Completed syntheses (15 minutes presentations)

Title: Hidden diversity as the source of biodiversity trait change in the tundra

Authors: G.N. Daskalova, I.H. Myers-Smith, C. Rixen, A. Bjorkman, M. Garcia Criado, J. Assmann and the ITEX consortium

Tundra plants are responding as the climate continues to warm, with biome-wide shifts in biodiversity and species traits. However, plant surveys often capture scales of only several square metres, leaving many unmonitored species that by chance could be absent in small plots, but found within the surrounding landscape. This hidden landscape diversity could be the source of future shifts in species richness, plant composition and plant traits. Here, we bring together plot-scale observations of up to 30 years with species pool and topography data to reveal the magnitude of hidden biodiversity in tundra ecosystems and its relationship with long-term shifts in species richness, composition and plant height. We found that across 17 sites representing 39 vegetation types, the magnitude of hidden diversity varied up to 10-fold from four to 80 species, but this variation was poorly explained by latitude, altitude, or topography features. Average plant height was higher outside plots than inside, suggesting that predictions of tundra change based solely on small-scale observations might be underestimating the magnitude of future changes. Quantifying not just plot-scale biodiversity changes but also their landscape context and potential future colonizing species could be the missing link that allows us to scale up observations from just a few square meters to predictions across the tundra biome.

Title: What 'sets the clock' on above and below-ground tundra phenology? A synthesis of phenocam and in-growth core data

Authors: Elise Gallois, Isla Myers-Smith, Colleen Iversen, Verity Salmon, Sarah Elmendorf, Anne Bjorkman, Courtney Collins, Gesche Blume-Werry, Ruby An, Lisa Pilkinton, Madeleine Anderson, Christian Rixen, Inge Althuizen, Michelle Mack, Craig See, Laura Turner

Abstract: Arctic and alpine tundra ecosystems are experiencing accelerated warming compared to the global average, causing significant changes in plant productivity and the timing of life histories of tundra species, with cascading effects on trophic interactions and carbon cycling. However, the sparsity of long-term and spatially-varied observations hinders our understanding of how these dynamics may continue to change in a warming tundra biome. I will discuss synthesis results representing both above- and below-ground phenology observations across spatial and temporal scales to resolve key questions about how heterogeneous tundra landscapes may respond to future warming and ecosystem change.

First, I used geographically varied time-lapse camera imagery to analyse tundra phenology variations across microclimates and snowmelt gradients. I found that growing seasons were consistently longer at warmer, lower-latitude sites with 11 extra days for each additional 1°C

in mean summer temperature. However, growing season lengths did not significantly vary across warmer or colder summers and earlier or later snowmelt timing despite warmer spring temperatures consistently advancing spring green-up.

Second, I tested phenology variation across microcliamtes. Green-up, mid-season, and early senescence phenophases generally occurred earlier in warmer microclimates and tracked snowmelt, although initial community-scale bud-burst and full community senescence was not related to microclimate. Across sites, I found that green-up occurred more slowly when snowmelt was earlier and faster when snowmelt was later.

Third, I combined above- and below-ground plant phenology metrics to compare the relative timings and magnitudes of leaf and root growth and senescence across microclimates and plant communities at five sites across the tundra biome. I observed asynchronous growth between above-ground and below-ground plant tissue, with the below-ground season extending up to 74% beyond the onset of above-ground leaf senescence. Community type, rather than microclimate, was a key factor controlling the timing, productivity and growth rates of roots, with graminoid roots exhibiting a distinct growth ‘pulse’ later into the growing season than shrub roots.

If growing season length remains relatively stable across space and time and is not extending into the longer snow-free autumn season, this indicates that tundra productivity and carbon sink capacity may not necessarily increase much as the climate warms. These results suggest the potential for greater below-ground carbon storage as roots grow into thawed soils that remain unfrozen for longer as the climate warms. Taken together, my findings indicate that long-term vegetation change, an indirect response to climate warming, is more likely than climate warming alone to impact below-ground productivity and carbon cycling in the tundra biome.

Title: Does earlier = more? Exploring the links between phenology and productivity

Authors: Sarah C. Elmendorf & Robert D. Hollister

A common assumption is that phenological changes which accompany climate warming lead to increases in productivity, as plants take advantage of an extended growing season. Here we explore the relationship between the timing and magnitude of plant growth in Atqasuk, AK. Increases in plant productivity are apparent in both the satellite record and plot-based monitoring at this site. However, weekly leaf-length measurements demonstrate a decoupling of the long-term productivity trends from phenological patterns. Maximum leaf length is increasing over time and in warming experiments, whereas phenology shows high interannnual variability and no consistent temporal trends. Additionally, those species with the greatest growth responses to experimental warming are not those that show the largest phenological responses. These results highlight the complex interplay between snowmelt timing, summer temperature and the phenology and growth of tundra plants.

Title: Can bryophyte groups increase functional resolution in tundra ecosystems?

Authors: S. Lett, I.S. Jónsdóttir, A. Becker-Scarpitta, C.T. Christiansen, H. During, F. Ekelund, G.H.R. Henry, S. Lang, A. Michelsen, K. Rousk, J. Alatalo, K.R. Betway, S. Busca, T. Callaghan, M. Carbognani, E.J. Cooper, J.H.C. Cornelissen, E. Dorrepaal, D. Egelkraut, T.G. Elumeeva, S.V. Haugum, R.D. Hollister, A.K. Jägerbrand, F. Keuper, K. Klanderud, E. Lévesque, X. Liu, J. May, P. Michel, M.A. Mörsdorf, A. Petraglia, C. Rixen, B. Robroek, A.M. Rzepczynska, N. Soudzilovskaia, A. Tolvanen, V. Vandvik, I. Volkov, I. Volkova, K. van Zuijlen

The relative contribution of bryophytes to plant diversity, primary productivity, and ecosystem functioning increases towards colder climates. Because bryophyte species are difficult to identify, they are often lumped into one functional group and bryophyte function remains poorly resolved. We explored how higher resolution of bryophyte functional diversity can be encouraged and implemented in tundra ecological studies. Based on previous grouping systems, shoot morphology and colony organization, we proposed twelve easily distinguishable bryophyte functional groups (BFGs). We tested how BFGs differ in a key bryophyte trait, water holding capacity. We found an improved separation of BFG means compared to previous grouping systems regarding water holding capacity. This suggests that our BFGs represent relevant variation in the functional roles of bryophytes in tundra ecosystems. I will also discuss how we may improve monitoring of bryophyte community changes in tundra study sites.

Title: Plant diversity dynamics over space and time in a warming Arctic.

Authors: Mariana García Criado, et al.

The Arctic is warming four times faster than the global average, and plant communities are responding through shifts in species abundance, composition and distribution. However, the direction and magnitude of local plant diversity changes have not been determined thus far at a pan-Arctic scale. Using a compilation of 42,234 records of 490 vascular plant species from 2,174 plots at 45 study areas across the Arctic, we quantified temporal changes in species richness and composition from repeat surveys that occurred at different intervals between 1981 – 2022, and identified the geographic, climatic and biotic drivers behind these changes. Despite plant species richness being greater at lower latitudes and warmer sites, pan-Arctic species richness did not change directionally over time at the plot level. However, 99% of the plots experienced changes in species abundance, with 66% of plots gaining and/or losing species. Species richness increased most where temperatures had warmed most over time. Shrub expansion was associated with greater species losses and decreasing richness. Yet, Arctic plant communities did not become more similar to each other over time, suggesting that no biotic homogenisation has occurred thus far. Overall, we found that Arctic plots changed in richness and composition in all possible directions, yet climate and biotic interactions emerged as the main drivers of directional change. Our findings show a variety of diversity trends, which could be precursors of future changes in ecosystem function, wildlife habitats and livelihoods for Arctic people.

Title: Plant abundance drives β-diversity changes in a warmer Arctic

Authors: Robert G. Björk, Ruud Scharn, Anne D. Bjorkman, Tinghai Ou, Mats Töpel, Alexandre Antonelli, R. Henrik Nilsson and the ITEX consortium.

Warming of the Arctic is now occurring four times faster than the global average, which is changing vegetation patterns and threatening biodiversity. To date, all biome-wide synthesis on vegetation changes in the Arctic has focused on α(alpha)-diversity, while there is a great need for an improved understanding of the spatial variation of plant β(beta)-diversity. By using several aspects of arctic plant diversity (taxonomic identity, abundance, functional and phylogenetic relations) together with a Pan-arctic warming experiment we found contrasting responses in α-diversity compared to β-diversity. For α-diversity, we found a warming sensitivity in the cold dry and moist communities, which for moist communities was driven by loss of functional important species. The cold dry communities were instead more sensitive to decreased evenness of species abundance, whereas wet communities did not show any α-diversity responses to warming. For β-diversity, changes in plant abundance was an important driver of increased β-diversity, where warming led to increased dissimilarity for warm wet communities and mid-warm moist communities. Interestingly, we also found that the temperature response window increased with increased abundance weight. Our findings reveal different diversity responses operating in the low Arctic compared to the high Arctic. Additionally, it highlights the sensitivity of β-dissimilarity metrics to climate warming and promotes their use when analyzing the impact of vascular plant diversity on ecosystem functions in the tundra biome.

Title: Warming differentially affects vegetative and reproductive phenology and drives reproductive fitness in a changing Arctic

Authors: Courtney Collins et al.

Here we present the results of two ITEX syntheses on tundra plant phenology responses to warming. First a global synthesis on the impacts of experimental warming on plant phenology across the growing season and second a cross-Canadian synthesis on the downstream effects of advanced flowering time on reproductive fitness. Globally, our results challenge the expectation that all phenophases will advance in unison to warming. Instead, we find that experimental warming caused: (1) larger phenological shifts in reproductive versus vegetative phenophases and (2) advanced reproductive phenophases and green up but delayed leaf senescence which translated to a lengthening of the growing season by approximately 3%. Across Canada, we find that warming, both experimental and ambient, drives earlier flowering across species, which leads to higher numbers of flowers and fruits produced, reflecting directional phenotypic selection for earlier flowering phenology. Furthermore, this indirect effect of climate warming mediated through phenology was generally ~2-3x stronger than the direct effect of climate on reproductive fitness. Under future climate predictions, individual plants showed a ~2 to 4.5-fold increase in their reproductive fitness (flower counts) with advanced flowering phenology.

