Integrating Tundra Structure, Function and Change

19th ITEX Meeting

25-27 April 2018

Stirling, Scotland UK

Utqiaġvik (formerly Barrow), 1999 (photo credit; Bob Hollister)

Abstracts

Oral Presentations

Warmer, longer, greener? The role of increased growing season length on shrub growth

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Arctic summers are getting warmer, and sometimes longer due to earlier snowmelt. Increased temperatures have conclusively been linked to vegetation change, and notably to the expansion of woody species. It is not as certain, however, whether longer summers, with more time for plants to grow, also play a role in driving these changes. Recent advances in remote sensing, with higher-resolution satellite imagery, allow to estimate the length of the growing season from greenness indices across the tundra biome. With time series just now reaching sufficient lengths to test for correspondence between remote-sensed data and on-the-ground measurements, it is timely to quantify the influence of longer summers on shrub expansion.

Here, we measure the sensitivity of annual growth in tundra shrubs to summer temperature and growing season length. We hypothesised that shrub growth would be positively influenced by both factors, but more strongly by temperature. We also hypothesised that individuals would be consistent in the direction and magnitude of their responses to both factors.

We measured annual growth rings in 250 shrubs from the genera *Salix* and *Betula* across four sites in Northern Canada, for the period overlapping satellite observations (2000-2014). We measured the sensitivity of growth for each individual as the slope of the regression between annual ring width and July temperature or growing season length. We found that temperature was the strongest control of shrub growth at all sites, but that individuals were not very consistent in their response to both factors. The weaker influence of growing season length may be due to more rigid genetic controls on the duration of photosynthetic activity, as opposed to more plastic, temperature-dependent growth. The de-coupling of sensitivity to these two drivers could affect rates of shrub expansion in parts of the Arctic with contrasting climatic regimes.

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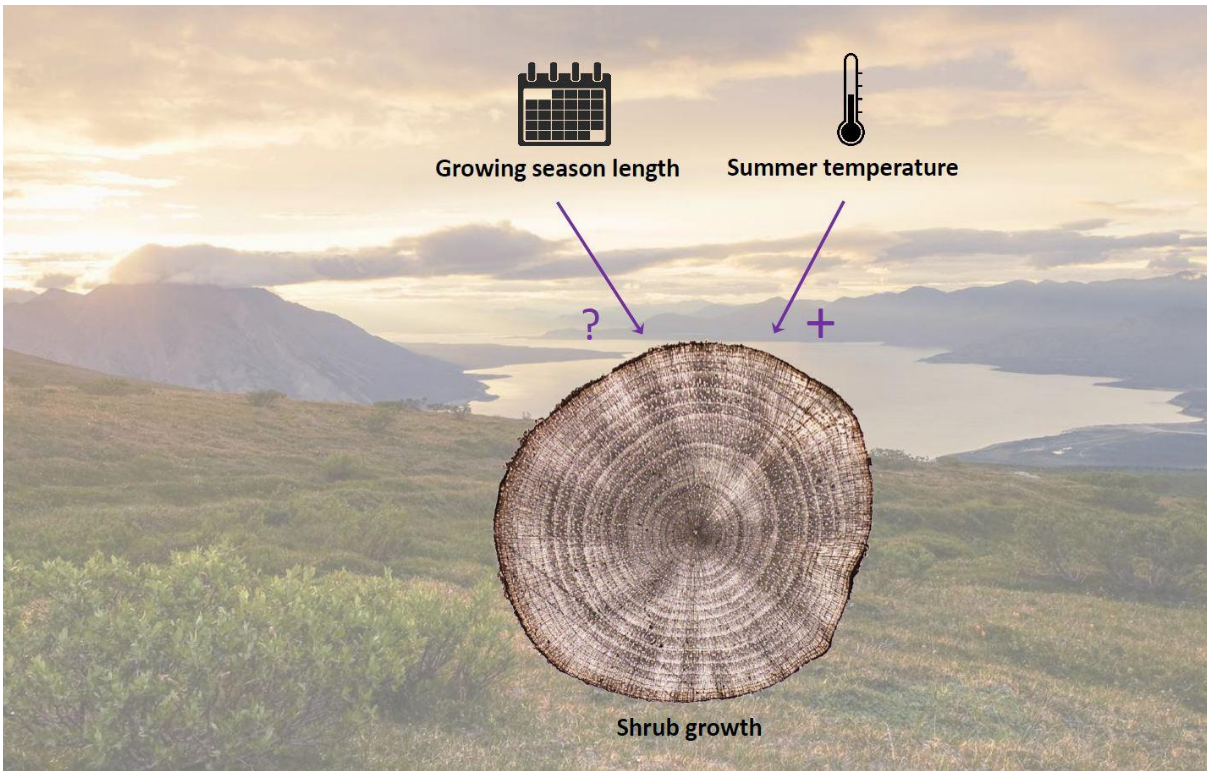

Do longer summers contribute to increased shrub growth in the tundra biome? A test of the relative importance of summer temperature versus growing season length.

Snow-melt and temperature - but not sea-ice - explain variation in tundra spring plant phenology at coastal ITEX sites

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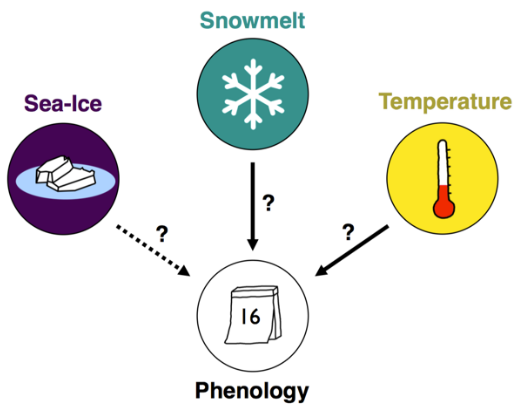
Rapidly rising summer temperatures and expanding growing seasons are leading to dramatic changes in Arctic vegetation phenology, productivity and community composition. However, cues governing early-season tundra plant phenology remain poorly understood. Some studies have shown strong correlations of circumpolar sea-ice indices with plant phenology and vegetation productivity, yet a direct biological mechanism linking plant phenology to sea-ice is lacking.



Here, we test the influence of snow-melt, early season temperatures and local sea-ice conditions on spring plant phenology at four coastal sites in the ITEX phenology control dataset (Alexandra Fiord, Barrow, Qikiqtaruk – Herschel Island and Zackenberg). Our analysis reveals that snow melt date and temperatures are key predictors for early season plant phenology in the coastal environments of the Arctic. Analysis is still in progress upon submission of this abstract, but preliminary results provide no evidence for a strong effect of local sea-ice conditions on spring plant phenology at the sites. Our findings highlight the value of long-term ecological monitoring for furthering our understanding of the processes governing tundra plant phenology in a changing Arctic.

Exploring Plant Traits as Predictors of Changes in Vegetation Cover

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Over twenty years of experimental warming have showed significant changes in vegetation cover at four study sites in northern Alaska. At the Atqasuk Dry site bryophytes and lichens decreased over time and with experimental warming. At the Atqasuk Wet site bryophytes decreased while deciduous shrubs and graminoids increased over time and with experimental warming. At the Utqiaġvik Dry site deciduous shrub and graminoids increased over time and with experimental warming. At the Utqiaġvik Wet site bryophytes decreased while graminoids increased over time and with experimental warming. We explored various plant traits as potential predictors of changes in vegetation cover over time. Plant height, leaf carbon, leaf nitrogen, leaf phosphorous, C:N ratio, leaf dry matter content, dry seed mass, and specific leaf area were correlated with cover change at the Atqasuk and Utqiaġvik study sites. Of these, plant height showed the most promise for predicting changes in vegetation cover over time. Leaf carbon, leaf phosphorous, and leaf dry matter content also showed potential as cover change drivers.

Species and functional diversity change over three decades of tundra monitoring

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Widespread changes in temperature and precipitation have the potential to drive substantial shifts in tundra biodiversity, with important implications for the functioning of tundra ecosystems. We combine three decades of tundra plant community surveys at nearly 200 Arctic and alpine locations with 75,000 tundra plant trait observations from the TRY and Tundra Trait Team plant trait databases to explore changes in both species and functional diversity in response to recent climate change.

Community turnover over time resulted in substantial changes in both species and functional composition, but preliminary results reveal little evidence of consistent changes in species or functional diversity *per se* (see figure). Despite trends toward biotic homogenization in many of the earth's ecosystems, within-site similarity (i.e., homogeneity) decreased slightly over time at most tundra locations, while among-site similarity did not change. These results indicate that tundra biodiversity is thus far remarkably resistant to recent rapid climate warming. Major vegetation-driven changes to tundra ecosystem functioning are thus most likely to result from direct shifts in the composition of tundra communities rather than indirectly through biodiversity change-mediated effects (i.e., biodiversity-ecosystem function relationships).

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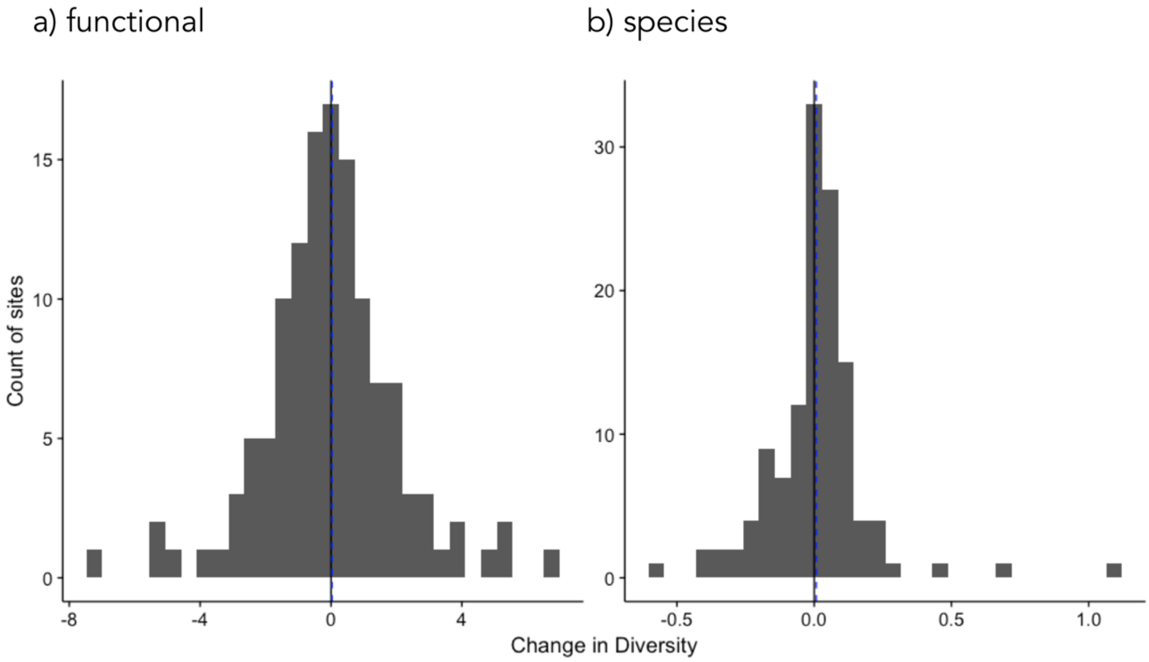

No significant change in functional (a) or species (b) diversity over three decades of community monitoring.

The sensitivity of carbon in Arctic permafrost soils to climate change

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Arctic permafrost soils contain huge amounts of stored carbon (C), which upon thaw releases ancient organic matter that has been stored in the frozen soil for centuries. However, the critical role that the Arctic C stocks may come to play in the future of our climate system has not been adequately investigated. Particularly, there is a gap in our current knowledge as to which extent permafrost-protected C is available for microbial metabolism once the soils thaw.

