# Mount Schrankogel (3497 m, Stubaier Alpen, Tyrol) – the GLORIA pioneer master site

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## Introduction

The uppermost vegetated zones of high mountain regions, i. e., the alpine-nival ecotone (or subnival zone), which forms the transition from the closed alpine grassland vegetation to the upper limits of plant life in the nival zone, is considered sensitive to climate warming. This assumption is based on the hypothesis that plants living at extreme altitudes are cold-adapted or cryophilic species governed by low-temperature conditions. Moreover, these species are dwarf and slow growing with weak competitive abilities and would therefore come under pressure when, triggered by climate warming, faster growing species move upwards. The starting point for the study of warming-mediated changes in high elevation floras was particularly favourable in the Alps owing to the availability of historic records on species occurrences on subnival to nival summits. The oldest records date back to 1835 and several other to the beginning of the 20th century; nowhere else are such old data available. The first modern surveys of these historic sites yielded evidence of an increase in species richness (Gottfried et al. 1994; Grabherr et al. 1994; Grabherr et al. 2001; Pauli et al. 2001) that was congruent with later repeat surveys in the Alps (Burga et al. 2004; Walther et al. 2005; Holzinger et al. 2007) and the Scandes (Klanderud & Birks 2003).

These well documented historical species inventories, while of outstanding value for the detection of the colonization of new species, were rather limited in spatial resolution and lacked precise information on the abundance of species. This was the initial motivation to scope for a suitable site for a fine-scaled monitoring setting. After a thorough reconnaissance throughout the Eastern Alps in 1993, we selected Mt. Schrankogel, one of the high peaks in the Austrian Alps and the second-highest in the Stubaier Alpen (Tyrol). The south-facing slope system on Schrankogel offers accessible areas from the alpine grassland zone across the alpine-nival ecotone to the true nival zone without interruption by glaciers and glacier forelands. The slope system is composed of all characteristic features of an alpine to nival environment, such as exposed rocky ridges, permanent snow fields in corries and ravines, scree-dominated slopes and scattered patches of cryophilic nival plants (see title image). These characteristics distinguish the site as a typical 'model mountain' of the central high Alps that, moreover, offers a safe location for a summer field camp at 2 630 m (Fig. 1).

*Fig. 1: Fieldwork in permanent plots; the field camp in the background.*

## An extensive monitoring setting across the alpine-nival ecotone

The alpine-nival ecotone on Schrankogel stretches from approximately 2 900 to 3 200 m, where its altitudinal limits rise slightly along a gradient from southwest to south to southeast (see title image). This ecotone is the transition zone between the more or less closed alpine grassland zone and the nival zone where plants occur in scattered assemblages. The upper alpine grassland is dominated by the mostly clonal-growing sedge *Carex curvula*, the pioneer grasses *Oreochloa disticha, Festuca intercedens*, and pioneer cushions such as *Silene exscapa* and *Minuartia sedoides*. The scarce nival vegetation is composed of a characteristic set of cryophilic species: *Androsace alpina, Cerastium uniflorum, Poa laxa,*

*Fig. 2: Examples of nival species (top, from left:* Androsace alpina, Ranunculus glacialis, Poa laxa*) and high-alpine species (bottom, from left:* Carex curvula, Oreochloa disticha, Silene exscapa*).*

*Ranunculus glacialis* and *Saxifraga bryoides*; see for examples Figure 2.

In 1994, an extensive setting of monitoring transects across this ecotone was established. Depending on the accessibility of the terrain, transects, built of grids constructed of flexible measuring tapes, were positioned in three target areas: the south-western slope, the southern ridge, and the south-eastern ridge (Fig. 3a). The transects were divided into permanent quadrats of 1 x 1 m²; in total, we set up around 1 000 such plots (Gottfried et al. 1998; Pauli et al. 1999). Most of the plots are hardly exposed to grazing by domestic ungulates (cattle, sheep) or not at all and sites are away from the paths of hikers. Therefore, impacts arising from direct anthropogenic activities are insignificant.

In all quadrats, the percentage cover of each vascular plant species and the cover surface types (solid rock, scree, open soil, vascular plant cover) were recorded through visual cover estimation.