Title: Genome-wide changes induced by long term warming in tundra plants

Authors: Cassandra Elphinstone, Marco Todesco, Marie Sandler, Mats P. Björkman, Petr Macek, Jeremy L. May, Greg H.R. Henry, Loren H. Rieseberg

The Arctic tundra is warming four times faster than the global average. Will tundra plants adapt through natural selection on genetic variants or through more rapid, but less stable, epigenetic adaptation? We use long-term experimentally warmed plots at International Tundra Experiment sites across the Arctic to study short-term responses to warming in Mountain Avens (Dryas octopetala and D. integrifolia). We identified differences in DNA methylation and gene expression that are consistently associated with the open top warming chambers in 102 plants across four circumpolar sites (Sweden, Svalbard, Alaska, Northern Canada). Some individuals were sequenced at two phenology stages (mature flower and senescence). The offspring of these plants were then grown in controlled environments and characterized for DNA methylation and gene expression. Overall, we found 385 differentially methylated regions (DMRs), ~10% of which appear linked to nearby differentially expressed genes. In addition, plants in the experimental warming plots have significantly higher than average expression of defense-related genes. Lastly, ~20% of the DMRs were inherited in the following generation and ~80% of the warming DMRs are independent of phenology stage. These results have implications for the potential heritability, importance of defense to pathogens and role of epigenetics in tundra plants responses to warming temperatures.

Title: Ecosystem respiration responses to warming across the tundra: magnitude, environmental drivers, and future needs

Authors: Sybryn L. Maes, J. Dietrich, G. Midolo, S. Schwieger, M. Kummu, V. Vandvik, R. Aerts, I.H.J. Althuizen, C. Biasi, R.G.B. Björk, H. Böhner, M. Carbognani, G. Chiari, C.T. Christiansen, K.E. Clemmensen, E.J. Cooper, J.H.C. Cornelissen, B. Elberling, P. Faubert, N. Fetcher, T.G.W. Forte, J. Gaudard, K. Gavazov, Z.-H. Guan, J. Guðmundsson, R. Gya, S. Hallin, B.B. Hansen, S.V. Haugum, J.-S. He, C. Hicks Pries, M.J. Hovenden, M. Jalava, I.S. Jónsdóttir, J. Juhanson, J.Y. Jung, E. Kaarlejärvi, M.J. Kwon, R.E. Lamprecht, M. Le Moullec, H. Lee, M.E. Marushchak, A. Michelsen, T.M. Munir, E. Myrsky, C.S. Nielsen, M. Nyberg, J. Olofsson, H. Óskarsson, T.C. Parker, E.P. Pedersen, M. Petit Bon, A. Petraglia, K. Raundrup, N.M.R. Ravn, R. Rinnan, H. Rodenhizer, I. Ryde, N.M. Schmidt, E.A.G. Schuur, S. Sjogersten, S. Stark, M. Strack, J. Tang, A, Tolvanen, J.P. Töpper, M.K. Väisänen, R.S. van Logtestijn, C. Voigt, J. Walz, J.T. Weedon, Y. Yang, H. Ylänne, M.P. Björkman, J.M. Sarneel, Ellen Dorrepaal

Tundra ecosystems contain large stocks of organic carbon in plants and soil, which are vulnerable to climate warming. We analysed how strongly ecosystem respiration (i.e from

plants and soil microbes together) responds to passive experimental warming across the alpine and arctic tundra, how long the respiration response lasts, and which site-specific or warming-induced variation in biotic or abiotic environmental conditions explain the variation in the magnitude of the respiration response.

Across 136 datasets from 56 open-top-chamber *in-situ* warming experiments (i.e. open-top chambers) at 28 arctic and alpine tundra sites, we found a mean 30% increase in growing-season ecosystem respiration in response to <1 up to 25 years of warming. Our analyses highlighted that variation in the respiration response to warming was primarily driven by variation in warming-induced changes in (mineral) soil total nitrogen concentration and pH, and by spatial variation between sites in (mineral) soil total nitrogen concentration and carbon:nitrogen ratio. While variation or changes in the vegetation or microbial community composition or abundance played no significant roles in explaining the total variation in ecosystem respiration response across the whole dataset, a subset (N=9) on respiration partitioning data suggested that both plant-related as well as heterotrophic respiration were stimulated by the warming treatments.

The following data collection efforts are needed to close crucial gaps in our understanding of trajectories and long-term effects of climate warming on the carbon stocks in these sensitive ecosystems: (a) respiration data from long-term (>15 years) warming experiments, (b) respiration partitioning data, and (c) measurements of a greater variety of environmental data (e.g. soil chemistry, microbial community) across more experiments.

Title: Tundra vegetation change does not alter community litter decomposability

Authors: Katrín Björnsdóttir et al.

The impacts of warming on the tundra carbon balance is a critical unknown for predicting global climate change feedbacks. Plant litter represents the primary carbon input to tundra soils, yet it is unclear whether vegetation changes are altering decomposability. We combined datasets of 1) a multi-site litter decomposition experiment, 2) the largest database of tundra plant traits, and 3) three decades of vegetation monitoring from ITEX sites to quantify the change in decomposability of tundra plant communities over time. We found that litter decomposability increases with temperature and soil moisture over biogeographic gradients, but we found no significant change in decomposability over three decades of vegetation monitoring. Our results suggest that tundra vegetation change has so far had no net impact on litter decomposability, but that in the long-term vegetation change could produce a positive feedback to climate change.

Title: Arctic soil labile nitrogen changes: A meta-analysis on the responses of soil labile nitrogen pools to experimental warming and snow addition

Authors: You Jin Kim, Junge Hyun, Ji Young Jung

Arctic terrestrial ecosystems are undergoing rapid climate change, leading to shifts in soil nitrogen (N) dynamics. This study synthesizes findings from 245 observations across 49 studies to understand the impacts of climate manipulation experiments on soil labile N pools in Arctic ecosystems, focusing on experimental warming and snow addition. A decision tree analysis was subsequently conducted to examine their responses varied with different settings of climates, soil conditions, vegetation types and experimental methodologies. Experimental warming showed no significant effects on the overall responses of soil labile N pools, but specific environmental and experimental factors led to significant changes. Their key determinants under warming were identified as follows: experimental duration and mean annual summer temperature for dissolved organic nitrogen (DON); annual precipitation, soil moisture, and sampling timing for ammonium (NH_4^+); and soil layer for nitrate (NO_3^-). Meanwhile, snow addition significantly affected on the overall responses of soil labile N pools, with their changes varying by the following factors: sampling timing and vegetation type for DON; experimental duration and soil moisture for NH_4^+; and soil pH for NO_3^-. In conclusion, this meta-analysis consolidates broad datasets, offering a comprehensive overview of soil labile N responses to experimental warming and snow addition. Moreover, the decision tree analysis identifies key determinants of soil labile N changes under these climate manipulations. Our findings provide comprehensive insights into soil labile N pools and their responses to climate manipulation experiments, highlighting the need for detailed analysis to understand the intricacy of Arctic N dynamics under climate change.

Title: Arctic Methane Dynamics under Warming: Evidence of Decreased Fluxes in Non-Permafrost Areas

Authors: Jan Dietrich, Ellen Dorrepaal, Sybryn Maes, Sarah Schwieger, Judith Sarneel, Joel White, Mats P. Björkman and Tundra Flux database contributors

Arctic ecosystems are on the frontier of climate change, with their vulnerability underscored by their significant impact on global carbon dynamics. Methane is suggested to play an important role in Arctic climate carbon-cycle feedback due to its high potency as a GHG, and potential release following permafrost thaw. Here, we analyse how Arctic methane dynamics are altered by increasing air temperatures through passive warming treatments utilizing a dataset from 38 study sites from the ITEX-network. We found that an increase of 1-3°C air temperature leads to varying responses of the net methane flux between sites underlain by permafrost but show a decrease in net methane flux at non-permafrost sites. This change in net methane flux can be driven by either a decrease in methane production/emission or an increase of methane oxidation/uptake or the combination of both. Both processes are mediated by microbial groups with specific abiotic habitat conditions. While methane production typically occurs in anerobic environments, methane consumption is facilitated by aerobic conditions. Consequently, variations in soil conditions show differential influences on these microbial communities, shaping the observed methane flux responses. Therefore, the divergence in response not only highlights the important influence of site-specific characteristics, but also the different responses of methane production and methane oxidation when summarizing Arctic methane dynamics. In addition, the duration of the experiment plays a pivotal role, with longer warming treatments significantly reducing the net methane flux. However, the long-term effects of warming on below ground ecosystem characteristics are yet to be fully understood. Our study provides new insights in the response of arctic ecosystems to warmer temperatures and highlights the importance differential changes of methane dynamics due to specific site conditions.

Title: Intraspecific trait variation in alpine plants relates to their elevational distribution

Authors: Christian Rixen, and the INTRATRAIT consortium

Cold-adapted plant species are under increasing pressure from novel competitors that are encroaching from lower elevations. Plant capacity to adjust to these pressures may be measurable as variation in trait values within a species. In particular, the strength and patterns of intraspecific trait variation along abiotic and biotic gradients can inform us whether and how species can adjust their anatomy and morphology to persist in a changing environment.

Posters

1. **Title: Ambient and experimental warming caused stronger changes in tundra plant communities in Iceland than grazing exclusion**

Author List: (Ingibjörg Svala Jónsdóttir), Jón Guðmundsson, Borgþór Magnússon, Járngerður Grétarsdóttir, Noémie Boulanger-Lapointe

Climate in Iceland has been warming on average by one degree per century since 1900. There is evidence of substantial 'greening' in Iceland (for 1982-2010), but trends were uneven across the country. Changes in greenness can only partly be attributed to climate, because over the last decades substantial reduction in livestock grazing and restoration measures occurred. In 1996, ITEX sites were installed in two different tundra habitats to disentangle the drivers of vegetation changes and to provide insights on the cause of the heterogeneity in response. The first site is in a moss heath (MH), dominated by Racomitrium lanuginosum with low diversity and abundance of palatable plant species and therefore not a favourable grazing habitat for livestock. The second site is a relatively diverse Betula nana dwarf-shrub heath (BH) in the highlands which has been degraded by centuries of heavy grazing. To evaluate the impact of grazing pressure, the second site also included a grazing exclusion treatment. In the MH changes were slow both in control plots and in response to experimental warming and small changes in vegetation cover and height occurred only in the last few years. The BH, however, responded quickly and strongly to the warming treatment with significant increase in the cover of Betula shrubs and a decrease of the dominating moss R. lanuginosum. The greatest change was found in community structure. Canopy height increased, especially in the OTCs where it was tenfold the increase in the ungrazed and grazed control plots, while moss layer depth and density responded differently to the treatments. Both variables decreased in the OTCs but increased when protected from grazing. We conclude that warming contributes to the greening in Icelandic tundra and most strongly where responsive shrubs are present. Grazing exclusion has minor effect on vegetation under ambient warming in the degraded highland tundra and then mainly through increased abundance of moss.