During 2012 samples were obtained from permafrost soils at two Arctic locations; Adventdalen (Svalbard) and Zackenberg (Greenland). At both locations sites were chosen to represent Meadow and Heath communities. Soil-pits were established and the A, B and C soil horizons were collected, together with the upper 20 cm permafrost, with three replicates for each community. Homogenized soil sample where further divided into three sub-samples. Two of the sub-samples have been incubated at +5°C with either Anaerobic or Aerobic conditions, with the third subsample sample working as a "control" incubated at -5°C.

Here we present data after three years of incubation where the CO_2 emissions from drained soils (A, B and Permafrost horizons) are generally higher from Zackenberg meadow sites than the heath communities. No difference can be found between the Adventdalen communities. Generally the organic rich A horizon generates higher fluxes than the C (mineral soil) and Permafrost horizons due to the higher C content in these horizons. First CH_4 production was detected after 56 days incubation (Zackenberg meadow A horizon) indicating that oxygen levels have dropped below the threshold for anaerobic decomposition. Furthermore, initial ^{14}C-dating of the emitted CO_2 indicates that the respired C is much younger then the bulk ^{14}C-dating of the soil.

Arctic tree expansion leads to more efficient N cycling due to changed mycorrhizal functioning

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Ecotones between forests, dominated by ectomycorrhizal trees, and heathlands, dominated by ericoid mycorrhizal dwarf shrubs, are naturally found in transitions towards arctic and alpine zones, and may be used as a space-for-time substitution to reflect consequences of arctic greening on ecosystem level processes such as nitrogen (N) circulation and carbon (C) sequestration. Here, we present results from a subarctic-to-alpine ecotone from mountain birch forest to heath tundra in northern Sweden. We found a strong positive coupling between tree abundance and ectomycorrhizal fungal growth, both of which were negatively coupled with C sequestration. By DNA-barcode sequencing, we identified a shift in dominance from root-associated ascomycetes (mostly ericoid mycorrhizal) in the heath to cord-forming ectomycorrhizal fungi (mostly *Cortinarius* and *Leccinum* spp.) in the forest. Higher C/N-ratios, lower inorganic N levels and lower abundance of functional genes reflecting inorganic N cycling in the forest suggested a more efficient organic N mobilization. We also transplanted organic substrates between forest and heath to investigate the decomposition capacities of microbial communities. Heath humus decomposed faster than forest humus, irrespective of where they were incubated, suggesting that the large carbon sink in the heath was not driven by low quality of the organic matter. Furthermore, when tree roots and ectomycorrhizal fungi – but not ericoid roots and associated fungi – were excluded, incubated sample mass increased, suggesting sustained belowground input, but decreased decomposition rate. Together, our data suggest that lower C sequestration rates in forests, despite higher litter inputs, are a consequence of more efficient ectomycorrhizal nutrient foraging from organic pools. When soil processes are dominated by stress-tolerant ericoid mycorrhizal plants and fungi, as in heaths, more C accumulates. Our results support the idea that the presence and relative decomposition capacity of mycorrhizal fungi, rather than different input quantities or qualities, determine long-term carbon sink strength across northern ecosystems.

Snow manipulation on Svalbard since 2006 - what have we learnt?

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Changes in temperature and precipitation in the High Arctic can alter snow depth and the length of the snow-covered and snow-free periods. We manipulated snow depth in Adventdalen, Svalbard, in the High Arctic, using fences that are c 6m long and 1.5 m high, in order to examine the relationship between snow cover and plant-soil ecosystem processes and functioning. I will give an overview of what we have learnt with this experiment.

Ecotypic variation in *Eriophorum vaginatum*: physiology and genetics.

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Eriophorum vaginatum is a widespread tussock-forming species that plays a dominant role in determining ecosystem structure and function in tundra of northern Alaska and Siberia. A 31- year reciprocal transplant experiment with *Eriophorum vaginatum* in Alaska showed that ecotypes from the northern part of the range were less capable of responding to an increase in temperature than ecotypes from warmer regions. Analysis of population genomic data using ddRAD sequencing showed significant differences between populations of *E. vaginatum* north and south of the tree line. Differences between northern and southern populations were also found in the timing of senescence when planted in a common garden, with southern populations remaining green later in the growing season. The response of photosynthesis to experimental warming also varied between the different ecotypes. Rates of tiller population growth and 17-year survival rates for tussocks suggest that the climate optimum for performance of *E. vaginatum* has been displaced ca. 140 km northwards from the home sites. As the climate warms, gene flow from south to north is likely to be limited for this long-lived species, thus the potential exists for reduction in its abundance followed by its replacement by shrubs.

It's not the end: How to close down an ITEX site

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In this discussion round we would like to discuss how to proceed when time comes that an ITEX site has to be closed down and the warming treatments discontinued. This would provide an opportunity to study if the vegetation returns to the original state (or that of the control plots), or if alterations in traits such as phenology continue. Also, future researchers may have good reasons to relocate and study the historical ITEX plots. Therefore, we would like to discuss the possibility of a common protocol that would be included in the ITEX Manual. This protocol about the decommissioning of an ITEX site should include topics such as: How should plots be marked and documented to ensure they can be relocated? How should data and meta data be archived for future use? This will be a growing concern and should be discussed by ITEX researchers.

Differential responses of Arctic plant senescence to snow depth and autumn warming

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In the Arctic, snow protects plants from harsh winter conditions and regulates soil moisture and nutrient distribution. In the spring, the timing of snowmelt determines the onset of the growing season and may affect the timing of phenological development. The climate in the Arctic is changing rapidly and may lead to higher winter precipitation and warmer, longer growing seasons in some areas. Deeper, longer lasting snow cover may therefore shorten the short growing season while warmer autumns may lengthen it. In this study we investigate the effects of spring snowmelt timing and autumn warming on the timing of the onset of autumn senescence in the Arctic plant species *Bistorta vivipara, Dryas octopetala, Oxyria digyna* and *Salix polaris* on Svalbard. Snowmelt timing was either manipulated experimentally with snow fences or varied naturally along a topographic gradient. Three groups of sequential timing of snowmelt were defined. Autumn warming was simulated with open top chambers in a natural snowmelt gradient. The effect of snowmelt timing on the onset of autumn senescence was only significant in *B. vivipara* which senesced later in mid-melting plots compared to early- or late-melting plots. Warming delayed senescence by 1.5 days but this was mostly driven by *D. octopetala* which senesced 3.8 days later in OTC plots compared to control. Snowmelt timing and warming therefore appear to affect species differentially and only cause small effects. However, considering the short growing season in the Arctic short delays in senescence could still be ecologically significant for the species and accumulate with increased duration and frequency of the warmer growing season.

Microbial communities are not linked to vegetation changes induced by long-term warming across the Arctic

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Large scale studies of soil microbial communities across the Arctic, similar to analyses regarding vegetation, are lacking which hampers general conclusions concerning the effects of warming and vegetation shift on soil nitrogen (N) and carbon balance. Here, we analyzed the microbial communities in the soil from 19 ITEX experiments across 13 subarctic-alpine and arctic sites to link directional changes in aboveground plant communities with belowground microbial communities. We test the hypothesis that warming-induced changes in vegetation towards increased shrub abundance results in a more closed N cycle, with N cycled mainly through organic forms, as a consequence of increased ectomycorrhizal fungal abundance. High-throughput sequencing was used to determine community composition of soil bacterial and fungal communities and several functional genes representing major inorganic N cycling pathways were quantified. The sites were heterogeneous with regards to soil properties as well as vegetation composition. As shown in previous studies, warming had a negative effect on the abundance of mosses and lichens, and a positive effect on shrubs in some sites, indicating that warming effects are site specific. However, these warming-induced changes in vegetation were not reflected in the belowground microbial communities. Similarly, the genetic potential for microbial nitrogen cycling varied more among sites than between treatments. Our results suggest that vegetation and soil microbial communities are tightly linked in the Arctic, but that overall response of microbial communities to warming may be slower than responses of the vegetation. However, belowground community responses may occur at a finer scale, e.g. specific taxonomic or functional groups might be responding and this is something we are currently looking into.

Changes in Vegetation Cover Across the Landscape Over Time at Atqasuk and Utqiaġvik, Alaska

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This paper presents changes in the plant canopy cover within the ARCSS grids at both Atqasuk and Utqiaġvik, Alaska. In each location 30 1m^2 plots distributed equally across the landscape were sampled annually, via a point-frame method, from 2010 to 2017 (excluding 2011). Plant specimens were identified to species and distributed into 6 functional groups based on their taxonomy (bryophytes, deciduous shrubs, evergreen shrubs, forbs, graminoids, lichens). There were significant changes in cover between years. The largest directional changes over time were increased cover of graminoids and deciduous shrubs in Atqasuk. This is present to a lesser degree in Utqiaġvik. Notable but non-significant changes included an increase in evergreen shrub cover in Atqasuk and a decrease in the cover of bryophytes in Utqiaġvik. We compared the changes in cover with the following abiotic factors: average air temperature in June, total precipitation in June, average number of thawing degree days, soil temperature, soil moisture, and active layer depth. Correlations between cover values and abiotic factors differed by growth form and differed by site. The strongest correlations suggest that changes in graminoid and deciduous shrub cover are being driven by temperature dynamics.

Planning for the inevitable loss of long-term sites: Alexandra Fiord

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ITEX is now into its 28th year, given the initial meeting in December 1990 as the starting point. I established the first ITEX site at Alexandra Fiord in the Canadian High Arctic in 1992, and have managed to maintain the site since then. A large data base of basic ITEX measurements and other related studies has been accumulated over the two decades, with the most recent addition of common garden studies showing evidence of small scale genetic differences, strong local adaptation and adaptation to the warming experiments. It has been a remarkable experience and the results have contributed to the understanding of high Arctic tundra response to climate variability and change. However, it is getting too difficult and expensive to maintain the site with the level of support received. Within the next 3-4 years, the annual research at Alexandra Fiord related to ITEX will come to an end. Planning for this is underway in order to ensure the legacy of the research is preserved and the various plots and data are properly documented and made available for visits by future researchers. There are and will be unique research opportunities with the experiments coming to a close. I will present a plan to put the ITEX research at Alexandra Fiord into “torpor” in a manner that will allow future researchers to easily find and re-measure plots and other sites. I will also examine the logistics of closing down the oldest warming experiment in Canada. This presents an opportunity to discuss the future of ITEX as the demography of the researcher population changes.

Plant functional groups regulate ecosystem properties in semi-natural alpine grasslands

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Plant communities affect, and are affected by their surroundings. The microclimatic variation across as little as 10 cm in grasslands can be large, which suggests that plants may establish themselves laterally, not only vertically, in their search for favourable growing conditions. The reciprocal role of plants on regulating the microclimate is equally important in determining the establishment and persistence of new individuals, as plant cover regulates not only heat exchange, but also radiation and water cycling. As climate change continues to drive warmer and wetter conditions in southern Norway, both abiotic and biotic mediators are predicted to regulate soil properties and ecosystem dynamics. The association of different plant species, and consequently plant functional groups, to various environmental conditions can lead to varying responses to climate change, with expected shifts in the roles and importance of each group. The resulting role of each functional group in regulating soil conditions is not certain. Feedbacks to ecosystem processes as a result of shifts in the regulating balance of the current grassland community could have knock-on consequences for carbon cycling. In a large-scale space-for-time climate and vegetation manipulation study in southern Norway, we tested for the role of bryophytes, forbs and graminoids in regulating soil heat flux and water cycling amplitudes and lags along two important climatic gradients.

The removal of any of the main functional groups resulted in greater amplitude shifts in daily mean summer temperature but no change in lag time to changes in air temperature, whereas the removal of bryophytes in combination with either graminoids or herbs induces a shorter lag time. Additionally, this trend was observed primarily on sunny days, and no functional group removal was significantly different on cloudy days. Overall, functional groups mediate extremes in soil conditions, but the magnitude of this effect varies among functional groups.

