EFFECTS OF LARGE HERBIVORES ON BIODIVERSITY OF VEGETATION AND SOIL MICROARTHROPODS IN LOW ARCTIC GREENLAND

Akia, West Greenland and southern Greenland

Scientific Report from DCE – Danish Centre for Environment and Energy No. 87 2014

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Data sheet

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Keywords: Vegetation, biodiversity, microarthropod, herbivores, sheep, caribou

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Misissuinerit Kujataani Narsarsuup eqqaani aammalu Nuup eqqaani Akiata pisimapput. Kujataani sumiiffiit savanit (*Ovis aries*) neriniarfiupput, Akianiittullu tuttunit (*Rangifer tarandus groenlandicus*) neriffigineqartarlutik.

Ataatsimut isigalugu nunat nerruigisimasut nerruigisimanngitsullu naasui assigiissuteqaqaat – aamma ukiut 25-it sinnerlugit ingerlareeraluartut. Naasut ilaat nerruigisimasuinnarni imaluunniit nerruigisimanngitsuinnarni nassaasaasut aallaavigalugit malunnarpoq neriniartarneq naasut assigiinngissitaarnerannut sunniuteqartarmat. Orpikkat naasullu ivigakkuunngitsut ungalusani amerlanerupput, aammalu uumassusillit kingunikui amerlanerullutik.

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Abstract

This report summarizes the results of a project that aims at documenting long term effects of grazing by comparing baseline data inside and outside exclosures. We collected data on vascular plants, mosses, lichens, microarthropod abundance and food-web structure, soil nutrients, decomposition, and soil temperature. Data provide a significant basis for understanding the interaction between large herbivores and vegetation in Greenland.

The report contains documentation of data collected in 2009 and 2012 as well as documentation of data from 1984-2004 made available by Jon Feilberg.

The study took place in South Greenland, and in Akia north of Nuuk in West Greenland. The southern Greenland localities are grazed by domestic sheep (*Ovis aries*), whereas Akia is grazed by caribou (*Rangifer tarandus groenlandicus*).

Generally there was a high similarity in plant species composition in grazed and un-grazed plots – even after more than 25 years. Few species only appearing inside or outside the exclosures, might indicate that grazing could have effects on the species composition. The cover of shrubs, herbs, and litter appeared to be favoured by not being grazed.

The nutrient content in soil was similar in grazed and un-grazed plots and generally, soil nutrients were at the same level in Akia and Kiattuut.

Generally temperatures were highest outside the exclosures and the cold season with temperatures below 0°C was longer in Akia than in Kiattuut.

The rate of decomposition was much higher in south Greenland than in West Greenland. The differences in decomposition rate between grazed and un-grazed plots were not significant in both Akia and Kiattuut.

The average diversity of microarthropods was highest in plots not being grazed.

Our dataset offers unique possibilities for analysing the relations between grazing, climate change and biodiversity in the low Arctic. Further in-depth analysis of the data collected will shed more light on the future effects of the large herbivores in the Arctic.

Sammenfatning

Denne rapport sammenfatter resultaterne af et projekt som skal undersøge langtidseffekter af græsning ved sammenligninger af data fra undersøgelsesfelter i indhegninger med data fra græssede felter. Vi indsamlede data vedrørende karplanter, mosser, laver, microarthropoder og fødenet struktur, næringsstoffer i jordbunden, nedbrydningshastighed og jordtemperatur. Data giver en betydelig baggrund for at forstå samspillet mellem store græsædere og vegetation i Grønland.

Rapporten indeholder dokumentation for data der er indsamlet i 2009 og 2012 samt data som er indsamlet 1984-2004 af Jon Feilberg.

Undersøgelserne fandt sted i Sydgrønland og i Akia nord for Nuuk i Vestgrønland. Lokaliteterne i Sydgrønland græsses af får (*Ovis aries*), mens Akialokaliteterne græsses af rensdyr (*Rangifer tarandus groenlandicus*).

