

## The phenology of four subalpine herbs in relation to snow cover characteristics

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**Abstract** To test vegetation development in relation to the snow cover characteristics of ski pistes, the soil temperature, time of snowmelt and phenology of flowering plants were recorded on plots with groomed artificial snow, groomed natural snow and untreated natural snow, on an experimental field near Davos, Switzerland. The soil temperature was lowest under the compressed artificial snow, and significantly lower under the compressed natural snow compared to the untreated natural snow. The snowmelt in April occurred first on the ungroomed natural snow, followed by the groomed natural snow and finally the groomed artificial snow. The phenology of the plants, postponed by the snow properties, followed the same pattern as the snowmelt until mid June. Although the difference in snow characteristics between the snow types was small, their impact on the early flowering plants was measurable for a relatively long time after the snowmelt.

**Key words** artificial snow; phenology; ski pistes; snowmelt; soil temperature; vegetation

### INTRODUCTION

The snow cover characteristics of alpine ski pistes are chemically as well as physically changed compared to natural snow cover. With the introduction of artificial snow, water and minerals are added to the system (Bonjour & Carle, 1997; Newesely, 1997; Kammer & Hegg, 1990). By grooming the pistes, the machines compress the snow cover, increasing its density and thermal conductivity. Cold temperatures may then more easily reach the soil and cause freezing (Stoeckli & Rixen, 2000). Furthermore, snowmelt could be retarded on pistes with artificial snow. The changed winter environment may therefore cause changes in the development and performance of plants wintering under the pistes. In this study, we focus on the physical properties of differently treated snow types and how the phenology of plants responds to them.

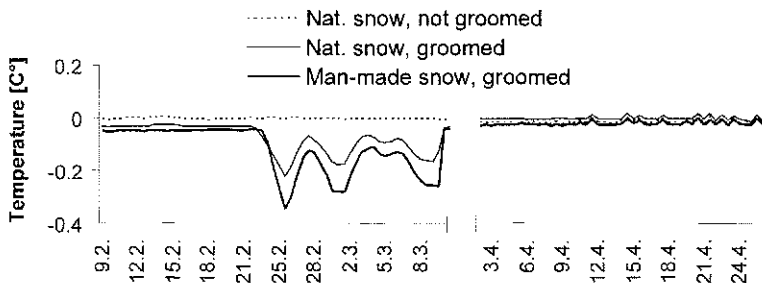
### MATERIALS AND METHODS

An experimental snow field was established in the valley of Davos, Switzerland (1530 m a.m.s.l.), on cultivated grassland (*Trisetetum flavenscentis*). It consisted of plots with different snow types: 10 plots with artificial snow, 10 plots with natural snow, both groomed and randomized within a block design, and 10 plots with untreated natural snow on the edge of the field. The snow depth throughout most of the

winter was 60 cm on the groomed plots and 90 cm on the untreated plots. The snow densities at the end of the winter were, on average, 569 g l<sup>-1</sup> in the groomed artificial snow, 498 g l<sup>-1</sup> in the groomed natural snow and 382 g l<sup>-1</sup> in the untreated snow. In five of ten plots, we recorded the temperature on the soil surface with temperature sensors every hour from February to May 2000. The disappearance of the snow in spring was observed visually on each plot. Similarly, the flowering phenology of four common plants (*Crocus albiflorus*, *Myosotis sylvatica*, *Taraxacum officinale* agg. and *Polygonum bistorta*), which flowered one after the other from the end of April until the end of June, was determined. Differences between the treatments were analysed using the Wilcoxon rank sum test.

## RESULTS

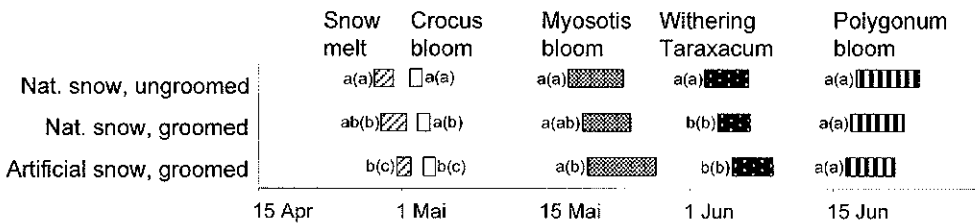
The soil temperature was constantly lower under groomed snow showing greater fluctuations until the onset of the snowmelt (Fig. 1). Under the natural snow cover, the temperature stayed at zero degrees ( $0.005 \pm 0.008^\circ\text{C}$ ) from the begin of the measurements (9 February) until the time of the snowmelt (28 April). In contrast, the soil temperature under the groomed snow cover was below zero, reaching minimum temperatures of  $-0.34^\circ\text{C}$  ( $\pm 0.23^\circ\text{C}$ ) under artificial snow and  $-0.22^\circ\text{C}$  ( $\pm 0.14^\circ\text{C}$ ) under the compressed natural snow.