Co-occurrence networks show response of microbial communities to warming in tundra soils

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The arctic tundra is experiencing dramatic changes due to global warming, especially through the directional changes in the vegetation cover. Those changes are expected to impact the soil microbial communities, and consequently the interactions between the above- and belowground communities and overall ecosystem processes. In order to assess changes in the soil communities, samples were collected from 19 ITEX experiments across 13 subarctic-alpine and arctic sites, harboring contrasting soil chemistry and vegetation cover, with 4 control plots and open-top chambers per site. We used metabarcoding of the ITS and 16S rRNA marker genes to describe the fungal and prokaryotic community composition, together with quantification of the prokaryotic genes involved in the nitrogen cycle. We investigated if the co-occurrence networks between the soil microorganisms across all sites were reorganized by the warming treatment by comparing the topologies of the “small-world” networks, typical of microbial systems. The network topologies were similar between the plots subjected to experimental warming and those from the controls, with common modules between the two conditions. These network modules, indicating microbial consortia sharing the same ecological niche, showed clear patterns of correlation with the soil carbon and nitrogen content, the abundance of nitrogen-cycling genes and the distribution of plant functional groups. However, fine-scale discrepancies between similar consortia were detected. For example, several consortia that were positively associated with the nitrogen-cycling genes, harbored different keystone taxa. Moreover, some consortia were disintegrated by warming, indicating a weaker potential to adapt to environmental changes. The network of the negative co-occurrences was strikingly denser in the warming treatment compared to the control. This expansion of negative links is indicative of disturbance as these typically increase stability of complex networks under perturbation. In conclusion, the warming experiment indicates disturbances on the soil microbial communities, which potentially impact nutrient cycling and above- and belowground interactions.

Simulated climate warming: The unexpected resilience of island tundra plant communities

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Tundra plant communities have often been assumed to be fragile systems under great threat by climate warming which is happening at fastest rates at high latitudes. Accordingly, high Arctic communities would show stronger and more rapid changes in response to warming than low Arctic communities. Furthermore, islands generally have smaller species pools than mainland. With each plant functional type being represented by fewer species, plant communities on islands may be expected to be more "fragile" than in mainland ecosystems and more responsive to ongoing environmental changes. However, long-term studies do not provide good support for these general assumptions. On the contrary, some plant communities both in the high and low Arctic seem to be relatively resilient to climate warming. In this talk I will explore some alternative explanations for such unexpectedly high resilience based on data from long-term warming experiments in Iceland and Svalbard in comparison with circumpolar community data of the International Tundra Experiment (ITEX).

Different responses of soil microbial communities to long-term experimental warming in northern Sweden

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The organic and mineral soil layers from dry heath, mesic meadow, and wet meadow were studied to determine phylogenetic and functional responses of the soil microbial communities to 20 years of experimental warming in the ITEX site in Latnjajaure in northern Sweden. We used high-throughput sequencing of soil microbial communities (fungi and bacteria) coupled with predictive functional profiling of the bacterial communities using PICRUST, ecological guild assignment of fungal taxa and quantification of functional genes representing major inorganic nitrogen cycling pathways. We found that the soil microbial communities were highly diverse, and that the structure of the bacterial and fungal communities was strongly shaped by the habitat type and soil layers. Warming had no effect on the bacterial community, but affected the fungal community composition in the dry heath. This coincided with pronounced warming-induced changes in vegetation in this habitat. Predictive functional profiling of bacterial communities revealed differences in carbon decomposition potential between habitats with heath being enriched in labile carbon (starch, hemicellulose, galactose, xylan) degradation pathways, whereas the two meadows included more recalcitrant carbon degradation pathways for terpenoids and aromatic xenobiotics. The two meadows had higher abundance of genes related to denitrification and respiratory ammonification compared to the heath, while genes for archaeal and bacterial ammonia oxidation were separated between mineral and organic soil layers, respectively. Our results indicate that belowground microbial communities are largely resistant to long-term warming at the community level, and climate warming will likely have site specific impacts on the C and N balance depending on the genetic potential of indigenous microbial communities for carbon and nitrogen cycling pathways.

Winter climate-change effects on tundra bryophytes

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Bryophytes are highly abundant in tundra ecosystems and play important roles in their carbon, moisture and energy balances. They cover the bottom layer of the vegetation and are evergreen, and therefore have the need and potential to be relatively active outside the growing season. During the harsh winter, thermal insulation by snow together with their poikilohydric nature might protect their tissues against frost damage. High-latitude climate change is especially pronounced in winter, increasing average air temperatures and changing the amount of precipitation. How such new climate conditions will affect bryophytes, and whether this differs between different species remains unclear.

We therefore experimentally increased and decreased snow cover thickness and duration at tundra sites at two different elevations, simulating different future winter climate scenarios. We transplanted intact cores covered with one of three common tundra bryophyte species to each snow treatment and site combination, and investigated the effects on frost damage of the bryophytes for two consecutive years in late-winter/spring.

Tissues of *Ptilidium ciliare*, a species that is often found in wind-exposed sites, had significantly lower frost damage than tissues of *Hylocomium splendens* and *Sphagnum fuscum*, which generally occupy more protected habitats. In contrast to our expectation, frost damage was lower at the colder, high site (710m a.s.l.) than at the lower elevation (380m a.s.l.) simulating warmer future conditions. Frost damage decreased with increasing snow cover thickness and duration, but this effect was weaker at the low site and for *P. ciliare*. Differences in adaptation, moisture content, and freeze-thaw cycle frequency rather than absolute minimum temperatures likely contribute to the observed differences in damage between species and sites.

Our results suggest that climate warming may intensify rather than alleviate the harshness of winter as experienced by tundra bryophytes, especially when and where higher temperatures are not accompanied by thicker snow.

Mosses mediate climate-change effects on tree seedlings at the alpine treeline

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In tundra, mosses form dense carpets, which via their physical structure and water balance control microclimate such as soil temperature and moisture. Through these properties they may mediate climate change effects on tree seedlings establishing beyond the present alpine tree line, and thus on tree line shifts. Because moss species show great variability in their morphology and physical characteristics these effects are likely to be species specific. We investigated how the impact of warming and precipitation on seedling survival and growth of *Betula pubescens* and *Pinus sylvestris* is mediated by the presence of three dominant moss species and their species identity. Tree seedlings were transplanted into plots exposed to combinations of moss removal and experimental warming treatments along a natural precipitation gradient for three growing seasons at the subarctic alpine tree line in northern Sweden.

Survival of both tree species was supressed by the presence of pleurocarpous moss relative to the presence of *Sphagnum.* In the case of *Betula pubescens*, presence of pleurocarpous moss removed a positive effect of precipitation on survival while the presence of *Sphagnum* masked a positive effect of warming on growth. For *P. sylvestris* responses to climate were not mediated by the presence of mosses. Surprisingly, mosses did not mediate the effects of experimental warming on soil temperature or of precipitation on soil moisture as we had predicted. Mosses thus mediated *B. pubescens* seedling response to climate through another mechanism, likely competition. We conclude that absence of mosses benefits tree seedling establishment more than the direct effects of one degree of warming, or present variation in precipitation. Further, climate change effects on seedling establishment are in some cases hampered by mosses. Changes in the abundance and species composition of mosses therefore have the potential to influence tree line expansion following climate warming.

Disentangling alpine vegetation response to warming and herbivory

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(2) Department of Biology, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway;
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Alpine vegetation faces changes in both climate and land-use. While climate warming is an important driver of vegetation growth and community composition, herbivory may have an opposing or preserving effect. The effect and magnitude of potentially opposing factors and their interactions is yet to be disentangled. Therefore, the present study, conducted in the forest-tundra ecotone in Dovre, Norway, experimentally analysed shrub growth, plant community responses and litter abundance to increased temperature (OTCs) and herbivory (exclosures) compared with ambient controls over 18 years (recordings each third year). Treatment effects and interactions over time were analysed using linear mixed-models and ordination. Results show significant and temporarily consistent increase in shrub height and cover due to reduced herbivory, but no significant additional warming effect. An initial dominance of lichens declined in all treatments over time, but more rapidly and earlier in the warming treatment (significant after three years). Contrary to expectations, there was no increase in dwarf-shrubs due to warming. Deciduous dwarf-shrubs showed no treatment effect, while evergreen dwarf-shrubs decreased in the warming treatment (significant from year six). Litter accumulated in all treatments, but at higher rate in the warming treatment (significant after nine years). In summary, results disclose land-use as the prominent driver of shrub growth, combined warming and land-use for most plant community components, and warming for lichens and litter abundance. However, timing differences in vegetation responses call for critical use of both short-term and long-term response data originating from experimental studies.

Nurse effect of cushion plants: Plant interactions in Arctic tundra ecosystems in the face of climate change

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In 2015, we selected two populations of *Silene acaulis* L. to investigate the potential for nurse effects of this cushion plant on the structure of Arctic tundra communities in Central Spitsbergen. Positive interactions between such engineer and subsidiary species are well described in alpine environments, but less reported in the High Arctic. Following the hypothesis of a collapse of facilitation at the edge of environmental gradients, artificial warming by OTCs allows testing the changes in plant interactions forestalling potential future climate in the High Arctic tundra. The idea is to compare subsidiary community structure and individual performances within and outside cushions along with monitoring of abiotic factors.

The two populations are located in the vicinity of the Czech Polar field station Nostoc in Petuniabukta and represent typical types of *S. acaulis* habitats: a flat fell field on the Horbyedalen terraces and an active slope on Muninelva riverbank. In each population, we selected 15 sets of three similarly sized cushions and paired each cushion with a similarly sized bare ground area. The warming treatment was achieved by OTCs around a pair of cushion-bare ground area. To disentangle the effect of herbivore exclusion and warming, the second pair was fenced (side and top) with a chicken mesh as well as the tops of OTCs. The third pair was used as full control. Growth rate and reproductive effort of marked subsidiary individuals and cushions are recorded yearly, while leaf temperature of some subsidiary individuals, soil temperature and moisture are monitored. The protocol was designed for flexibility in terms of material as well as in terms of potential investigation.

Effects of warming on growth rates and remotely-sensed normalized difference vegetation index (NDVI) values across eight ITEX sites in northern Alaska

Jeremy May, Steven Oberbauer, Robert Hollister, Katlyn Betway, and Jacob Harris

Climate change is increasing temperatures in the Arctic and affecting plant growing season length and growth rates. Monitoring shifts in plant community phenology using both manual and remote sensing techniques are critical in understanding how phenology is affected across the Arctic. Here we report a combination of remotely sensed normalized difference vegetation index (NDVI), manual leaf growth measurements, and community composition for eight International Tundra Experiment (ITEX) sites across four locations in northern Alaska. Each study location consisted of a dry heath and a moist acidic or wet meadow community. Warming was achieved by open top chambers and resulted in increased shrub and graminoid cover at most sites. Peak season NDVI values reflected shifts in community dominance in response to warming by increasing at most sites (+0.01 to +0.11). The effect of warming on timing of peak NDVI values was site specific; however the southernmost sites, Toolik Lake and Imnavait Creek, showed the most pronounced timing shifts. Warming increased the rate of early season greening (+0.001 to +0.002 NDVI day^{-1}) and leaf length growth rates in all communities, except the Barrow wet meadow and Atqasuk dry heath. Senescence was delayed at most sites as a result of warming; however this was most pronounced at the southernmost sites (-0.001 to 0.003 NDVI day^{-1}). We show that warming shifts phenology and peak season NDVI values and that the direction and magnitude of warming effects are mixed across latitude and community type.

Climate change brings the greedy moth *Eurois occulta* to Disko

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During field work from the Arctic Station on Disko we encountered caterpillars of the Great Brocade Moth (*Eurois occulta*) also known as the Great Gray Dart. The larvae are very greedy, and here in Greenland they forage preferably on dwarf shrubs, especially willows, eg. *Salix glauca*.