Generelt var der stor lighed i artssammensætningen af karplanter i græssede og ugræssede undersøgelsesfelter – selv efter mere end 25 år. Få arter, som kun fandtes enten i ugræssede felter *eller* i græssede felter tyder på at græsningen har indflydelse på artsammensætningen. Dækningen af krat, urter og ”førne” blev favoriseret af ikke at blive græsset.

Indholdet af næringsstoffer i jordbunden var næsten ens i de græssede og i de ugræssede felter og indholdet var på samme niveau i Sydgrønland og i Vestgrønland.

Generelt var jordtemperaturen højere i de græssede felter og perioden med jordtemperaturer under 0°C var længere i Akia end i Sydgrønland.

Nedbrydningsraten af organisk materiale var meget højere i Sydgrønland end i Vestgrønland, mens der ikke var forskel mellem græssede og ugræssede felter hverken i Vestgrønland eller i Sydgrønland.

Gennemsnitsdiversiteten af microarthropoder var højest i ugræssede felter.

Datasættet giver gode muligheder for at analysere relationerne mellem græsning, biodiversitet og klimaændringer i lavarktis. Mere dybtgående analyser af de indsamlede data vil give ny viden om fremtidige effekter af græsning i arktis.

1 Introduction

Biodiversity is a product of the history of the habitat, its physico-chemical properties and the organisms living in the habitat. The local geology and climate, the local weather, human impacts, and the interactions between organisms at different trophic levels all determine the biodiversity of an area. Herbivores may have a significant effect on biomass and species composition (Oksanen 1990, Olofsson et al. 2001, Olofsson et al. 2002, Post & Pedersen 2008). In Greenland, important interactions occur between sheep and vegetation in the sheep farming districts in southern Greenland, and between caribou and vegetation in central West Greenland. This project aims at studying the effects of grazing on biodiversity at these areas.

The project sampled baseline data on vascular plants, mosses, lichens, microarthropod abundance and food-web structure, soil nutrients, decomposition, and soil temperature. Data can be used as a basis for future monitoring of biodiversity and for monitoring the effects of herbivores on biodiversity. Hence, data provide a significant basis for understanding the interaction between large herbivores and vegetation in Greenland.

The report contains the documentation of 2009 and 2012 studies and the data that were generated by the project. The report presents comparisons of species composition of vascular plants in grazed as well as un-grazed areas in Akia (West Greenland) and in Kiattuut in South Greenland at a number of already existing stations.

The report also contains documentation of data made available by Jon Feilberg. These data cover the studies performed in 1984-2004 along with data collected in 2009 and 2012 in the sheep farming district in southern Greenland in plots within exclosures and outside exclosures in areas grazed by sheep.

The present project has been funded by the Danish Environmental Protection Agency as part of the climate and environmental support programme to the Arctic. The authors are solely responsible for all results and conclusions presented in this report, which do not necessarily reflect the position of the funding agencies.

2 Study areas

The study took place at two areas, one in the low arctic area in South Greenland, and at one locality in low arctic Akia north of Nuuk in West Greenland (Figures 1-3). The southern Greenland localities are grazed by domestic sheep (*Ovis aries*), whereas Akia is grazed by caribou (*Rangifer tarandus groenlandicus*). Fourteen stations were investigated in South Greenland in 2009 and 2012, and three stations were investigated in Akia in 2009. At each locality, we selected one station as the main station. Each station consisted of one plot inside an exclosure, and one or two plots outside the exclosure (Table 1).

At all stations, we conducted analyses of the vegetation cover using the point-intercept method and the Raunkiær Circle method. At the main stations, we also investigated microarthropods, decomposition rate, isotopes, temperature, and nutrients in the soil. We created databases of the cover of plants for all stations. This report, however, reports only detailed information from the main stations.

Figure 1. Map of West and South Greenland. Overview of locations visited in 2009 and 2012.

