International Tundra Experiment ITEX

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More than 20 years of tundra vegetation change research

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Abstracts

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Input talk I

Plant and ecosystem responses to climatic warming in mountains

Christian Körner
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High elevation terrain is commonly assumed to be hostile for life, and alpine biota in particular have been attributed to be low temperature limited and stressed. Climatic warming is now often considered very dangerous for these biota. Obviously these two assumptions are mutually exclusive, illustrating some misconceptions about life in the cold. In this overview I will suggest to make distinctions between slow (log term) and rapid (short term) effects of temperature changes, and I will ask, which type of observations and experiments will most likely bear predictive power for the fate of these biota in a warmer climate. I will illustrate the power of thermal gradient studies for assessing ecosystem metabolism in response to temperature. In the last part of my talk I will briefly address micro-climatological diversity in treeless high elevation terrain, which opens a different view point at warming effects on biota. Such data argue strongly against an isotherm based space for time approach in vegetation modelling. I will highlight the usefulness of temperature indicator values for alpine taxa and comment the often forgotten insurance system of nature against impacts of year-to-year weather curiosity: photoperiodic controls of development. These evolutionary constraints of plant phenology prevent climatic tracking in many taxa, and thus, may cause a transitory conflict between ecotypic differentiation and climatic demands in a warmer environment.

Session A: ITEX experiments

A.01

Introductory talk: ITEX a history of collaboration and high impact syntheses

Robert Hollister
Grand Valley State University, United States of America

The ITEX network was established in 1990 and the first sites were formally established in 1992. The network was designed around common protocols to allow researchers to compare findings from sites across the tundra biome. The network has been very successful and has resulted in many synthesis activities. These have led to many high impact papers including a special issue of Global Change Biology which included comparisons of plant response across sites; a meta-analysis of the response to the first several years of warming on plant phenology and performance published in Ecological Monographs; a meta-analysis of the initial community change due to warming published in PNAS; an analysis of carbon exchange in response to warming published in Ecological Monographs; an analysis of long-term community change in response to warming and in the control plots published in Ecology Letters and Nature Climate Change; an analysis of OTC functioning published in Global Change Biology; and an analysis of phenologic change in the control plots published in Philosophical Transactions of the Royal Society B. It is hoped that as many future syntheses activities will continue and result in many new papers.

A.02

Thermophilization of tundra plant communities in response to ambient and experimental warming

Sarah Elmendorf
National Ecological Observatory Network (NEON), United States of America

Forecasting ecological responses to climate warming is notoriously challenging. Inference typically relies on one of three methods: long-term observational records observational records, space-for-time substitutions, or experiments. Potential limitations to all three have long been recognized. Concerns about warming experiments in particular were bolstered by a recent meta-analysis concluded that warming experiments substantially underestimate near-term climate warming impacts. We compared tundra plant community composition shifts in response to spatial gradients in ambient summer temperature, inter-annual variability in summer temperature using long-term observations, and experimental warming treatments, using long-term data from observational studies, as well as experimental data from warming experiments. We found that over broad scale spatial gradients, community composition shifted more dramatically with temperature than in response to either temporal variability in temperature or temperature increases induced by experimental warming. The latter two effect sizes were nearly identical. These results support the idea that spatial gradients may be effective at predicting equilibrium composition after millennia of change, while simultaneously endorsing both experimental and in-situ monitoring approaches as effective way to project more moderate, decadal scale responses.

A.03

Summer and winter warming impacts on decomposition-controlled shrub nitrogen uptake in a low-Arctic dry shrub heath at Disko Island, West Greenland

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Arctic warming has led to an increase in shrub growth in arctic tundra, evidenced by several syntheses of pan-Arctic observational and experimental studies. An increase in shrub growth may lead to multiple feedbacks to climate warming in the Arctic. Both summer (surface albedo changes) and winter warming (snow-shrub hypothesis) climate-vegetation feedbacks have been proposed as major driving factors for tundra shrub expansion. However, the exact nature of the driving factors of shrub expansion remains unknown. We hypothesize that shrub expansion is mainly controlled by N-availability, driven by a warming-induced increase in litter decomposition rates during summer as well as winter. Here, we present initial results of a novel decomposition study using ^{15}N-labeled leaf material of the deciduous shrub Salix glauca and the evergreen shrub Cassiope tetragona in order to follow the fate of decomposition-released nitrogen from litter through shrub leaves, roots, microbes and soil. During summer 2012, litter bags with ^{15}N-enriched leaf material were incubated in a new large-scale ecosystem manipulation field experiment in a dry shrub heath at Disko Island, W Greenland. Three treatments were applied in a full-factorial setup (n = 6 replicates) to disentangle summer and winter warming effects: (1) snow height was elevated using snow fences to mimic soil winter warming, (2) summer air warming using ITEX open-top chambers, (3) summer soil warming by clipping aboveground shrub biomass. Our litter study may yield new insights into the effects of seasonal warming on litter decomposition rates and associated feedbacks to shrub expansion through changes in nitrogen cycling.

A.04

Reproductive responses to experimental and observed climate change in High Arctic tundra plants

Greg Henry[1], Sarah Elmendorf[2], Rebecca Klady[1], Anne Bjorkman[1], Sarah Desrosiers[1], Sam Robinson[1], Alison Beamish[1]

[1]University of British Columbia, Canada; [2]National Ecological Observatory Network (NEON), United States of America

One of the ultimate goals of research in plant ecology is to understand the effects of environmental changes on plant fitness. Changes at the plant community and ecosystem levels depend on the ability of individual plants to successfully reproduce and survive. Most ITEX studies have concentrated on phenology and growth variables of individual species, including flowering phenology. However, few studies have examined the effect of the warming treatments on the reproductive effort and success of tundra species (cf. Klady et al. 2011). Research at Alexandra Fiord, Ellesmere Island, Canada, has examined the effects of experimental warming on reproductive effort and success and on the overwinter survival of seedlings over the past 20 years. Studies have included reproductive effort at the individual species and community levels: a) biomass allocation to flowering tissues and seeds; b) germination rates in aerial and soil seed banks; c) flower densities of all species in most years; and d) overwinter survival of seedlings. All the studies have been conducted in at least three of the seven tundra plant communities with experimental warming treatments. In this presentation, we provide an overview of the effects of experimental and ambient warming on these reproductive variables on species and communities at Alexandra Fiord. We also propose a set of studies to be conducted across the ITEX network that could give regional and biome wide results of the effects of climate change on plant fitness.

A.05

Interactions in the Tundra: EXperimental warming and precipitation effects on mosses and their interactions

Ellen Dorrepaal[1], Signe Lett[1], Laurenz Teuber[1], Marie-Charlotte Nilsson[2], David Wardle[2]
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Moss-dominated, tree-less tundra ecosystems are important for the earth's carbon and energy balance because of long-term carbon storage in recalcitrant moss tissue and high reflectivity when covered with snow. Climate change may alter these functions, by affecting the composition and functioning of tundra plant and soil communities. Analyses of previous research have shown that warming effects on vegetation are rarely consistent over space and time but depend on local conditions, including moisture availability and interactions within the local plant community (Dorrepaal 2007, Elmendorf et al 2011). Moss species differ in characteristics important for carbon storage, responses to the environment and interactions with vascular plants. The presence or absence of different moss species may thus drive the responses to climate change of tundra plant communities and their functioning. However, despite their importance, mosses are often overlooked during experimental design or data collection. Current data are therefore insufficient to analyse how different mosses vary in response to climate change over space and time and how they modify climate change impacts on the vascular plant and soil communities. We aimed to improve this and set up a new warming experiment in subarctic, alpine tundra communities dominated by one of three common tundra mosses. To analyse the interactive effect of spatial variability in moisture availability, we distributed eight experimental sites above the treeline along a strong precipitation gradient between Abisko (322 mm/yr) and Riksgränsen (940 mm/yr) in North Sweden. At each site, we applied factorial combinations of passive experimental climate warming (ITEX open-top chambers versus ambient), moss species identity (Pleurozium schreberi, Hylocomium splendens and Sphagnum spp. (S. fuscum and S. warnstorfii)), and moss presence (mosses intact versus experimentally removed). The experiment was initiated in 2011 and effects of the experimental design on environmental conditions (soil and air temperature, soil moisture, summer precipitation) and moss growth during the first three growing seasons will be shown.