This is a new Northern border for the moth. Its distribution limit used to be around Sisimiut-Kangerlussuaq, along the Arctic Circle. Apart from very rare encounters, the moth or its larvae have not previously been seen on Disko, nor have remnants been observed in sediment cores from the neighbouring Lake Fortunebay covering the last 4000 years. In 2004 and 2005 an immense number of larvae were seen in the Sisimiut-Kangerlussuaq area, and it is probably from that outbreak the newly encountered larvae at Disko derive. Our observation at Fortunebay in 2012 may be a result of long distance dispersal from the mass population observed at Sisimiut - Kangerlussuaq in 2004 and especially in 2005 by Pedersen and Post (2008). It is very likely that the adult moths can be carried away if wind conditions are right.

It is believed that an extraordinary outbreak of *Eurois occulta* in medieval times was part of the severe conditions the Norsemen faced, and which eventually led to their disappearance from Greenland. Iversen (1934) in his excavations and sediment samples from the end of the period when the Norsemen lived in Greenland has indeed found remnants of such insects.

Iversen Johs (1934): Moorgeologische Untersuchungen auf Grönland. Medd. Dansk Geol. Foren. 8: 341.

Pedersen Chr. & Post Eric (2008): Interaction between herbivory and warming in aboveground biomass production of arctic vegetation. BMC Ecology 8 (17): 1-12.

Post Eric & Pedersen Chr. (2008): Opposing plant community responses to warming with and without herbivores. PNAS 105 (34): 12353-8.

ITEX syntheses: Attribution of ecological change to warming across the tundra biome

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The tundra is experiencing some of the most rapid warming on the planet, and this warming is leading to vegetation change at sites around the tundra biome. The 2014 IPCC reports suggest that tundra ecosystems are one of the best examples globally of detecting an ecological change that can be attributed to anthropogenic climate warming. Over the past decade, a number of data synthesis efforts have explored the evidence for vegetation change and the attribution of this vegetation change to climate warming most of which stem from the ITEX network. Here, we summarise the evidence for the detection and attribution of tundra vegetation change to climate change including: phenology change, vegetation change, climate sensitivity of shrub growth, a warming of the combined thermal niches of plant communities and community-level plant trait change. Taken together, these data syntheses provide compelling evidence for the detection and attribution of tundra vegetation change to climate warming, but the evidence also points to variability in plant responses and the importance of other controlling factors such as soil moisture, topographic context, herbivory and permafrost thaw. To conclude, we will summarise future priority research areas including quantifying below-ground vegetation change, range expansion, local adaptation, dispersal limitation, trophic interactions and ecosystem functions such as carbon storage or surface reflectance. We will also suggest future avenues of new data collection and synthesis across the ITEX network. By capturing the landscape context of vegetation change, we can better understand the mechanisms reshaping the tundra biome.

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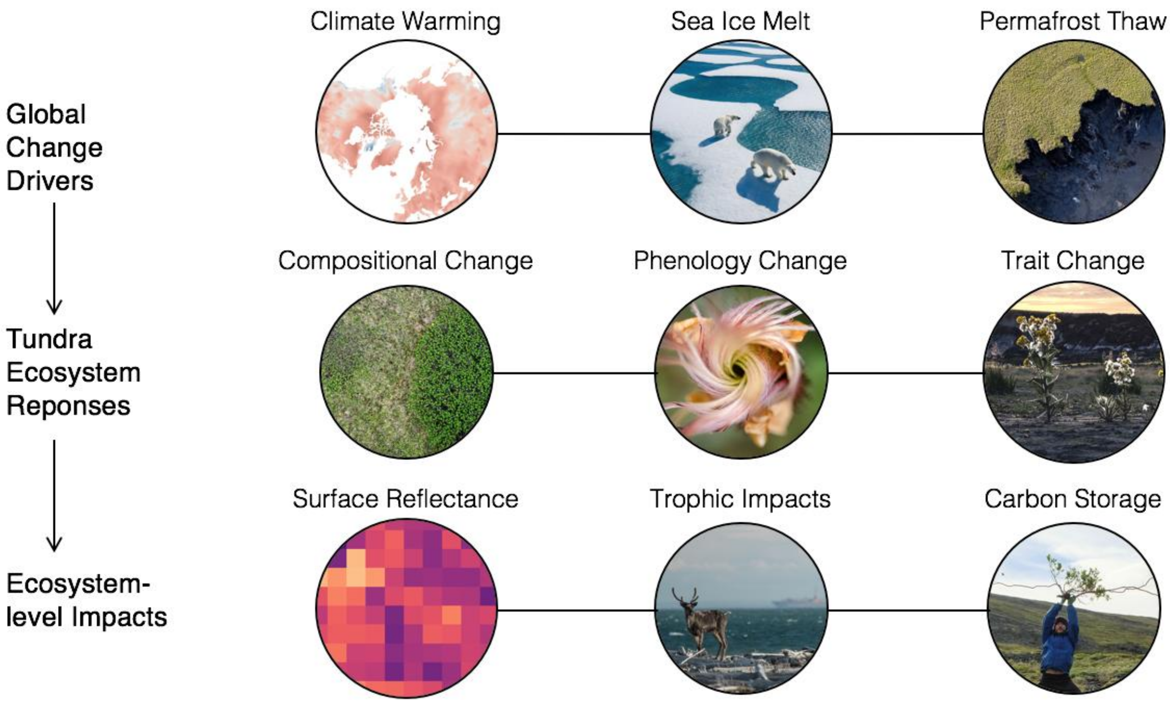
Climate Warming
Sea Ice Melt
Permafrost Thaw
Global Change Drivers
Compositional Change
Phenology Change
Trait Change
Tundra Ecosystem Reponses
Surface Reflectance
Trophic Impacts
Carbon Storage
Ecosystem-level Impacts

Eighteen years of ecological monitoring reveals multiple lines of evidence for tundra vegetation change

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We present the findings of a collaboration between government scientists, local people, park rangers and academic researchers that provides insight into biodiversity change and its potential drivers on a focal research site, Qikiqtaruk-Herschel Island. Over 18 years of ecological monitoring, we have documented: 1) a nine day per decade advance of spring phenology, 2) a doubling of average plant canopy height per decade, and 3) a doubling of shrub and graminoid abundance and a decrease by half in bare ground cover per decade. In 2017, we carried out additional protocols focusing on active layer depth and the regional species pool on the island, following the 2017 ITEX species pool monitoring protocol. We then used species-accumulation curves to test the proximity of new species that could potentially occur in the ITEX long-term monitoring plots in future. We documented deeper active layers than previously reported in 2009 and warming soil temperatures across the soil profile. We found 39 vascular plant species within 100 m of the ITEX plots, with 19 species within 10 m of the plots that could represent a source of future biodiversity change. Ecological changes suggest that indirect warming from increased growing season length and active layer depths, rather than warming summer air temperatures alone, could be important drivers of the observed tundra vegetation change. Our results highlight the vital role that long-term and multi-parameter ecological monitoring plays in both the detection and attribution of biodiversity change.

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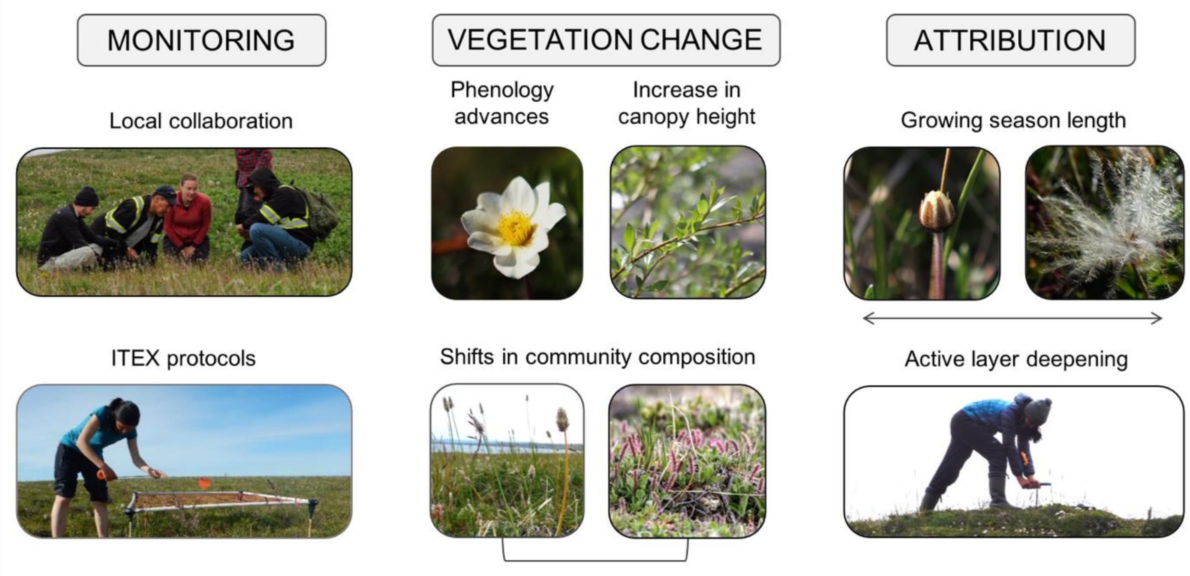

Conceptual diagram of ecological monitoring on Qikiqtaruk-Herschel Island and key findings

Effect of herbivores on species richness in a changing climate

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Climate warming is altering the diversity of plant communities but it remains unknown which species will be lost or gained under warming, especially considering interactions with other factors such as herbivory and nutrient availability. Here, we experimentally test effects of warming, mammalian herbivory and fertilization on tundra species richness and investigate how plant functional traits affect losses and gains. We show that herbivory reverses the impact of warming on diversity: in the presence of herbivores warming increases species richness through higher species gains and lower losses, while in the absence of herbivores warming causes higher species losses and thus decreases species richness. Herbivores promote gains of short-statured species under warming, while herbivore removal and fertilization increase losses of short-statured and resource-conservative species through light limitation. These results demonstrate that both rarity and traits forecast species losses and gains, and mammalian herbivores are essential for preventing trait-dependent extinctions in a warmer climate. We also test if this herbivory-species richness is true also at larger spatial and temporal scales using a suite of long term reindeer exclosures that have excluded reindeer for two decades in contrasting habitats throughout Scandinavia. The spatial pattern does to a large extent corroborate with our experimental results, since reindeer increased species richness in productive habitats and decrease species richness in unproductive habitats. We will discuss if the results from the warming experiment and the natural gradient are driven by the same mechanisms or not, and by that discuss if we now have a general understanding of how herbivores influence species richness in a warming climate.

INCLINE: Indirect climate change impacts on alpine plant communities

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Climate warming is already having large impacts on plant communities, including changes in species composition and diversity and species range shifts. But to what extent plant responses represent direct effects of the altered climate or indirect effects mediated by changing interactions among species is unclear. Novel species interactions, arising because species do not migrate in synchrony, could have large impacts on species, community and ecosystem responses to climate change, and especially so if newly arriving species introduce novel functional traits and trait combinations. These indirect effects are the focus of the new project INCLINE. The project will include 1) transplantation of lowland species into alpine plant communities subjected to experimental warming, 2) a global meta-analysis of community transplant experiments and 3) construction of species distribution models explicitly accounting for changing species interactions. The combined warming (using OTCs) and transplant experiment aims to simulate migrating species establishing in alpine plant communities under climate warming. To assess the effect of migrating species traits on alpine plant communities, the transplanted lowland species will include species with both novel and extant functional traits. Further, the direct and indirect effects of warming will be disentangled by performing removal experiments in combination with the experimental warming. To examine the combined effect of temperature and precipitation, all treatments will be replicated along a precipitation gradient. INCLINE is starting this spring, and any input on experimental design or interest in doing side projects within the same experimental setup is most welcome.

Are Arctic plant phenological responses to temperature evolutionarily conserved or related to life history traits?