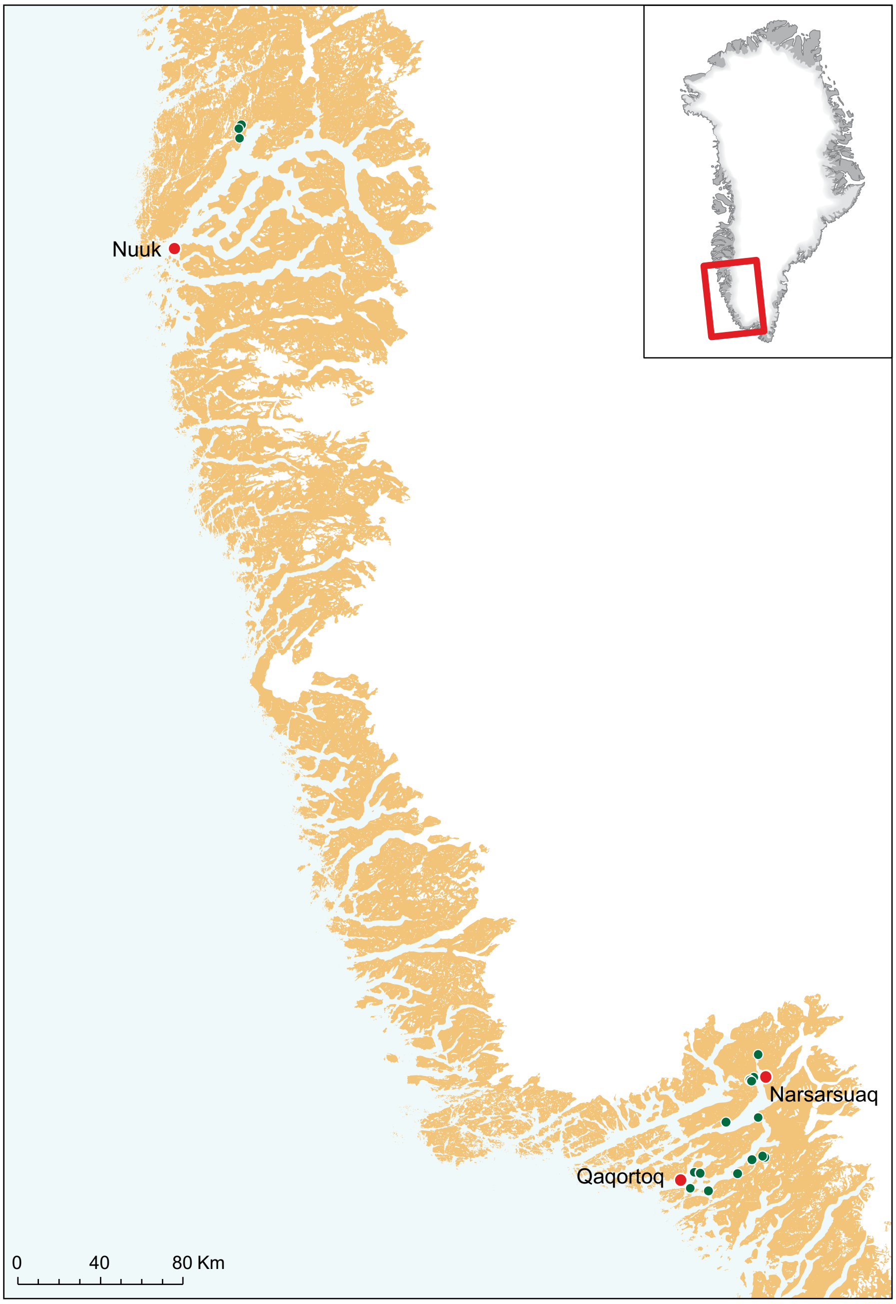


Figure 2. Stations in South Greenland marked by dots. The main station is labelled 323–326 denoting the grazed and un-grazed plot respectively.