2. **Title: Increased biocrust cover and activity in the highlands of Iceland after five growing seasons of experimental warming**

Author List: Alejandro Salazar, Eyrún G. Gunnlaugsdóttir, Ian Klupar, Ruth-Phoebe T. Wandji, Ólafur Arnalds, Ólafur Andrésson, (Ingibjörg S. Jónsdóttir)

One of the most important questions of our time is how ecosystems will be transformed by climate change. Here, we used a multi-year field experiment to investigate the effects of climate warming on the cover and function of a subarctic ecosystem dominated by biocrust (biological soil crust)—a system that plays major ecological roles in a substantial part of the terrestrial surface. We used Open Top Chambers (OTCs) to simulate warming; standard surface and NDVI analyses to measure plant composition, cover and function; gas analyzers to monitor biocrust respiration; and the Tea Bag Index (TBI) approach to estimate decomposition and soil carbon stabilization rates. Contrary to our initial hypothesis of warming accelerating an ecological succession of plants growing on biocrust (i.e. "greening effect"), we observed a warming-induced decreased abundance of green plants (mosses and vascular plants), and an increase in the cover of visible biocrust—possibly caused by high temperature summer peaks that resemble heat waves. The functional responses of biocrust to warming, including increased respiration rates and a lower capacity to store labile carbon into recalcitrant forms, may suggest climate-driven depletion of soil nutrients. It remains to be studied how the effects of warming on biocrusts from high northern regions could interact with other drivers of ecosystem change, such as grazing; and if in the long-term global climate change will lead to a greening of the Icelandic highlands and similar ecosystems, for example via changes in the plant community. For the moment, our experiment points out towards a warming-induced biocrusting.

3. Title: The missing methane sink: Arctic methane consumption responses to future vegetation regimes

Author List: (Joel D. White), Christoph Keuschnig, Simone Lang, Alejandro Salazar Villegas, Ingibjörg Svala Jónsdóttir, Ólafur Sigmar Andrésson, Catherine Larose, Mats Björkman et al

The Arctic tundra is currently undergoing rapid changes with thawing permafrost and changing vegetation. One of the most pronounced effects among the vegetation is a shift towards taller plant communities and higher root biomass, which can lead to increased evapotranspiration and drier soils. This response has the potential to alter the below ground carbon cycle, especially the magnitude of methane fluxes. We observe that the current Arctic methane budget is strongly biased towards the carbon-rich wetlands , which act as methane emission hotspots, while less attention has been given to the carbon-poor and methane consuming mineral soils that cover 87% of the region. In-situ measurements of methane fluxes, especially consumption rates in experiments simulating future climate conditions are lacking and heavily biased towards two locations, leaving a gap in our understanding of climate feedback responses for the entire pan arctic region. Therefore, measurements from experiments simulating future arctic vegetation regime, i.e. the ITEX network, become vital to understanding spatial variability of methane fluxes, in particular methane consumption across the arctic. In this pan Arctic project, we will investigate the response of methane consumption to a future Arctic vegetation change, using both in-situ measurements at plot level as well as developing and utilizing the process-based dynamic vegetation-terrestrial ecosystem model: LPJ-guess to upscale our results to a regional level. We will use the long-term warming experiments in Sweden, Greenland, Svalbard, Iceland, Canada and Alaska where the vegetation has reached a state similar to 2050-2080 projections. Therefore, the need for long term manipulated plots, such as the ITEX plots found across the arctic are vital for our study. In this presentation we will introduce the project motivation, methods and initial results with a hope of attracting more collaborators with similar data.

4. Title: Three decades of environmental change studies at alpine Finse, Norway: responses across ecological scales

Author List: (Siri Lie Olsen), Ruben E. Roos, Johan Asplund, Tone Birkemoe, Aud H. Halbritter, Linn Vassvik, Kristel van Zuijlen, Kari Klanderud

Global environmental change is affecting ecosystems at all levels of organization, particularly in the Arctic and alpine. However, we lack knowledge of ecosystem responses to environmental change across ecological scales. As part of the International Tundra Experiment (ITEX), studies of environmental change have been carried out at alpine Finse, southern Norway, using different methods and different focal species, communities, and processes. In this study, we synthesize three decades of research on the ecological effects of environmental change at the Finse ITEX site, including 80 studies. Studies across environmental gradients showed that species distributions depended on microtopography and microclimate. However, a modest ambient climate warming (+0.36 °C per decade) resulted in minor species responses. Experimental warming had contrasting effects on abundance and traits of individual species and only modest effects at the community-level above and below ground. In contrast, nutrient addition experiments caused strong shifts in primary producer and arthropod communities. The experimental treatments and species responses also affected litter quality, decomposition, and soil nutrient contents. This within-site synthesis enables us to show how different environmental changes (experimental and ambient warming, nutrient addition, and environmental gradients) impact the alpine ecosystems across ecological scales, and how altered species interactions and traits at the community-level may translate into altered ecosystem processes. Finally, our work identifies lines of further research that will strengthen our understanding of the effect of environmental change on alpine ecosystem structure and functioning.

5. Title: Changes in soil organic matter characteristics under warming in Arctic tundra

Author List: (Ji Young Jung), You Jin Kim, Mats P. Björkman, Robert G. Björk, Min Sung Kim, Kyoung-Soon Jang, Sungjin Nam, Sujeong Jeong

Warming in the Arctic is four times faster than the global average, and this is projected to be intensified in near future. This accelerated Arctic warming is particularly critical because of the considerable amount of SOC storage along with its vulnerability. Lots of efforts have been made on investigating SOC contents and stocks, the quantitative ones, however, the studies on qualitative perspectives of SOC such as fractionation or its molecular composition are relatively rare. The distribution of differently-stabilized SOC fractions can provide valuable insights for SOC biodegradability and stability. Therefore, we investigated the distribution of SOC fractions through the size-density fractionation in the soils from two dry tundra ITEX sites, Cambridge Bay in Canada and Latnjajaure Field Station in northern Sweden. Mean soil temperature increased about 0.6-0.7°C via OTC in both sites. Despite the low increase in soil temperature under OTCs, NDVI was higher in OTC in the Canada site. The relative abundance for graminoid and evergreen shrub in OTC were higher than control in the Sweden site. SOM fractionation did not find any significant differences between control and warming plots in the Canada site, however, a labile fraction increased with warming in the Sweden site. Further, we measured the composition of DOM using FT-ICR mass spectrometry for Canada samples. There were no significant differences in DOM composition between control and warming in the organic layer. However, the HUP (Highly unsaturated and phenolic compounds) class was initially higher under warming in the mineral layer. Moreover, biological-derived compounds increased at the later stage of the growing season in the warming plot. Thus, we concluded that warming-stimulated plant growth had an impact on the labile fraction of SOC under long-term warming, and induced changes in the DOM molecular compositions in short-term simulation.

6. Title: Macro-environment strongly interacts with warming in a global analysis of decomposition

Author List: (Sarah Schwieger); Judith M. Sarneel; Ellen Dorrepaal; Rien Aerts; Evgenios Agathokleous; Juha Alatalo; Inge Althuizen; Katrín Björnsdóttir; Stef Bokhorst; Matteo Petit Bon; Michele Carbognani; Angelica Casanova-Katny; Casper T. Christiansen; Karin Clark; Rocío Alonso; Nina Filippova; Wang Genxu; Ibrahim A. Hassan; Annika Hofgaard; Robert D. Hollister; Ingibjörg Svala Jónsdóttir; Ellen Haakonsen Karr; Kari Klanderud; Qi Li; Jørn Olav Løkken; Anders Michelsen; Tariq Munir; Isla Myers-Smith; Alessandro Petraglia; Maria Strack; Satoshi Suzuki; Takayoshi Koike; Mariska te Beest; Haydn Thomas; Fernando Valiño; Vigdis Vandvik; Susanna Venn; Yan Yang; Thomas W. Crowther; Johan van den Hoogen; Johan Asplund; Elizabeth le Roux

Empirical studies worldwide show substantial variability in plant litter decomposition responses to warming, leaving the overall impact of climate change on this process uncertain. We conducted a meta-analysis of 109 experimental warming studies across seven continents, utilizing natural and standardized plant material, to assess the overarching effect of warming on decomposition and identify potential moderating factors. Warming influences decomposition differently across macro-environmental gradients of moisture and temperature. Negative warming effects on decomposition in warmer, low-moisture areas were counterbalanced by the positive, though not significant, warming effects in colder areas, resulting in an overall non-significant effect. We determine that at least 5.2 degrees of warming is required for a significant increase in decomposition. This is particularly relevant given the past decade's global warmth in higher latitudes, holding a significant proportion of terrestrial carbon. Low-quality plant litter was more sensitive to warming. Therefore, future vegetation changes toward low-quality, temperature-sensitive plants could increase carbon release and reduce the net supply of stored organic matter in the soil by increasing the decomposition of low-quality litter with warming. Our findings emphasize the connection between warming responses, macro-environment, and litter characteristics, refining predictions of climate change's consequences on key ecosystem processes and its contextual dependencies.

7. **Title: Plant sex expression, but not experimental warming, affects the pollination success of Silene acaulis**

Author List: (Kari Klanderud), Sara Linn Hofgaard Prince, Erik Aschehoug

This study investigates the impact of climate warming on the Arctic alpine cushion plant Silene acaulis. Cushion plants create unique micro-environments and are therefore crucial for these ecosystems. By comparing Silene acaulis across an elevation gradient and inside and outside OTCs at Finse, Norway, the study aims to examine how temperature affects flower sex expression, plant health (photosynthetic efficiency), and reproductive success. Due to extreme heating inside OTCs during warm periods, we have previously observed lower plant health inside OTCs. We collected data summer 2023 and will present the results at the conference.

8. **Title: Heating the heath: 23 years of experimental warming in an alpine biodiversity hotspot**

Author List: (Kari Klanderud), Gaute Eiterjord, Siri Lie Olsen

Climate warming will impact alpine biodiversity. One of the most diverse plant communities in Scandinavian mountains are Dryas heaths. We studied changes in a Dryas octopetala heath at Finse, SW Norway, after 23 years of experimental warming. Our results show significantly lower cover and richness of bryophytes and lichens with warming, as well as increased cover of litter and dead Dryas leaves. Vascular plant cover and richness were not affected. Species composition differed with and without warming, and warmed plots had taller vegetation and lower soil moisture. Lichen and bryophyte cover and richness declined with warming, likely due to taller vegetation intercepting light and producing litter, along with reduced soil moisture. As a result, the Dryas heath was impoverished and lost diversity. Our findings show the importance of including lichens and bryophytes when studying the effect of climate change on alpine plant communities.

