropogenic pressures such as grazing. In these cases, management should not focus exclusively on regulating habitat pressure, but above all on actively recovering plant communities after removing the source of the disturbance, through reseeding, transplanting, and structural restoration.

The experimental results highlight the importance of local adaptation on species and community performance, while photoperiod plays a marginal role compared to other environmental factors. In other words, local ecotypes and genotypes, adapted to the microclimatic conditions of their environments of origin, perform better than non-local populations.

For the restoration of these long-term snow-covered communities, and more generally of alpine meadows subject to degradation at mid-latitudes, it is therefore recommended to prioritize local provenance as a primary criterion for selecting plant material (seeds, plants, and other propagules), evaluating and comparing the microclimatic conditions between the restoration site and the site(s) from which the material was obtained.

In the High Arctic, day length during the growing season will increase the intensity of the negative effects of climate change, in some cases exceeding the acclimation and (in the long term) adaptation capacity of Nordic ecotypes. This is evident from the collapse in performance recorded by Arctic swards following transplantation at the experimental latitude of approximately 45° North. Under the experimental conditions, photoperiod had an effect, but it generally worsened performance even when the Arctic sample was subjected to a 24-hour photoperiod. The continuous physiological activity triggered by the constant presence of light has increased the stress on the species, widening the performance gap between local and Arctic ecosystems. This highlights that if, due to warming, climatic conditions comparable to those of mid-latitude mountains were to occur in the Arctic, local ecotypes may not be able to respond.

The findings regarding the low productivity of Arctic soils in the warmer Alpine climate also show how large areas of Arctic vegetation linked to prolonged snow cover could increase carbon dioxide release.

This highlights the need to evaluate restoration, genetic rescue, and assisted migration activities using ecotypes or genotypes from more southern areas in northern settings, since photoperiod has not compromised their performance under stressful conditions. This approach is similar to that already adopted in forestry, where, in reforestation following felling, seeds from southern regions are increasingly being used, which are better adapted (and prospectively) to the expected future climate at the intervention sites.

6.3 Limitations and suggestions for improvement

However, the spatial and temporal limitations of the PHOTOPANT experiment require caution in adopting this type of approach, which certainly requires further studies on a large scale and over multiple growing seasons.

7. GLOSSARY

- *Assisted migration*: Assisted colonization involves the relocation of species populations outside their current range when their ability to survive in their natural habitat in the face of future climate change is threatened.
- *Common garden*: An ecological experiment in which plant populations or communities from different geographic areas are grown in the same site and under the same environmental conditions, in order to compare their responses and distinguish genetic from environmental effects.
- *Photoperiod*: The photoperiod is the daily duration of light, a stable environmental signal linked to latitude and determined by the tilt of the Earth's axis. Unlike temperature, which varies unpredictably, the photoperiod follows a regular annual cycle: it is constant at the equator (12 hours) and varies markedly at high latitudes.
- *Genetic rescue*: conservation intervention that consists in the intentional introduction of individuals from genetically different populations into a small or isolated population, with the aim of increasing genetic diversity, reducing the effects of inbreeding and improving the fitness and viability of the population itself (Whiteley et al., 2015).
- *OTC*: An open-top chamber (OTC) is an experimental chamber with an open top used in ecology to simulate in situ climate warming on natural vegetation. It is a passive structure, usually with transparent plastic or plexiglass walls arranged around a small plot of land, which traps solar heat and increases the temperature of the air and soil inside compared to the surrounding environment, without completely enclosing the upper part. The opening at the top allows light, precipitation, and air exchange, reducing unnatural effects while maintaining a slight thermal elevation useful for studying plant responses to warmer climates.
- *Alpine meadows*: herbaceous vegetation formations typical of the Alpine horizon, located above the tree line, characterized by a short growing season, low temperatures, and species adapted to extreme climatic conditions, such as late frosts, strong radiation, and wind.
- *Snowbeds*: environments shaped by geomorphology to favor the long-term permanence of snow cover. Their presence is therefore linked to topographical conditions where snow accumulates and melts slowly. Since it is difficult to identify them based on landforms alone, snowbeds are recognized primarily based on floristic criteria, that is, the presence of plant species typical of environments with persistent snow, particularly those belonging to the Salicetea herbaceae class.

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