The permanent plot transects on Schrankogel represent the largest vegetation data set of the alpine to nival transition zone in the Alps or elsewhere. Any plots here can be precisely re-installed due to a photo documentation of all plots and precise tachymeter measurements of the corner point positions of each quadrat. In 1997, we added temperature measurement points to the permanent plot grid system on Schrankogel at 32 positions across the alpine-nival ecotone which continuously measure the temperature at hourly intervals at a shaded point 2 – 3 cm above the soil surface.

## Analysis of permanent plot baseline data and model approaches

We classified several plant communities along a gradient from closed grassland to open nival plant assemblages. An analysis of habitat types showed that sward-forming graminoids and pioneer species of alpine grassland prefer stable rocky ridges, whereas nival species, being restricted to high elevations, also occur in less exposed habitats with longer snow cover where the substrate can be more mobile during the growing season (Pauli et al. 1999). Hence, the potential pathways of upwardly migrating alpine plants would be mainly confined to the ridges rather than to the entire slope system.

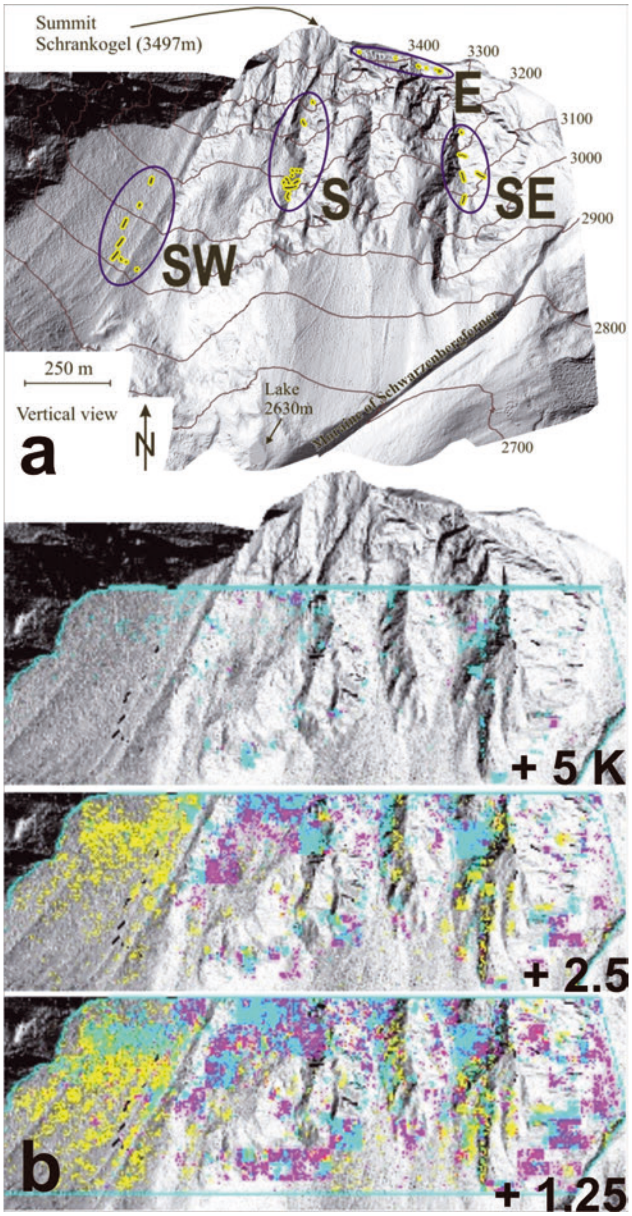


*Fig. 3: Permanent plot transects on Schrankogel (a) and the modelled distribution of the nival species* Androsace alpina *under different climate change scenarios (b); predicted relative abundance, magenta: high, yellow: medium, cyan: low.*

Using topographic habitats descriptors derived from a specifically generated high resolution digital elevation model (1 m resolution) in combination with the permanent plot data, the distribution of individual species as well as of community assemblages could be spatially extrapolated for the entire southern slope system of Schrankogel (Gottfried et al. 1998). This pioneering modelling study showed a general decrease in species richness from the alpine to the nival zone, but interrupted by a maximum of species richness at the ecotone itself. This was the basis for a first model of climate change-induced impacts of plant distribution patterns at high altitudes. Based on the lapse rate and on definitions of topographical niches of species, warming scenarios suggested that nival species would drastically reduce their distribution range and would shrink to small-scaled refugia (Fig. 3b), whereas alpine grassland species would expand upwards along stable surface situations (Gottfried et al. 1999).