9. **Title: Assessing terrestrial Lidar precision in an Arctic tundra setting for use in detecting fine-scale permafrost subsidence**

Author List: (Tabatha L. Fuson), Ryan P. Cody, Sergio A. Vargas, Stephen M. Escazarga, Robert D. Hollister, Steven F. Oberbauer, Craig E. Tweedie

Ground subsidence caused by thawing permafrost in the Arctic is a critical issue with regional and global implications. Because subsidence can occur at sub-centimeter scales, it is essential to develop high-quality surface elevation models capable of detecting small-scale change. Terrestrial Laser Scanning (TLS) technology has emerged as a viable method for high-resolution surface modeling and change detection analysis across various ecosystems. However, knowledge of its performance for modeling tundra features and detecting subsidence is limited. The few studies that have explored TLS performance in tundra environments, do not account for all factors affecting surface models, including variable sampling conditions. Additionally, previous studies focus on TLS accuracy while overlooking precision. In the context of assessing subsidence through repeat scans, instrument precision may offer another effective approach for gauging errors within and between surface models. This study investigates the precision of repeat TLS surface models collected under various environmental conditions and analyzes the spatial effects of complex geomorphology in precision performance. Additionally, this study compares TLS accuracy and precision and examines the potential of utilizing multiple repeated TLS point clouds for enhancing repeatability. Results from the study indicate that environmental conditions during data collection, along with landscape geomorphology, significantly affect TLS precision. Moreover, results indicate that TLS precision outperforms TLS accuracy across conditions and geomorphology, and model precision can be improved through increased repeat TLS scans. Insights from this research will guide future studies in maximizing model repeatability and error estimation for spatial analyses over time.

10. **Title: Intraspecific trait variation drives plant community responses to longterm experimental warming in a High Arctic shrub tundra ecosystem**

Author List: (Nicola Rammell), Greg Henry

In the tundra biome, rapid climate warming is driving shifts in plant community traits with implications for ecosystem function. However, functional responses to warming are not well understood, especially in High Arctic tundra ecosystems where changes to plant community composition occur slowly and functional trait variation may exist primarily within species. We hypothesised: (1) plant size increases with warming, since nutrient availability is temperature-limited in tundra ecosystems; (2) plant resource-acquisition strategies are more acquisitive with warming due to increased competition; and (3) these responses are driven by intraspecific trait variation (ITV) rather than species turnover in the High Arctic where species richness is low and niche breadths are broad. To test these hypotheses, we used a longterm field experiment (est. 1992) to increase growing season air temperature of warmed plots by 1-2 °C above control plots. In 2023, we measured treatment effects on plant community composition and on eight size- and resource-related traits of common species. We found a significant increase in plant community height and leaf area in warmed treatments; however, resource-related traits were less responsive. Further, the majority of total trait variation was due to ITV. This study suggests ITV may drive shifts in High Arctic plant community traits under longterm climate warming, but not necessarily towards more acquisitive plant strategies.

11. **Title: Vegetation change in the alpine tundra of the Changbai Mountains, Northeast China**

Author List: (Shengwei Zong), Christian Rixen

The alpine tundra of the Changbai Mountains stands as one of the two rare alpine tundra distributions in China, undergoing significant climate warming over recent decades. In response to these environmental shifts, alterations in vegetation composition and plant distribution within this alpine tundra have been observed. Specifically, we note the following trends: The treeline tree species, Betula ermanii, has gradually ascended to higher elevations within the alpine tundra. Lowland herbaceous plants, exemplified by Deyeuxia angustifolia (Komarov) Y. L. Chang, have encroached upon the alpine landscape, experiencing notable expansion in recent decades. The indigenous evergreen shrub, Rhododendron aureum, has been observed shifting towards higher elevations, likely in response to earlier snowmelt patterns. These significant changes in tundra vegetation serve as indicative "fingerprints" of climate change. Further monitoring and experimental efforts are necessary to elucidate the mechanisms underlying these shifts in response to climate change.

12. **Title: The continuation of ITEX carbon synthesis – The hunt for GPP and NEE data**

Author List: (Mats P. Björkman), Sybryn L. Maes, Jan Dietrich, Sarah Schwieger, Judith Sarneel, Ellen Dorrepaal

Arctic tundra ecosystems are changing rapidly. With temperatures in the Arctic rising four times faster than the global average (~0.4 °C increase per decade), and fundamental changes expected in precipitation, the Arctic vegetation is bound to change. However, soil microbial activity and the overall ecosystem function in terms of carbon sequestration and release, due to autotrophic and heterotrophic respiration, are also bound to change. The International Tundra Experiment (ITEX) network offers valuable insights into climatic effects on vegetation structure, dynamics, traits (e.g. height and leaf area), and phenology through standardized open-top chamber experiments. Furthermore, a recent effort, synthesizing ecosystem respiration (ER) response to warming experiments, has highlighted the importance of the ITEX network when it comes to the understanding of future carbon dynamics across tundra ecosystems. Here, we propose a new synthesis to investigate the whole carbon cycle, including gross primary production (GPP), net ecosystem exchange (NEE), and ER data. The Tundra Flux Database (www.arcticflux.com) will serve as the platform, incorporating existing data (56 communities, 28 sites, 400,000+ measurements) and welcoming new contributions on GPP and NEE data from open-top chamber experiments. We hypothesize that soil moisture with be a major driver for the carbon source-sink relationship, where the timing of snowmelt plays a key component of the growing season sequestration of carbon, both in terms of determining growing season length, but also as a determinator of soil moisture conditions due to the generally low precipitation pattern in Arctic during summer.

13. Title: Plant species and communities respond differently to human trampling disturbance

Author List: (Teagan Maclachlan), (Annabelle Damude), Philippa Stone, Natalie Krause, Nathalie Chardon, Cassandra Elphinstone, Courtney Collins, Nina Hewitt

Alpine ecosystems in BC are currently impacted by climate change and increasing recreational pressures. In particular, human trampling disturbance is intensifying in many areas, but the effects on alpine plant communities remain understudied. In order to address this research gap, we quantified the impacts of human trampling using presence-absence surveys of plant species and soil compaction measurements. These studies were conducted across 14 paired, trampled and non-trampled transects along hiking trails in three zones of the T’ak’t’ak’múy’in tl’a In’inyáxa7n region (Garibaldi Provincial Park), located in Southwest British Columbia. Overall, we found distinct differences in both species composition and soil compaction between trampled and non-trampled sites. Generally, forb species exhibited higher frequencies at non-trampled sites, with a few notable exceptions, such as Luetkea pectinata, which was slightly more frequent at trampled sites. Graminoid species generally had higher frequencies in trampled sites, indicating some resilience to trampling. Additionally, trampled soils were more compact, with a reduced cover of leaf litter, bryophytes, and cryptogamic crust compared to their untrampled counterparts. Our results align with those of similar studies and suggest that graminoid species are more resilient to trampling than non-graminoid species, offering important implications for recreational trail management.

14. Title: Spatiotemporal variability in plant community phenology revealed from decadal phenocam time series on the north slope of Alaska

Author List: (Sergio Vargas Zesati), Katherine Young, Victoria Villagomez, Mariana Mora, Gesuri Ramriez, Geovany Ramirez, Daniel Cruz, Tabatha L. Fuson; Jeremy May, Sarah Elmondorf, Nathan Healey, Robert D. Hollister; Steven F. Oberbauer; Craig E. Tweedie

Climate change is pronounced at high northern latitudes where the ensuing impacts on ecosystems caused by climate change has become a well-recognized research priority. Plant phenology is sensitive to climate variability and has the potential to elucidate climate-ecosystem coupling over multiple spatial and temporal scales. This study is a component of the US International Tundra Experiment - Arctic Observing Network (ITEX-AON) and assesses the effectiveness of hourly plot and landscape-level time lapse images acquired from phenocams to derive measures of phenological variability (e.g. slope of productivity, slope of senescence and end of season) for dominant vegetation communities near Utqiaġvik (formerly Barrow) and Atqasuk, Alaska. Ten growing seasons of environmental data (e.g. soil moisture, soil temperature, and active layer thaw depth) along with digital imagery were assessed by extracting time series of the green chromatic coordinate (GCC) index, derived from Red-Green-Blue digital numbers. Seasonal and inter-annual variability in GCC were greatest in low arctic and wet plant communities, while high arctic and dry plant communities 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 work will extend 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.

15. Title: Arctic tundra microtopographic variability: comparing remote sensing approaches for change detection analysis

Author List: (Sergio Vargas Zesati), Tabatha L. Fuson; Stephen M. Escarzaga; Ryan P. Cody; Christian G. Andresen; Mayra Melendez-Gonzalez; Robert D. Hollister; Steven F. Oberbauer; Craig E. Tweedie

Considering the important controls of small-scale microtopographic variability on ecosystem structure and function in arctic polygonal tundra ecosystems, it is crucial to enhance the precision of geospatial techniques and approaches for effectively tracking changes in microtopography over time. This study assesses the capacity of different remote sensing approaches to map and characterize microtopography and their associated changes in elevation. We assess the capacity of (a) terrestrial based laser scanning (TLS), (b) aerial-based laser scanning (ALS), (c) Unoccupied Aerial Vehicle (UAV) Structure-from-Motion (SfM) and (d) satellite-derived ArcticDEM to model microtopographic variability and change at the landscape scale in polygonized tundra near Utqiaġvik, Alaska. Point cloud densities were greatest for TLS and UAV approaches (~300 points/ m2), followed by ALS (~15 points/ m2). Final mean DEM RMSE values for UAV-SfM and TLS yielded an accuracy of ± 0.4 cm and ± 1.99 cm respectively, with a 95% confidence. DEM elevations acquired by the TLS and UAV-SfM approaches were highly correlated with the in-situ reference elevations, while little-to-no agreement resulted from the ALS approach and the ArcticDEM product. Between 2018 and 2022, we observed a strong surface lowering response using UAV and TLS approaches, which had a mean elevation decrease of -1.33 cm/yr. (troughs), and -0.85 cm/yr. (high-centered polygons) respectively. This study demonstrates the suitability of UAV-SfM and TLS for enhancing the acquisition and mapping of microtopographic features in tundra ecosystems. In addition, the fusion of data across approaches (e.g., UAV-SfM & TLS) can enhance capacities to characterize microtopographic gradients, change detection and spatiotemporal coverage. This research serves as a valuable technical foundation for ongoing and planned observing of Arctic landscapes.

16. Title: Examining Tundra Greening from Ground-based to Satellite Observations

Author List: (Sergio Vargas Z.), Karl F. Huemmrich, Craig Tweedie, Petya P.K. Campbell, Robert Hollister, Elizabeth Middleton

Multiple studies have shown positive multiyear trends in satellite measured Normalized Difference Vegetation Index (NDVI) in tundra ecosystems. These positive trends are often referred to as "greening." However, the ecological meaning of these trends is not currently clear. Ongoing ground data collections of tundra spectral reflectance that begun in 2010 near Utqiaġvik (Barrow) and Atqasuk, on the Alaskan North Slope, provide a unique opportunity to link ground measurements to moderate-resolution satellite observations. These observations illuminate how surface characteristics relate to arctic greening inferred from satellite data. We examine trends in NDVI from plot level to MODIS pixel scales to evaluate year to year change along with multi-year trends. Results show how vegetation cover types affect the potential for multiyear NDVI change as well as the rate of springtime green-up, showing how land cover characteristics can affect spatial patterns of phenology and multiyear greening across the tundra. For these sites the greening trend is mostly driven by an increase in graminoid coverage, and NDVI successfully tracks the change in green vegetation cover.

