Winter climate change in snow-rich environments: Reactions of a sub-arctic tundra community

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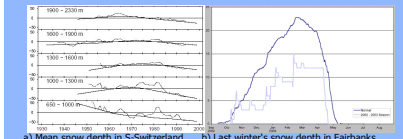
Abstract
Arctic and alpine regions are particularly affected by global climate change. Winter climate has been especially subject to major changes: in the two to three last decades, the measured temperature rise in the American Arctic and the European Alps was greatest during winter, and the snow cover extent decreased in many regions. However, climate change research mainly focuses on the effects of increased summer temperatures, CO_2 concentrations and nutrient availability. Previous studies on snow-vegetation interactions suggest that changes in snow cover duration (which determines the start and length of the growing season) and changes in snow depth and composition (which define the subnivean temperatures and the spring water and nutrient input) have differential effects on the phenology, the population dynamics and the composition of arctic and alpine plant communities. We (1) experimentally disentangle the two factors: duration of snow cover and snow depth, (2) quantify their effects on phenology, population biology of single species and community composition in an arctic and an alpine study site, and (3) illuminate the mechanisms which may lead from changes in phenology to changes in community structure and composition. While an advanced snow-melt generally results in an advanced vegetation development, our results of snow manipulation experiments in alpine and subarctic habitats reveal that increased temperature conductance of the snow cover and subsequent decreased subnivean temperatures can delay the development of early flowering plant species. In our experiments, we control the interactions between start of the growing season and winter temperature regime and explore their effect on phenology, productivity and reproduction of tundra species

Introduction

Winter temperature and precipitation patterns have altered in the American subarctic as well as in the European Alps during the last decades as part of global climate change (Figure 1). In many regions, declines of winter snow depths, advanced spring snow melt, or both have already occurred, which not only frustrates arctic skiers and alpine mountaineers (Figure 2), but may result in changing patterns of phenology, population dynamics and the composition of arctic and alpine species communities.



a) Mean snow depth in S-Switzerland (% deviation from long term mean)

b) Last winter's snow depth in Fairbanks, AK, and long term mean

Figure 1. Recently declining snow depths a) in the Alps and b) in Interior Alaska...

Balmhorn, Switzerland

Quartz lake, Alaska

Figure 2 ...frustrate alpine and arctic Skiers likewise

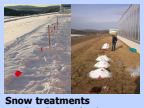
By experimentally disentangling snow depth and snow melt patterns, we aim at quantifying the effects of snow cover characteristics on phenology, productivity and reproduction of subarctic and alpine tundra communities.

Methods

We are currently carrying out field studies in Alpine and Subarctic tundra communities. The preliminary results presented here are from two Alaskan field experiments after one winter of snow manipulation.

Study 1

Design
108 Pots with 2 individuals ea. with 2 species:
3 mixtures
x 4 treatments
x 3 replicates



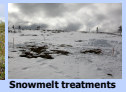
Snow treatments
- reduced snow depth
- reduced snow duration
- both reduced
- control

Factors measured
- Snow depth+density
- Subnivean temp.
- Snow melt
- other site factors

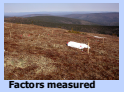
Dependent variables
- Phenology
- Growth
- Reproduction
- Disease

Study 2

Design
3 sites
x 3 blocks
x 4 snow melt treatments



Snowmelt treatments
- very early (~1.5-2 w)
- early (~1 w)
- control
- late (~ 10d)

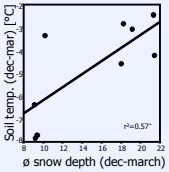


Factors measured
- Snow depth+density
- Subnivean temp.
- Snow melt
- other site factors

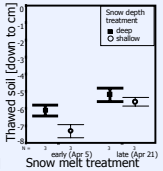
Dependent variables
- Vegetation composition
- Phenology
- Reproduction
- Individual fitness
- Productivity
- Diseases/parasites

Results: Study 1 – Pot experiments

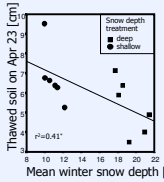
1) Subnivean temperatures and soil thawing
Temperatures under the snow (measured at the soil surface) correlated with the mean snow depth (r^2=0.57, p<0.05), with a difference of approx. 3.25° C per 0.1 m snow depth. Lower snow depth also accounted for higher temperature variability and lower temperature minima. The active soil layer in spring was deeper 1) in plots that had been longer free of snow (early treatment) and 2) that had had shallow snow during winter. Thus, although a **shallow snow cover** meant **colder winter temperatures,** it allowed for **rapid soil thawing** in spring.