A.06

Short-term effects of warming on Gyneaphora groenlandica, an ITEX insect

Isabel C. Barrio, David S. Hik
University of Alberta, Canada

Invertebrates will be highly responsive to climate change, particularly to warming, because their life cycles strongly depend on temperature, and more so in alpine areas where their active season is restricted to the summer months. Therefore, predicted impacts of climate change imply changes in populations of invertebrates and, in the case of invertebrate herbivores, their subsequent effects on the alpine plants they feed on. Warming too, will likely affect invertebrate herbivory rates and their metabolic efficiency, which will ultimately impact ecosystem processes mediated through frass deposition. We used the Arctic moth (Gynaephora groenlandica) as a model for investigating the effects of warming on invertebrate herbivory on tundra plant communities. Within a single season, we manipulated temperature using open top chambers at two different elevations, in the alpine tundra of SW Yukon. We will discuss measurements of consumption rates of Arctic moth caterpillars on their main food plant (Salix arctica) over their active period, and how temperature influences caterpillar performance (growth rate and metabolic activity) and potential impacts to ecosystem functioning (e.g. impacts of frass quality on decomposition processes) in the field. Responses of invertebrate herbivory to warming may occur through altered metabolic efficiency and growth rates. These results can expand our understanding of the combined effect of warming and invertebrate herbivory on tundra ecosystems and their resilience to climate changes.

A.07

Twenty years of experimental warming in a high Arctic plant community: plasticity or adaptation?

Anne Bjorkman[1], Mark Vellend[2], Greg Henry[1]
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Experimental warming chambers were established at Alexandra Fiord on Ellesmere Island in 1992. Over the past 20 years we have recorded substantial shifts in plant phenological and phenotypic traits within the warming treatment. However, it is unknown whether these changes are a result of the phenotypic plasticity of individuals, or whether evolutionary adaptation has taken place within the warming experiment. We conducted a reciprocal transplant experiment with three species (Papaver radicatum, Oxyria digyna and Arctagrostis latifolia) in two different habitat types to answer this question. Preliminary results indicate that both processes account for the responses of plants to experimental warming at this site, and that for some species, adaptation to warming within the warming treatments has occurred.

A.08

Recovery of an alpine plant community from simulated environmental change and the effects of herbivory on the recovery process

Siri Lie Olsen, Kari Klanderud
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Global environmental change has been predicted to induce regime shifts in natural ecosystems, thereby causing potentially non-reversible changes. Climate warming and nitrogen deposition are two of the main drivers of global change, and more than two decades of experiments have shown profound changes in plant community composition following warming and nutrient addition. The ability of plant communities to recover from environmental change has received less attention, and we still lack knowledge of the reversibility of the changes induced by increased temperatures and nutrient availability. Further, while herbivores can modify the response of plant communities to global change, the effect of herbivory on the recovery process remains unclear. We examined the recovery of an alpine plant community from a combined warming and nutrient addition experiment with and without the presence of herbivores. Many aspects of the alpine plant community had not recovered from experimental warming and nutrient addition six years after the cessation of the treatments. A lack of recovery of the vascular plant community, with a persistent increase in the abundance of highly competitive graminoids and subsequent accumulation of litter, seemed to prevent recovery of lichens and bryophytes in the absence of herbivores. The presence of herbivores increased the recovery rate of the lichen and bryophyte communities, most likely due to removal of vascular plant biomass and litter. Our study shows that plant community changes due to increased temperatures and nutrient availability are not readily reversible. However, herbivory may increase the rate of recovery.

A.09

Phenological response of tundra plants to background climate variation tested using the International Tundra Experiment (ITEX)

Steven F Oberbauer
Florida International University, United States of America

The rapidly warming temperatures in high latitude and alpine regions have the potential to alter the phenology of arctic and alpine plants, affecting processes ranging from food webs to ecosystem trace gas fluxes. The International Tundra Experiment (ITEX) was initiated in 1990 to evaluate the effects of expected rapid changes in temperature on tundra plant phenology, growth, and community changes using experimental warming. Here we used the ITEX control data to test the phenological responses to background temperature variation across sites spanning latitudinal and moisture gradients. The data set overall did not show an advance in phenology; instead, temperature variability during the years sampled and an absence of warming at some sites resulted in mixed responses. Phenological transitions of high arctic plants clearly occurred at lower heat sum thresholds than those of low arctic and alpine plants. However, sensitivity to temperature change was similar among plants from the different climate zones. Plants of different communities and growth forms differed for some phenological responses. Heat sums associated with flowering and greening appear to have increased over time. These results point to a complex suite of changes in plant communities and ecosystem function in high latitudes and elevations as the climate warms.

A.10

Mosses as mediators of changing climate: Consequences for forest expansion

Signe Lett[1], Laurenz Teuber[1], David Wardle[2], Marie-Charlotte Nilsson[2], Ellen Dorrepaal[1]
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Mosses are dominating the ground cover in tundra ecosystems. There, mosses work as important mediators of climatic conditions, for example by insulating the soil and intercepting precipitation. As tree lines advance due to climate change, mosses are likely to form establishment sites for tree seedlings. Seedlings are sensitive to desiccation and low temperatures; under harsh conditions mosses may be able to provide a favorable microclimate for seedling growth. Seedlings are therefore likely to be affected by the characteristics of mosses related to these factors. In addition, moss growth is also affected by temperature and moisture and they may therefore exert stronger or weaker competition on tree seedlings when climate changes. We hypothesized that seedlings would differ in their performance depending on moss species. We expected the moss effect on tree seedlings to change depending on the climatic conditions. For example mosses could switch from being facilitators of seedlings in a harsh environment to being competitors when climatic conditions are more favorable. To test this, we transplanted seedlings of Betula pubescens and Pinus sylvestris into plots dominated by one of three common tundra moss species and into plots where mosses had been removed since 2011. During summer, temperature was increased in half of the plots by using OTC's. A full combination of treatments (moss species, moss removal, and warming) was replicated at eight sites distributed along a precipitation gradient (322-940 mm yr^{-1}). We evaluated seedling performance by measuring seedling survival and height increase during two growing seasons (2012 and 2013). The survival data show that seedlings are indeed affected, not only by the presence of mosses, but also differently by different moss species. We will additionally present seedling growth response and link this to moss growth and soil temperature and moisture data.

A.11

Structural comparison of Arctic plant communities across a soil moisture gradient in response to climate warming in Northern Alaska

Jessica Lynn Gregory
Grand Valley State University, United States of America

Monitoring the response of Arctic ecosystems to climate change is especially critical for understanding long-term consequences on resource availability and cycling, as well as biotic community structure. Arctic vegetation is a particularly valuable platform for studying the effects of climate change because it drives energy distribution to other trophic levels and thus impacts the success of the ecosystem as a whole (IPCC, 2007). Ongoing research in Atqasuk, Alaska has shown consistent increases in plant growth, height, and cover with warming since the mid-1990s. These trends likely correspond with increased individual abundance, or density, thus leading to changes in vegetation composition over time (Hollister et al., 2005b). However, cover has not formerly been compared with species density in this area, nor has the consistency of the response been evaluated over a climatic gradient such as temperature or moisture. If warming trends continue to escalate as predicted, we expect higher density and more extensive distributions of cover-dominating plants such as shrubs and graminoids due to competitive interactions (Klady et al., 2011). Conversely, we expect lower density and reduced distributions of species exhibiting less dominant growth responses, such as forbs, lichens, and mosses (Hollister et al., 2005b; Walker et al., 2006). Given the need for a more rounded understanding of structural modification within Arctic plant communities, the goal of this project is to provide a detailed comparison of vegetation composition change across a moisture gradient using two sampling techniques. Two research questions are addressed: 1) how do vegetation cover and density vary across a soil moisture gradient, and 2) how might these small-scale alterations in community structure explain the response of the tundra ecosystem to warming on a much broader scale. The patterns and relationships observed will play a major role in refining current predictive models of long-term consequences of warming on Arctic plant community structure.

A.12

ITEX and grazing: The OTCs, the geese and the aphid

Elisabeth J. Cooper[1], Mark Gillespie[2], Karolina Paquin[3,4], Ingibjorg Jonsdottir[4]
[1]University of Tromsø, Norway; [2]University of Leeds; [3]University of Tromsø; [4]UNIS

Herbivores play an important role in shaping the vegetation composition, structure and dynamics in the Arctic. Here I will present some interesting findings from our ITEX site on Svalbard where we added geese in a non-goose grazed area to increase the goose grazing pressure in 2003-5 followed by subsequently removal, allowing the vegetation to return to a background level of little grazing. OTCs have been erected on the plots each summer since the start of the experiment.We are currently analysing the plots again to look for signs of recovery from grazing. Aphids were monitored at the site during two seasons and the theme of phenological match/ mismatch will be discussed.

A.13

Arctic plant responses to changing abiotic factors in northern Alaska

Robert Thomas-Slider Barrett, Bob Hollister
Grand Valley State University, United States of America

Grand Valley State University, United States of America Arctic plants play critical roles in ecosystem regulation and understanding their relationships with abiotic factors is necessary to predict the impact climate change on the Arctic. Using data from long-term research sites in Barrow and Atqasuk, Alaska, we sought to investigate trends in abiotic factors (snow melt and freeze-up dates, air and soil temperature, thaw depth, and soil moisture) and plant traits (inflorescence height, leaf length, reproductive effort, and flowering date) over time and to elucidate potential relationship between these factors and traits. Though mostly non-significant, several abiotic factors showed trends over time consistent with the regional warming pattern observed in the Barrow area including increasing air and soil temperatures, earlier snowmelt, delayed freeze-up, drier soils, and increasing thaw depth. Over the same time period, plants showed trends toward increasing inflorescence heights and reproductive effort. Air and soil temperatures, measured as degree days from snowmelt, were consistently correlated with plant growth and reproductive effort. We also found that varying the base temperature used to calculate degree days could increase the number of species predicted such that leaf lengths were better predicted using a lower base temperature while inflorescence heights showed the opposite And that the number of flowers produced was best predicted using abiotic conditions from the previous year. For eleven species we found strong evidence to suggest that climate change at these sites has already caused a significant shift in their growth and reproductive effort.