17. Title: Effects of subalpine species on community composition of alpine ecosystems. A transplant experiment

Author List: (Mikel Moriana Armendariz), Siri Lie Olsen, Kari Kandlerud, Joachim Paul Töpper, Ragnhild Gya, Vigdis Vandvik

Temperatures are rising globally due to climate change, and this is affecting especially alpine ecosystems, for instance through the upward migration of lowland species into mountain areas. To experimentally assess the effect of lowland species on alpine vegetation in a warming climate, six lowland species were transplanted into four alpine sites, and warming was simulated using OTCs. Three of the introduced species had similar functional traits to the plants currently growing at the sites (extant traits, E species), while the other three had new traits which made them better competitors (novel traits, N species). N species are better competitors than E species and the local flora, and we expect them to dominate the vegetation as time passes. This will lead to a lower cover of the native species, as well as to a reduced species richness close to the transplant. We expect this effect to be more profound within the OTCs, as the lowland species are better adapted to the warmer environment.

18. Title: The role of intraspecific trait variability in Arctic plant productivity

Author List: (Xiaoyi Wang), Mats Björkman, Anne D. Bjorkman

Climate warming is changing plant community and ecosystem functions in the Arctic. Intraspecific trait variability (ITV) could enable plants to respond rapidly to climate change while also contributing to trait variation (community-weighted means: CWM, and functional diversity: FD). However, the importance of ITV in determining trait responses to warming and in modulating warming effects on ecosystem functions, such as plant productivity, remains unknown. Taking advantage of a long-term passive warming experiment at Latnjajaure, Sweden, we measured both plant functional traits for all vascular species and plot-level NDVI as an estimate of productivity in five community types. We disentangled the relative contribution of ITV and species composition to changes in community functional composition and functional diversity by using a variance partitioning method. We found warming did not uniformly influence plant productivity across all community types, but deceased productivity in the dry meadow. Responses of community functional composition and functional diversity to warming were modest, with a significant increase in the wet meadow. Community-level height, leaf area and specific leaf area (SLA), as well as FD of height and SLA, increased under warming in the wet meadow. Community-level height in the mesic meadow and in the dry heath and leaf dry matter content (LDMC) also increased under warming. The variation in CWM and FD caused by warming was primarily captured by ITV – not turnover in composition – while the variation in CWM and FD between different community types was primarily due to differences in composition. ITV substantially improved the proportion of the explained variation in NDVI in the dry meadow. Our study suggests that warming has a slight effect on community functional composition and functional diversity, and ITV helps explain the change in the productivity caused by warming in an Arctic ecosystem.

19. Title: No problems only opportunities: Cape Bounty vegetation cover changes with snow and warming treatments

Author List: (Zoe Panchen), Sean Arruda, Neal Scott

ITEX plots were established at Cape Bounty, Melville Island, Nunavut, Canada in 2008. A full factorial design for snow and warming treatment was set up with 8 snow fences and four plots per snow fence. Plot treatments per snow fence were thus: (i) Snow-warming, (ii) Snow-ambient temperature, (iii) Ambient snow-warming and (iv) Ambient snow-ambient temperature. However, the two plots intended to be ambient snow plots are too close to the snow fence and receive snow amounts more than ambient snow but less than the snow treatment plots. Additional plots were subsequently added well away from the snow fences as true ambient snow-warming and ambient snow-ambient temperature plots. Thus, creating a potential opportunity to study three snow treatment levels. In addition, the north-south snow fences are no longer at right angles to the north-westerly prevailing wind resulting in the two plots on the northern side behind the fences receiving less snow than the southern side plots. Vegetation cover surveys were conducted in 2009, 2016 and 2023 using the ITEX pointframe technique. Here I present preliminary results from these surveys and seek input and suggestions on harnessing the opportunities presented by the multiple snow levels. In general, vegetation cover increased between 2009 and 2016, particularly for Salix arctica which aligns with findings at other sites such as Alexandra Fiord. By 2023, bryophytes were most abundant in the true ambient snow-ambient temperature plots, lichens were least abundant in the two levels of snow-warming plots while litter and woody plants were most abundant in these same snow-warming plots. These results suggest that willow does really well with warmer temperatures and deeper winter snow and lichens are possibly being out competed by the willow.

20. Title: A decade of climate change research in the Yukon-Kuskokwim Delta, Western Alaska

Author List: (Karen H. Beard), Katharine C. Kelsey, Matteo Petit Bon, Tyler Williams, A. Joshua Leffler

We have conducted three research projects in the Yukon-Kuskokwim National Wildlife Refuge over the past decade. These projects examine how different factors of change play a role (alone and in combination) in altering ecosystem properties and processes in these high-latitude regions. The first project was focused on how changing the timing of the growing season and migratory goose arrival influences plant growth, carbon and nitrogen storage, and greenhouse gas exchange. This project, completed in 2019, determined that both a later start to the growing season and later goose arrival increased above- and belowground vegetation biomass and the carbon sink strength of the ecosystem. The second project is motivated by how increased flooding through sea-level rise and increased storm surges will impact these ecosystems in the coming decades, and more specifically on how increased flooding and warming, in light of changing goose herbivory patterns might influence communities from lowland wetlands to upland tundra. This project has two main experiments, one larger-scale experiment with flooding and warming treatments in two plant communities, and a mesocosm experiment with flooding, warming, and herbivory treatments in three plant communities. Thus far, the results show that flooding and warming increase graminoid abundance, and that flooding decreases soil respiration while warming increases it. The third project focuses on the impacts of Typhoon Merbok, a 50-year flooding event. We found that soils on the flooded side of debris lines were twice as saline, had higher pH and somewhat higher soil respiration than soils that were not flooded. We are still analyzing data from these latter two projects focused on how these disturbances influence plant communities, phenology, species traits, and gas exchange. We hope results provide an integrative view of how these ecosystems respond to the combined forces of different, yet interconnected, environmental change drivers.

21. Title: Influence of experimental warming and wetting on methane and carbon dioxide fluxes in an Arctic tundra landscape

Author List: (Minna Rolfson Bergenhorn), Joel White, Abbey Serrone, Mats P. Björkman

Increases in both air temperature and precipitation in the Arctic are two consequences of climate change, both of which alter ecosystem functions including vegetation composition, soil temperature, soil moisture and the carbon (C) cycle. Increased soil temperature can accelerate microbial decomposition of soil organic matter (SOM) and cause permafrost to thaw, which results in more SOM available for further decomposition. These changes alter the soil-atmosphere exchange of carbon dioxide (CO2), through plant and root respiration and photosynthesis, as well as the production and consumption of methane (CH4). The Arctic consists of a diverse mosaic of different soil and vegetation types with varying C source-sink balances and it is not yet fully understood how increases in air temperature and precipitation will reshape these processes. This project aimed to further understand how increased air temperature and precipitation alter the soil biogeochemistry and the ecosystem fluxes of CO2 and CH4 in both a dry and wet Arctic ecosystem. The study site is Latnjajaure Field Station, Abisko, northern Sweden. At the site, plots of 1 m2 in a factorial design were established at two contrasting plant communities in 2023, Dry Meadow and Tussock Tundra. Each community included three replicates (n = 3) of a set of four treatment types, a) Control, b) warming, c) increased precipitation, and d) warming + increased precipitation. The increase in precipitation caused an increase in soil water content, whilst warming had no effect on soil temperature, although higher soil temperatures decreased soil water content. The different treatments had a significant effect at the Tussock Tundra, where additional precipitation as well as warming stimulated emissions of CH4, while the combination of warming and wetting had little to no effect. The CH4 flux of Dry Meadow remained relatively unchanged, although the added precipitation occasionally turned a net uptake to net emissions.

22. Title: Warming and permafrost degradation stimulates above and belowground processes to affect greenhouse gas exchange

Author List: (Hanna Lee), Inge Althuizen, Casper Tai Christiansen, Ruben Van Daele, Jeongeun Yun, Peter Dörsch, Hojeong Kang, Anders Michelsen, David Risk, Martijn Vandegehuchte, Sebastian Westermann

Permafrost degradation is expected to release large amounts of greenhouse gasses to the atmosphere, creating positive feedback to climate warming. The current understanding supports that warming, permafrost thawing, and land surface degradation will in combination lead to increased greenhouse gas emissions. But over time, natural succession may occur leading to decreased methane release and increased carbon uptake by growth in vegetation. We investigated how warming, permafrost degradation, and subsequent natural succession affect above and belowground processes to alter CO_2 and CH_4 exchange in a degrading permafrost peat plateau in northern Norway. Permafrost degradation shifted vegetation composition dominated by evergreen shrubs (intact permafrost) to increased presence of deciduous shrub (thaw slumps), towards sedges and cotton-grass dominated vegetation (thaw ponds). This transition corresponds to a shift in functional traits from conservative to resource acquisitive. Warming primarily led to an increase in size related traits. In the investigation of belowground processes, intact permafrost hosted higher abundances of all nematode guilds and warming negatively affected bacterivorous and omnivorous nematodes. In addition, the net CH_4 production ratio from metatranscriptomic analysis based on mRNA increased along the permafrost thaw gradient. Permafrost thaw accelerated CO_2 release greatly with degradation of permafrost. The vegetation shift enhances CO_2 uptake but leads to high CH_4 emissions. During the growing season, peat plateau was a small sink of atmospheric CH_4, whereas permafrost thaw slumping and pond formation increased CH_4 release dramatically. Furthermore, CH_4 release continues to increase even in natural succession likely due to aerenchyma transport of CH_4 from deeper soil. Warming generally enhanced ecosystem carbon exchange of CO_2 and CH_4, but to a different degree along the permafrost gradient.

23. Title: Timing of the end of plant growth season is influenced by snowmelt and soil moisture on Svalbard

Author List: (Elisabeth J. Cooper), Andreas Jørgensen, Philipp Semenchuk, Lennart Nilsen, Stein Rune Karlsen

Arctic regions are undergoing rapid climate change with warmer summers and winters and increasing proportion of the precipitation as rain. Advancing spring snowmelt is leading to an earlier spring green-up. Yet there is limited knowledge regarding drivers of end-of-season (EOS) phenology, even though EOS has important implications for both ecological processes and global climate. Autumnal leaf senescence (marking EOS) was monitored in the field for common plant communities over an eight-week period at a high-Arctic site in Svalbard (78°10'N, 16°04'E) in July – September 2023. Snowmelt date was recorded as well as soil moisture and temperature. Our data shows that senescence timing differs between common plant communities. Furthermore, heterogeneity in senescence timing is influenced by spring snowmelt date and soil moisture. Earlier spring snowmelt can be expected to advance end-of-season timing. This effect may be augmented by wetter summers which are expected to delay senescence. Future work will investigate inter-annual differences in senescence timing related to climate.