**Fig. 1** Average soil surface temperatures of the different snow types for 9 February–11 March and 1–28 April. The temperature minima of the groomed snow types are significantly lower than those of the undisturbed snow ( $p < 0.01$ ,  $n = 5$ ).

The timing of the snowmelt differed between the treatments. Compressed natural snow was free of snow one day after the untreated control, whereas the artificial snow cover was snow free two days after the control (Fig. 2).

The phenology of the three first plant species differed between the treatments whereas the last showed no difference. The flowering of *Crocus* at the begin of May was earliest under the untreated control plots, followed by the compressed natural snow and finally the artificial snow (Fig. 2). Fourteen days later, the second flowering plant *Myosotis* showed the same pattern as *Crocus*, and also *Taraxacum* at the end of May flowered in the same order. However, the *Polygonum* bloom in mid June occurred at the same time in all treatments or even later on the plots with untreated natural snow.



**Fig. 2** The beginning of snowmelt and the phenology of meadow plants (beginning of flowering) in relation to different snow treatments (the length of the bars represents the standard deviation above and below the mean value). If letters at the bars are different, the effects between the snow treatments are significant ( $p < 0.05$ ,  $n = 10$ ), the letters in brackets show marginal significant differences ( $p < 0.1$ ).

**DISCUSSION**

Although the differences between the snow treatments in all measured parameters were small, they all showed the same pattern. The delayed phenology of the plants corresponded to low winter soil surface temperatures and late snowmelt. Hence, plant development was directly reacting to the snow cover characteristics.

On ski pistes, soil frost and postponed snowmelt are even more distinct than in our experimental field. Temperature minima in the soil of  $-10^{\circ}\text{C}$  and retarded snowmelt of three weeks are frequent phenomena on ski pistes in the alpine zone (Stoekli & Rixen, 2000; Mellini, 1996). Therefore, the impact of ski piste grooming on the vegetation could be intense. The retarded phenology is indicating a decreased plant performance, e.g. through frost damage, decreased nutrient supply due to reduced microbial activity in the cold soil, or increased chemical load of the melt water (Devarenes, 1994). Further studies should focus on plant species composition, productivity and phenology in relation to these changed conditions in winter.

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**REFERENCES**

Bonjour, C. & Carle, G. (1997) Risiko und Auswirkungen von Zusätzen bei der Beschneigung und bei der Pistenpräparation (Risk and impact of additives in snow production and ski piste preparation, in German). Semesterarbeit, Umweltnaturwissenschaften, ETH, Zürich, Switzerland.

Devarenes, G. (1994) Effet de la neige artificielle sur des écosystèmes montagneux (Effect of artificial snow on mountain ecosystems, in French). Mémoire présenté à l'INRS, Université du Québec, Canada.

Kammer, P. & Hegg, O. (1990) Auswirkungen von Kunstschnee auf subalpine Rasenvegetation (Impact of artificial snow on subalpine grassland vegetation, in German with English abstract). *Verhandlungen der Gesellschaft für Ökologie XIX(II)*, 758–767.

Mellini, K. (1996) Skipisten und Permafrost—Untersuchungen der Permafrostverbreitung auf der Diavolezza unter besonderer Berücksichtigung der Einwirkung von Pistenpräparation und Pistenbeschneigung auf die Bodentemperatur (Ski pistes and permafrost—a study of the distribution of permafrost at Diavolezza in consideration of the impact of piste preparation and snow production on soil temperature, in German). Masters Thesis, Geografisches Institut der Universität Zürich, Switzerland.

Newesely, C. (1997) Auswirkungen der künstlichen Beschneigung von Schipisten auf Aufbau, Struktur und Gasdurchlässigkeit der Schneedecke, sowie auf den Verlauf der Bodentemperatur und das Auftreten von Bodenfrost (Impact of artificial snowing of ski pistes on structure and gas permeability of the snow cover, as well as soil

temperature characteristics and the occurrence of soil frost, in German with English abstract). Dissertation, Naturwissenschaftliche Fakultät, Leopold Franzens Universität, Innsbruck, Austria.

Stoeckli, V. & Rixen, C. (2000) Characteristics of artificial snow and its effect on vegetation. In: *Conf. Proceedings of the Int. Snow Science Workshop* (Big Sky, Montana, USA, 1–6 October 2000) (ed. by K. Birkeland, E. Adams & F. Johnson). American Avalanche Association, Bozeman, USA.