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Here I present research to address the question 'are there evolutionary and life history trait patterns in phenological timing or phenological sensitivity to climate change of Arctic plants?'. There is evidence to support leaf out and flowering times of temperate and alpine plants are evolutionarily conserved and hence one would expect phenological sensitivity to temperature would also show similar patterns. However, there is conflicting evidence for the latter and little is known for Arctic plants. I am investigating whether some groups of species (phylogenetic clades, pollinator syndromes, growth habits, Sørensen's wintering floral bud stages etc.) flower or green up significantly earlier or later than would be expected by chance, and similarly, whether groups of species' flowering times or green up times are significantly more or less sensitive to temperature than average. I will present my proposed project, some preliminary results and seek input and suggestions. My research builds on the research by Janet Prevey et al. (2017 & 2018) and Steven Oberbauer et al. (2013). I propose employing a Bayesian hierarchical modeling and phylogenetic analysis approach using the 25-year ITEX flowering and green up phenology data set for my analysis. My preliminary findings suggest that flowering times of some growth forms and some families are more sensitive to temperature than others. There is no significant difference in flowering time sensitivity to temperature of wind- versus insect-pollinated species. Flowering times of species with more developed overwintering flower buds may be more sensitive to temperature than species whose overwintering flower buds are less well developed.

Soil respiration from sub-arctic tree and shrub communities is driven by recent photosynthate

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Arctic ecosystems are changing rapidly due to climate change and other factors; one such observable change has been the increase in cover of tall shrubs on the tundra, especially in the low and sub-Arctic. This is contributing towards increases in productivity and fixation of carbon (C) into biomass, raising hypotheses that increased shrub and tree cover will result in greater soil carbon storage.

We conducted a girdling experiment at a tree-line at Abisko, Swedish Lapland, to understand the fate of recently fixed C in shrub and forest systems. Large plots of mountain birch (*Betula pubescens*) and downy willow (*Salix lapponum*) were girdled in early 2017 at the base of every stem in order to stop delivery of autotrophic C to the rhizosphere. In the peak growing season girdling resulted in up to 53 % (37 % average) reduction in soil respiration in the birch plots and up to 38 % (28 % average) reduction in the willow plots. Reduction in soil respiration coincided with a 54 % and 34 % reduction in root production in birch and willow plots, respectively. ^{14}C content of soil CO_2 emissions shows that soil respiration in shrub and forest plots is dominated by recent inputs by the canopy and is unaltered by girdling treatment. This indicates that heterotrophic respiration is strongly dependent on autotrophic respiration and recent litter or root inputs.

This experiment demonstrates that although arctic shrub and forest plant communities fix larger amounts of carbon than other tundra communities, the carbon is rapidly turned over and recycled back to the atmosphere through soil respiration. Expansion of shrubs in the Arctic is therefore unlikely to result in increased net sequestration of C into the ecosystem.

The local species pool: How much does our measured vegetation change depend on the potential colonizers at our sites?

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Previous ITEX-related analysis showed that relationships between temperature and traits were mainly explained by species turnover across space rather than by changes in abundance. However, we usually only record species and their traits in our plots and not the ones growing in close proximity although these represent the most likely potential invaders into the permanent plots.

Therefore, we asked ITEXers to follow a protocol to record all vascular plant species and their height in the surrounding of their ITEX site. Knowing the local species pool and their traits in comparison to those in the plots gives us an opportunity to understand the potential for future change. It can also help us to understand which species from the surroundings have already colonized the plots in the past.

Preliminary analysis showed large differences between Arctic and Alpine sites. Alpine sites had significantly taller species in the surroundings than in the plots indicating a large potential for taller vegetation in a warmer climate. Arctic sites showed the opposite, i.e. smaller plants around the plots compared to inside.

Our results suggest that the local species pool may explain observed vegetation changes and the lack thereof across ITEX sites. Expanding the study of the local species pool may considerably improve our understanding of Arctic and Alpine tundra change.

Hearing the grass grow: vegetation records at automatic climate stations

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Many ecological studies lack detailed information about the local climate and the climate history. This problem can be solved if vegetation studies are carried out in the immediate vicinity of (long-term) climate stations that measure e.g. air temperatures, precipitation and timing of snowmelt.

We studied climate, vegetation and phenology at 100+ climate stations in Switzerland, at elevations ranging from 1139 to 2950 m asl, some of which have been running for 45 years. We are currently in the process of extending this study to climate stations in cold regions world-wide.

In this presentation I will show
(i) that snow cover duration has significantly shortened in Switzerland on average by 8.9 days per decade over the 1970-2016 period,
(ii) that snow cover is an excellent predictor for spring plant phenology,
(iii) that despite climate warming the frost risk for alpine plants during the early growing season has not decreased, and
(iv) how snowmelt timing modulates effects of temperature on alpine vegetation.

Consistent responses of soil nitrogen to experimental warming across cold ecosystems: a meta-analysis

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Cold regions such as the subarctic, are experiencing warming above global average. Our understanding of the ecological consequences of such warming has been recently improved with meta-analyzes that synthesize observations across large spatial and temporal scales. Most of these efforts have been focused on above-ground processes, especially related to carbon cycling. Comparatively, we have a poorer understanding of the ways warming affects nitrogen (N) cycling below ground. Transformation rates of N-based compounds are sensitive to temperature and contribute to determine the productivity and species composition of ecosystems. In this meta-analysis, we synthesize observations from over 50 field studies that have been conducted in cold ecosystems (i.e. with mean annual temperature equal or lower than 5 °C) across several continents over more than 2 decades. Experimental warming consistently increases N mineralization rates and the activity of N-relevant enzymes, such as proteases and urease. In contrast, warming has a weak effect on soil N pools and the composition and structure of soil microbial communities, and a weak or negative effect on the abundance of N-relevant genes such as *nosZ* and *nifH*. Although the confidence in some of our findings is constrained by a limited number of studies, our meta-analysis highlights common responses of soil N cycling to warming in cold ecosystems across the globe.

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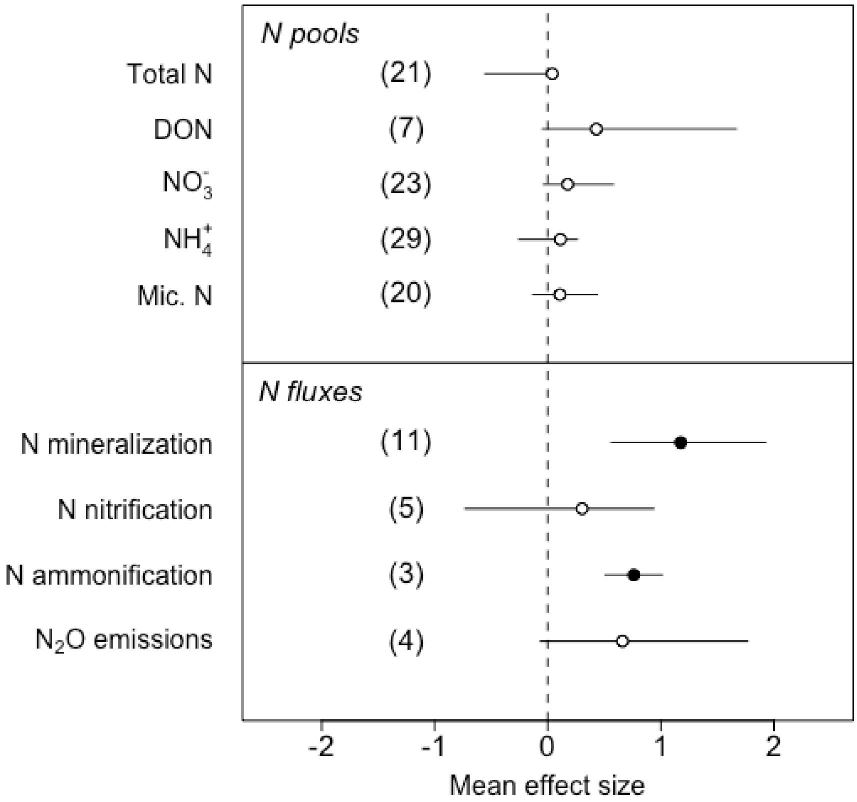
N pools
Total N
(21)
DON
(7)
NO_3^-
(23)
NH_4^+
(29)
Mic. N
(20)
N fluxes
N mineralization
(11)
N nitrification
(5)
N ammonification
(3)
N_2O emissions
(4)
-2
-1
0
1
2
Mean effect size

A note on phylogenetic community structure in the Arctic

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Measures of phylogenetic community structure are ever more common within ecology. However, when using these methods we assume that the evolutionary distance (measured in time) between species is linearly related to the amount they vary in ecologically relevant traits. This is important because phylogenies often cover vast spans of time. For instance, it is unlikely that adaptations accumulated during a period where alligators were swimming in arctic waters are as relevant to arctic plants than those accumulated in more recent times. To help explore this issue I will discuss some preliminary results of our study on the ITEX site in Latnja in northern Sweden. Here we developed some functions we use to visualize the weight of each branch on a commonly used metric of phylogenetic community structure. These functions can additionally be used to compare results from phylogenetic alpha and beta community structure, which is currently the focus of a new ongoing Tundra Vegetation Change synthesis.

Forty years of change in composition and structure of monitored and manipulated Alaskan tundra ecosystems

Gaius R Shaver (1) and many others

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Since the Dalton Highway opened in 1976, production, biomass, and species composition of moist tundra have been measured using identical harvest methods at multiple sites, often in multiple years, along this north-south transect across Alaska. Also since 1976, long term fertilizer experiments have been maintained and responses monitored as climate itself has warmed over the past 40 years. The aim of this talk will be to present this work in the context of two questions driving much contemporary research in arctic tundra: First, how is climate warming affecting tundra ecosystems in the long term, and what controls the rate and pattern of response at the community and ecosystem levels? Second, how do changes in species composition interact with direct effects of climate change to control canopy structure, production and biomass, and overall ecosystem functions?

Several conclusions may be drawn from this retrospective analysis:

1.) Although aboveground biomass and production at a single site may vary by 30-50% among years, there is no large or significant long term trend in biomass or production at any site where we have a long term record (>35 years). In contrast, dramatic increases in biomass and production consistently occur at sites disturbed by fire, fertilizer, or other direct manipulations.
2.) Changes in species composition also occur among years but the changes are inconsistent among sites, and deciduous shrub abundance is not increasing except at one site. Again, dramatic changes in composition occur on disturbed or manipulated sites.
3.) Despite significant annual variation in species composition in control sites, and dramatic changes in composition in fertilized plots, canopy structure in moist tussock tundra appears to follow a single, constant relationship between canopy N content and leaf area, as well as a constant production:biomass relationship.

Tundra vegetation change has no net impact on tundra litter decomposition rates

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The tundra biome is a globally important store of carbon, with up to 60% of soil carbon found at high latitudes. Although there is strong evidence that litter quality is a key driver of decomposition, the impact of vegetation change on decomposition in the tundra biome is unclear. Expansion of relatively recalcitrant shrubs may decrease the decomposability of litter inputs, yet changes to community-level functional traits, such as an increase in specific leaf area, could enhance litter decomposability. Here we quantify change in community-weighted decomposability of vegetation communities across the tundra biome, over space, over time, and with warming.

We combine i) a multi-site litter decomposition experiment, ii) the largest database of tundra plant traits, and iii) three decades of vegetation community change from ITEX sites (Figure 1). We model relationships between two-year litter mass loss and a suite of plant functional traits to estimate species-specific and community-weighted decomposability. Based on community-weighted decomposability for all ITEX sites, we quantify the decomposability of plant communities over space and time.

We find that community-weighted litter decomposability increases with temperature over space, but find no significant trend in decomposability over three decades of vegetation monitoring, despite changes in temperature and vegetation community composition. Our

results suggest that changes in community composition observed over the last three decades have so far had no net impact on litter decomposition rates in the tundra biome.

Our findings align with evidence for biogeographic gradients in trait expression across the tundra biome, but that only plant height has changed significantly over time. Our results suggest that decomposition in the tundra is more likely to be directly affected by changing environmental conditions in the short term, but that warming may increase the decomposability of tundra vegetation communities in the long term, creating a potential positive feedback to climate change.