24. Title: Using seasonal NDVI to predict plant cover in tundra ecosystems

Author List: (Taylor Doorn), Jeremy May, Sergio Vargas, Robert Hollister

Vegetation changes occurring in the Arctic is of interest globally. In this research, plant cover data is paired with Normalized Difference Vegetation Index (NDVI) to determine whether or not we can use seasonal changes in plot level NDVI to estimate the cover of different plant growth forms. The research was conducted at the ITEX sites near Utqiaġvik and Atqasuk, Alaska. Each location has a dry site and a wet site that was established in the mid 1990's. Plant cover for each plot was assessed using the point intercept method during the 2022 field season. NDVI was collected at the four sites 2-3 times each week using a handheld Greenseeker. The dates of phenological development were used to predict which growth form was the most likely to have the strongest influence on plot level NDVI in a given time period. We hypothesized that the NDVI of the pre-green-up period of the growing season would be influenced the most by evergreen species, deciduous shrubs would influence NDVI the most from green up until the start of July, at which point the graminoids have the largest impact on for the remaining season. Linear regressions were performed between each growth form cover value and the change in NDVI during the respective time periods. During the pre-green-up period, evergreen shrubs, and bryophytes were correlated with NDVI in both locations. Deciduous shrubs were stronger correlated with NDVI at Utqiaġvik; however, the relationship was significant at both locations during the green-up period. Graminoids were significantly correlated with NDVI at both locations in the time period after deciduous shrubs; however, a stronger relationship was found at Atqasuk. The results of this research will be used in work to see how well the method can predict annual vegetation changes across the landscape.

25. Title: Documenting mycorrhizal infection of plant species in Atqasuk, Alaska

Author List: (Jenna Boelkins) and Robert Hollister

Mycorrhizal networks are integral to nutrient transport in nearly every terrestrial ecosystem and the warming climate may heavily impact their role, diversity, and abundance. Baseline studies of mycorrhizal abundance are needed in the Arctic because the region is experiencing rapid climate warming. Arctic plants tend to be nutrient-limited and have low mycorrhizal specificity and concentrated root systems leading to high mycorrhizal activity. Arbuscular mycorrhizal, ectomycorrhizal, and other types of fungi have been noted in several species of Salix and Betula in various Arctic territories, however they have yet to be studied at Atqasuk, Alaska. This study assesses the current presence and abundance of various fungal types in the roots of Betula nana, Salix pulchra, Salix polaris, and Salix phelbophylla. These species were chosen because they are abundant and have a high likelihood of arbuscular mycorrhizal (AM) and ectomycorrhizal (EM) fungi presence due to their woody structure. Roots of these species were collected from various ecological community types and shipped to Allendale, Michigan where they were cut, cleared, and stained for analysis under a dissecting scope. Percent infection of each type of mycorrhizae was determined using a grid line method. The end product of this investigation is a baseline dataset that will be submitted to the TRY Plant Trait Database.

26. Title: Phenology and reproductive effort in Arctic tundra plant species exposed to passive warming

Author List: (Cole G. Brachmann), Aurora Patchett, Ruud Scharn, Ulf Molau, Anne D. Bjorkman, Robert G. Björk, and Mats P. Björkman

Arctic plants can respond to warmer temperatures due to climate change by shifting the timing of critical life history events or adjusting the effort put into reproduction. Examining long-term datasets on the timing of key phenophases, such as those related to reproduction, can help elucidate species-specific phenological responses of Arctic plants to changing climate. We utilized snapshot phenology and flower count data collected between 2009 and 2023 at Latnjajaure Field Station in northern Sweden to estimate the effects of time, temperature, and passive warming on the timing, total and maximum abundance of six phenophases related to reproduction in eight common Arctic plants. Plant phenological responses varied strongly by species. The data indicated a potential shift to earlier timing in some evergreen shrub species. Generally, passive warming did not affect reproductive effort, but several species displayed higher total and maximum abundances of reproductive phenophases over time. The lack of consistency in species' responses to passive warming indicates potential complex changes in plant communities due to differences in both the timing of reproduction and reproductive effort.

27. Title: Flooding and warming alter summer land-atmosphere gas exchange in a high latitude coastal wetland

Author List: (Kathy C. Kelsey), A. Joshua Leffler, Matteo Petit Bon, Karen H. Beard

Climate change is expected to impact the ecosystems of Western Alaska through both warmer temperatures and increased frequency of coastal flooding due to sea level rise. To examine the consequences of warming and flooding on wetland greenhouse gas (CO2 and CH4) exchange, we conducted a two-year experiment in the Yukon-Kuskokwim (YK) Delta, where we increased summer temperature using open-topped chambers and applied two artificial flooding regimes mimicking those expected with high-tide flooding under rising sea level. These treatments represent the warming expected at our site by the 2030-2039 decade; a low-intensity flooding treatment simulating likely high tide conditions towards the end of the 2020's; and a the high-intensity flooding treatment simulating high tides expected in the early 2030's. Our results demonstrate both warming and more frequent flooding will impact the land-atmosphere exchange of greenhouse gases from the coastal YK Delta. Low-intensity flooding had the largest effect on greenhouse gas exchange, larger than warming or high-intensity flooding. However, the effects of low-intensity versus high-intensity flooding were opposed, with low-intensity flooding increasing summer-long emissions to the atmosphere, and high-intensity decreasing emissions. Warming reduced CO2 uptake similarly in all flooding treatments but interacted with flooding to produce the greatest CH4 emissions under a scenario of high intensity flooding and warming. The scenario that represents the most likely future in 10 years, warming and tidal flooding that inundates our study site multiple times per month all summer, increased mean summer season CO2 uptake by 21% (1.09 µmol CO2 m-2 s-1) but increased CH4 emissions by 138% (4.69 nmol CH4 m-2 s-1). The net warming effect of these opposing responses would decrease the warming potential of gas fluxes from this site by 19% during the summer months as the increased CH4 efflux will be overwhelmed by increased CO2 uptake.

28. Title: Occurrences and consequences of extreme weather events in the terrestrial Arctic

Author List: (Abbey Serrone), Maja Sundqvist, Henni Ylänne, Anne Bjorkman, Aurora Patchett, Didac Pascual Descarrega, Frans-Jan Parmentier, Geerte Fälthammar-de Jong, Heather Reese, Johan Ekroos, Johan Eckdahl, Katrín Björnsdóttir, Margareta Johansson, Paulina Wietrzyk-Pelka, Sirpa Rasmus, Stef Bokhorst, Tim Horstkotte, Maja Wadling, Malin Hannibal, Mats P. Björkman

Extreme weather events (EWE) in the Arctic are becoming more frequent and variable, exerting a growing impact on the ecosystem and its services. These events exacerbate the vulnerability of the Arctic ecosystem, already experiencing a fourfold warming rate. This systematic review delves into published literature concerning extreme weather events in the terrestrial Arctic and their repercussions on both the ecosystem and human communities. Our findings reveal a rising trend in research on these events over the past four decades, with a nearly equally-scaled growth across all topics. However, it remains unclear whether this surge in publications reflects the actual increase in the frequency of extreme weather events or merely a heightened interest in the subject matter. Moreover, the potential implications of a heightened frequency of such events on the Arctic ecosystem as a whole remain inadequately understood. This study underscores the need for further investigation to understand these complex dynamics and long-term impacts of EWE, especially to address the situation for communities whose livelihoods depend on Arctic ecosystem services. Embracing a more holistic and interdisciplinary research approach is crucial for effectively addressing the vital needs of these communities and developing informed strategies for resilience.

29. Title: Experimental flooding and warming rapidly increase graminoid biomass in high-latitude coastal wetland

Author List: (Matteo Petit Bon), A. Joshua Leffler, Katharine C. Kelsey, Tyler J. Williams, Karen H. Beard

With rapid rates of climate warming, high-latitude coastal ecosystems are experiencing more tidal floods; yet little is known about tundra plant-community responses to flooding. In a two-year, full-factorial field experiment in a low-Arctic wetland of the Yukon-Kuskokwim (YK) Delta (W Alaska), we simulated periodic river tidal flooding events at two levels under both ambient and warmed conditions, and measured plant-community responses. Low-level flooding represented overbank flooding one day per month consistent with projections in the next 5 years. High-level flooding represented a greater increase (3 days per month) that is projected to occur in the next 10 years. Our warming treatment (~1 °C) also represented a change projected in the next 10 years. Regardless of temperature, high-level flooding enhanced aboveground biomass of the already dominant graminoids by >45%, which translated to a >18% increase in the biomass of the whole plant-community. Low-level flooding had similar, yet weaker, effects. Warming also enhanced graminoid biomass by 20%, regardless of flooding. High-level flooding or warming alone decreased root productivity by >35%, yet when combined there were no differences with unflooded/ambient plots. What is striking about these results is the rate at which alterations have occurred, becoming largely apparent after only two flooding events in the first year of the experiment. Moreover, the effects of flooding dominated over those of warming, while conditions simulated by both treatments are expected to occur in the YK Delta over the same time frame. Our results indicate that more tidal floods in these tundra wetlands will further increase the dominance of graminoids relative to other plant functional groups, and that background Arctic warming will additively reinforce this pattern. These rapid, near-term plant-community changes may have large implications for ecosystem carbon and nutrient cycling of more flooded coastal wetlands in a warmer Arctic.

30. Title: Effects of warming, flooding, and herbivory on plant communities and greenhouse gas emissions: a mesocosm study in the Yukon-Kuskokwim Delta, Alaska

Author List: (Tyler J. Williams), Matteo Petit Bon, A. Joshua Leffler, Katharine C. Kelsey, Karen H. Beard

The Yukon-Kuskokwim (YK) Delta (W Alaska) is currently undergoing large ecosystem changes due to rapid climate warming and increased tidal flooding. In turn, these environmental change drivers may modulate when and where abundant migratory herbivorous birds, such as geese, influence this high-latitude coastal landscape. Predicting alterations in ecosystem functioning requires an integrative understanding of how these forces, alone and in combination, affect key ecosystem properties. In an ongoing mesocosm field experiment established in three different plant communities of the YK Delta found along a flooding gradient, we simulated periodic tidal flooding under both ambient and warmed temperatures, further combined with the absence and presence of simulated goose herbivory. We measured plant community and ecosystem respiration responses. Preliminary, one-year results suggest that responses to warming, flooding, and herbivory vary among communities. We found that (1) in the least flooded and intermediately flooded communities, flooding canceled out the decrease in ecosystem respiration caused by herbivory, ultimately increasing respiration in warmed conditions (in the least flooded community). Not surprisingly, (2) lower biomass with herbivory decreased respiration in all communities. Yet, (3) the naturally most flooded community showed biomass compensation, with herbivory having no effects. Here, flooding alone decreased respiration, with warming partially offsetting this effect. Overall, our results suggest that considering warming, flooding, and herbivore influences, and how they play out across plant communities, is crucial to understand future changes in high-latitude coastal ecosystems. Alterations in ecosystem respiration and plant communities have implications for carbon and nutrient cycling. As an ongoing

experiment, future data collection will help inform on sustained ecosystem responses to these environmental change drivers.

