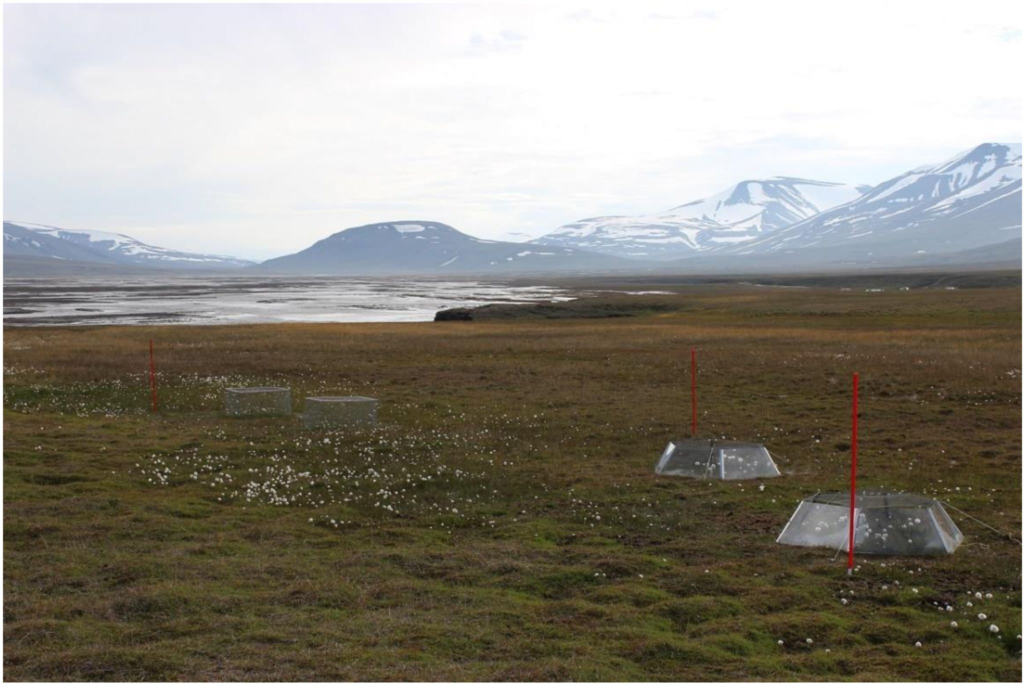
Effects of simulated herbivore disturbance and summer warming on plant nutrient dynamics and ecosystem processes of three High Arctic plant communities

Effects of geese and temperature on Svalbard tundra (SEPF *project no.* 15/128)

Matteo Petit Bon *et al.*



Greenhouses (right) and metal cages (left) have been employed in this project to increase summer temperatures and exclude natural herbivory, respectively (Photo: Matteo Petit Bon, July 2016)

Highlights

Background: The Arctic is warming faster than any other region on Earth. However, the extent to which Arctic ecosystems respond to higher summer temperatures may be modulated by biotic interactions. For instance, Svalbard pink-footed goose population has dramatically increased over the last decades

Methods: Using a 2-year experiment in Adventdalen (Svalbard) with no and simulated grubbing by geese and ambient and warmer temperatures, we focused on how these factors may affect nutrient content in plants and ecosystem processes of three High Arctic plant communities

Main outcomes (at the 31st of March, 2018):

- The experiment has been successfully conducted during the experimental seasons 2016 and 2017. To our knowledge, we conducted the biggest assessment of plant nutrient content ever made in Arctic ecosystems. In addition, measurements of ecosystem processes have been made. Together, these data provide a unique overview of how goose grubbing and summer warming may affect plant nutrient content and ecosystem processes and functions in the fragile Svalbard tundra
- The project has successfully led to the involvement and completion of a Master thesis delivered by The Albert Ludwig University of Freiburg in cooperation with The University Centre in Svalbard: "The effect of simulated goose grubbing and warming on biomass, nitrogen, phosphorus and silicon concentrations of graminoids in High Arctic tundra ecosystems" (MS thesis by Hanna Böhner, 2017 – Supervisors: Michael Scherer-Lorenzen, Ingibjörg Svala Jónsdóttir, Matteo Petit Bon)
- Conference presentations: 1) Oral presentation at the "Biomass Workshop" – 9th-12th of October, Longyearbyen (Svalbard); 2) Poster presentation at the "Svalbard Science Conference" – 6th-8th of November, Oslo (Norway); 3) Oral presentation at the "OIKOS conference" – 20th-22nd of February 2018, Trondheim (Norway)

Planned outcomes:

- Scientific papers: Data collected during this project will be published in 3 scientific papers, with the following working titles: 1) Plant functional types, herbivory, and warming effects on spatial and temporal plant nutrient dynamics across a soil moisture gradient in the High-Arctic Svalbard; 2) Nutrient-related traits of plant functional types mediate herbivory and climate warming effects on ecosystem carbon fluxes in three High-Arctic plant communities; 3) Herbivory and warming effects and plant trait control on the early-decomposition across a soil moisture gradient in three High-Arctic plant communities
- Conference presentations: 1) Poster presentation at the "ITEX meeting" – 25th-27th of April 2018, Stirling (Scotland); 2) Other presentations still to be planned

Introduction

This document is the final audience-friendly report of the research project "Effects of geese and temperature on Svalbard tundra" (SEPF project no. 15/128). The application was approved in date 25/11/2015 and the project was granted up to NOK 308 000 for the period 25/11/2015 – 31/12/2017.

Data collected under the crucial funding received from the Svalbard Environmental Protection Fund form the core of Matteo Petit Bon's PhD thesis entitled "Effects of simulated herbivore disturbance and summer warming on plant nutrient dynamics and ecosystem processes of three High Arctic plant communities". The PhD position of the main applicant is financed by The University Centre in Svalbard (UNIS) in collaboration with The Arctic University of Norway (UiT). The overall outlines of the project are registered in the Research in Svalbard database (RiS) with RiS-ID no. 10346 (HERBWARTUNDRA). Further updates and developments of this project will be uploaded in the RiS portal as soon as available.

The PhD project of the main applicant also received important additional funding from The Research Council of Norway in summer 2017 (Arctic Field Grant – AFG – project no. 269957). The Scientific report for the project no. 269957 will be soon available in the document "AFG reports 2017" regularly published by the Svalbard Science Forum (SSF) in the dedicated website.

This final report of the preliminary data analysis and interpretation of the results has been written to meet the requirements of the reimbursement. The publication of the data collected and analysed under the present project will bring the latter as a whole to conclusion.

Project background

Warming of the climate system is unequivocal. However, some regions have been more affected by climate change than others and climate warming has been and is predicted to be most pronounced in Arctic and alpine environments. Several studies have already shown how these rapid changes are affecting tundra vegetation, which in turn drive shifts in ecological processes and ecosystem functions. The extent to which Arctic plant communities and ecosystems respond to changes in abiotic factors such as summer warming may be modulated by biotic interactions and vertebrate herbivores may be the keystone to fully understand how plant communities respond to climate changes. In the archipelago of Svalbard, pink-footed goose population has notably risen from 1970 to present. The huge expansion of the Svalbard pink-footed goose population suggests a substantial increase in the potential for disturbance of the tundra caused by goose herbivory. Pink-footed geese normally reach Svalbard in spring, i.e. middle of May, and forage for few weeks on below-ground plant parts. This is a well-known forage strategy called grubbing. Grubbing activity is particularly destructive for vegetation and can cause a widespread disturbance for high Arctic tundra ecosystems (Fig. 1).