Multi-Scale Analysis of Vegetation Phenological Variability on the North Slope of Alaska

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Climate change is pronounced at high northern latitudes where the ensuing impacts on ecosystems have become a well-recognized research priority. Plant phenology is sensitive to climate variability and change and has the potential to elucidate climate-ecosystem coupling over multiple spatial and temporal scales. This study assesses the effectiveness of multi-temporal plot and landscape-level imagery acquired from low-cost hand-held digital cameras, pheno-cams and kite-based aerial photography to derive measures of phenological variability (e.g. start of season, seasonal greening trends and end of season) for dominant vegetation communities near Utqiaġvik (formerly Barrow) and Atqasuk, Alaska.

Seven growing seasons of digital imagery were used for the study. Time series of the green chromatic coordinate (GCC) were derived from Red-Green-Blue digital numbers and compared to time series of the normalized difference vegetation index (NDVI) derived from ground-based hyperspectral reflectance measurements and single-pixel MODIS NDVI. NDVI is an effective proxy of primary productivity across multiple ecosystems including the Arctic. Phenological metrics derived from the three low-cost digital imaging platforms correlated well with ground-based NDVI and showed an improved capacity to document fine-scale species and plant community-level phenological change at high spatiotemporal scales. Seasonal and inter-annual variability in GCC and NDVI were greatest in low arctic and wet sites while high arctic and dry sites showed less variability.

Overall, findings suggest that sometimes strong seasonal and inter-annual variability in arctic landscapes are likely driven by moist to wet land cover types. Future studies are extending cross-scale analyses to a variety of satellite platforms (i.e. WorldView, Landsat, MODIS) to understand how such patterns transcend sensor platforms and sampling at different spatial scales.

Implications of evergreen shrub advancement: The need for a more comprehensive view of Arctic shrubification

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Arctic shrub expansion is occurring rapidly across the tundra biome and its potential ecological repercussions have been widely discussed. These include reduced albedo, higher winter soil temperatures due to increased snow trapping and higher nutrient mineralization rates. But while the term "shrub expansion" often implicitly refers to an increase in tall, deciduous species such as birch and willow, several studies have also found a strong increase in evergreen dwarf shrubs in response to warming, a fact which has received far less attention. The effects of an evergreen dwarf shrub expansion are markedly different compared to an increase in taller, deciduous species. While the low stature of these shrubs means that they are unlikely to influence snow cover, they also produce more recalcitrant litter, which reduces microbial activity and may thereby decelerate turnover rates. Here, we argue that basing predictions of how shrub expansion will affect tundra ecosystems on characteristics only applicable to tall deciduous shrubs, hampers our understanding of the complex feedbacks related to arctic vegetation shifts. Furthermore, we emphasize the potentially crucial role of mycorrhizal type in regulating ecosystem carbon dynamics, which has been highlighted in recent research, and propose a new conceptual model on ongoing shrub expansion that distinguishes between several important aspects connected to the ecological differences of deciduous and evergreen shrubs, and accentuates how herbivores may act as mediators between these two groups.

Faster, taller, more – patterns and drivers of change in arctic and high-alpine plant communities

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Climate warming is the most prominent driver of community change in regions relatively unaffected by direct human impact. High altitude and high latitude regions are much more affected by warming than the global average.

Within the sUMMITDiv working group, we merged a Europe-wide re-survey initiative on mountain summits (summit flora network) and data of the GLORIA summit monitoring network, to investigate long-term (>100 years) plant community change at high altitudes. We re-surveyed species composition of European alpine mountain summits, of which previous (historical and/or modern) species lists were available. We analyzed changes in richness and functional composition as well as characteristics of species prone to local extinctions, and their relationships to rates of warming.

In this presentation, we compare the findings on warming-driven community change at high altitudes throughout Europe with the findings of the ITEX network, identify generalities and differences, and discuss potential reasons thereof.

Transplants, OTCs and gradient studies: different approaches ask different questions in climate change effects studies

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Manipulative *in situ* experiments and space-for-time substitutions along gradients are common modes used to understand effects of climate change on alpine and arctic plant communities. Although general patterns emerge from studies using different approaches, there are also some inconsistencies. To examine how different methods in climate change effects studies may ask different questions, we integrated three approaches in a single study in the Hengduan Mountains of southwest China. We conducted warming experiments using open top chambers (OTCs), transplantation along an elevation gradient, and monitoring plots over five years. The general trend across all the approaches is decreased species richness and evenness with climate warming in the lowest elevations, suggesting increased competition from immigrating lowland species, and/or from the taller vegetation canopy of the species already growing in the plots. In the colder climates in the higher elevations, on the other hand, plant community responses depended on the warming approach. In the transplants, species richness and evenness increased in plots transplanted towards warmer climates. This suggests that alpine vegetation is easily invadable, and that species migrated into these plots from the new neighborhood exposed to after transplanting. The OTCs are likely not so easily invaded, and the plots are not exposed to new neighbours in the same way. We also show that loss of alpine species is a slow process. Thus, it appears that alpine species are resistant and that loss of species is a slower process in cold environments than in warmer environments. Approaches that compare responses between different areas on the same (short) timescale, or that compare results based on different approaches, may yield misleading patterns. Generally, our results suggest that transplanted alpine plant communities are especially prone to be invaded by new species, but that the alpine flora also very slowly goes extinct under future warming.

Poster Abstracts

Permafrost thaw – decadal responses to climate change

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Permafrost soils contain approximately 1672 Pentagram carbon (C), twice the amount of the current atmosphere, and constitute 50% of the world's belowground C pool. Along with the current change in climate these high latitudinal soils experience increased temperatures, with permafrost degradation as a result. This releases ancient organic matter where the following microbial degradation can release the previously stored C and nitrogen (N) to the atmosphere as carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), further influencing the climate systems. Thus, a changed climate leads to sever alterations of the C and N balance in Arctic and high altitude ecosystems.

This project aims for understanding the future that lies ahead, following thaw and the establishment of new non-permafrost ecosystems, and how the predicted climate variability will influence these soils on a long-term timescale. By using a natural occurring permafrost degradation gradient in the northern part of Sweden, this project investigates: the change in C and N dynamics following thaw, the decomposability of ancient carbon (through radiocarbon dating), the chemical/physical protection of ancient C, and the microbial response following degradation and during the transit to new ecosystem types. Furthermore, by using laboratory incubation of soils from the gradient, the project will provide insights of how the C and N cycles at different stages of permafrost degradation will respond to the changing climate, giving a decadal perspective on permafrost thaw.

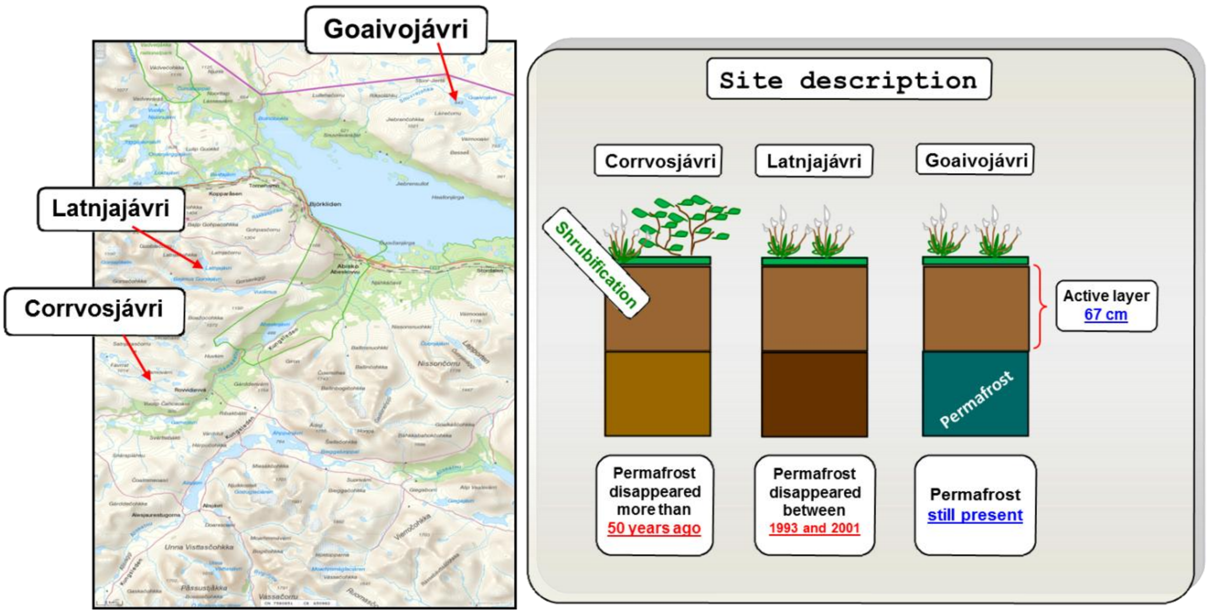

Figure 1 - The permafrost degradation gradient used in this study is situated in the northern part of Sweden, in the vicinity of Abisko.

Effects of climate warming on rate of decomposition in the high and low Arctic

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Tundra ecosystems contain almost 50% of the global belowground organic carbon and therefore play a crucial role in the global carbon cycle. If temperature changes follow current predictions, these carbon pools could potentially shift from a sink to a source of CO_2 by the end of this century due to accelerated decomposition rates. The aim of this study is to examine how climate warming affects decomposition rate within contrasting bioclimatic sub-zones in the Arctic. The impacts of warming on decomposition rate was assessed in five different habitats in high Arctic Svalbard and sub-Arctic Iceland, using open-top chambers (OTCs) to enhance temperature. Protocols from the Tea Bag Index were used in order to estimate decomposition rate. Two types of commercially available tea were used to represent dead plant material. 800 tea bags were buried into the ground in 90 plots (OTCs and controls) and the decomposition rate estimated as weight loss over three months and one year. The effect of warming on decomposition rate differed significantly between high and low Arctic. Decomposition rate was significantly higher in warming treatments in Iceland, but surprisingly the opposite occurred in Svalbard where, in some habitats, control plots had significantly higher decomposition rate than warming treatments. This study shows that interactions between warming and decomposition rate are complex and need further investigation. Decomposition rate is affected by warming, but in different ways depending on bioclimatic zones and different habitat types.

Quantifying vegetation shifts under climate change in extreme biomes

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Shrub encroachment has been increasingly reported at locations across the planet, including in the tundra and the savannah, two biomes thought to be particularly vulnerable to climate change. While shrub expansion has taken place at similar temporal scales, the drivers and magnitude of change across biomes differ. In this poster presentation, we will provide an overall synthesis of shrub encroachment including a meta-analysis to quantify the rates of vegetation change and calculate the contribution of different drivers to shrub expansion in each biome. In addition, we will identify the plant traits that play a key role in determining tundra and savannah shrub species' vulnerability to climate change. Using these analyses, we will identify taxa that are more prone to population increases, declines and extinction, i.e. the winners and losers, under climate change. Finally, we will examine how the distribution ranges of dominant species in the tundra and the savannah could shift as a consequence of climate change. We will use four different climatic scenarios issued by the Intergovernmental Panel on Climate Change and spatial modelling to test possibilities of future shrub encroachment. This work will enable cross-biome comparisons of climate change responses by identifying whether species' responses are generalizable or highly linked to the biomes they inhabit.

Using remotely-sensed hyperspectral data to help understand vegetation cover change at Utqiaġvik, AK

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Accelerated global warming is affecting vegetative growth and reproduction. Arctic vegetation is especially susceptible to climatic shift. In a long-term warming experiment in Utqiaġvik, Alaska, vegetation cover was sampled via a point intercept method from 1995 to 2016 across 48, one-square meter plots. Recent remote-sensing data has provided additional metrics for assessing landscape-level vegetation changes. The change in plant cover was mapped alongside hyperspectral data in ArcGIS, revealing possible patterns of spatial clumping across the research site. Analysis of the change in graminoid, lichen cover, and hyperspectral data revealed correlations between plant cover, aspect, elevation, and wetness indices. Graminoids and lichens show a response to existing biomass, NDVI, and MSI indices. These findings suggest that remote-sensed data can help understand the complexities of changing vegetation in response to climate change.