31. Title: Warm Pockets in cold places: Landscape heterogeneity and plant adaptation

Author List: (Kai Sattler), Karin Johansson, Anne Bjorkman, et al.

The Arctic, Earth's fastest-warming region, plays a pivotal role in the global climate system, with vast carbon reserves locked in its permafrost. The dynamics of its vegetation are critical in determining whether this carbon remains sequestered or is released, thereby amplifying climate change. Despite the well-documented impacts of climate warming on species' survival and fitness, the role of landscape heterogeneity and microclimatic variation in mitigating these effects is not well understood. This project aims to fill this research gap by exploring whether warmer microclimates in the Arctic's diverse landscapes harbor warm-adapted genotypes of tundra plants, potentially enabling species adaptation to warming and acting as a natural buffer against drastic shifts in vegetation and community composition. Utilizing reciprocal transplant and warming experiments at the Latnjajaure field station in Sweden, our study will evaluate the adaptability of Arctic plant species to climate change. By transplanting seeds of key species from and into various microclimates and warming chambers, we aim to compare the resilience of warm-adapted plants with that of their cold-adapted counterparts. Following transplantation, we will assess phenology, reproductive success, and key functional traits related to plant size and resource economics to understand plant response mechanisms. This research aims to address a significant knowledge gap regarding the contribution of microclimatic variation to biodiversity and ecosystem resilience in the face of climate warming. By enhancing our understanding of plants' response mechanisms to climate change, the study is set to significantly influence predictions on Arctic plant community dynamics, regional and global carbon cycling, and the broader implications of climate warming.

32. Title: The mechanism driving leaf senescence in Eriophorum vaginatum is maladaptive under the fast climate warming of the Alaskan Arctic

Author List: (Marcel Caritá Vaz), Bjorn Larson, Colleen McDonald, Brenda del Cid, Wesley Mahler, Luis Pallares, Gaius Shaver, Michael Moody, Ned Fetcher

Polar amplification challenges the survival of plant species, whose ecotypes may need more time to adapt to the ever faster warming climates. A prominent expression of these genotype-climate mismatches is the premature leaf senescence commonly observed in the tundra: although the end of the growing season is steadily getting delayed, native plants are still senescing at about the same time as before. The main explanation for such maladaptive phenology is that plants respond to light cues provided by shifts in light regime in anticipation for the winter. While light regimes are virtually constant over millennia, they change drastically latitudinally, which might promote the evolution of local adaptation and hence the emergence of ecotypes. We focused on Eriophorum vaginatum, which is both the foundation species of most of the tundra in Alaska and one of the most widespread species in the Arctic. We used field data from a decades-long reciprocal transplant experiment involving tundra (Sagwon and Toolik) and taiga (Coldfoot) ecotypes to test the extent to which ecotypes are adapted to their local climates. To confirm these results experimentally, we also grew the Coldfoot and Sagwon ecotypes in growth chambers where we manipulated light and temperature regimes. We show that leaf senescence is triggered by seasonal shifts in either light or temperature regimes. While long term field data indicated that responses to early summer frosts are mediated by light regime, plants artificially deprived of either thermal or light cues – but not both – were still triggered to senesce. More interestingly, lab grown plants used light cues to anticipate in a week the late summer drop in temperatures observed in their home site. We also found no experimental evidence in support of the sink limitation hypothesis. Our findings thus show that the physiological mechanism driving leaf senescence is well tuned for present local climates, but by no means well suited for warming climates.

33. Title: Changes in the frequency of flowering in forbs over time

Author List: (Clair Czadzeck) and Robert Hollister

With the warming climate, the amount of energy Arctic plants allocate to reproduction, measured by flower production, is of interest. To explore shifts in flowering effort, we focused on flowering frequency, specifically in forbs at established research sites near Atqasuk and Utqiaġvik, Alaska. These ITEX sites were established in the mid-1990s and provide long-term flowering information from control and experimentally warmed plots, in wet and dry areas. Previous research at the site suggested that Thawing Degree Days (TDD) may help predict the number of flowers produced in a year for some species and that warming may increase the number of flowers produced for some species. For methods, we documented whether or not a species flowered in a plot each year. We also correlated flower frequency with year and the accumulated TDD for the summer of flowering and the previous summer. Results show that year predicts flowering frequency the best out of the variables in question: there was a significant relationship between year as a predictor and flowering frequency across many species and sites. More specifically, we found large declines in flowering at the Barrow Dry site across many forb species. Temperature, expressed as TDD and TDD of the previous year, was not correlated with flowering frequency except for a few cases. Overall, the changes in flowering frequency and further examination of resulting trends help to illustrate the dynamics of reproduction effort as climate change rapidly impacts the Arctic; furthermore, forbs are of particular interest because many visitors enjoy seeing showy flowers as part of the tundra landscape.

34. Title: Outreach, interactivity, and the Arctic Ecology Program at GVSU

Author List: (Justin Blough) and Robert Hollister

Outreach, accessibility, and public engagement should be some of the most important deliverables in scientific work. Though not always accessible, the dissemination process of publishing, posters, and oral presentations are important for interaction and cooperation within the scientific realm, but also in the broader scope of the public eye. To increase accessibility and ease public understanding of the complicated data presented under the scope of “climate change related research”, the website and outreach materials of the Arctic Ecology Program at Grand Valley State University are being updated, expanded, and reconfigured with interactive images and data to increase public access and provide a more user friendly and entertaining experience for those seeking to learn about the tundra, climate change, and Arctic ecology.

35. Title: Vegetation community change at Toolik Lake, Alaska

Author List: (Katlyn R. Betway-May), William A. Gould, Jeremy L. May, Robert D. Hollister, Sarah C. Elmendorf

Global climate change phenomena are amplified in Arctic regions. Tundra vegetation is adapted to harsh, cold growing conditions and has been shown to respond to warming. Here, we examine changes in vegetation community structure over more than thirty years near Toolik Lake, Alaska. Sampling was done every 4 to 6 years on permanent 1 m2 plots using a point frame. Our site showed steady increases in maximum canopy height, which increased by 7.9 cm over the sampling period. Our site also experienced a 47% increase in canopy cover over time which was attributed mostly to increasing deciduous shrubs (which increased by 153% over the sampling period). However, different growth forms and species were responsible for increasing canopy cover depending on the community type. Despite the steady closing of the canopy layer, bryophyte and lichen communities persisted in the understory with no significant changes in cover. Contrary to other sites within the Arctic, temperatures in the Toolik Lake region have not significantly increased over the sampling period. Changes in vegetation community structure may therefore be the result of either delayed responses to warming that occurred in the decades preceding our study, responses to other changing climatic variables, or natural successional changes.

36. Title: Using ArcGIS Pro Raster Classification Tools to map Salix patches and plant communities

Author List: (Scott Branham), Robert Hollister, Sergio Vargas

Understanding how the tundra is changing has implications for the health of the Arctic as well as global climate change. As the tundra warms, the abundance of shrubs has increased in many locations. Increases in shrubs have important ecosystem implications. For this study we used aerial imagery captured via drone during the field season of 2022 to document the distribution of shrubs and other land cover types near Utqiaġvik, Alaska. Individual images were mosaicked together to create a raster image of the 1 square kilometer study site. The area sampled has been used to document ecosystem change since the 1990's and is commonly referred to as the ARCSS grid. The images were captured at a resolution of 4.14 cm/pixel with a RedEdge-M sensor in RGB and multispectral wavelengths. Analysis of the raster took place in ArcGIS Pro. A custom classification schema was created in the classification manager window. The schema classes consisted of Salix, Water, Wet meadow, Dry heath, and Moss dominated. Training samples of each class were then made from known locations to train the schema. The schema was then run on the raster using the imagery classification wizard to classify pixels into one of the schema classes. The output of these methods is a map with each pixel set to a chosen color based on which class it was classified into. Preliminary results show roughly 3.02 hectares of Salix present on the grid. This map will be used in future research to document Salix expansion and model future scenarios for vegetation in the region.

37. Title: Exploring HSV Color Space Indices for tracking Arctic Tundra vegetation phenology

Author List: (Victoria Villagomez), Katherine I. Young, Sergio A. Vargas, Daniel Cruz, Tabatha Fuson, Craig E. Tweedie

From analyses of satellite-derived data, Arctic tundra is generally thought to be 'greening' (becoming more green plant biomass) in response to climate change. Time lapse photography (phenocams hereafter) is a proven tool for monitoring responses of plant biomass and phenology at plant to landscape scales and can be used to tease apart controls of remotely sensed greening signals at finer spatial and temporal resolutions than is possible with satellite imagery. Phenocam data is traditionally analyzed using the Red Green Blue (RGB) color space, which mimics the physiology of the human eye and how humans 'see' the world. Several other machine-readable color spaces exist but have not been fully explored for their potential application in phenocam image analysis. For example, the Hue-Saturation-Value (HSV) color space can be used to quantify hue, saturation, and luminosity through its separate color channels. In this study we will report results from an initial investigation that utilizes RGB and HSV phenocam imagery and assesses how proxies of plant biomass and seasonal phenology respond to weather events at two arctic tundra sites in Alaska spanning 2011 - 2022. Spectral indices for HSV and RGB color space were extracted from Regions of Interest (ROI) representing plant community types at each study site. We then created threshold HSV values representing clear, overcast, and foggy weather conditions. We then compared time-series from both color spaces to determine which color space is more/less responsive to weather-related events. Results from this study will be used to guide analytical workflows associated with the planned ITEX phenocam synthesis effort.

38. Title: Mapping the spatial distribution of alpine plant communities in Garibaldi Park, BC, Canada

Author List: (Ciara Norton), Cassandra Elphinstone, Paul Pickell

Our warming and increasingly variable climate is causing changes in the distributions of many Arctic and alpine plant species. Mapping vegetation change at a landscape scale is challenging due to the lack of detailed species composition data for many remote areas, and the difficulty of defining realistic vegetation units that are distinguishable using only multispectral imagery. Here we use both bottom-up and top-down approaches to map the land use and land cover (LULC) vegetation communities in

Sphinx and Sentinel Bays, Garibaldi Provincial Park, British Columbia, Canada. The top-down approach defined vegetation classes using unsupervised classification models, and the bottom-up approach defined vegetation units through a landscape-scale vegetation survey. Both approaches used supervised machine-learning models to classify the 3 m resolution PlanetScope multispectral imagery into varying numbers of vegetation classes (varying thematic resolution). We compare the relative classification accuracies of both bottom-up and top-down approaches while considering the costs and benefits of sampling techniques in relation to the reproducibility of the study at a global scale. Overall, higher classification accuracy scores were recorded for models developed using the top-down approach. However, this was at the cost of lower thematic resolution for the vegetation classes. The inverse was recorded for the bottom-up approach.