Fig. 1 – Natural grubbing disturbance following pink-footed goose arrival in spring. It is evident that goose grubbing removed the vegetation and completely destroyed the moss mat, with possible consequences on plant community dynamics and ecosystem processes (Photo: Matteo Petit Bon, June 2017)

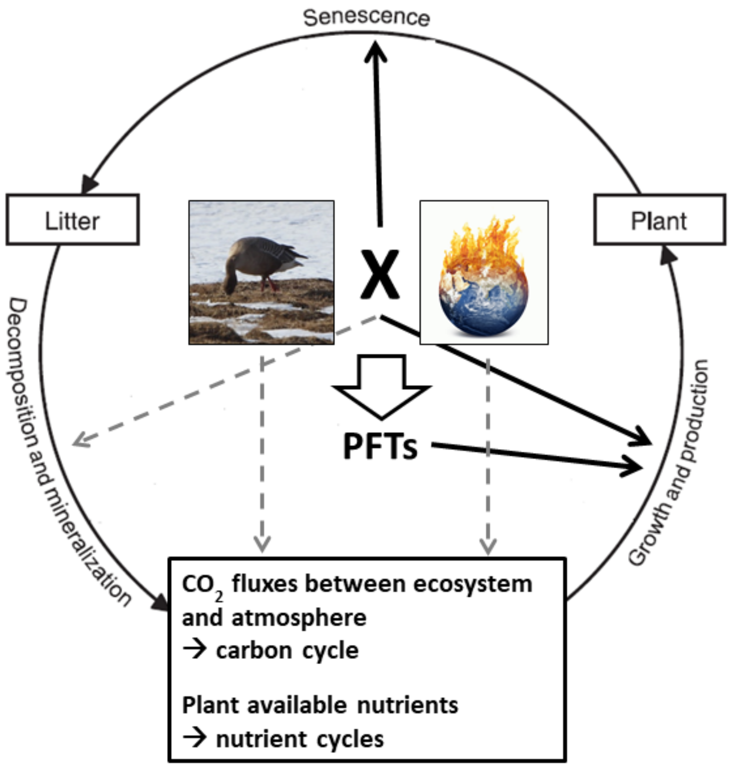


Fig. 2 – Overview of the main aims of the project. The two images inside the circle depict the main factors considered here (left side: pink-footed goose while grubbing on the vegetation in spring; right side: climate warming, which is affecting Arctic regions more than any other place on the planet). The X sign in between the two pictures stands for the interaction effect that these two factors may have on the response variables of interest, which is also one of the main novelty of this project. Black solid arrows indicate the effects of the main factors (and their interaction) on whatever response variable concerning plants (and PFTs), from vegetation composition to phenological development and nutrient content/dynamics. In turn, these effects can scale up to ecosystem processes such as decomposition and mineralization and instantaneous CO2 carbon fluxes between ecosystem and atmosphere (in the last part of the circle and in the black box at the bottom). Gray dashed arrows indicate direct effects of the main factors (and their interaction) on ecosystem processes, without first going through effects on plant communities (modified from Dorrepaal, 2007)

We are asking to what extent an experimentally increased pink-footed goose grubbing disturbance at the beginning of the growing season and summer warming may interact in modifying tundra plant nutrient dynamics, which, in turn, govern ecosystem processes in high Arctic plant communities (Fig. 2).

Material and methods

Study area

The study has been based in Adventdalen (78˚10’ N, 16˚05’ E), and experiments were carried out during the summers 2016 and 2017. Seven sites were identified and used for the present experiment (Fig. 3a). In particular, each site encompassed three major plant communities (mesic community, moist community, and wet community), which in turn are dominated by different plant species depending upon micro-topographical features and moisture regime at very small spatial scale (Fig. 3b). These plant communities are also recognized as the habitats mainly utilized by pink-footed geese during arrival and pre-breeding periods in Svalbard.

The community of resident vertebrate herbivores in Svalbard consists of wild Svalbard reindeer, rock ptarmigan, and sibling vole. The species are widely distributed across the archipelago, except for the vole, which is only found in a small bird cliff area and hence not affecting the vegetation at our study sites. However, the summer period is crowded by many species of migratory birds that reach Svalbard to utilize plenty of high quality food resources and 24-h light to raise their chicks before migrating back further south at the end of the growing season. In particular, three species of migratory geese are found in Svalbard during the summer period: the pink-footed goose, the barnacle goose, and the brent goose. We here focus on the disturbance caused to the vegetation and ecosystem by pink-footed goose, which is the only species of geese in Svalbard known for its destructive grubbing behaviour during the pre-breeding period in spring.

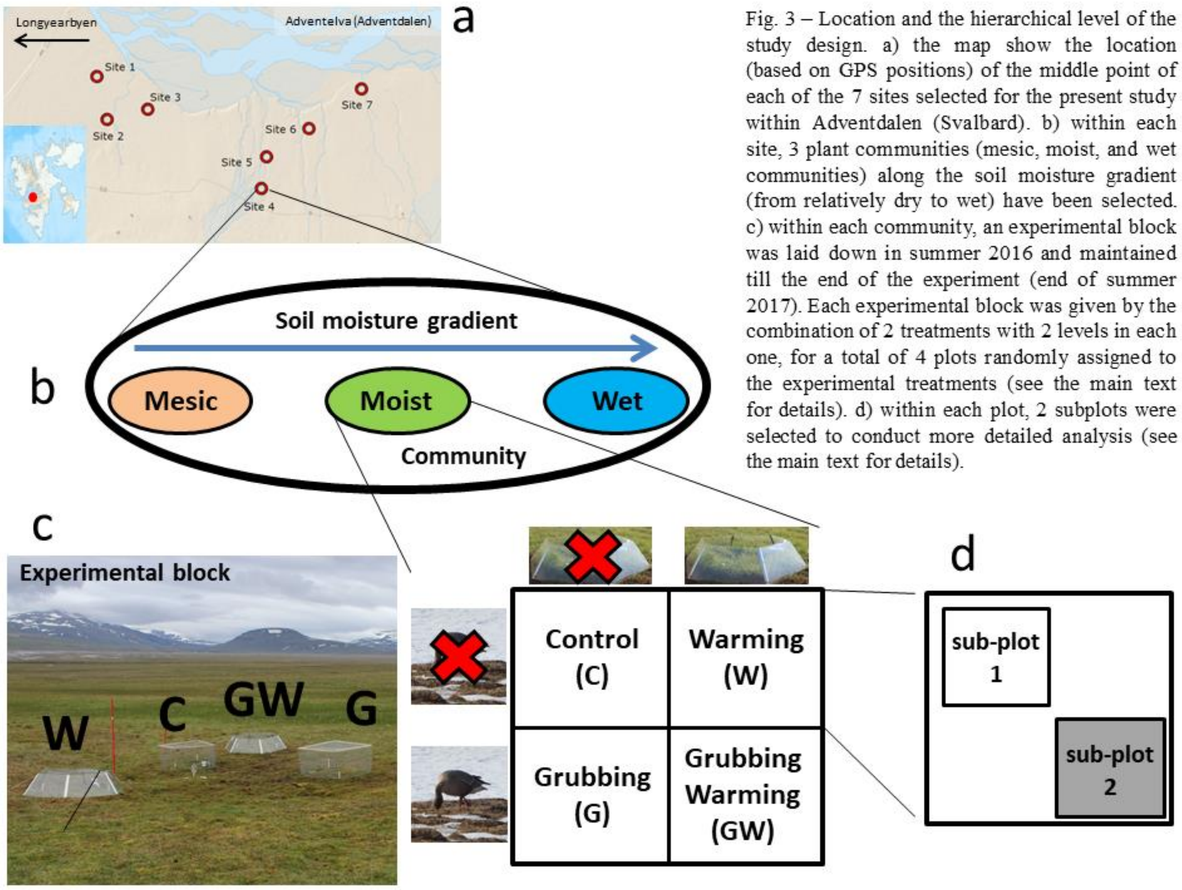


Fig. 3 – Location and the hierarchical level of the study design. a) the map show the location (based on GPS positions) of the middle point of each of the 7 sites selected for the present study within Adventdalen (Svalbard). b) within each site, 3 plant communities (mesic, moist, and wet communities) along the soil moisture gradient (from relatively dry to wet) have been selected. c) within each community, an experimental block was laid down in summer 2016 and maintained till the end of the experiment (end of summer 2017). Each experimental block was given by the combination of 2 treatments with 2 levels in each one, for a total of 4 plots randomly assigned to the experimental treatments (see the main text for details). d) within each plot, 2 subplots were selected to conduct more detailed analysis (see the main text for details).