An analysis of temperature data revealed that nival species are indeed well distinguished from alpine species by their habitat preferences concerning temperature and snow duration (Gottfried et al. 2002): alpine plants tend to avoid sites where summer night-time temperature commonly drops below +1 °C, but nival species also frequently occur where summer temperature drops below +1 °C or even below 0 °C. On the other hand, nival species dwell at sites where snow persists during most of early summer, whereas alpine grassland plants can hardly be found at such sites. These studies showed that alpine and nival species clearly have different habitat preferences and, presumably, a different fate in warmer climates.

Besides the ecological findings, the recording method designed for 1 x 1 m² permanent quadrats was adopted for the GLORIA Multi-Summit Approach (Pauli et al. 2004; www.gloria.ac.at); see also Grabherr et al. 2010 in this volume) that was first applied four years later in 1998 at Hochschwab in the north-eastern Alps. On Schrankogel, a summit approach was not feasible because the terrain is too steep and a frequented hiking trail runs across the summit area. Further testing

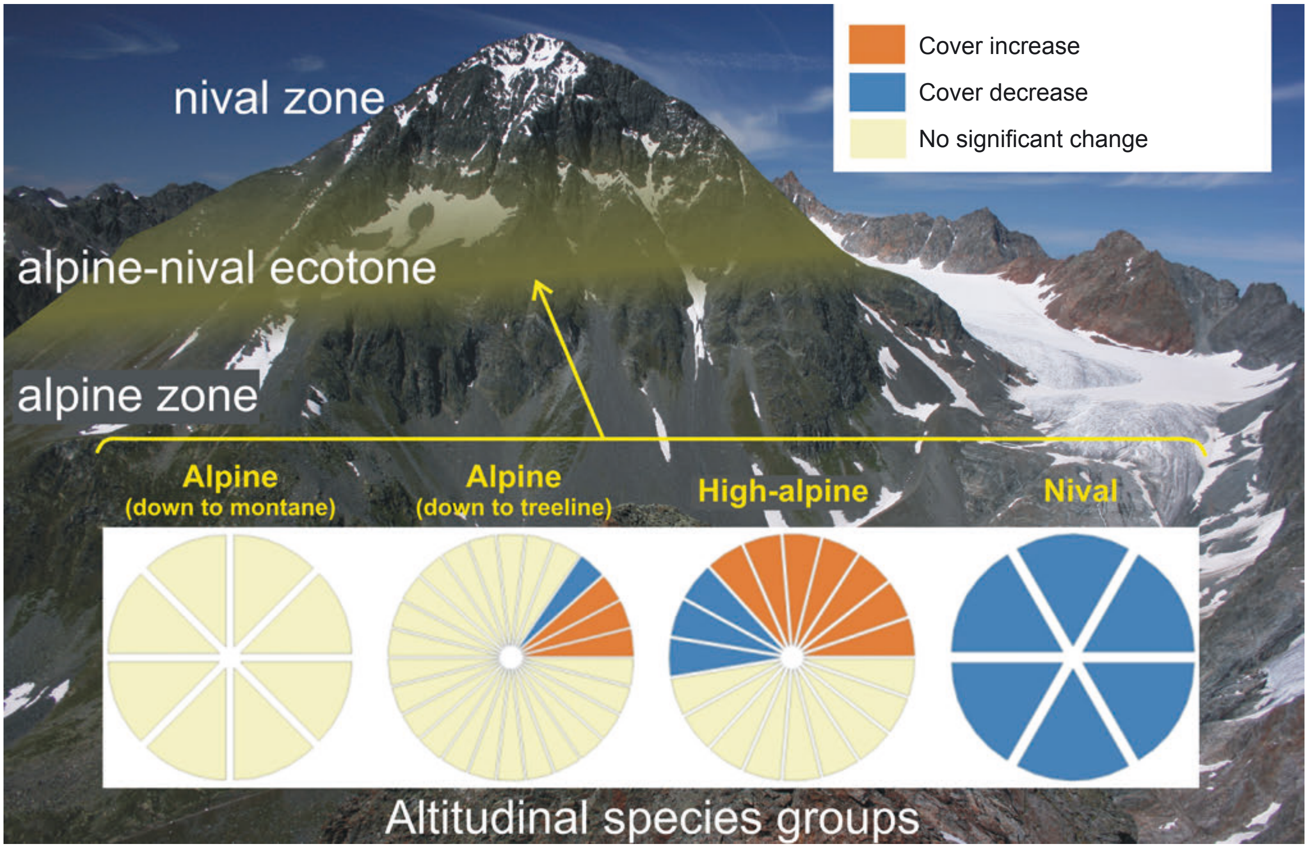


*Fig. 4: Differential changes in species cover at the alpine-nival ecotone between 1994 and 2004.*

of recording methods was conducted on Schrankogel: a comparison of visual cover assessment as used in the GLORIA Multi-Summit Approach with a point framing method showed rather consistent results, but the latter did not capture species with low cover.

## Repeat survey of permanent plots

In 2004, ten years after the baseline, a representative subset of 362 permanent quadrats was resurveyed (Pauli et al. 2007). A ten year interval was estimated as being adequate due to the slow-growing and long-lived nature of almost all species occurring at the alpine-nival ecotone. Moreover, intermediate visits and photo documentation suggested a rather low inter-annual variability of species abundance and cover patterns. Out of a total of 54 species, 23 showed a significant increase in plot occupancy, but only 3 were significantly decreasing in plots. The increase in species richness in plots of nival communities was more than twice as high than in those of alpine grassland communities. The rate of increasing species richness in nival plots calculated per decade was consistent with previous results from modern surveys of historical summit sites. A comparison of species cover changes, however, yielded more striking results. Ten species showed a significant increase in cover, whereas 10 other species were decreasing (Fig. 4). Among the declining species were all true nival species, indicating a contraction of their range at the lower distribution margin, whereas the increasers were pioneer species of alpine grassland, indicating an expansion of their upper range (Pauli et al. 2007).