A.14

Plant community responses to five years of simulated climate warming in an alpine fen of the Qinghai-Tibetan Plateau

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In the present study we investigated the effects of two levels of experimental warming on plant community species richness, diversity, cover, and above- and below-ground biomass and abundance of two graminoid species, the dominant Kobresia tibetica and the sub-ordinate Carex moorcroftii, in an alpine fen at 4700 m in the Qinghai-Tibetan Plateau. Five years of experimental warming decreased species richness and diversity, primarily due to decreased diversity of graminoids. Above-ground biomass, vegetation height and cover increased in both levels of warming. Below-ground biomass increased at 5-20 cm but not at 0-5 cm, indicating resource allocation to plant roots at deeper soils. Our results from the mid-latitude permafrost region at the hinterland of the Qinghai-Tibetan Plateau support previous results from alpine or arctic tundra at higher latitudes of decreased diversity under global warming. Our study documented a decline in species richness and diversity also in the control plots during the five year experimental period, which, together with results from other studies in the region, suggest that the alpine fens are already changing as a response to the ongoing climate warming in this area. The different responses to warming within a functional group, as seen for graminoids in our study, suggest that more studies on species specific responses are needed to understand the regional differences in responses to long term warming recently documented in other studies.

A.15

A decade-long experiment of warming and grazing in alpine, oceanic vegetation

Anna Maria Fosaa
Faroese Museum of Natural History

In the alpine area of the subarctic oceanic Faroe Islands, a combined warming and grazing experiment has been made for twelve years, beginning when an ITEX site was established in 2001. Ten Open Top Chambers (OTC) were placed inside an enclosure with control plots inside and outside the enclosure in order to study the combined effects on the vegetation of warming and sheep grazing. The study site is on the mountain of Sornfelli (62°04´N, 6°57´W) at 600 m a.s.l. on Streymoy in the central part of the Faroe Islands. Temperatures are measured 1 cm below the soil surface but due to the cloudy weather conditions in the area the experimental warming has varied from year to year with almost no effect some years. Despite this, significant changes in the measured vegetation parameters have been observed. The vegetation was monitored during the period in 0.25 cm^2 plots in the OTCs and control (grazed and un-grazed) and the changes in species composition as well as the changes between life forms are studied. Changes in leaf size of the two species Salix herbacea and Polygonum vivipara were measured And phenological studies of Silene acaulis were conducted during the growing season. A summary of the results from these studies will be presented and the effects of warming and grazing will be compared.

Session B: Climate change experiments

B.01

Update on IPCC (Intergovernmental Panel on Climate Change)

Ulf Molau
University of Gothenburg, Sweden

B.02

Phenology and growth of three dwarf shrub species after six years of soil warming at the treeline

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We evaluated the effects of a 6-year experimental soil warming treatment (+4 °C) on the phenology and growth of three major dwarf shrub species growing in the understorey of Larix decidua and Pinus uncinata at treeline in the Swiss Alps. We monitored vegetative and reproductive phenology of Vaccinium myrtillus, Vaccinium uliginosum and Empetrum hermaphroditum throughout the early growing season of 2012. Following a major harvest later in the season, we measured the aboveground biomass and length of new shoot increments in all three species, as well as growth ring widths of V. myrtillus ramets. Soil warming only led to an earlier anthesis in V. myrtillus flowers, and it did not affect the phenology of the other two species. In contrast, natural snowmelt showed a strong correlation with the phenology of all three species, and plot tree species (Larix or Pinus) was important for the timing of major phenological phases of V. myrtillus. The warming treatment led to increased Vaccinium myrtillus aboveground biomass (+32%), new shoot increment length (+30%) and xylem growth ring width (+44% for 2007-2012), whereas neither snowmelt nor tree species had any effect on these variables. Vaccinium uliginosum and E. hermaphroditum did not show any clear growth or biomass responses to soil warming. Vaccinium myrtillus was the most responsive species in terms of growth, showing persistent effects of soil warming over 6 years, but these responses were not explained by a shift in phenology. Our results suggest that V. myrtillus will adapt faster to a warmer climate and, therefore, could increase in dominance in detriment to the other co-occurring alpine dwarf shrub species.

B.03

An active soil warming system powered by alternative (renewable) energy for remote field sites

Jonathan Henkelman, Jill Johnstone
University of Saskatchewan, Canada

Experiments using controlled manipulation of climate variables in the field are critical for developing and testing mechanistic models of ecosystem responses to climate change. Despite rapid changes in climate observed in many high-latitude and high-altitude environments, controlled manipulations in these remote regions have largely been limited to passive experimental methods with variable effects on environmental factors. In this study, we developed a method of controlled soil warming suitable for remote field locations that is powered by alternative (renewable) energy sources. The design was tested in high-latitude, alpine tundra of southern Yukon Territory, Canada from 2011 to 2013. Electrical warming probes, powered with a photovoltaic array, were inserted vertically in the near-surface soil and controlled and monitored by a Campbell Scientific CR1000 based system. The warming manipulation achieved a stable target warming of 1.3 to 2 °C in 1 m^2 plots while minimizing disturbance to soil and vegetation. Active control of power output to the warming plots allowed the treatment to closely match spatial and temporal variations in soil temperature while optimizing system performance during periods of low power supply. Controlled soil heating with vertical electric probes powered by alternative energy is a viable option for remote sites and presents a low-disturbance option for soil warming experiments. This active heating design provides a valuable tool for examining the impacts of soil warming on ecosystem processes.

B.04

AlpGrass: Alpine grassland global change, first results of multiple interactions

Matthias Volk, Seraina Bassin, Andreas Gauer, Jürg Fuhrer
Agroscope, Switzerland

We established a new, mid-term (6 years) field-experiment in Switzerland. The AlpGrass experiment combines turf monoliths from six different Alps in Graubünden, that were brought to a common garden site in Unterengadin and reimplanted at six different altitudes along a gradient from c. 1700 to 2400 m asl.. In addition to the resulting temperature gradient, a two level precipitation supplement and a three level atmospheric N deposition (3 kg and 15 kg N ha^{-1} a^{-1}) treatment are applied. Extensive atmosphere and soil monitoring supplies data for high resolution regression of ecosystem responses to environmental drivers. Results of the 2013 growing season gas exchange (Net ecosystem CO_2 exchange) and productivity (aboveground biomass) measurements will be presented. We analyze specific responsiveness of different grassland types to warming, N deposition and drought. Possible effects on ecosystem carbon sink-/source-properties are discussed.

B.05

Relationships between landscape position, soil temperature, and vegetation cover at three mountain sites in southern Norway: Preliminary results from an ongoing project.

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The evidence for global climate change is overwhelming. A warmer climate can have profound effects on alpine vegetation, especially on alpine lichen heaths. Lichens grow slowly and cannot tolerate shade and are thus quickly outcompeted by faster-growing vascular plants. Vegetation changes in alpine environments can mean that lichens have "no place to go". Although soil temperature is the most relevant temperature variable for plant growth, air temperature is the common output from climate models and there is little information on the relationships between lichen cover and soil temperature on alpine sites. In order to evaluate the likely consequences of climate change it is crucial to understand the relationship between soil and air temperatures and vegetation distribution. Soil and air temperatures have been measured at three sites representing a climatic gradient from semi-oceanic to continental in the southern Norwegian mountains. The sites are considered nutrient-poor and are dominated by terriculous lichens, with few species of vascular plant present. Air temperatures were measured two meters (m) above the ground, while soil temperatures were measured at five centimeters (cm) below the surface. Soil temperature recorders were placed at three different landscape positions to determine effect of local topography on soil temperature. Vegetation analyses were performed in July and August 2012, and the percent cover of both lichens and vascular plants was estimated. The relationship between soil and air temperatures and the effects of landscape position on soil temperatures will be presented. Some relationships between lichens, vascular plants, and soil temperature will also be discussed. There were significant differences in soil temperatures between the landscape positions, and these relationships were not the same at each research site nor were they the same across the course of the measurement period. Winter soil temperature and frost sum was correlated with the percent cover of both lichens and vascular plants.

B.06

How does flowering phenology and morphology of Empetrum hermaphroditum respond to changing snow cover regimes?