Study design

One experimental block was established in each community (Fig. 3c). Each experimental block contained 4 plots given by the combination of 2 treatments with 2 levels in each one. The 4 plots within block were randomly assigned to one of the following treatments:

- Control (C): Neither experimental grubbing/faeces addition nor warming were applied;
- Grubbing (G): Experimental grubbing was implemented using a sharpened metal tube (see below) and faeces addition was performed;
- Warming (W): Experimental summer warming was implemented using Open Top Chambers (OTCs – see below);
- Grubbing + Warming (GW): Both experimental grubbing/faeces addition and experimental summer warming were applied.

In addition, a fifth plot (natural plot – N) was added to each experimental block to control for natural variation in grubbing patterns. In total, 105 plots have been established and used for the present experiment.

Grubbing disturbance was implemented at the beginning of summer 2016 and 2017 using a sharpened 20 mm diameter steel tube inserted to a depth of 50 mm and twisted to remove and export contents from the plot (see the same methodology successfully applied by other researchers). Faeces were then added to G and GW plots immediately after the simulated disturbance was applied. The design of the grubbing treatment was based upon detailed observation of naturally grubbed vegetation within

Adventdalen (Fig. 4a). As far as the warming treatment is concerned (W and GW plots), Open Top Chambers (OTCs) were used to enhance temperatures during the summer period (Fig. 4b). OTCs are passive devices which have no direct control on energy and work primarily on trapping solar energy and stopping the heat dissipation effect of the wind. They have been receiving particular attention because widely used in the International Tundra Experiment (ITEX). OTCs increase mean summer temperatures in the range of 2-3 °C, which is one of the most probable warming scenario predicted in the mid-term (2081-2100) for future summer warming in the Arctic.

Within each plot, 2 subplots have been selected to conduct measurements of ecosystem processes (Fig. 3d). In total, 210 subplots have been established and used for the present experiment. All plots within the experiment were fenced off, except the natural plots (N). In such a way, natural herbivory was excluded and all plots were only subjected to our experimental treatments (natural herbivory was excluded as a confounding factor).

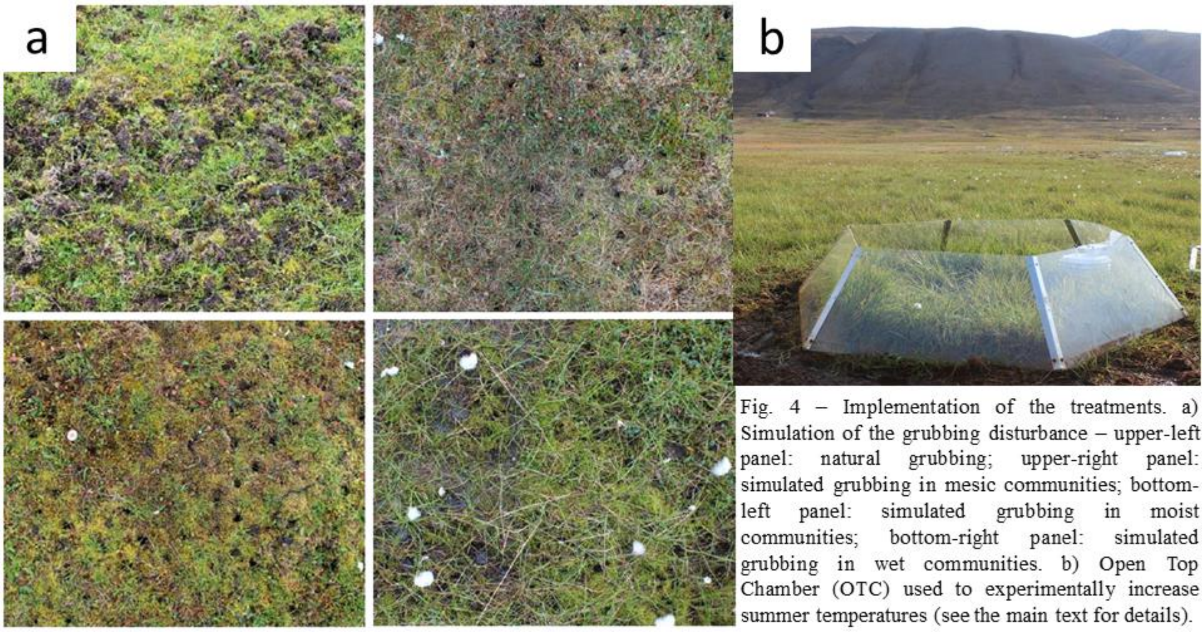


Fig. 4 – Implementation of the treatments. a) Simulation of the grubbing disturbance – upper-left panel: natural grubbing; upper-right panel: simulated grubbing in mesic communities; bottom-left panel: simulated grubbing in moist communities; bottom-right panel: simulated grubbing in wet communities. b) Open Top Chamber (OTC) used to experimentally increase summer temperatures (see the main text for details).

Environmental data collection

During the experimental period (May 2016 – September 2017):

- Soil temperatures have been monitored in all plots, both at the surface (underneath the first layer of vegetation) and at 5-cm depth, which is the major rooting zone for Arctic plants;
- Air temperatures and air relatively humidity at 10 cm above ground have been monitored in some randomly selected plots (see *Environmental conditions* section in the *Preliminary results* part – Fig. 7);
- Soil moisture measurements have been taken at regular intervals during the summer seasons.

In addition, some other environmental variables have been measured throughout the experimental period at the landscape level. In particular, two weather stations have been employed and equipped with the following sensors:

- Photosynthetically Active Radiation (PAR) at 2 m height;
- sun's relative intensity at 2 m height;
- air temperature/relative humidity at 2 m height;
- soil temperature at 10 cm below the surface.

Measurements collected with these sensors form the background information of the entire study area.

Data collection

The following data have been collected and some are presented graphically in the "Preliminary results" section:

- Species composition and vegetation biomass at the subplot level (210 subplots) have been recorded in both 2016 and 2017 (see *Plant community composition and abiotic variables* section in the *Preliminary results* part – Fig. 8);
- We measured the Normalized Difference Vegetation Index (NDVI) in each subplot at regular intervals (in both 2016 and 2017). NDVI is a commonly used index of photosynthetic activity and thereby plant greenness (see *Normalized Difference Vegetation Index* section in the *Preliminary results* part – Fig. 9);
- We collected plant samples for nutrient content analyses in each plot at regular intervals (in both 2016 and 2017) (Fig. 5). The leaves were then analyzed for N and P concentrations using Near Infrared Reflectance Spectroscopy (NIRS), an easy and non-destructive method to determine plant primary and secondary compounds In total, over 7000 plant samples have been analysed for N and P content establishing what to our knowledge is the biggest assessment of plant nutrient content ever made in Arctic ecosystems (see *Plant nutrient content* section in the *Preliminary results* part – Fig. 10);
- We measured CO2 fluxes between ecosystem and atmosphere in each subplot at regular intervals (in both 2016 and 2017) (Fig. 6). These measurements give an overview of how the ecosystems responded to our treatment in terms of ecosystem processes (see *Ecosystem processes* section in the *Preliminary results* part – Fig. 11).

Fig. 5 – Matteo Petit Bon is collecting leaves for nutrient content (N and P) analyses (Photo: Calum Bachell, July, 2017).