*Fig. 5: Installation of an automatic snow camera at 3 100 m.*

This was the first documentation of a very likely warming-mediated species decline in a high mountain area of the Alps. Owing to the fine-scaled and quantitative species data from Schrankogel, we could show that both processes of expansion and retreat of species are at work in similar magnitude. Thus, we presume that a decrease in cryophilic species may not be exceptional in the Alps, but rather that the rare evidence of species declines reflects the lack of old enough high-resolution permanent plots.

In contrast, all plot-less repetitions of species inventories on historic high summit sites in the Alps resulted in a considerably higher rate of new species than that of disappeared species (Grabherr et al. 2001; Walther et al. 2005). This might be interpreted as suggesting that established high mountain plants are highly resilient to climate warming and that biodiversity losses may not be expected in the short or medium term (cf. Kammer et al. 2007; Kullman 2006). A simple but often ignored or overlooked consideration, however, provides a strong argument that repeat inventories of species usually are not very sensitive to the detection of species losses: a single individual of an invading species would be counted as a new species, whereas an evidence of a species loss would require that all of an unknown number of previously occurring individuals have disappeared. Besides, the potential species pool in the lower source area of newcomers is larger than that of an observation summit from where species would potentially disappear.

Therefore, reassuring messages resulting from species presence/absence data or from coarse species abundance data that climate warming has not yet led to biodiversity losses must be treated with great caution and rather underline the need for fine-scaled quantitative data from permanent plots.

The above finding from the Schrankogel master site suggested that data on the vertical distribution range (or distribution optimum) of species (e. g. alpine versus nival species) have a strong indicative power for discerning species' range expansions and contractions in relation to climate change. Hence, the Schrankogel results provided the stimulus for developing an alpine plants indicator with European GLORIA data in cooperation with the European Topic Centre on Biological Diversity and the European Environment Agency (see also Grabherr et al. 2010 in this volume).