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Patterns and processes within the biosphere are currently under a number of pressures from global change. To understand and predict the potential response of plant species to these rapidly changing conditions, it is necessary to analyse factors controlling adaptation, distribution and abundance. In arctic ecosystems, snow cover represents a complex but very strong selection gradient with significant effects on the growth, phenology and reproduction and the distribution and abundance of plant species and communities. One important question is how plants respond to changing snow cover regimes as a consequence of climate change. The study species is Empetrum hermaphroditum Hagerup, a small evergreen dwarf shrub and a characteristic and dominant element of boreal forest and arctic heath systems. The main aim of this investigation is to understand how selection in this wind-pollinated plant affects its adaptation to three different habitat types in continuous populations: (i) sub-alpine birch forest with deep snow cover, (ii) low-alpine with deep snow cover in depressions and (iii) low-alpine with shallow snow cover on elevated ridges. Our study takes place in two study areas in northern Sweden (Abisko and Vassijaure) and two study areas in central Norway (Samsjøen and Dovre). We investigated how the morphology of E. hermaphroditum varies among the different habitat types (Hypothesis 1: Morphology of E. hermaphroditum varies among sites with different snow cover). Furthermore we observed the flowering phenology of E. hermaphroditum directly after snow melt in spring (Hypothesis 2: Asynchronous flowering reduces the potential for gene flow in E. hermaphroditum among sites with different snow cover). First results show that shoot morphology of E. hermaphroditum differs significantly among sites with deep and shallow snow cover. The analyses of flowering phenology shows that E. hermaphroditum flowers earlier in sites with shallow snow cover than in sites with deep snow cover. Nevertheless there is a small overlap of the full flowering phase between the three habitat types.

B.07

Carry-over effects of winter conditions to summer processes: plant growth and reproduction in the Arctic

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Many observational and experimental studies à la ITEX have revealed important aspects of eco-physiological functioning of Arctic tundra and its responses to climate change. Most of these studies focused on the effects of summer conditions on growing-season processes. However, there is increasing evidence that winter conditions can be equally important for ecosystem functioning during summer. In this talk, we want to raise awareness of, and exemplify how conditions during winter can be carried over to summer. We present two examples of winter carry-over effects from our snow-fence site in Adventdalen, Svalbard. Over six consecutive years we increased snow depth with the help of snow fences and thereby (a) delayed snowmelt and shortened growing season length, and (b) insulated canopy and soil from cold winter air by maintaining warmer and more stable winter temperatures than in ambient conditions. We tested short- and medium-term influences of these winter perturbations on summer flower abundance and plant growth. (1) Flower pre-formation and thereby the following years' flower abundance was reduced in areas with deepened snow through the shortened growing-season length. Similarly, flower abundance increased after years with early snow melt. However, winter warm-spells interacted with that pattern by removing snow and exposing previous years' flower buds to detrimental winter air temperatures, thereby reducing the following years' flower abundance strongly. Plants under deepened snow were protected and maintained high flower numbers. (2) Insulating properties of deepened snow increased soil temperatures and thereby mineralization rates during winter, resulting in higher nutrient supply and faster early-season plant growth during summer. These and other examples illustrate how winter conditions are carried over into the summer and control important ecosystem processes. Direct and short-term as well as indirect and mid- to long-term effects on plant life-cycles and growth can be identified, with implications on plant-pollinator dynamics and carbon balance. These winter conditions are likely to be influenced by a changing climate, emphasizing the importance of winter studies in Arctic tundra.

B.08

All about temperatures? Global change influences alpine plant communities in multiple ways

Christian Rixen
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Arctic and alpine shrub- and grasslands are shaped by extreme climatic conditions such as a long-lasting snow cover and a short vegetation period. Such ecosystems are expected to be highly sensitive to global environmental change. Temperature is a key variable influencing arctic and alpine ecosystems but other factors like snow cover and atmospheric CO_2 levels are also likely to influence plants. In this presentation, I will report from several studies that investigated how changes in snow cover, elevated atmospheric CO_2 levels and warmer temperatures can affect alpine plants. The studies range from short-term experiments to long- and very-long-term monitoring. I will show evidence, 1) that elevated atmospheric CO_2 levels have the potential to enhance plant growth at tree line but that at the same time they can also increase the plants susceptibility to freezing events, 2) that snow cover can influence alpine plants as much as temperatures, 3) how the plant diversity of mountain summits has increased in recent decades and centuries probably due to higher temperature and reduced snow cover.

B.09

On the impact of global climate change on the alpine flora and vegetation of Armenia (on example of Mountain Aragats).

Alla Aleksanyan
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Armenia is one of the best zones for climate change research, because of mountain landscapes, well expressed vertical zonation and diversity of climatic, soil conditions, flora and vegetation, rich geological history. On the basis of bioclimatic modeling is given evaluation of vulnerability of ecosystems of Armenia. The bioclimatic scheme of Holdridge's life zones was specified and adapted for conditions of Armenia. On the basis of the predicted climate change according to the scenario A2 (Second National Communication of the Republic of Armenia, 2010) is carried out forecasting of changes of ecosystems and is evaluated their vulnerability on the basis of data from 44 meteorological stations which are located across all Armenia at different heights and actually enveloping all main ecosystems and particularly alpine vegetation. The alpine zone in Armenia covers the highest part of the mountainous zone of Armenian Highland. Its hosts an outstandingly rich flora and vegetation. Unfortunately for alpine zone vegetation we have data from only one station-Aragats and now we can forecast changes of alpine vegetation only for Aragats. On the other hand since 2011 we joined the GLORIA (Gloria - Global Observation Research Initiative In Alpine Environments) network and started annual monitoring of changes in alpine vegetation of mountain Aragats. As a result we forecast that changes of bioclimatic conditions that alpine meadows of Aragats will show the tendency of their change to subalpine tallgrass and the rehumidified habitats (subalpine bogs). On subalpine meadows favorable forest vegetation conditions will be created, however depending on the region (forest or not forest) here will develop most likely or forests (in the territories of modern meadows), or meadowsteppes. The majority of the meadowsteppes territories remains to meadowsteppes, some part of this vegetation will transfer to the real steppes territories. Thus, modeling changes of alpine ecosystems in connection with climate change scenarios, we can conclude that as a whole (with rare exception) there will be the general aridization which will lead to considerable changes as in structure and composition of existing ecosystems, and in their distribution on high-rise belts and floristic regions of Armenia.

B.10

Does competition influence alpine plants? Responses under simulated herbivory, and long-term warming and fertilization

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Variation in individual responses produced by warming, nutrient addition or herbivory will influence the relative competition abilities of plants. Interactions among these factors may be synergetic or antagonistic, and predicting the responses of individual species under different conditions remains difficult. Using a factorial design, we analysed the competition abilities of three alpine-tundra species (Carex consimilis, Polygonum bistorta & Saussurea viscida) growing within long-term (> 18 years of warming treatment) OTC, fertilizer addition and control plots, removing or not their plant neighbours continuously during a two-year experiment. We manipulated herbivory by clipping the focal plants in each of two years (2012 & 2013). Responses to competition were evaluated by comparing the growth of the focal species with and without plant neighbours, Our initial results showed specifically that Carex changed its competition ability from competitive, in warmed and fertilized plots, to non- competitive in the combination of warmed and clipped plots. Polygonum, in turn, increased its competition ability in warmed plots regardless herbivory, while, when warming was not present, only non-clipped individuals showed a reduction in their competition ability. Finally, Saussurea was unresponsive to any of these factors. These results indicate an inconsistent response among species and treatments, where competition ability in response to warming is highly variable, species-specific, and dependent on other main processes (herbivory) and/or patterns (nutrient patchiness).

B.11

Reduction of spring shrub performance under earlier snowmelt

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Alpine dwarf shrub communities are phenologically linked with snowmelt timing, so early spring exposure may increase risk of freezing damage during vulnerable early development, and consequently reduce seasonal growth. We examined whether environmental factors (duration of snowcover, elevation) influenced functional growth, and the vulnerability of four shrubs to spring freezing along elevational gradients and snow microhabitats. Moreover, we modelled the past frequency of spring freezing events. We sampled and measured growth in stem/leaf biomass from Salix herbacea, Vaccinium myrtillus, V. uliginosum and Loiseleuria procumbens in late spring. Leaves were exposed to freezing temperatures to determine LT-50 for each species and sampling site. By linking site snowmelt and temperatures to long-term climate measurements, we extrapolated the frequency of spring freezing events at each elevation, snow microhabitat and per species over 37 years. Snowmelt timing was driven by strong microhabitat effects, but independent of elevation. Shrub growth was neither enhanced nor reduced by earlier snowmelt, but decreased with elevation. Freezing resistance was strongly species-dependent, and did not differ along the elevation or snowmelt gradient. Microclimate extrapolation suggested that potentially lethal spring freezing events (May and June) occurred for three of the four species examined. Spring freezing events never occurred on late snowbeds, and increased in frequency with earlier snowmelt and higher elevation. Extrapolated spring freezing events showed a slight, non-significant increase over the 37-year record. We suggest that earlier snowmelt does not enhance growth in four dominant alpine shrubs, and for less freezing-resistant species, increases the risk of lethal spring freezing exposure.