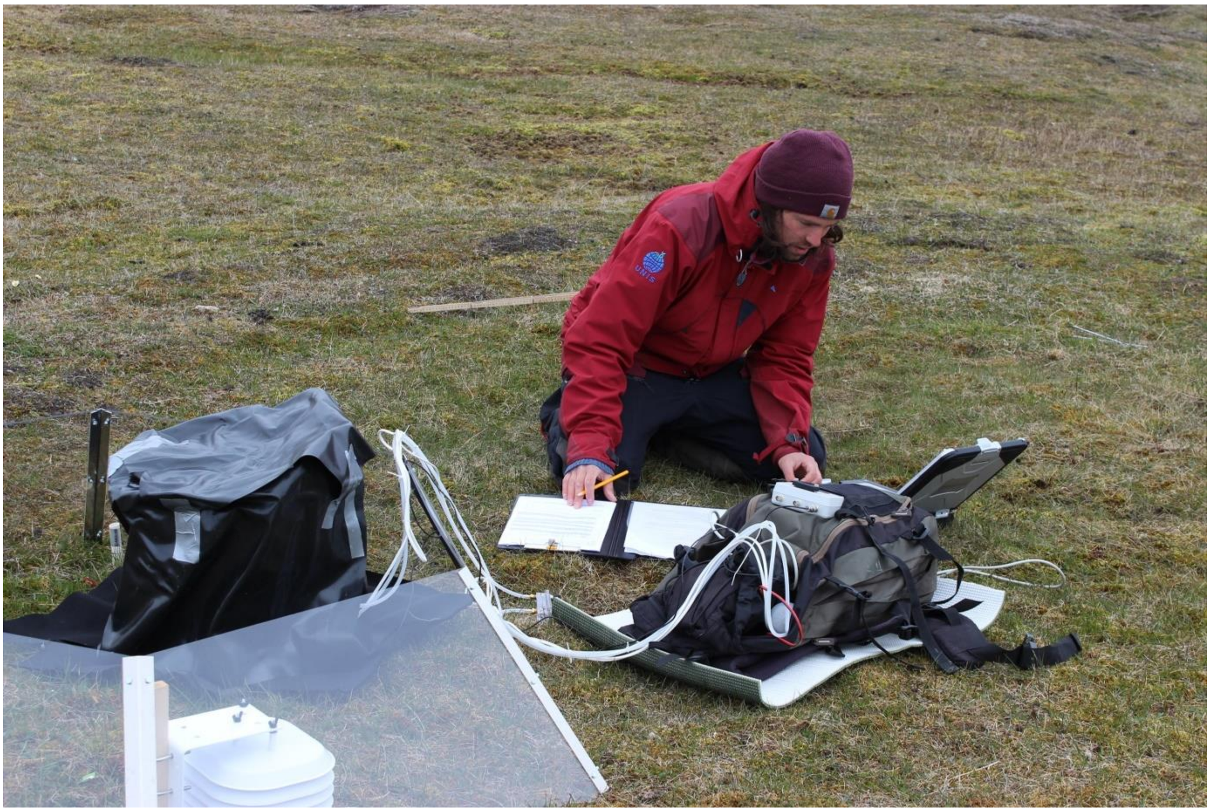


Fig. 6 – Matteo Petit Bon is measuring CO2 fluxes (dark measurement – ecosystem respiration) inside an OTC (Photo: Anton Hochmuth, June 2016).

Preliminary results

Environmental conditions

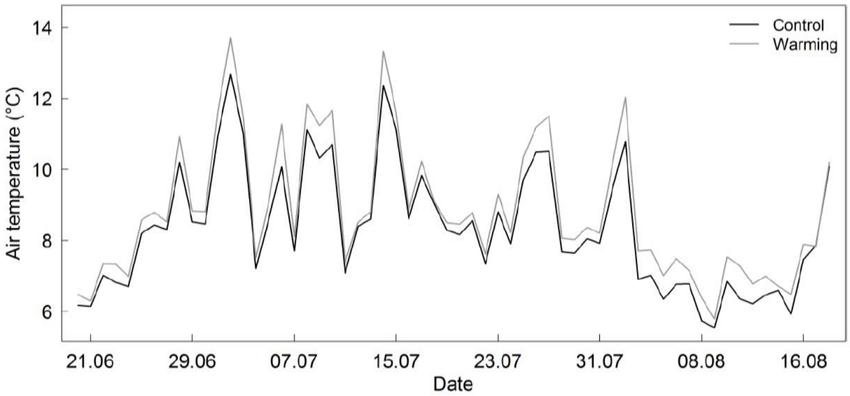


Fig. 7 – Air temperature (daily means) in control (C) and warming (W) plots during the experimental season in 2016 (n = 3). The graph has been taken from Böhner, H., 2017 (Master thesis). Notice that the warming treatment increased daily temperatures of about 1 ˚C compared to the control.

Plant community composition and abiotic variables

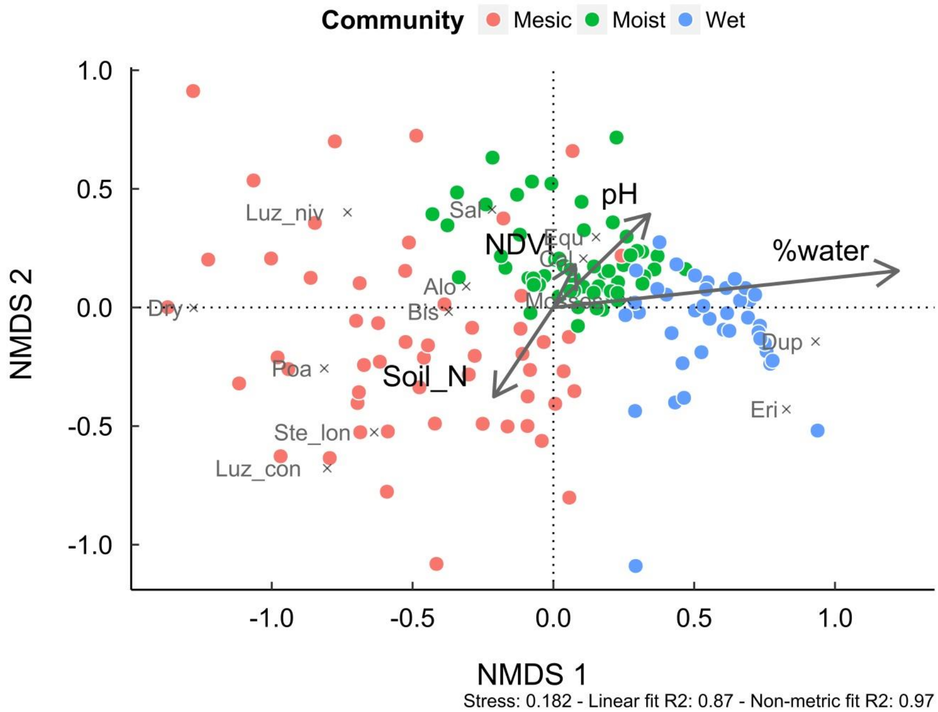


Fig. 8 – Overall plant community composition in our subplots (data shown here were collected at the peak of the season in 2016). Notice how the three different plant communities cluster well in respect to species composition. Environmental data (soil moisture, soil N, soil pH, and NDVI) were super-imposed to the ordination diagram. Notice how soil moisture (%water in the figure) is the main driving factor of the three clusters formed by the three communities and their species composition.

Normalized Difference Vegetation Index

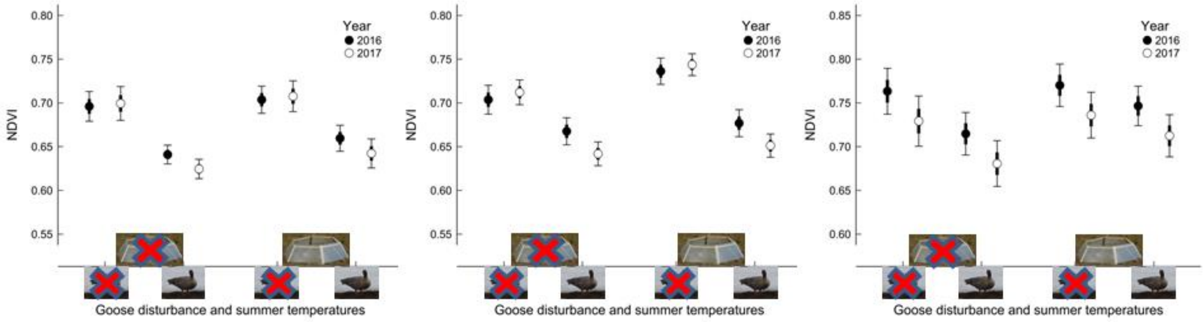


Fig. 9 – NDVI data from 2016 and 2017 in mesic communities (left panel), moist communities (middle panel), and wet communities (right panel). Points represent the average, whereas bars represent the error around the average. Notice how the grubbing (G) treatment significantly reduced the NDVI values (greenness) in all communities, independently of the warming (W) treatment. The latter only significantly increased NDVI values in moist communities and in absence of grubbing disturbance.