## Other past, current and planned activities at the Schrankogel master site

Since the mid-1990s, a number of studies using different methodologies have been conducted on climate change effects or other anthropogenic impacts. These are only briefly mentioned here along with a short outlook on upcoming activities.

The alpine vegetation from its lower parts at approx. 2 300 m upwards to the alpine-nival ecotone was classified and described on the basis of Braun-Blanquet relevés and mapped in two diploma theses (Abrate 1998; Dullinger 1998).

In order to assess the influence of domestic and wildlife herbivores on the alpine vegetation, exclosure experiments were performed over three years, where the impact on vegetation structure at the currently low to moderate grazing intensity in the upper alpine zone was low (Hülber et al. 2002). A related approach focused on the role of ungulates on dispersal: a study on diet selection showed that they prefer flowers and fruit to leaves and thus herbivores could support long-distance dispersal (Huelber et al. 2005). An analysis of diaspores in faeces, however, showed that only 15% of the species found in the faeces were germinating, amounting to 3% of the flora of the study area (Ertl et al. 2002).

Another focus was on the phenology of alpine and nival plants in relation to photoperiodism and on the date of snow melt. About half of the studied species are photosensitive and may not be able to utilize a future earlier onset of the growing reason (Keller & Körner 2003). The start of the reproductive development was not directly linked with the date of snowmelt but rather with the cumulative energy input after snowmelt (Huelber et al. 2006).

A study on soil nitrogen dynamics at the alpine-nival ecotone suggested that N cycling is mainly controlled by temperature, soil age and development, atmospheric N deposition and plant competition (Huber et al. 2007).

Approaches to use bryophytes as indicators of climate change along a snowbed to ridge gradient were explored by Hohenwallner et al. (at press). A combined diploma thesis in its final stage focused on the altitudinal ranges of alpine vascular plants using a transect approach (Hofer & Scholz 2010).

Currently, two diploma theses are concerned with patterns of cushion plants in relation to climate change: one study focuses on the differences on north- and south-facing sites on an evenly shaped glacier moraine, the other compares the growth dynamics of an alpine and a nival cushion plant by diameter measurements from photos made in 1994, 2004 and 2009 and field records from the latter year.

In 2009, colleagues from the University of Passau were starting permanent plot observations on glacier forelands of Schrankogel's Schwarzenberg Ferner. An excursion team from the University of Münster tested laser-scanning techniques for detecting high-alpine to nival vegetation patterns.

A dissertation thesis is concerned with modelling alpine and nival vegetation in dependence of snow and temperature as well as derived climatic variables and topographic factors. The study builds on previous models (Gottfried et al. 1998) on local temperature series (including additional logger installations), on photo material from two automatic snow cameras installed at 3 100 m in summer 2009 (Fig. 5), and species data from the permanent plot at the alpine-nival ecotone.

Within the framework of an interdisciplinary research platform at the University of Vienna involving vegetation ecology and climatology, a novel approach was developed showing congruent sensitivity of snow and vegetation at the alpine-nival ecotone.

In addition to the ongoing activities listed above, distribution models are planned of permafrost on Schrankogel (in cooperation with the University of Zurich; see also Monreal & Stötter 2010 in this volume), combined with vegetation patterns.

## Conclusions

Given the role of master sites in supporting the scientific strength of the GLORIA multi-summit network, the activities at the Schrankogel site were and continue to be important in several respects:

- for developing a globally applicable monitoring method,
- for assessing ecological climate change effects through observations,
- for generating predictive modelling approaches, and
- for contributing to ecological theory.

Refined models and continued monitoring are expected to elucidate further the complex dynamics near the limits of plant life under warming habitat conditions and to support the interpretation of findings out of the GLORIA network.

## Acknowledgements

Research on Schrankogel was supported by the Austrian Academy of Sciences through the international programmes IGBP and MAB, by the Austrian Federal Ministries BMFLUW and BMWF, the University of Vienna through an interdisciplinary research platform, the Swiss MAVA Foundation for Nature Conservation and by the Government of Tyrol. We thank Karl Reiter for his efforts in coordinating former Schrankogel projects and Sonya Laimer for logistic and administrative support of current activities.

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