B.12

Effects of advanced snowmelt and increased temperatures on flowering phenology of three snowbed species

Alessandro Petraglia, Michele Carbognani, Marcello Tomaselli

University of Parma, Italy

In the alpine life zone, snow-cover and temperatures are the most important factors controlling plant phenology. Among the expected climate changes, alpine regions will experience warmer temperatures and an advanced snowmelt time. Thus, the most realistic scenario for alpine habitats is the combination of a reduction in the snow-cover period and warmer temperatures in the snow-free period. Several studies showed the effects of an increased summer temperature on phenology of alpine plants, but few studies tested the combined effect of these two environmental factors. In a field experiment, performed in an alpine snowbed habitat, we removed manually the snow to simulate an advanced snowmelt, and used OTCs to increase summer temperature. We selected two snowbed species with relatively different phenological timing (Cardamine alpina and Veronica alpina) and an alpine generalist frequent within snowbeds (Leucanthemopsis alpina) to test how these species could be affected by an advanced snowmelt and by an advanced snowmelt coupled with higher summer temperature. The snow removal treatment did not affect significantly the date of achieving of all the phenological phases of the three species studied in comparison with the control. On the contrary, the snow removal + warming treatment caused significantly earlier phenological timings. The time needed to achieve the phenophases was significantly extended by the snow removal treatment for the three species studied. The same behaviour was registered in the snow removal + warming treatment with the exception of the last phenophase of Cardamine alpina. The species studied did not show any difference in the time needed to seed dispersal in the control treatment. On the contrary, in the two experimental treatments Cardamine alpina showed a significantly earlier seed dispersal compared to Veronica alpina. Our study seems to suggest that the snow removal treatment did not changed significantly the phenological timing of the species studied. It is highly probable that, under the predicted climate changes, temperature will be the most important factor in the control of the phenology of snowbed species.

Input talk II

Shorter flowering seasons and declining abundance of flower visitors in a warmer Arctic

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Advancing phenology in response to global warming has been reported across biomes raising concerns about the temporal uncoupling of trophic interactions. Concurrently, widely reported flower visitor declines have been linked to resource limitations. Phenological responses in the Arctic have been shown to outpace responses from lower latitudes and recent studies suggest that differences between such responses for plants and their flower visitors could be particularly pronounced in the Arctic. The evidence for phenological uncoupling is scant because relevant data sets are lacking or not available at a relevant spatial scale. Here, we present evidence of a climate-associated shortening of the flowering season and a concomitant decline in flower visitor abundance based on a long-term, spatially replicated (1996–2009) data set from high-Arctic Greenland. A unique feature of the data set is the spatial and temporal overlap of independent observations of plant and insect phenology. The shortening of the flowering season arose through spatial variation in phenological responses to warming. The shorter flowering seasons may have played a role in the observed decline in flower visitor abundance. Our results demonstrate that the dramatic climatic changes currently taking place in the Arctic are strongly affecting individual species and ecological communities, with implications for trophic interactions.

Session C: Long-term observations

C.01

Shaping forces of biodiversity in the Arctic – exploring the feasibility of a coherent research framework

Ingibjörg Svala Jónsdóttir
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Rapid changes in Arctic environments are expected to affect structural biodiversity (genetic diversity, species diversity, community diversity, ecosystem and landscape diversity) as well as functional diversity (phenology, life history, behaviour, functional types/guilds, trophic efficiency) with consequences for ecosystem functioning. A conventional approach to biodiversity studies is to focus on specific organism groups and biological hierarchies. Such studies are extremely valuable and have recently been summarised (Arctic Biodiversity Assessment report, ABA). However, testing hypotheses about biodiversity trends in the face of climate change in the Arctic demands a coherent research framework on biodiversity shaping forces that considers different spatial and temporal scales and identifies commonalities across biological hierarchies and organism groups. As a first step in exploring the feasibility of such research framework a small group of scientists, representing a wide range of disciplines, were called to a workshop in Reykjavik in January 2013. A special emphasis was on distinguishing between external and internal biodiversity shaping forces, how they interact, whether they differ between small and large organisms and how they relate to organism mobility and dispersal. To reach a wider audience the outcome of the workshop was presented at the Science Symposium during the ASSW 2013 in Krakow and will also be presented also at the ITEX Conference in Switzerland in September 2013. The next step will be to write up a conceptual paper outlining such research framework aiming at publication in a special issue of a relevant scientific journal together with invited papers on case studies that may fit within the framework.

C.02

Trait, phylogenetic, and B-diversity patterns reveal community assembly mechanisms on Mount St. Helens

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University of Washington, United States of America

How do traits, environmental factors, and stochasticity interact during community assembly? Examining trait, phylogenetic, and β-diversity patterns following a large disturbance (e.g. primary succession) are invaluable for addressing this question. Overdispersion or clustering of traits and phylogenetic relationships in communities allow us to infer how competitive exclusion versus envirornmental filtering influences patterns, while patterns of β-diversity allow us to understand whether species turnover is more rapid early or late in succession. To address these questions, we use a 30-year dataset of alpine plant community composition from Mount St. Helens (Washington, USA) following the 1980 volcanic eruption, in both primary and secondary plant succession sites. We examine community assembly from a trait and phylogenetic perspective by calculating functional trait diversity and phylogenetic net related index (NRI) and comparing to null model values. We also examine changes in species turnover across space (between sites) and over time (between years) by calculating β-diversity and comparing to null model values. Together, these analyses allow us to determine whether 1) diversity increases or decreases through time and 2) assess whether diversity in growth, dispersal, or nutrient-related traits explain community assembly patterns through time.

C.03

Relationships between climate and phenology of high elevation plants. A 6-years snow and phenology monitoring in the Italian central Alps

Nicoletta Cannone, Michele Dalle Fratte, Mauro Guglielmin
Insubria University, Italy

Here we show the results of 6 years of monitoring (since 2006) of snow, plant phenology and their relationships with air temperature in a high elevation site above the treeline in the Italian Central Alps (Foscagno Valley). We selected 54 plots along an elevation range of 250 m (2360-2610 m a.s.l.) and 36 target species of the subalpine and alpine belts. The phenological measurements were carried out according to the ITEX protocol with measurements every 2-3 days from the snowmelt to the beginning of the permanent snow cover in Fall. Snow depth was measured also during the winter. Climatic data were provided by the La Foppa AWS (ArpaLombardia), located at 2700 m a.s.l. at less than 1 km far from our site. The snow data were analyzed to identify its spatial distribution and persistence within the study area and its intra- and inter-annual variation since 2006. The phenological data were analyzed at: a) species, b) community, c) growth form level to identify their intra-annual and inter-annual trends and assess how snow and the main climatic factors affect the development of the phenological stages. Snow melting is a key factor influencing the vegetative development of all species (formation of the first buds and new leaves), while photoperiod is the most significant factor for flowering stages (in particular for floral anthesis) and, indirectly, for seed ripening. Despite a pronounced Fall warming, leave senescence occurs in a very restricted period (<15 days) for all species. The 36 selected species showed two main strategies in relation to snowmelt, with implications on the following phenological stages. Half species concentrated their stages within a relatively short period, while the others showed a gap of more than one month between vegetative stages – flowering - seed ripening. Shrubs showed a marked advance (10 days) in the beginning of the vegetative stages compared to the other growth forms. This trend exerted important consequences also on plant communities: while shrub communities showed an advance in the phenological cycle, pioneer and snowbed communities had an average delay of ten days in all phenological phases.

C.04

Reproducibility, precision, and time efficiency of three methods for vegetation monitoring in alpine tundra

Jill F. Johnstone, Nathan Young, Steven Mamet
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Understanding the strengths and weaknesses of different methods of vegetation monitoring is an important aspect of designing a successful monitoring program. Here we evaluated three common methods used for estimating plant abundance in tundra vegetation: point-intercept method (PIM), visual cover estimation (VCE), and presence/absence (PA) scoring. Four observers conducted repeated vegetation surveys in n=12 plots located in alpine, low shrub tundra in southern Yukon Territory, Canada, and then harvested aboveground biomass to obtain an estimate of true vascular plant abundance. When comparing time efficiency, performance ranking of the three methods was PA>VCE>PIM. The sensitivity of each method to variations in species richness ranked as PA>VCE>PIM, with PA consistently better at detecting rare species. The precision of each method in estimating species abundance depended on the relative abundance of the species. At low abundance (<1 g dry biomass per m^2), all methods were similarly poor at estimating true abundances (correlation between estimated and true relative abundance, $r < 0.4$). At higher abundance (1 to 10 g dry biomass per m^2), PIM and VCE performance was substantially improved ($r \sim 0.7$) and was highest for the most abundant species ($r \sim 0.9$ for species with >10 g dry biomass per m^2). Abundance estimates with PA were substantially less precise ($r < 0.5$), but showed no significant observer effect. Both VCE and PIM showed some significant differences in abundance estimates between observers, but reproducibility of the two methods was similar when comparing only between two well-trained observers. Of all plant groups sampled, reproducibility and precision were lowest for graminoids and highest for woody shrubs. The comparison of methods suggests that PA is the best approach when monitoring objectives are focused on the detection of rare species or assessing species richness with requirements for extensive sampling. However, when the focus is on monitoring changes in the abundance of common species, VCE or PIM should be preferred. VCE may provide the most generally suitable method as it has the advantages of greater time efficiency and sensitivity to species richness compared to PIM, while maintaining similar observer reproducibility when using well-trained observers.