Plant nutrient content

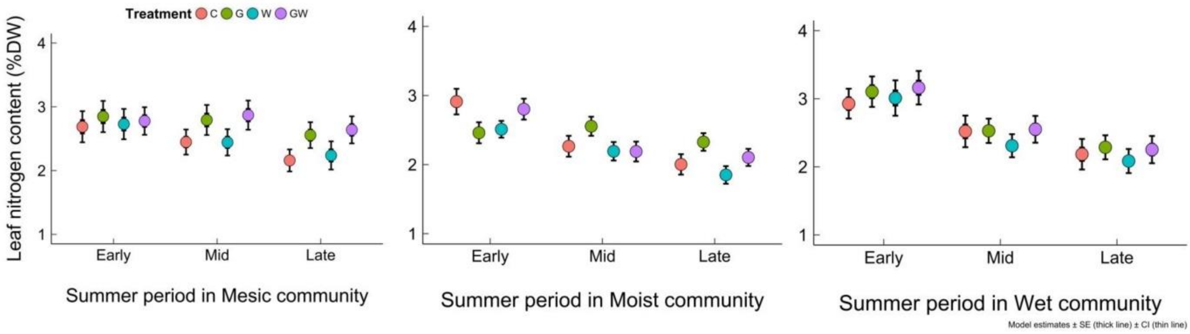


Fig. 10 – Plant nutrient (nitrogen) content in 2016 for graminoids. Data are shown separately for the different communities. Points represent the average, whereas bars represent the error around the average. Notice how the experimental grubbing treatment significantly increased the overall N content in leaves. Interestingly, the warming treatment either had no substantial effects or decreased the N content in leaves (see the example for moist communities in the late season).

Ecosystem processes

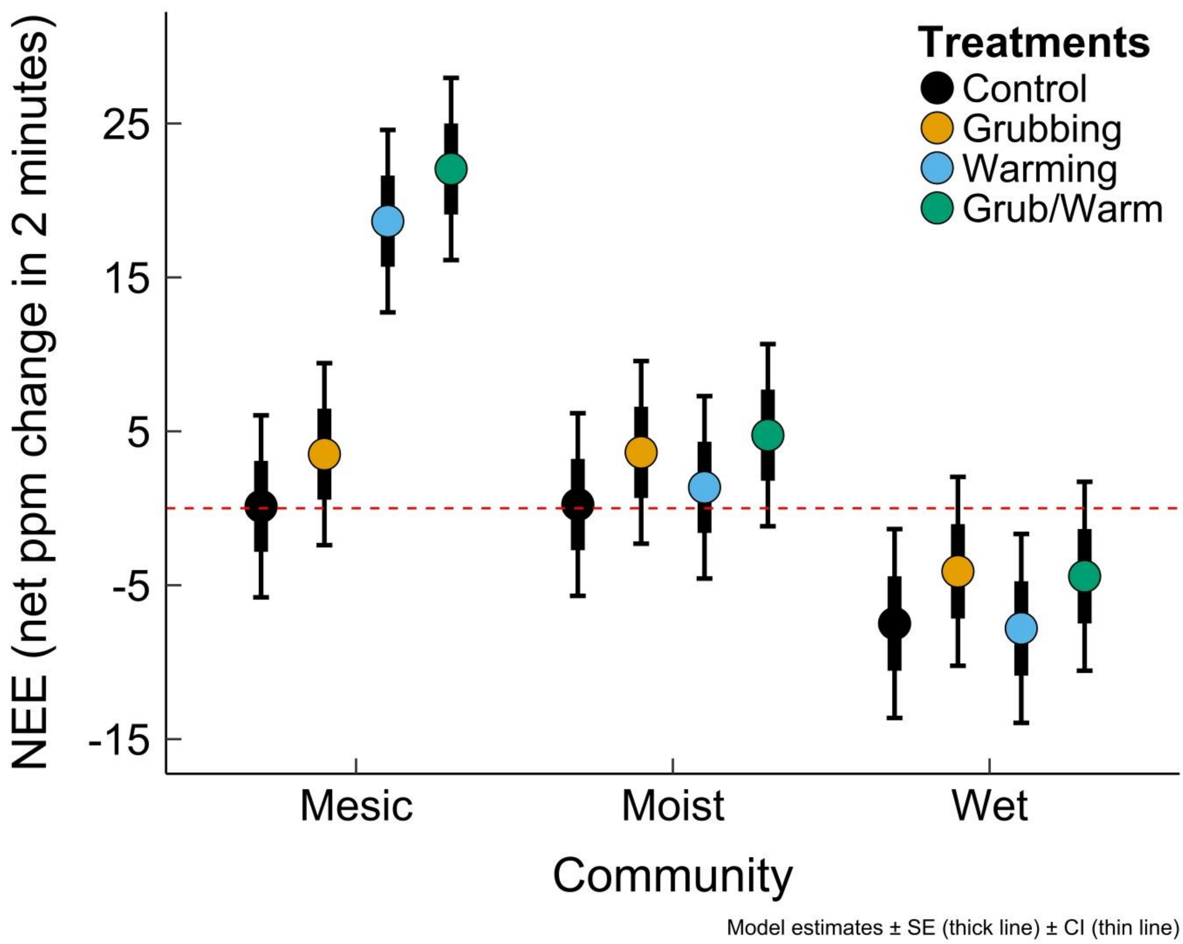
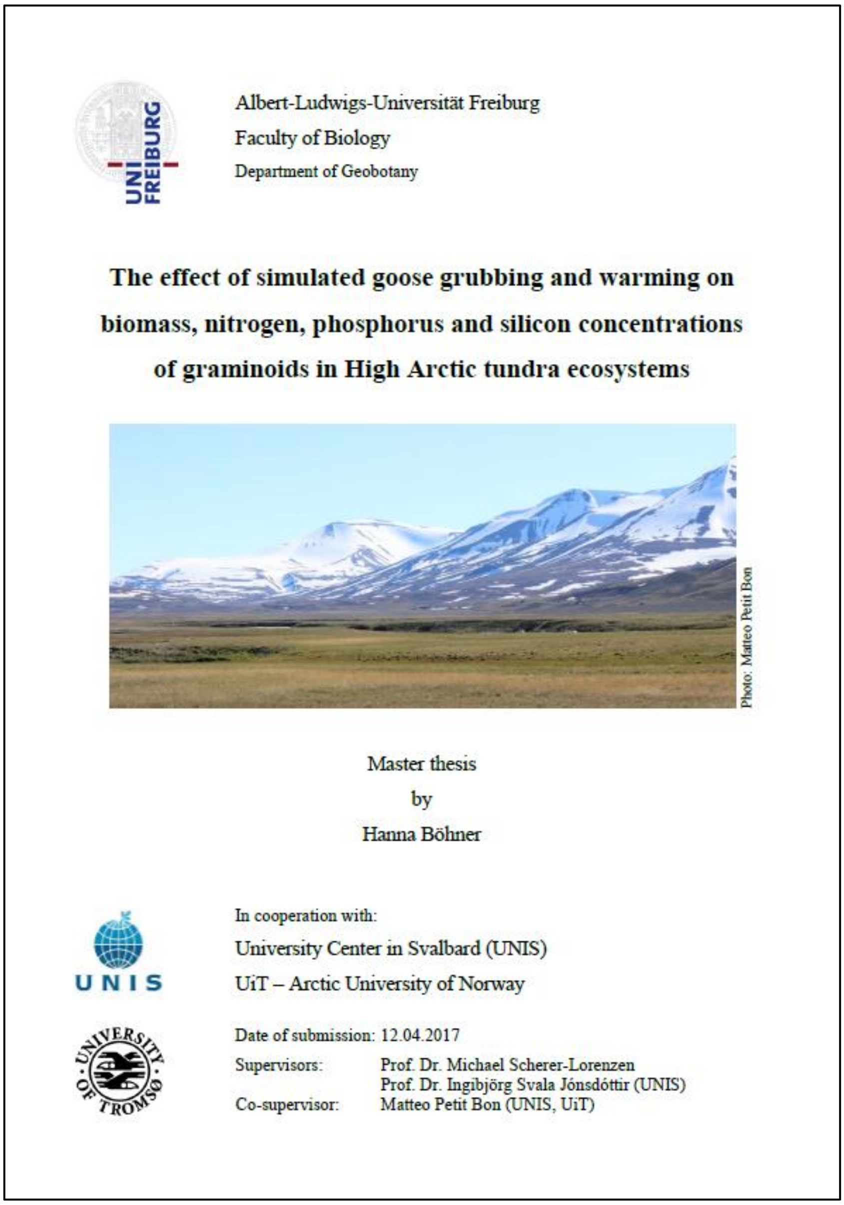