ø snow depth (dec-march) [cm]

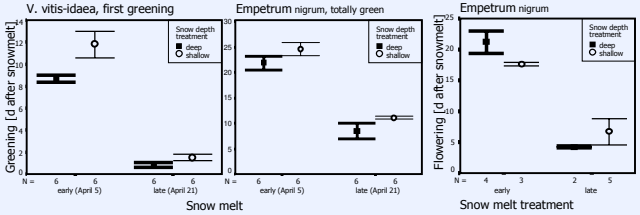


Snow melt treatment

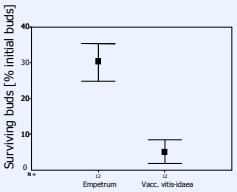


Mean winter snow depth [cm]

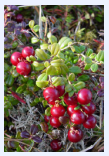
2) Phenology
Both *Empetrum nigrum* and *Vaccinium vitis-idaea* were largely brown from accumulated pigments when emerging from under snow. The **timing of the greening differed between snow melt treatments** (p<0.001). Within treatments, the **greening of plants from shallow snow cover was postponed in both species** (*Vaccinium* p<0.01, first greening; *Empetrum* p<0.05, total greening). The **timing of flowering** of *Empetrum* was influenced by **depth and duration of the snow cover** (p<0.1 and p<0.001).



2) Reproduction
Only *Empetrum nigrum* was flowering and reproducing in sufficient numbers for analysis. We found no influence of any snow treatment on the number of flowering or reproducing plants per plot. The fruiting of *Empetrum* was significantly **more successful** when grown **together with its own species than when grown with *Vaccinium*** (Whitney-Mann p<0.05).

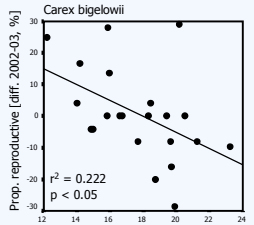


Empetrum plants grown with

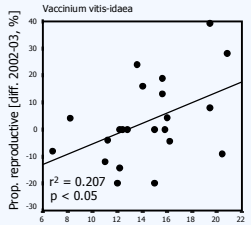


Results: Study 2 – Field experiments

1) Reproduction
The proportion of reproductive plants per population and plot did not depend on snow melt treatments. In all species but *Carex bigelowii*, it was very similar in 2002 and 2003. The proportion of **reproductive *Carex bigelowii* was negatively correlated with the mean winter snow depth per plot** (which was not manipulated in this experiment). In *Vaccinium vitis-idaea*, the difference in reproduction between 2002 and 2003 correlated with snow depths of the first half of the winter only, when the coldest air temperatures occurred.

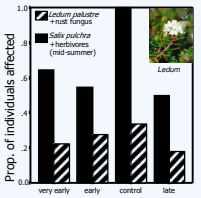


Mean winter snow depth [cm]

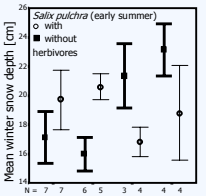


Snow depth during coldest period

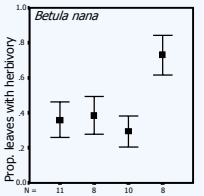
2) Disease and Herbivory
The tundra dwarf shrubs *Ledum palustre, Salix pulchra* and *Betula nana* were affected by a rust fungus (*Ledum*) and herbivory, respectively. In mid-summer, *Ledum* and *Salix* in **controls** were **more often affected by disease and herbivores** than those in snow melt treatments. In early melting plots, **herbivores preferred *Salix*** that had been under **deep snow cover** over winter, while the opposite was found for control plots (melt treatm. x snow depth p<0.05). There was no difference between treatments in the proportion of *Betula* affected, however, when a plant was affected, it was **more heavily affected** in the treatment with **late snowmelt** than in the other treatments (p<0.05).



Snow melt treatment



Snow melt treatment



Snow melt treatment

Conclusions

- Timing of snow melt and snow depth during winter both impact on plant performance.
- Phenology and reproduction of tundra plants was affected in different ways.
- Snow cover characteristics have effects on species sensitivity to diseases and herbivory.
- Ongoing analysis and future projects may highlight a) more impacts of snow cover characteristics on plants and b) mechanisms leading from changes in phenology to changes in fitness, reproduction and species interactions.

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