39. Title: Plant species richness, stability and homogenization of two alpine snowbed communities in response to summer warming

Author List: (Filippo Grillo), Michele Carbognani, T'ai Gladys Whittingham Forte, Giorgio Chiari, Andrea Vannini, Alessandro Petraglia

A further temperature increase is predicted for the Alps by the end of the century. Upward migration of species from lower elevations has already been observed in response to warming, resulting in an overall increase in species richness in high-mountain areas. These changes may affect plant communities by altering the temporal stability of community-level species abundance (positively correlated with species richness) and the stability of the dominant species. Changes in species richness and composition may also reduce dissimilarity levels in composition among different plant communities, leading to increased community homogenization following warmer conditions. Although many studies have addressed how alpine plant communities will change under global warming, few studies have investigated the mechanisms driving community temporal stability and homogenization in alpine ecosystems. In this study we assess the impact of summer warming on plant species richness, temporal stability and homogenization of two alpine snowbed communities, one dominated by the moss Polytrichastrum sexangulare (Brid.) G.L. Smith, and the other by the shrub Salix herbacea L. The study was conducted in the Italian Alps, where a 16-year summer warming experiment was performed using open-top chambers. Species richness and species abundance were recorded annually. Analyses revealed no effects of warming on species richness in either communities. Temporal stability was only reduced in the moss-dominated community. Lastly, the similarity of the two communities increased under warming through reduced abundance of the dominant moss and expansion of the other vascular species. Overall, our results suggest that, even without changes in species richness and composition, there is potential for change in snowbed communities under future warming during the snow-free period.

40. Title: Multi-modal segmentation of tussock cotton grass (Eriophorum vaginatum) in UAV imagery using deep learning approach

Author List: (Harshavardhini Bagavathyraj), Sergio Vargas Zesati, Olac Fuentes, Craig E. Tweedie

Tussock cotton grass is widely distributed across much of the Arctic and often dominates the structure and function of tundra plant communities where present.. Importantly, several allometric relationships between tussock size and density and ecosystem properties such as plant biomass have been developed. Thus, accurately mapping tussock size, abundance, and distributions across tundra landscapes from unoccupied aerial vehicle (UAV) imagery can assist with estimating carbon stocks in the Arctic. Our primary objective is to develop an effective method for the segmentation and quantification of individual tussocks, employing orthorectified UAV imagery that includes multispectral bands and structure from motion-derived digital elevation models (DEMs). To achieve this, we adopted a U-Net deep learning segmentation approach to delineate tussocks. Following segmentation, we quantified the area covered by tussocks . Recognizing the reliance of U-Net on human-annotated data, we explored two approaches to mitigate this dependence. In the first approach, a small manually labeled subset was used to train the model, generating segments for ground truth labels, followed by retraining for enhanced performance. Secondly, an unsupervised segmentation strategy, based on differentiable feature clustering was employed, which eliminates dependence on human labels. The efficacy of both approaches was validated using independent in-situ data. The validated results from our study will provide a new baseline datasets and capacity to better define ecosystem properties and processes in tundra landscapes. This study not only contributes to the field of remote sensing and environmental monitoring but also opens avenues for further exploration of automated segmentation techniques in broader ecological studies using artificial intelligence.

41. Title: Effects of winter warming events on dry heath tundra vegetation mortality and community productivity near Toolik Lake, Alaska

Author List: (Jeremy May), Steven Oberbauer, Katlyn May, Robert Hollister, Roxaneh Khorsand, Steven Unger, Kyla Morris, and Caroline Brose

Warming in high latitude regions have been documented for decades although these trends are not consistent between summer and winter seasons. Winter warming events are increasing in frequency and magnitude driving alterations to plant mortality, community cover, and phenology. Here we present the results of a dry heath plant community following a winter warming event near Toolik Lake, Alaska, USA. For five growing seasons (2019-2023) following the winter warming event we monitored individual mortality and community productivity in 20 30cm2 (10 control and 10 freeze burn plots) dry heath community plots. Individual mortality was measured at peak growing season, July, during 2019, 2021, and 2023. Individual plant productivity was measured as peak season photosynthesis rates for four species, two deciduous and two evergreen shrub species, during 2019 and 2021. Community productivity was monitored through twice-weekly canopy level Normalized Difference Vegetation Index (NDVI) measurements throughout the growing seasons (June-August). Individual plant mortality was high during 2019 (65%), directly following the winter warming event, however evergreen shrubs (75%) were impacted significantly more than deciduous shrubs (41%), and all growth forms showed decreasing mortality levels over the following years. Peak season plant photosynthesis rates were initially (2019) lower for all species in freeze burnt plots however that difference disappeared by 2021. Community productivity, measured by NDVI, were significantly lower initially in freeze burn plots across all growing season months and peak values while those differences diminished with community recovery. Our results show that while winter warming events produce individual mortality and subsequent reductions in community productivity, these effects are short-lived and diminish as the community recovers.

42. Title: Three decades of vegetation change at the alpine ITEX site Val Bercla

Author List: (Frei, Esther R.), Prevéy, Janet S. and Rixen, Christian

Alpine and arctic tundra ecosystems are warming more rapidly than other regions on Earth. This rapid climate change leads to changes in the structure and composition of tundra plant communities with unknown consequences for ecosystem functioning. A site of the International Tundra Experiment (ITEX) was established at Val Bercla (46° 29’ N, 9° 35’ E) in the Central Swiss Alps in 1994. Open-top chambers (OTCs), passively warming the vegetation, have been put up after snowmelt in July and removed at the end of September to prevent wind blow and snow breakage. The Val Bercla site is located at an elevation of 2490 m a.s.l., on a north-north-west (NNW) facing, c. 20% steep slope. The rock fraction of the soil consists of greenschists, argillaceous calcschists, and some serpentinite. Species commonly occurring include Saxifraga oppositifolia, Silene acaulis, Polygonum viviparum, Salix retusa, Primula integrifolia, and Sesleria caerulea. Short term responses of Saxifraga oppositifolia showed no marked phenological change but reduced reproductive vigour of plants under experimental warming, which may have been a result of competition from taller growing neighbours. Later-on, Val Bercla contributed data to many research syntheses providing evidence for biome-wide trends of tundra vegetation change with increased height for most vascular plants and increased shrub abundance. A more recent global analysis of tundra plant phenological observations showed that warming shortens flowering seasons of tundra plant communities due to a greater advancement in the flowering times of late flowering than early flowering species. The findings contributed to the global evidence of climate change induced changes in the structure and function of tundra vegetation.

43. Title: Warming underpins community turnover in temperate freshwater and terrestrial communities

Author List: (Christian Rixen), Imran Khaliq, et al.

Rising temperatures are leading to increased prevalence of warm-affinity species in ecosystems, known as thermophilisation. However, factors influencing variation in thermophilisation rates among taxa and ecosystems, particularly freshwater communities with high diversity and high population decline, remain unclear. We analysed compositional change over time in 7123 freshwater and 6201 terrestrial, mostly temperate communities from multiple taxonomic groups. Overall, temperature change was positively linked to thermophilisation in both realms. Extirpated species had lower thermal affinities in terrestrial communities but higher affinities in freshwater communities compared to those persisting over time. Temperature change's impact on thermophilisation varied with community body size, thermal niche breadth, species richness and baseline temperature; these interactive effects were idiosyncratic in the direction and magnitude of their impacts on thermophilisation, both across realms and taxonomic groups. While our findings emphasise the challenges in predicting the consequences of temperature change across communities, conservation strategies should consider these variable responses when attempting to mitigate climate-induced biodiversity loss.

44. Title: Exploring the role of mycorrhizal associations in shrub expansion across the tundra biome

Author List: (Lisa C. Pilkinton), Isla H. Myers-Smith, Claudia Colesie, Kevin Newsham, Lorna Street, Mariana García Criado, Sarah Elmendorf, Anne Bjorkman and ITEX and MyCF co-authors

Shrub expansion, termed 'shrubification' has been a well observed phenomenon of climate-induced changes across the tundra biome. The shrubline has been extending northwards into higher latitudes, into higher elevations and infilling previously unvegetated areas. Temperature has been considered the main driver of this change, however, more recently, nutrient availability has been given greater consideration as a driver of shrubification. A common feature of most shrub species is that they form belowground mycorrhizal associations. Mycorrhizal fungi are both the means by which shrubs acquire nutrients and they are also responsible for mediating the carbon cycle. Thus, mycorrhizal interactions could prove to be a potential mechanism for both plant growth and for carbon sequestration and/or losses. At present, the role of mycorrhiza associations in shrub expansion has not been well explored, nor have the different mycorrhizal types and functions been compared when analysing community competition dynamics. Here, we conduct a cross-site synthesis to explore the role that different mycorrhizal types play in shrubification, asking whether different mycorrhizal types are associated with winner and loser shrub species. Primary analyses indicate differences in plant cover change over a period of three decades across mycorrhizal types. These early results indicate that mycorrhiza may be an important driver of tundra shrubification. By forming a deeper understanding of the mechanisms driving shrubification, we will be able to determine how and where future shrubification will occur across the tundra biome contributing to modelling of climate change responses of the tundra biome.

45. Title: Expanding the range of phenology measurements using low-cost phenocams

Author List: (Bjorn Larsen) Marcel C. Vaz, Ned Fetcher, Michael L. Moody, Gaius Shaver

As the Arctic climate warms, only some of the cues that plants use for phenology timing are changing. While increased temperature at the beginning and end of the season might allow for an extended

period of growth, photoperiod patterns will remain constant. This means that plants could be forced into early senescence, following light cues that are increasingly maladaptive.
Although phenological studies have been conducted for many Arctic sites and species, variation in phenology across a single species' range is poorly understood. Studies of Arctic plant phenology have relied primarily on seasonal measurements of growth or transitions (e.g., bud break, flowering) which are labor-intensive and challenging to scale. To better understand variation in phenology across the Arctic at a higher resolution, we used low-cost digital cameras to track the phenology of *Eriophorum vaginatum* across a wide latitudinal gradient in Alaska. We also tracked phenology in previously established reciprocal transplant gardens to compare phenocam data to manual growth measurements and to measure the plants' ability to adjust to new environmental cues.
Manual growth measurements and greenness data from the cameras were tightly correlated, suggesting that the cameras successfully captured patterns of growth across the season. Results from the latitudinal gradient showed that there was a split in phenology at treeline; northern populations had a shorter growing season by roughly 20 days. Additionally, populations retained their phenological differences once transplanted. These results are consistent with previous studies showing ecotypic variation in *E. vaginatum* with treeline as a key differentiator. They suggest that *E. vaginatum* may be experiencing adaptive lag, as locally adapted populations are not able to adapt to changing environmental conditions by extending their growing season.

INDEX (attendees)