Fig. 11 – Net CO2 fluxes between ecosystem and atmosphere in the three communities during the summer 2016 (data for the different summer periods have been pooled together). Points represent the average, whereas bars represent the error around the average. Notice how the experimental grubbing treatment significantly decreased the overall C sink strength of the three communities under study (NEE became more positive). Interestingly, the

warming treatment had a huge effect on mesic communities only, leading the latter to switch from neutral to highly C source (NEE became more positive). Hence, both experimental grubbing and warming had the potential to reduce the capacity of ecosystems to assimilate carbon, which in turn may have huge consequences in terms of future rate of climate warming.

Main outcomes of the project (31st of March, 2018)

Together with the conference talk and poster presentations, the main outcome we have had so far from this project has been the successful completion of the Master thesis by Böhner, H., 2017.



Albert-Ludwigs-Universität Freiburg
Faculty of Biology
Department of Geobotany

The effect of simulated goose grubbing and warming on biomass, nitrogen, phosphorus and silicon concentrations of graminoids in High Arctic tundra ecosystems

Photo: Matteo Petit Bon

Master thesis
by
Hanna Böhner

In cooperation with:
University Center in Svalbard (UNIS)
UiT – Arctic University of Norway

Date of submission: 12.04.2017
Supervisors: Prof. Dr. Michael Scherer-Lorenzen
Prof. Dr. Ingibjörg Svala Jónsdóttir (UNIS)
Co-supervisor: Matteo Petit Bon (UNIS, UiT)

Fig. 12 – Front page of the Master thesis “The effect of simulated goose grubbing and warming on biomass, nitrogen, phosphorous, and silicon concentrations of graminoids in High Arctic tundra ecosystems” (Böhner, H., 2017)

Planned outcomes

Together with the conference talk and poster presentations, data collected during this project will be subdivided in a minimum of 3 scientific papers, aiming at international high impact factor peer-reviewed journals. The conceptual framework of the PhD project is well highlighted by Fig. 13. The figure supports my subdivision of the PhD project in 3 main scientific papers.

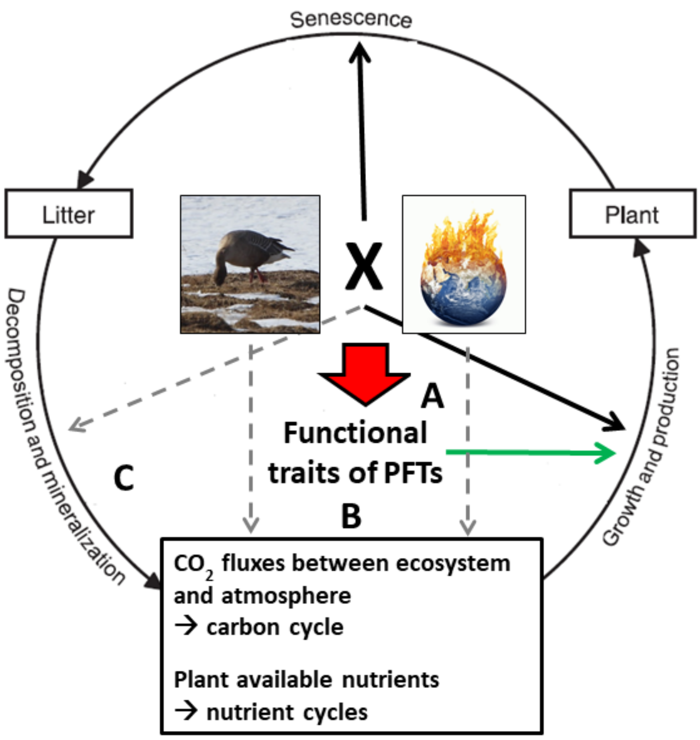


Fig. 13 – Conceptual framework of my PhD project. The major aim of the project is to get new insights into the coupling between N, P, and C cycles in tundra plants and, in particular, how changes in plant functional traits, such as foliar nutrient content, due to both abiotic and biotic factors can scale up on ecological processes at a higher level (i.e. carbon cycling, decomposition, and nutrient leaching) in different tundra plant communities. Plant species and plant functional types strongly control the feedbacks of ecosystems to climate changes because functional traits at both species and PFT level (physiology, morphology, and physical and chemical properties) affect all ecosystem processes and functions (green arrow and then black arrows). While herbivore disturbance and summer warming may directly affect vegetation (black solid arrows) and ecosystem processes (grey dashed arrows), PFT-mediated effects, through changes in vegetation composition and effects on plant functional traits, such as total foliar nutrient content, are also extremely important in determining overall ecosystem responses to such perturbations (red arrow and then black arrows). In this context, the position of the 3 main scientific papers planned as outcome of this project is highlighted by the letters A, B, and C (see the main text for details) (modified from Dorrepaal, 2007)

Paper I (A): Plant functional types, herbivory, and warming effects on spatial and temporal plant nutrient dynamics across a soil moisture gradient in the High-Arctic Svalbard

Here we ask to what extent different biotic (PFTs and simulated goose grubbing + feces addition) and abiotic (simulated climate warming and soil moisture regime) factors act alone and in concert in modifying nitrogen (N) and phosphorus (P) content in plant leaves in three high Arctic plant communities on a gradient of soil moisture.

Paper II (B): Nutrient-related traits of plant functional types mediate herbivory and climate warming effects on ecosystem carbon fluxes in three High-Arctic plant communities

Here we ask to what extent the magnitude of ecosystem CO2 flux responses to herbivory and warming on a gradient of soil moisture is mediated by the nutrient-related traits (N and P content) of the resident plant community, which differs in PFTs composition and relative responses to grazing and climate warming.

Paper III (C): Herbivory and warming effects and plant trait control on the early-decomposition across a soil moisture gradient in three High-Arctic plant communities

Here we ask to what extent short-term (*i.e.* herbivory disturbance expected by a goose population increase and higher temperatures during summer) and long-term (*i.e*. via change in litter quality [N and P content]) effects of climate changes can influence early-decomposition (mass loss and nutrient release) of litter belonging to 4 different PFTs on a gradient of soil moisture.

Collaborations and main difficulties

Scientific collaborations have been strengthened during the carrying out of the project. In particular, samples for nutrient analyses have been analyzed within the "Plants and Northern Ecosystems" group (leader and supervisor: Kari Anne Bråthen) at the Arctic University of Norway (UiT – Tromsø). CO2 flux measurements have been taken following the precious advice by Hanna Lee (Uni Research – Bergen), who is an expert in ecosystem carbon dynamics and fully involved in the ecosystem CO2 flux part of my PhD project. Finally, all the fieldwork activities have been coordinated with other projects registered in the RiS database (i.e RiS-ID 10667, RiS-ID 10484, and RiS-ID 10030), which aim to answer closely related questions to our main experimental framework. Data sharing and collaborations in the production of scientific publications have already begun.