C.05

How to monitor vegetation in the circumarctic – towards adaptive monitoring of shrub tundra

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Pronounced environmental change in the terrestrial Arctic has prompted an increasing need to understand and monitor change in shrub tundra vegetation, and yet there is limited scientific discussion on how to plan field-based monitoring. We discuss steps in adaptive monitoring in shrub tundra with a focus on the development of conceptual models and on issues of spatial and temporal scaling. Patterns and impacts in shrub tundra suggest that some characteristics of change may be common among locations in the Arctic and allow for similar monitoring questions to be posed. Our overview of the status of field-based monitoring shows that there is a need to complement existing efforts, particularly at two spatial scales. At the global scale, the coverage of monitoring in Arctic regions that differ with respect to climate change and anthropogenic pressure needs to be improved. Within Arctic regions, shrub tundra monitoring is currently undertaken at very localized scales such as within one site. However, knowledge gained from the local-scale may not match landscape scale ecological drivers of vegetation change or management. Monitoring that encompasses multiple landscapes along ecological gradients and targeted to cover management contrasts could improve the scale mismatch of ecological monitoring in tundra ecosystems. Our examples show that some commonly used methodological approaches, such as selecting one site to represent larger landscapes, or measuring branches of the shrub patches to represent sites or landscapes may lead to bias. We suggest, based on published protocols, methods that can be applied when extending the spatial coverage. We believe that some of the challenges related to harmonization of circumarctic research and monitoring can be overcome with a transparent and coordinated process of adaptive monitoring.

C.06

The climate sensitivity of shrub growth is highest away from range margins

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Though recent evidence indicates widespread expansion of canopy-forming shrubs across the tundra biome, we still have a very limited understanding the sensitivity of shrub growth to changing climate. At their range margin, treeline species exhibit greater growth sensitivity to climate variability than to competition; however such patterns have yet to be explored for tundra shrubs. Future climate warming is predicted to convert as much as half of current-day tundra to shrubland by the end of the 21st century, with projections of 50% increases in tundra shrub and tree cover for as early as 2050; however, the uncertainty of these estimates remains substantial. An increase in shrub cover is expected to change the structure of tundra ecosystems by altering energy fluxes, soil temperatures, soil-atmosphere exchange of water, carbon and nutrient cycling, species composition and interactions, potentially creating significant feedbacks to climate warming. In order to project climate feedbacks from future vegetation change at high latitude and elevation locations, we must first quantify the climate sensitivity of growth across latitudinal gradients. We analysed multi-decadal growth data from 37 sites and 25 shrub species from across the tundra biome and compared annual growth to climate. Climate sensitivity to growing season temperatures was weakest at the range margins and greatest under benign growing conditions with intermediate growing season lengths and higher soil moisture. Our findings indicate that the most prominent shrub increases will occur in less extreme environments, rather than at the range edge, where shrub growth responses to climate variation are highest.

C.07

How to choose habitats of interest- based on prior defined criteria or subjective judgment in the field?

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Sampling ecological information requires the ecologist to locate the habitat of the organism(s) in focus, yet what defines such a target habitat is not always clear. That is, ecological knowledge on habitat characteristics is often used, but this knowledge may not be transparent to other ecologists. Here we compare two ways of using ecological knowledge for choosing target habitats: defining a priori criteria, making the choice more transparent to other researchers, vs. choosing habitats subjectively in the field. Our hypothesis is that such different approaches of choosing target habitats will affect the ecological information retrieved. We tested this hypothesis by studying two types of tundra plant communities. The two target habitats for these communities were in sloping, concave terrain: Intermediate slopes provided mesic moisture conditions (mesic habitats) while gentle slopes provided moister conditions combined with a long lasting snow cover (snow bed habitats). In 20 mesic and 15 snow bed habitats, we collected information about plant community characteristics. For the approach of a priori defined criteria, we located potential habitats within suitable terrain using GIS. In the field, these habitats were only accepted if given criteria for vegetation cover were fulfilled. For the subjective approach, we chose habitats based on typical plant communities in the field. The two approaches revealed significantly different estimates of within community plant diversity and the biomass of plant functional groups. Furthermore, the magnitude of these effects differed between two districts of contrasting reindeer density. Our study suggests that the way of choosing target habitats can cause unintentional differences in the sampling frame and may therefore be essential for the outcome of ecological field studies, even to the extent of creating idiosyncratic results.

C.08

The contribution of dendrochronology to arctic research: Examples of challenges and opportunities

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A long-term perspective is required when assessing for progressive changes in Arctic and Alpine plant responses to global warming. The ITEX network, with more than 20 years of monitored experiments, represents a fundamental tool for better understanding the impacts of climate change on plant species in tundra and alpine vegetation. Shrubs dendrochronology, with some limitations, can also be considered as an additional complementary tool providing valuable long-term perspective. Dendrochronology, i.e., the use of dated tree-rings in trees, can in fact supply (intra)-annually resolved information about how the trees were growing and responding to changing climatic conditions. However, its application in arctic and alpine shrubs imply some challenges, which complicates its use. In this presentation I would like stimulate the discussion about the application of shrubs-rings analyses by sharing my 5-years long experience in Arctic dendrochronology. In particular, based on material collected and measured from high Arctic (120-years long chronology of Salix polaris from central Spitsbergen) and low Arctic (120-years chronology of Betula nana from Western Greenland) I will present and discuss 1) the issue of recognizing, measuring and correctly dating Arctic shrubs rings, and 2) demonstrate with some examples the potential of using arctic shrubs rings and wood anatomical features for climate warming related questions.

C.09

A mobile instrumented sensor platform for long-term terrestrial ecosystem observation: A case study in the Arctic

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To address impacts of climate change on natural ecosystems, researchers need efficient and integrated ground-based sensor systems capable of detecting plant to ecosystem alterations to productivity, species composition, phenology, and structure and function over seasonal, inter-annual, and decadal time scales. Here, we introduce the Mobile Instrumented Sensor Platform (MISP), a versatile robotic sensor system that is suspended above or within the canopy and is designed to be adaptable for both short and long-term observations, and suitable for multiple ecosystems. The system is novel in that it is mobile, rather than static, the suite of sensors can be customized, and installation and operation requires minor surface disturbance relative to comparable systems already in use. MISP was developed as a contribution to the Arctic Observation Network's International Tundra Experiment (AON-ITEX), where at five locations between the low and high Arctic we record observations of different tundra plant communities over a 50 m transect. Observations include air temperature, surface temperature, incoming and outgoing long- and short-wave radiation, albedo, Normalized Difference Vegetation Index (NDVI), three-dimensional video, two and three-dimensional photography, and hyperspectral reflectance. Data analysis has proven the system's suitability for detecting subtle ecosystem changes across small-scale soil moisture and other gradients due to the mobile nature of the sampling. Long-term studies will benefit from this approach because sampling is repeatable with high spatial and temporal resolution and the system can be adapted to incorporate future technologies.

C.10

Analyzing vegetation cover change at the landscape level from Barrow, Alaska

Timothy Frederick Botting, Robert David Hollister
Grand Valley State University

Many studies have been conducted to identify vegetation changes due to warming, however, knowledge gaps remain. For example, most plant studies are conducted at the plot level, not the landscape level, potentially masking larger scale impacts of climate change. An Arctic Systems Science (ARCSS) grid was established in Barrow, Alaska in the mid 1990's and approximately 100 vegetation plots were implemented along that grid in 2010. The vegetation plots are 1 meter squared, spaced 100 meters apart, and span 1 kilometer squared. This project will focus on how vegetation cover has changed, using the point frame method, at the landscape level from 2010 to 2012 on a subset of 30 plots. Preliminary data analysis indicates that graminoid plant species such as Carex aquatilis-stans show increased cover, while little change has occurred with moss, lichen, shrub and forb cover. Future work will involve expanding vegetation cover analysis to the entire grid, relating various ecosystem parameters to vegetation change, and predicting what ARCSS grid vegetation communities will look like in the future based on anticipated warming.