Maintaining individuality through scaling with equitable transformation: Applications to long-term phenology rates in tundra plants

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Using a new data analysis technique, known as an equitable transform, air temperatures at Alexandra Fiord, Ellesmere Island were found to have warmed by 1.8 ±0.4 °C/decade (winter) and 1.1±0.2 °C/decade (summer) from 1986 to 2007. The same transformation was applied to phenology data of *Dryas integrifolia* from the same site. By allowing the day number of phenological events to correspond to one variable within the equitable system and individual plants under various conditions to represent different replicates, we determined that the yearly cycles of phenology events could be modelled accurately using this transformation. We introduce the idea of scaling and shifting the seasonal cycle of a reference plant via the equitable transform in order to approximate the behaviour of multiple phenological cycles. Relative phenology rates of *Dryas integrifolia* were found to have increased over time at Alexandra Fiord indicating that the duration of phenological stages has become shorter. These two examples, along with simulations, demonstrate the potentially wide applicability of this technique for modelling and data analysis of ecological systems. An equitable transformation maintains systematic differences between instances when the underlying pattern for each instance is a separable function in two variables. This technique allows any reference instance to be transformed into any other instance. This is similar to the Boltzmann transformation used in soil science to describe water content in comparable media; however, the equitable transform creates a system in which all instances can be interchangeably used as the reference case. It partitions the original data approximately into the underlying separable function and its residuals. This transform can be used to: impute missing data points, determine systematic patterns underlying the data, observe baseline changes, and detect different amplitudes in the replicated sequences. It has potential applications in soil science, life history studies, population dynamics, climate and spatial/temporal modelling.

Long-term plant responses to experimental warming and altered snowmelt timing in the Canadian High Arctic

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Arctic regions are particularly affected by rapidly rising temperatures and altered snow fall regimes. Snowmelt timing, which determines the start of the growing season, not only depends on spring temperatures but also on the amount of winter precipitation. Therefore, predictions about future snowmelt timing are difficult and experimental evidence for its ecological consequences is scarce. We investigated how changes in snowmelt timing and warming affect common tundra plant species in a High Arctic evergreen shrub heath community at the International Tundra Experiment (ITEX) site at Alexandra Fiord, Ellesmere Island, Nunavut. A factorial experiment combining passive warming, snow removal, snow addition and control treatments was established in 1995. While open-top chambers (OTCs), that passively warmed vegetation by 1 – 2°C, remained on plots all year round, snow manipulations were applied each spring before snowmelt. Between 2009 and 2013 only the warming treatment was sustained. We examined responses to earlier and delayed snowmelt as well as experimental warming by measuring phenological and growth traits of *Cassiope tetragona*, *Dryas integrifolia*, *Luzula arctica* and *Papaver radicatum*. Despite a trend for increasing snow depth, there was no long-term trend in natural snowmelt timing, but high inter-annual variability. Snowmelt timing primarily controlled early season phenology, but had less influence on later phenological stages and plant growth. Experimental warming generally advanced flowering and warming effects persisted over the course of the growing season influencing other traits such as growth increment and flower height. Our results underline the importance of understanding the complex interactions between temperature and winter precipitation that drive species responses to climate change in the Arctic.

Plant interactions in Arctic tundra ecosystems in the face of climate change

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High Arctic ecosystems are characterized by extreme environmental conditions. According to the stress gradient hypothesis, plant interactions change from competition to facilitation along gradients of increasing environmental severity. Under harsh environmental conditions, positive plant interactions are frequently observed with nurse species, such as cushion plants, facilitating the growth of beneficiaries in tundra ecosystems. However, theoretical considerations suggest that facilitation may decline at the extreme end of environmental gradients. Furthermore, climate change is expected to alter plant interactions in cold environments since temperature largely determines levels of environmental stress for Arctic plants. However, the timing and the underlying mechanisms of these changes are still largely unknown. In this project we aim at a better understanding of altered plant interactions in tundra ecosystems in the face of climate change. In 2015 we established an experiment on Svalbard to study interactions of the common cushion plant *Silene acaulis* with beneficiaries in their natural environment as well as in experimentally warmed plots (OTCs). By measuring growth and reproductive traits of beneficiary species, we studied interactions of cushions with their beneficiaries. Preliminary results show reduced growth of some beneficiary species inside as compared to outside of *Silene acaulis* cushions indicating a decline of facilitation in extreme High Arctic environments. However, elevated temperatures lead to increased growth of the same beneficiaries inside as compared to outside of cushions indicating an onset of facilitation under less severe environmental conditions. Expanding these measurements will improve our understanding of climate change impacts on plant interactions in tundra ecosystems.

Small scale biogeochemical cycling in sub-Arctic mountain birch forests

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Large amounts of organic carbon stored in arctic soils are vulnerable and may be lost to the atmosphere through soil respiration mediated by changes in plant and microbial communities affected by climate change. At the sub-Arctic forest-tundra ecotone of Abisko in Sweden, the more productive mountain birch forests store less carbon below-ground than the adjacent, less productive, tundra-heath. These mountain birch forests often have an open structure with 3-8m between trees and we therefore sought to investigate the influence of individual trees on surrounding soil processes. This work focused on soil processes at the scale of individual trees rather than habitat or vegetation-type scales. We established transects extending 3m radially from the base of individual trees along which soil respiration, root production and mycorrhizal hyphal production were measured. We found no difference in soil respiration along the transects measured throughout the growing season. Similarly, root production did not vary significantly along the transects and comparable results are expected for hyphae production (data pending CHN analysis at time of writing). This uniformity in fundamental soil and rhizosphere processes suggests more homogeneity throughout the open forests than first assumed, which has implications for global change modelling and future carbon stocks. This work also provides an early indication of the existence of a ‘Wood-Wide Web’, or common mycelial networks; these have not yet been explored in sub-Arctic mountain birch forests but may be key to ecosystem processes and biogeochemical cycling in these globally important ecosystems.

A retrospective analysis of long-term experimental warming in the Canadian High Arctic using *Cassiope tetragona*

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Annual stem growth and reproductive effort of the evergreen dwarf-shrub, *Cassiope tetragona*, exhibit a strong positive relationship to summer temperature and have been used in dendroclimatology analyses to reconstruct climate in the High Arctic through the application of transfer functions. Retrospective analysis of the annual growth increments (AGI) have also been used to examine the impact of short term warming in a few tundra sites. The proposed research will include a full retrospective analysis approach to reconstruct the impact of long-term experimental warming in tundra communities at Alexandra Fiord (Ellesmere Island) on growth and reproduction variables using a before-after-control-intervention (BACI) design, from before the installation of open-top-chambers (OTCs) in 1992 to the present day. Additionally, chronologies of experimentally warmed *Cassiope* samples from multiple ITEX sites will be compared to investigate the extent to which growth and reproductive responses to experimental warming vary across the Arctic. We will also present the preliminary results of a comparison of AGI measurements using microscope image software analysis against a traditional manually operated caliper approach.

Using drones to quantify aboveground carbon in Arctic tussock tundra

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Over the past 20 years, Arctic vegetation has undergone significant structural changes with increasing temperatures leading to enhanced plant productivity in some areas. Until now, these greening signals have largely been observed through satellite acquired data, and scaled-up using ground measurements. However, very few studies have been conducted on the use of unmanned aerial vehicles (UAVs) for this specific purpose.

We put forward and evaluate the use of UAVs for the quantification of aboveground carbon in the tundra, and compare its accuracy to aboveground carbon estimates attained by up-scaling ITEX plot data on Herschel Island. We make use of multi-image photogrammetry (Structure from Motion), to create high resolution digital surface models (DEMs) of our site-specific ITEX plots, and use data obtained through supervised satellite classification and elemental analysis to quantify the total aboveground carbon throughout the two main vegetation types on Herschel Island.

Analysis is still in progress upon submission of this abstract, but preliminary results show that there are differences in aboveground carbon between the two most abundant vegetation types on Herschel Island. Our findings highlight the importance that UAVs could play in advancing spatial ecology and improving upon the ITEX protocol.

HERBS ARE HURT – SHRUBS WILL THRIVE in a warmer Arctic climate

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It was anticipated that a global climate change would first and most severely take place in the Arctic, in terrestric ecosystems. A rapid change in plant performance took place in 1996 in a fell field area near the Arctic Station on Disko Island in West Greenland, coinciding with a marked decline in winter ice coverage in Disko Bay.

Climate change in West Greenland has led to mild winters and shorter winter ice coverage in Disko Bay, associated with warm spells on land with snow melting and bare frost conditions.

Herbal plants known for their winter hardiness, e.g. *Papaver radicatum*, suffer from such interruptions during hibernation, and reduced biomass and fecundity is the result.

In contrast, woody plants, e.g. *Salix arctica*, benefit from the warmer winter with increased growth rate. Hence, global warming accelerates a change in arctic plant communities from fell field to dwarf shrub conditions, very much like increased rate of secondary succession.

This poster was first presented at the Climate Change Conference in Copenhagen in 2009, Global Risks, Challenges & Decisions, which was the scientific congress in connection with the COP 15 same year. It was organised by The University of Copenhagen in cooperation with the partners in the International Alliance of Research Universities.

Peak season CO_2 fluxes in OTC-warmed and control plots in wet and dry tundra at two ITEX sites in northern Alaska, 2000-2017

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Low temperatures and waterlogged soils have contributed to maintain low ecosystem respiration (ER) rates and decomposition in the Arctic. As a result, Arctic ecosystems hold large amounts of soil organic carbon under cold and conditions. Climate models predict a significant increase of global temperatures, with the largest increases in the polar regions. An increase of the ER rates in the Arctic could represent a positive feedback to the atmospheric CO_2 concentration and further increase the global temperature. Warming also will likely increase gross primary productivity (GPP), counteracting some of the increase in ER. To evaluate the long-term effect of warming on tundra CO_2 exchange processes of sites with different temperature and moisture regimes, we measured ecosystem CO_2 fluxes on experimentally warmed plots in dry and wet sites from two locations in northern Alaska. The study sites were established in the mid 1990's as part of the International Tundra Experiment (ITEX) network. We used passive warming for the temperature manipulation and static chamber techniques to measure CO_2 exchange. After 18 years of manipulation, warming still has a significant effect on CO_2 exchange in some of the sites, but the response was not the same at each site and location. The coastal location presented stronger responses of the CO_2 flux components to warming than the inland location. The dry site in the coastal location was frequently a CO_2 source as a result of warming. Ecosystem respiration presented a positive significant response to temperature across years, but the relationship with year was not significant. Our results suggest that the coastal location responded differently to warming than the inland location. Dry areas can be sources of CO_2 even after more than a decade of warming. Conversely, after a period of aboveground biomass increase, wet sites presented no significant response to warming after several years of warming. Arctic ecosystems can readily respond to warming, however over time nutrient reallocation, self-shading, and soil insulation may down-regulate GPP and ER in wet areas. In dry areas where absorption and reallocation of nutrients by the vegetation is slow, the ecosystem could sustain high ER rates for long periods in response to warming.

High Arctic plant functional type nutrient dynamics under simulated herbivore disturbance and summer warming

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The Arctic is warming faster than any other region on Earth and warmer summers have been shown to strongly affect soil nutrient cycling and plant nutrient dynamics. However, the extent to which Arctic ecosystems and tundra plants respond to higher summer temperatures may be modulated by plant-herbivore interactions. For instance, the Svalbard pink-footed goose (*Anser brachyrhynchus*) population has dramatically increased over the last decades. Geese started exploiting previously rarely utilized habitats raising the issue of how plant nutrient content and dynamics may be modified by the combination of warmer summers and herbivore perturbations. Using a two-year (2016 and 2017) fully-factorial randomized block design with ambient and elevated summer temperatures (by means of ITEX open top chambers) and no and simulated spring goose disturbance (grubbing and feces addition), we explored how these drivers may interact in determining plant nutrient content in three high Arctic plant communities developed along a soil moisture gradient (*i.e.* mesic, moist, and wet communities). In addition, repeated sampling along the two experimental seasons allowed us to test for treatment effects on plant nutrient dynamics. Using Near-Infrared Reflectance Spectroscopy, we analyzed nitrogen and phosphorous concentration in over 6000 leaf samples encompassing the main plant functional types (PFTs) structuring these communities, namely forbs, grasses, sedges, rushes, deciduous and evergreen dwarf shrubs, and mosses. Here, we present the first results of this large effort aiming to shed some light on how Arctic PFT nutrient dynamics may be affected in a scenario encompassing warmer summers and higher herbivore disturbance following a population expansion.