The main difficulties encountered during fieldwork and laboratory parts were: 1) Bad weather interfering with the "experimental cycles" – each experimental cycle encompassed about 10 days of continuous fieldwork. The gas analyser used for carbon flux measurements is not suitable in case of rain or strong wind. As a consequence, "experimental cycles" have been occasionally interrupted because of these unpredictable factors. 2) Polar bears in the area towards the end of the season – fieldwork has been continuously delayed from the 1st of September to the 18th of September 2017 because of the presence of three polar bears close to the study sites (all fieldwork activities were not allowed in that period). 3) Litter bag processing in the lab – bags containing plant material for the decomposition experiment have been recently processed in the lab. The main difficulty encountered was the removal of soil particles from litter bags incubated in wet communities.

Appendix - images

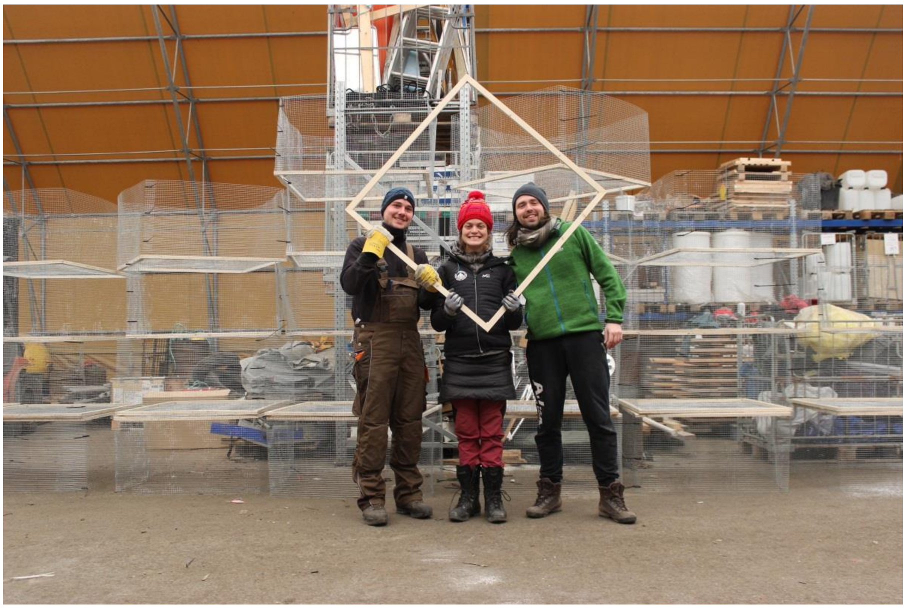


Fig. 14 – Cage preparation in May 2016 (from left to right: Anton Hochmuth, Mathilde Le Moullec, and Matteo Petit Bon)

Fig. 15 – Cage transport in Adventdalen in May 2016 (in front: Matteo Petit Bon; in the back: Anton Hochmuth)

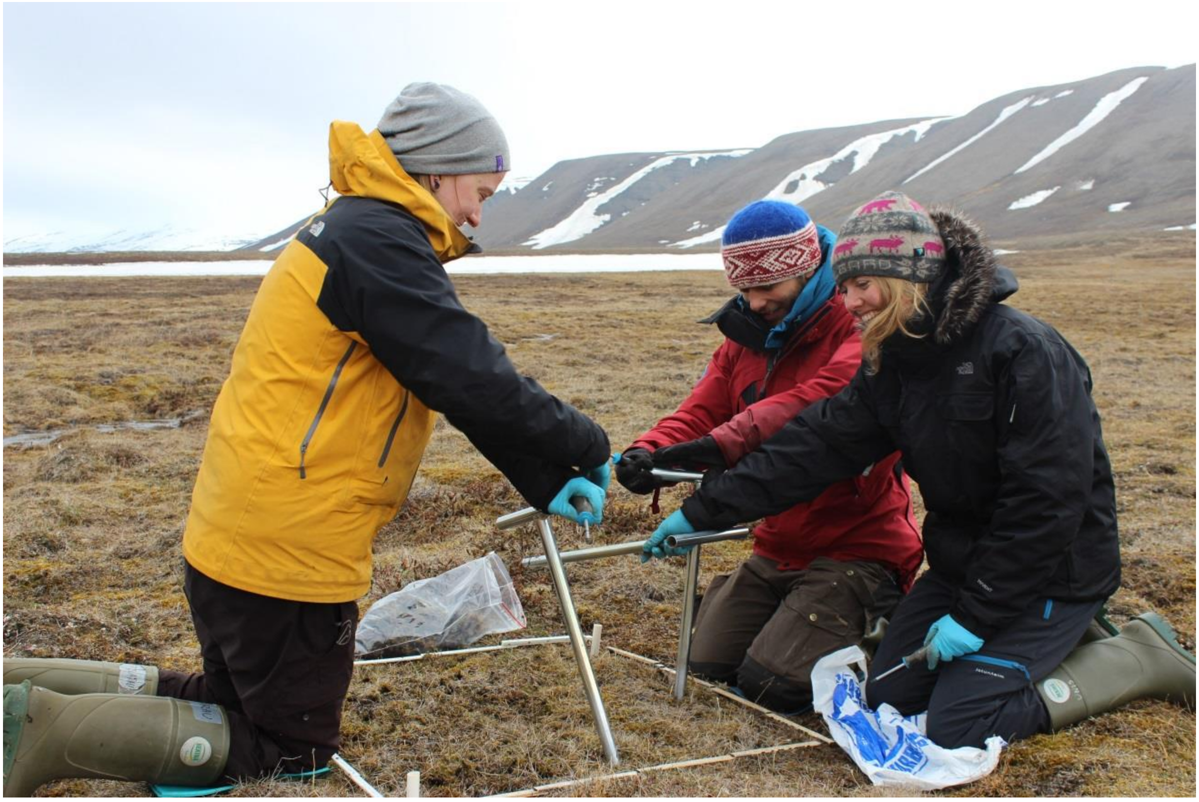


Fig. 16 – Some students helping out with the simulation of the grubbing treatment in June 2016

Fig. 17 – Matteo Petit Bon (in front) and Hanna Böhner (in the back) while taking NDVI measurements on an experimental plot (July 2016)

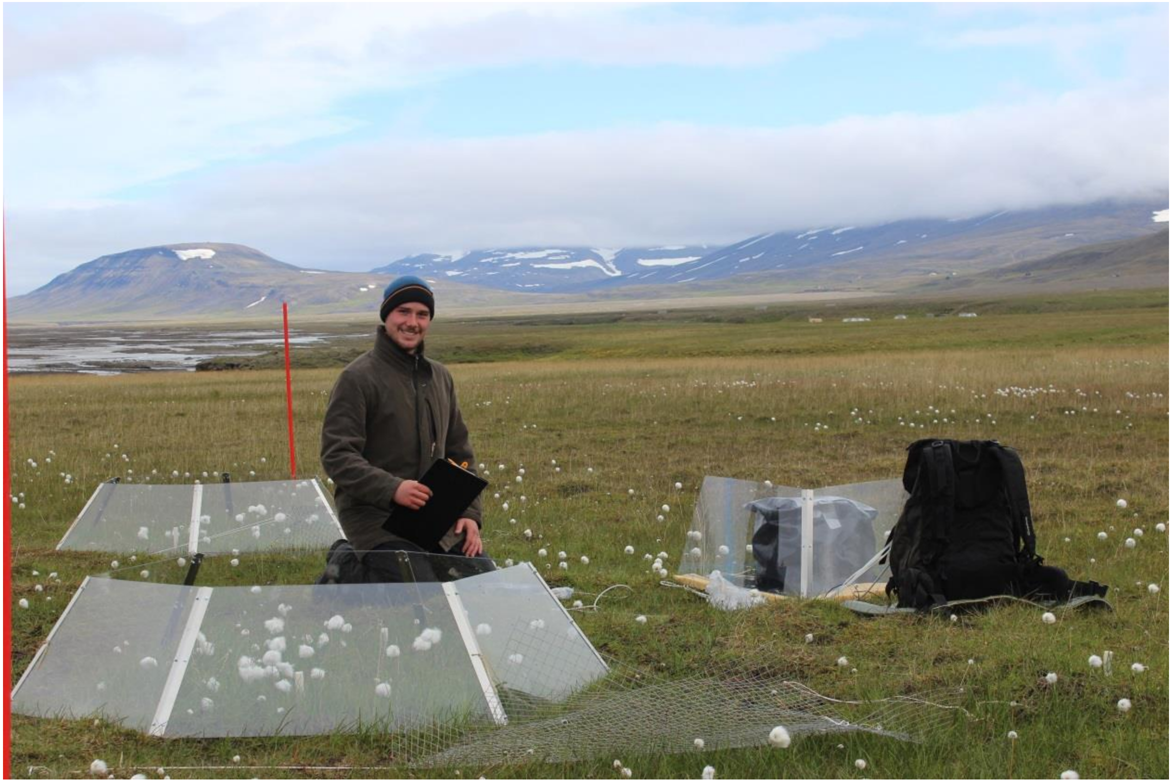


Fig. 18 –Anton Hochmuth is taking CO2 flux measurements (dark measurement – ecosystem respiration) in one of the wet communities selected for the present study (August 2016)