Posters

P.01

Heterogeneous response of tundra vegetation to warming

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This study documents changes in plant communities occurring naturally and due to experimental warming over 15 years at four plant communities in northern Alaska with emphasis on the consistency of the response over time and across locations. Vegetation sampling was done using a point frame method. Changes between years were generally larger than responses to warming, however changes between years were mostly in different directions and the changes were not consistent across locations. Most taxa and growth forms responded inconsistently to warming over time (46 taxa) or did not respond (14 taxa). The number of taxa that responded consistently over time, although relatively few, was greater in response to warming (11 taxa) than that observed in the control plots (4 taxa). Of the plants that were consistently changing over time, graminoids and bryophytes increased in cover while lichens decreased. These data show that current trends in response to warming are a poor predictor of future tundra plant community dynamics. This is because the response to warming is heterogeneous across time and locations. These findings emphasize the need for long-term monitoring networks of sites to properly document vegetation change in response to climate change and better understand the underling mechanisms driving community change.

P.02

Warming and flower pollination effects within OTCs

Samuel Victor Joseph Robinson, Greg Henry
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Climate change is expected to alter the community dynamics of high-arctic plants. The International Tundra Experiment (ITEX) uses Open-Topped Chambers (OTCs) to increase air temperatures by 1-3 °C in order to simulate the effects of future climate change on current arctic plant communities. OTCs alter reproductive timing and magnitude of flowering plants, but the effect of the OTCs on insect visitation and alteration of pollen exchange is poorly studied. We tested how pollination and warming interact within OTCs in Dryas integrifolia (L.), Salix arctica (Pall.), and Papaver radicatum (L.), at Alexandra Fiord, Nunavut, Canada. We found that OTCs have the potential to create pollination deficits, and that this interacts with the induced warming effect to change flower production, seed production, and seed germinability in ways that may not happen in a future warmed arctic.

P.03

Use of digital photography to detect plot level changes in greenness

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High Arctic ecosystems are experiencing some of the earliest and most extreme changes in climate as a result of global climate change. Temperature increases twice the hemispheric average are initiating changes to terrestrial systems including shifts in timing of phenology, aboveground biomass and community composition of Arctic vegetation. Satellite imagery from the last 30 years has shown a greening across tundra ecosystems with increases in peak productivity and growing season length. Small-scale field studies support these large-scale trends but overall validation at the plot scale is still lacking. Current manual and automated methodology for monitoring vegetation at the community and plot scale is both time consuming and employs expensive, sensitive multispectral instrumentation that can be cumbersome to use in the Arctic. In this thesis I examine the utility of colour digital photography in monitoring tundra vegetation across different vegetation communities, inside and outside of passive warming chambers. Colour digital and spectral photos were taken on one day peak season in 2010. Relationships between a greenness index derived from colour digital photographs and biomass data were compared to relationships with NDVI derived from spectral photographs. Results suggest that colour digital photos are a suitable proxy for productivity and biomass in multiple tundra vegetation communities. This data was then used to infer phenological signals at multiple spatial scales from a set of colour digital photos taken on six days during the 2012 growing season. Results show that a treatment signal is identifiable at the landscape and community scale but not at the species scale suggesting quantitative (i.e. above ground biomass), not qualitative (i.e. vigor) differences in vegetation due to treatment. However at the species scale, site differences emerged for single species suggesting a qualitative difference in vegetation. The phenological signal is stronger at the species scale due to reduced interference from bare soil, litter, and standing water. Overall, this methodology offers a simple and novel opportunity for monitoring vegetation in the tundra biome. This simplicity represents a unique opportunity for public outreach and community involvement in phenological observations in high latitude ecosystems.

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Impact of warming on the physiology of Nostoc colonies (Cyanobacteria) and on the decomposition rate in wet hummock tundra, Spitsbergen

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We studied the effect of simulated warming on (i) photosynthetic and nitrogenase activity in colonies of a cyanobacteria Nostoc commune s.l. and on (ii) cellulose decomposition rate in a wet hummock tundra, Petuniabukta, Billefjorden, Central Svalbard. In 2009, we installed three passive open-top chambers (OTCs) and three control cage-like structures (CCSs), equipped with probes for continuous microclimatic measurements of soil temperature and volumetric water content (VWC). The first two years of manipulation resulted in negligible warming in the OTCs vs. CCSs; mean summer temperature differences were 1.6 °C in hummock tops and 0.3 °C in hummock bases, respectively. Such warming influenced neither the parameters of Nostoc photochemistry, nor the decomposition potential in subsurface soil in hummocks tops and bases, measured as the rate of cellulose mass loss in litter bags. To increase the temperature in the OTCs we covered them by a perforated transparent acrylic lid in 2011. After a year, the mean temperature difference between the CTCs and CCSs reached 1.1 °C on hummock bases and 3.8 °C on hummock tops. Data on the physiological parameters of Nostoc colonies and on the rate of cellulose decomposition under the enhanced warming will be introduced.

P.05

Effects of long-term experimental warming on plant species richness, biomass and soil microbial community structure in a Kobresia humilis meadow on the Qinghai-Tibet Plateau, China

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Climate change is likely to alter plant functional groups and interactions between plants and soil microbes that maintain alpine meadow ecosystem functions and processes. However, we know little about how warming-induced alterations in aboveground biomass (AGB) affect soil nutrients and microbial communities, particularly for bacteria and fungi. To determine how warming affects plant community structure, function and the microbial community, we investigated community characteristics and analyzed soil from a soil warming experiment in Geduo, China. Plant sampling from control and warm open top chambers (OTCs) (of three sizes) took place from 2002-2009, while soil sampling from the OTCs took place from 2007-2009. We monitored plant community characteristics and soil total and available nutrients. The microbial community composition was assessed via phospholipid fatty acid (PLFA) analysis. We found that (1) experimental warming altered plant functional groups and plant community AGB and structure, and warming significantly increased biomass in chamber A. (2) Experimental warming significantly decreased community diversity (Shannon-Wiener index) and species richness in chamber A. (3) Fungal and bacterial abundance increased in the warmed OTCs (chambers A, B and C) but decreased with increasing soil depth. (4) Experimental warming significantly increased total N, available N and soil organic matter at 0-10 and 10-20 cm depths in the warmed OTCs. (5) Gram-positive and Gram-negative bacterial PLFAs, fungal PLFAs and total PLFAs significantly decreased at 0-10 and 10-20 cm in the warmed OTCs. No fungi were found in chamber A or at 10-20 cm in any treatment, except for chamber C, indicating that long-term soil warming decreases fungal PLFAs. Our results indicate that climate change drivers and their interactions may cause changes in soil nutrients and microbial PLFA abundance and contents, and temperature changes tend to have a much greater effect on grass aboveground biomass.

P.06

Warming effects on low and high elevation populations of three grassland species

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The local persistence of plant species in the face of climate change is largely mediated by adaptation and phenotypic plasticity. In species with a wide elevational range, population responses to global warming are likely to differ at contrasting elevations. Using climate chamber and transplant experiments, we investigated the responses of low and high (1200 and 1800 m a.s.l.) elevation populations of three nutrient-poor grassland species, Trifolium montanum, Ranunculus bulbosus and Briza media, to ambient and elevated temperature. We assessed growth, reproduction and reproductive phenology. Reproductive phenology was advanced under elevated temperature in all three species independent of their altitude of origin. Moreover, elevated temperature resulted in plastic responses in several growth-related traits, whereas reproductive traits were less affected. The responses of low and high elevation populations to warmer temperatures did hardly differ but the observed species-specific responses suggest that climate change will affect species of nutrient-poor grassland communities differently. Furthermore, the remarkable degree of plasticity in growth and reproductive phenology suggests that the three studied semi-dry grassland species can cope with climate warming, at least in the short term, without shifting their ranges to higher elevations.

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Effects of experimental climate change on the decomposition of Fagus sylvatica leaf litter along an altitudinal gradient in contrasting land use types

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Climate can affect the process of carbon cycling and leaf litter decomposition in multiple ways, both directly and indirectly, though the strength and direction of this relationship is often times context dependent. In this climate manipulation experiment we have used a standard litter type – senescent leaves of European beech Fagus sylvatica, and recorded the dynamics of its decomposition along a climatic gradient over a period of 2.5 years. Using mesocosms with intact soil turfs transplanted at different altitudes we have attained standard edaphic conditions. This has allowed us to pull apart the effects of climate (temperature and precipitation) change on the decomposition process in three structurally different (unwooded or wooded) land use types within a subalpine pasture-woodlands landscape. Our results from a gradient spanning 1000 altitudinal meters with a change from a warm and dry to a cold and wet climate indicate a strong moisture constraint on the decomposition of Fagus sylvatica but no clear soil temperature effect. The different land use types have further influenced the decomposition process since mass loss from litter bags incubated in mesocosms with turfs from shaded woody pastures was entirely decoupled from the climatic conditions. This is also reflected in the lack of response to the climate treatment by the functional composition of microbial communities (fungal/bacterial PLFA ratio) on the litter within those mesocosms. Both the abundance and composition of the microbial communities have been furthermore strongly influenced by the quality of the remaining litter and by the seasonal and climate driven biogeochemical processes in the transplanted turfs. We believe that our findings bring substantial evidence for the controlling role of soil moisture on litter decomposition as well as for the indirect effects of climate through changes in the decomposers community. The results present plausible feedback mechanisms to climate and land use change driven beech encroachment into subalpine pasture areas, which are worth exploring under future scenarios.