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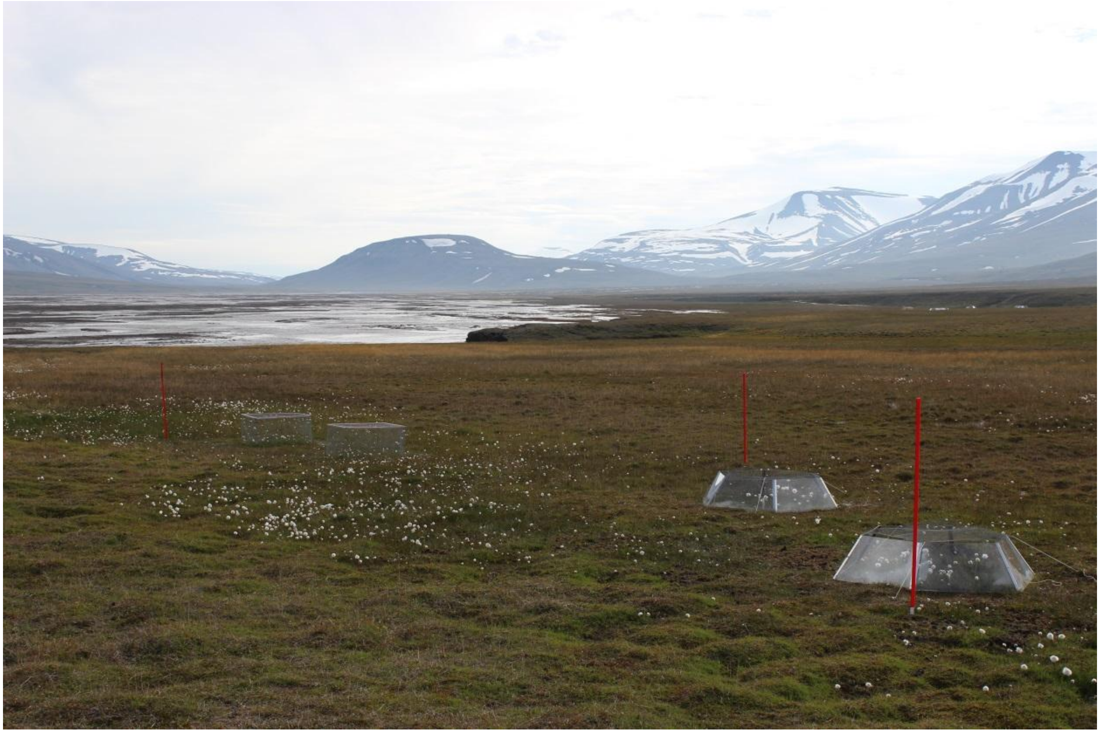

Example of a wet community as selected for this study. Open Top Chambers (OTCs) have been used to increase summer temperatures, while cages were employed to exclude the confounding effect of natural herbivory. Photo: Matteo Petit Bon (year 2016)

Using drones to study plant communities, herbivore driven plant cycles and carbon fluxes

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Changes in Arctic ecosystems are typically monitored using coarse resolution satellite images or with detailed plot scale studies. However, this creates a tremendous mismatch in spatial scales and makes it hard to understand small scale spatial heterogeneity and dynamics of Arctic vegetation. Drones can bridge this mismatch by providing high resolution spatial data and also offer a convenient opportunity to analyze temporal changes over the growing season. This project uses multispectral data from drones combined with plot scale ground control data and satellite imagery to bridge temporal and spatial scales. We aim to develop a long-term monitoring strategy of vegetation changes and want to link this with data on carbon fluxes and on plant-herbivore impacts with a particular interest in dramatic vegetation changes caused by vole and lemming cycles.

This contribution presents first results from fieldwork in 2017. Four study areas with an extent of 15-20 ha were monitored using a drone near Abisko, northern Sweden. The areas are dominated by tundra vegetation and located at or above the treeline. In each area 33 randomly distributed ground control plots were set up. Monitoring was performed in ±12 day intervals over the growing season. During each interval multispectral drone imagery was collected to estimate the normalized difference vegetation index (NDVI). This is accompanied by handheld NDVI measurements and phenology photographs of each ground control plot. The data will be compared to open access satellite imagery time series and is complemented with point-intercept data, biomass and soil samples from each ground control plot. Furthermore, we are open to link this research to other research initiatives.

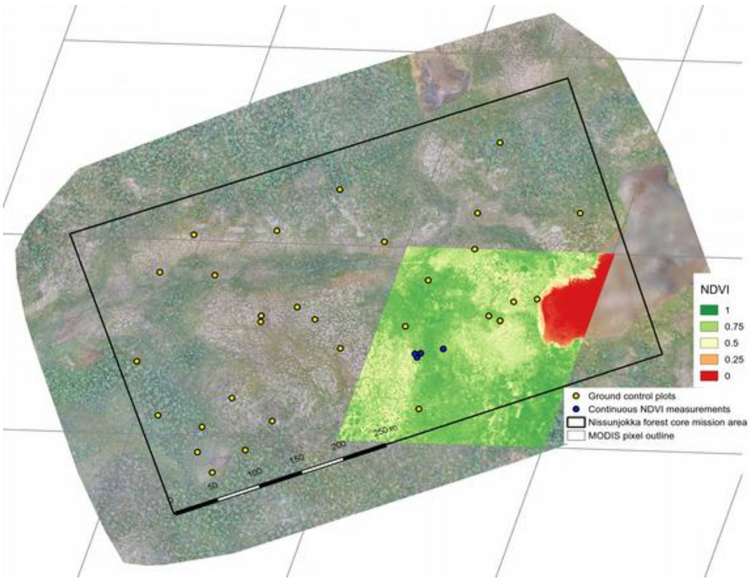

Fig. 1: Orthophoto and NDVI inlet generated from drone imagery. Gridded overlay represents the size of MODIS pixels.

Forecasted homogenisation of high-arctic vegetation communities under climate change

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ABSTRACT

Aim: Climate change is increasing temperature and modifying precipitation regimes in the High-Arctic. Models can help anticipate future changes on the vegetation. In rugged terrains, forecasts should consider fine-scale variability in environmental variables that are proximally linked to plant performance. Here, we forecast how plant communities may respond to climate change using high-resolution environmental maps.

Location: Zackenberg in high-arctic Greenland.

Methods: Using a combination of remote sensing data and field measurements, we produced maps of soil moisture and temperature at 1m resolution together with spatial data on snow cover and solar radiation. We calibrated stacked species distribution models (S-SDMs) on 200 vegetation plots. To explore the sensitivity of arctic communities to climate change, we forecasted models under simulated increases in temperature and changes (positive or negative) in snow cover and soil moisture.

Results: S-SDMs associated with high-resolution environmental variables were able to reproduce the spatial variation in species richness and plant community structure at Zackenberg. Model forecasts revealed that most species reacted to a combination of changes in soil moisture and temperature, and changes in these two variables resulted in an extensive restructuring of the distribution of species assemblages. In most scenarios, a gradual homogenisation of communities was forecasted due to shrub expansion.

Main conclusions: Increasing temperatures and altered soil moisture were predicted to turn the currently highly heterogeneous tundra landscape at Zackenberg into homogenous dwarf-shrub tundra. Such homogenisation of vegetation communities may have profound ramifications for species and interaction webs, not only locally but ultimately also globally via modifications of surface albedo, energy and water balance, as well as snow accumulation and permafrost.

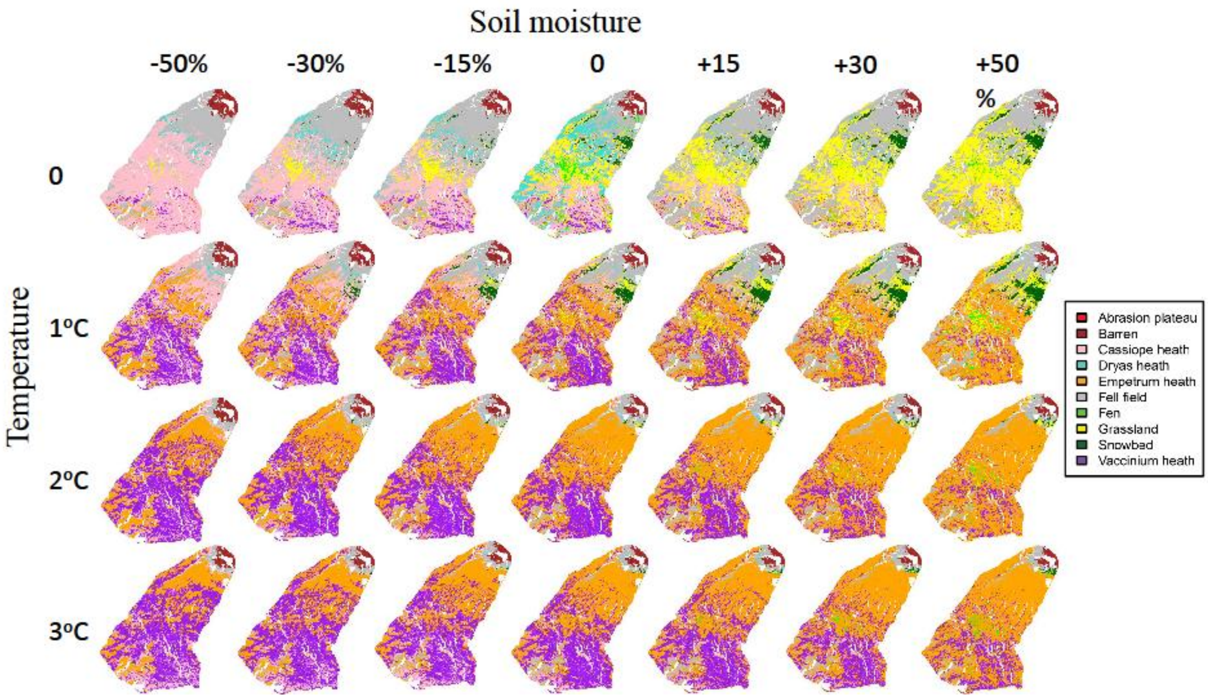

Figure 1: The distribution of vegetation types predicted by stacked species distribution models (S-SDMs) under changing soil moisture and temperature conditions in Zackenberg, northeast Greenland. Environmental predictors used were temperature, soil moisture, snow, and solar radiation (Solar radiation was only included for species, when it showed a marked increase in the explanatory power of the generalised linear model).

‘Svalbard’

by Friederike Gehrmann

Here, the spirits rule the seasons
With their magic and their might
Bringing summer, spring and autumn
And the endless winter night

You may think that it is cruel
Bitter cold and biting gusts
So to find this place’s beauty
Is a little of a quest

Only when a solar storm
Hits the earth’s magnetosphere
And the darkness of the night
Is exquisitely clear
Light unfolds across the sky
In the colours of your dreams
The Aurora Borealis
Is much more than what it seems

Spirits cast this spectacle
Across the winter canopy
To remind us how unearthly
Nature’s beauty may well be

[*Continued …*]

Ice and snow seem endless here
Brutal, restless, breath-taking
But their power is not evil
As their duty's life-guarding

Underneath the shielding snow
Life survives the winter's cold
To the spirits, perseverance,
Is a virtue to behold

When the winter with its hardship
Has been born for long enough
From the thawing springtime sparseness
Life revives from barren soil

One may find a revelation
In the talent of such force
How extraordinary beauty
Such adversity can forge