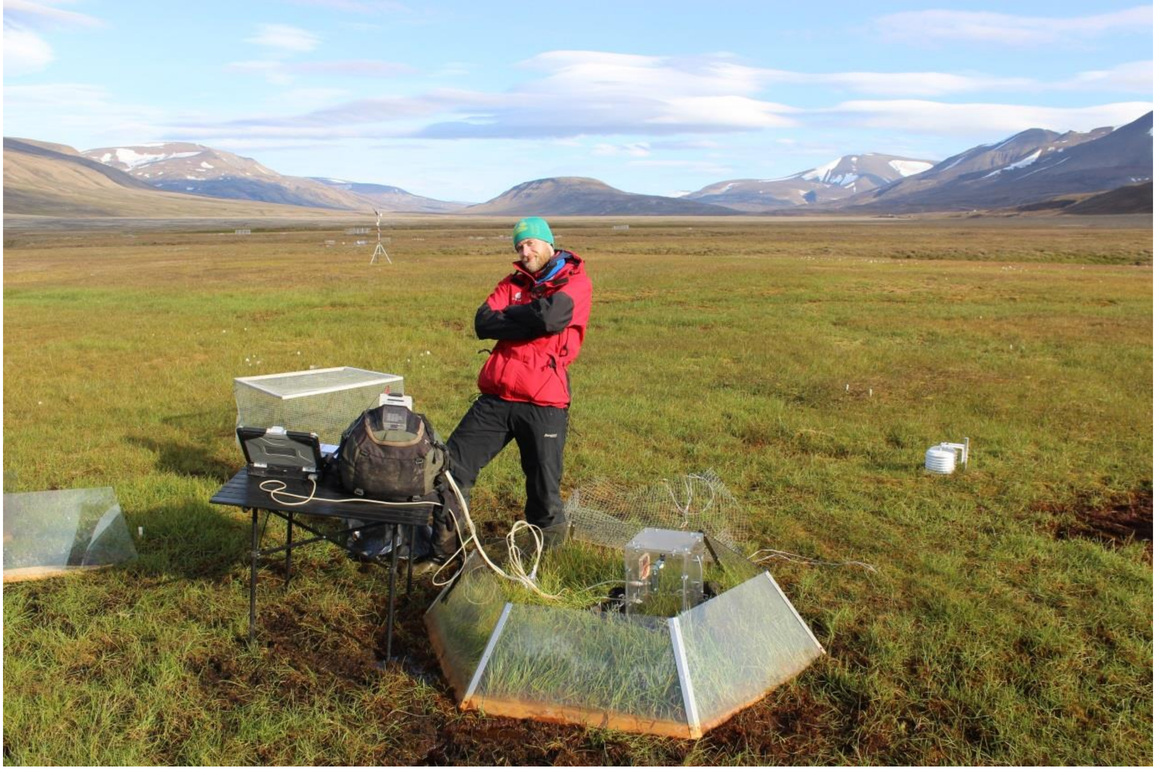


Fig. 19 – Calum Bachell is taking CO2 flux measurements (light measurement – net ecosystem exchange) in one of the wet communities selected for the present study (July 2017)

Fig. 20 – Hanna Böhner is preparing the litter to be scanned with Near Infrared Spectroscopy (NIRS) (organization is everything!) (August 2016)

Fig. 21 – Matteo Petit Bon while scanning leaves with NIRS in Tromsø (August 2016)

Fig. 22 – Some students helping out with the dismantling of the experiment in September 2016

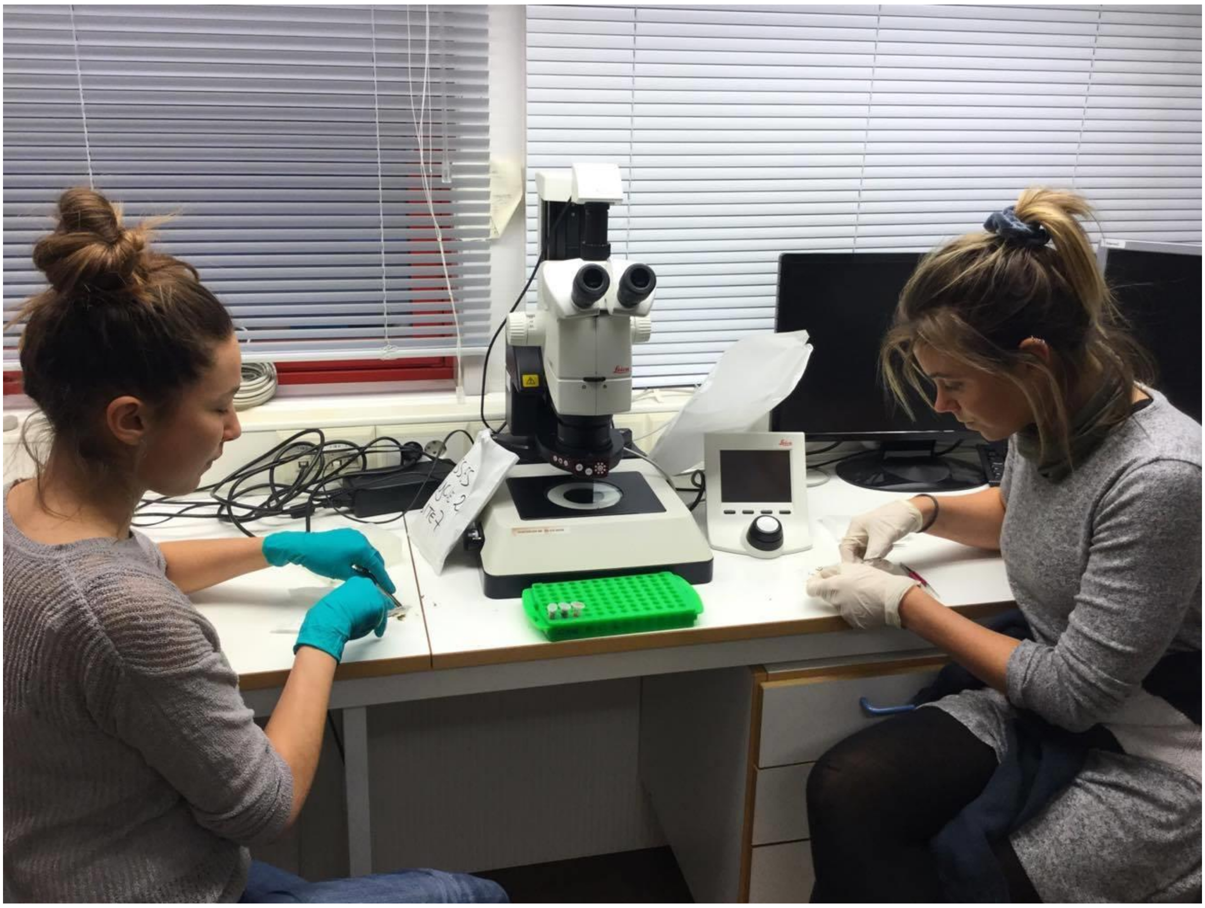


Fig. 23 – Majsofie Christensen (left) and Henninge Torp Bie (right) while cleaning the leaf samples before being processed with NIRS (August 2017)