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Consistency of short-term and long-term response of arctic plants to warming

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The effects of global climate change have been linked to shifts in arctic plant communities. The objective of this study was to determine the consistency of the response of arctic plants to warming in Northern Alaska over time. The study examined the impact of experimental warming and natural temperature variation on plants at Barrow and Atqasuk, Alaska. Observations collected from 1994-2000 were considered "short term" and observations collected from 2007-2012 were considered "long term". Here we report on the plant traits number of inflorescences, inflorescence height, leaf length, and day of flower emergence. The traits of all species monitored at each site were categorized into temperature response types. Results showed that 48% of plants changed temperature response type from short term to long term. The percent of plants that were responsive to warming decreased from 57% to 46%. For both short term and long term, graminoids were the most responsive and showed a positive response to temperature, while shrubs were the least responsive and the most inconsistent from year to year. The percent of species that showed a positive response to temperature increased between short term and long term at Atqasuk wet meadow, but decreased at all other sites. These results indicate that the response of plants to warming varies by growth form and over space and time. We also tested to see if the relationship between phenological sensitivity and performance sensitivity held for both short term and long term. For both short term and long term models, phenological sensitivity was a significant predictor of performance sensitivity, and there was no significant difference between the two models. These results indicate that, despite changes in response type, the relationship between phenological sensitivity and performance sensitivity is sound.

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Lichens of the alpine zone of the Central Greater Caucasus (baseline data)

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Literature and herbarium data on alpine lichens recorded in Georgia are analyzed to make up a lichenological component of the baseline for an on-going field study on Sensitive Ecosystems of the Central Greater Caucasus (Kazbegi region of Georgia) supported by Committee for Research and Exploration of the National Geographic Society. Georgia is situated in the central and western parts of the Caucasus - on the boundary between Europe and Asia. The relief of the country in constituted by two latitudinal mountain systems - the Greater Caucasus (5068 m, the highest point) in the north and Minor Caucasus (3301 m, the highest point) in the south - with an intermountain depression between them divided into Colchian (West Georgia) and Iberian (East Georgia) parts by a mountain range. The country is characterized by rather contrasting natural conditions that account for extremely high vegetation diversity on a comparatively small area. Great diversity of habitats supports rich lichen biota. However, the knowledge of the lichen biota of Georgia is incomplete. Although more than 700 species of lichens are recorded in the country, many regions are still lichenologically uninvestigated and continued collecting efforts must result in a large number of new records. The least studied are alpine areas; the existing records allow for the following estimation: c. 230 species are known from altitudes about 2000 m a.s.l. and c. 70 species from the altitude of 3900 m a.s.l. Among them are five species from the Red List of Macrolichens in the European Community (of the 26 European Red List species recorded in Georgia in total) occurring on alpine rocky areas of Kazbegi region: Parmelia koflerae Poelt ex Clauzade & Rondon, Pilophorus cereolus (Ach.) Th. Fr., Stereocaulon glareosum (Savicz) H. Magn., S. paschale (L.) Hoffm., Teloschistes flavicans (Sw.) Norman. The on-going field study aims at investigation of the lichen biota along two altitudinal gradients in alpine tundra up to subnival zone of the Kazbegi region: 1700-3200 m a.s.l., Mt. Kazbegi profile: village Gergeti - glacier Gergeti; and 1900-3100 m a.s.l., Mt. Kuro profile: village Kazbegi - Mt. Kuro slope. The results of the study will be reported in a scientific article.

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Changes in floristic structure of alpine vegetation in Rodna Mountains (Eastern Carpathians, Romania): 7 years of monitoring (2001-2008)

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Plant species composition, abundance and frequency were investigated in four summits above the treeline ecotone in Rodna Mountains (Eastern Carpathians, Romania). The research was carried out within the project GLORIA-Europe (Global Observation Research Initiative in Alpine Environments), following a standardized protocol. The four summit areas were comprehensively sampled in 2001 and 2008, from the highest point down to the 10 m contour line (The GLORIA Multi-Summit Approach, www.gloria.ac.at). In this context, the main aim of the present study was to determine if there have been any changes in the alpine vegetation in Rodna Mountains within the monitoring period and whether such changes can be related to changes in the climate in the same period. On lower summits (Gropile, 2063 m, and Golgota, 2010 m) the vegetation was represented by dwarf shrubs communities (Rhododendro myrtifolii - Vaccinietum) and siliceous alpine grasslands (Oreochloo - Juncetum trifidi), whilst the higher summits (Rebra, 2268 m and Buhăiescu, 2221 m) are covered by siliceous meadows in which Carex curvula is dominant. The highest plant species richness was found on the two peaks located on lower alpine belt (Gropile and Golgota). Over the 7 years of field surveys, an increase in species richness was recorded at the whole four summits area, from 45 to 58 species (+ 33.3%). The highest peak of the target region had the biggest increase in species richness (+54%), whereas in the lower alpine zone and treeline ecotone that trend was less important (+26% new species in 2008). A thermophilization trend was indicated by the higher abundance in 2008 of treeline or treeline-low-alpine species, compared to 2001. Meteorological data showed an increase in temperature for the study area in the course of the 7 years vegetation monitoring (+ 0.8 °C more than the previously recorded Tmean). These changes detected at the level at regional climate could be a plausible explanation for the observed changes in alpine plant communities.

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Micro relief and vegetation of melting non-sorted polygons as an indicator of future changes - example from the Abisko area

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Subalpine heaths around the Abisko (Northern Sweden) are characterised by non-sorted polygons in different stage of development, which is probably dependent on various microclimate in different parts of heath and on the state of the permafrost. In 2010, during our comparative studies between Scandinavian tundra and tundra of the Krkonose Mts (Czech Republic, started in 1998), we obtained several photos of different polygons and also described few polygons for our future observations. According above mentioned we can describe three types of micro relief and vegetation changes of non-sorted polygons and express the vision for the future under influence of climate warming. First type is at the beginning connected with plant species overgrowing over the edge to the centre of the non-sorted polygons–(Equisetum arvense, Empetrum hermaphroditium, Toffieldia pussila), and with the lichen cover declination. The final stage brings completely vegetated (by Empetrum hermaphroditum, Rubus chamaemorus, grasses etc.) former non-sorted polygons without marked changes of their relief. The second type is characterised by cracks inside non-sorted polygons, consequently by drop of some parts of non-sorted polygons, and uncover of previously hidden stones. On higher parts is reduced lichens cover and depressions are occupied mostly by mosses (Empetrum hermaphroditum , Betula nana, Salix species, Eriophorum vaginatum). Degradation is locally finished in form of stony pits filled by water. The third one is represented by deep planar drop of all central parts of non-sorted polygons. Lichens cover is then replaced by different plants (Juncus triglumis, Tofieldia pussila etc.). Relief is characterised by relatively large flat depressions. All this changes occurs only in some isolated parts of heath at present time. We suppose that in the future will be those changes evident at much large scale as consequence of the climate warming. Future monitoring will deal with determination of soil nutrients favoured by different heath plant species.

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Relating Multi-Scale Phenology to Arctic Ecosystem Parameters Using Various High Spatial and Spectral Resolution Remote Sensing Techniques

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The need to improve the spatial and temporal scaling and extrapolation of plot level ecosystem properties and processes to the landscape level remains a persistent research challenge in the Arctic. Plant and landscape phenology is sensitive to a number of variable environmental factors such as soil moisture, temperature, and radiation. Seasonal and inter-annual environmental differences in these factors and phenology can affect surface energy and carbon balance and reflectance. Therefore improved scaling and extrapolation of phenological dynamics from the plot level to the landscape level is key to further understanding the impact of climate and other environmental change in arctic terrestrial ecosystems. This study contributes to the US Arctic Observing Network's International Tundra Experiment (AON-ITEX) and focuses on a range of remotely sensed spectral indices of various vegetation types (i.e. dry, moist, wet) derived from ground-based hyperspectral reflectance, time-lapse photography, kite aerial photography (KAP), and satellite imagery. Measurements were acquired during the 2010-2013 snow free periods over 50 meter transects located in Barrow and Atqasuk, Alaska. Preliminary results show that all platforms demonstrated a capacity to record seasonal green up and both seasonal and inter-annual variability. The wet vegetation was phenologically more dynamic than the drier vegetation in both locations and vegetation in Atqasuk showed greater variability than vegetation in Barrow. The 2G_RB index values differed inter-annually between pheno-cam and kite platforms, possibly due to differences in camera view angle. This study shows that utilizing simple small format aerial photography systems such as KAP, can help reduce the persistent scaling issues (i.e. spatial and temporal coverage, cloud cover, high remote sensing costs) involved with Arctic ecology. Large-scale studies will benefit from this type of approach because the system is highly adaptable to different ecosystems and can be deployed at a high spatial and temporal frequency.

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