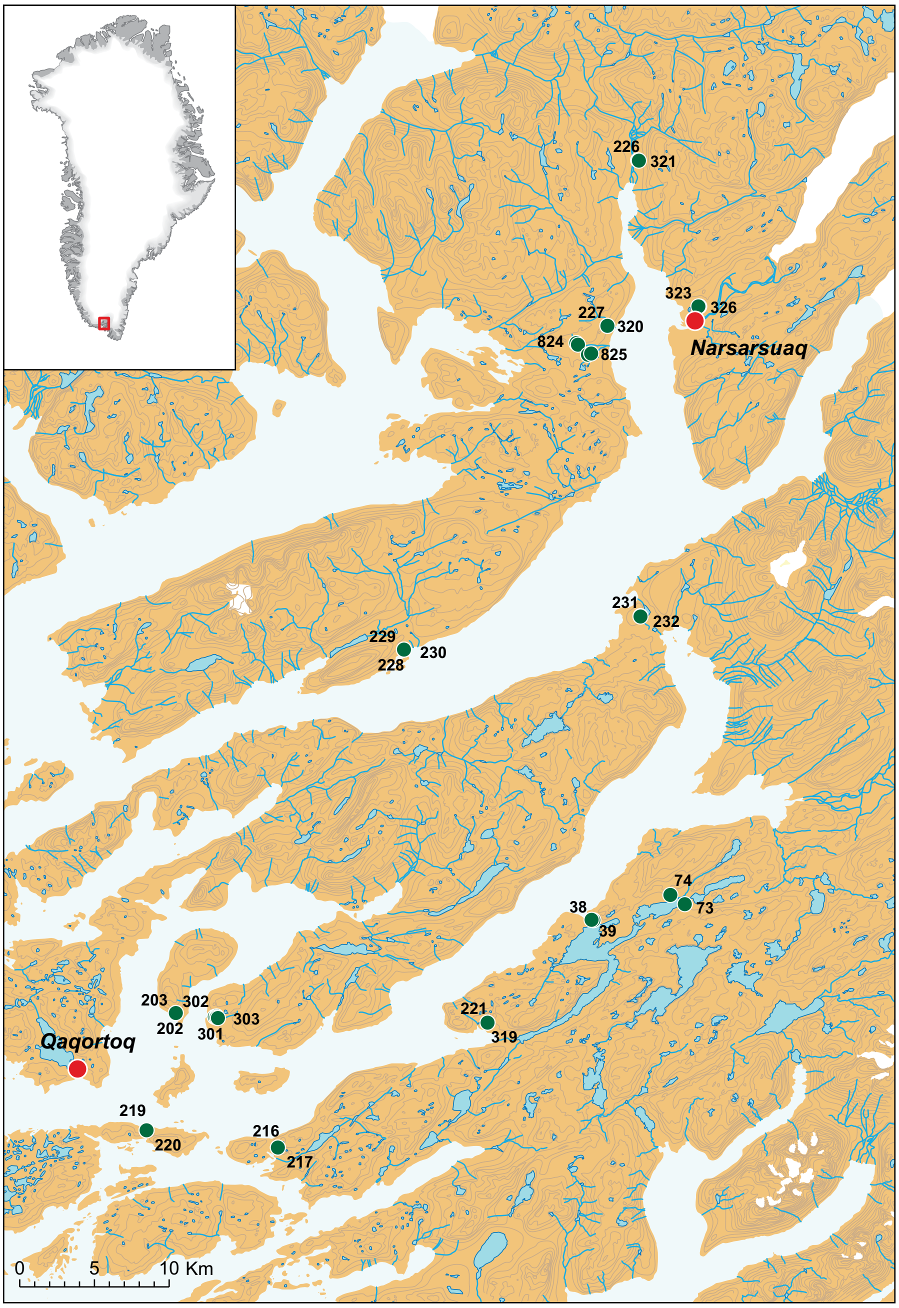


Figure 3. Stations in Akia marked by dots. The main station is labelled 2 and 5 denoting the grazed and un-grazed plot respectively.

Table 1. Overview of plots investigated in 2009 and 2012. Names in bold are main stations and GPS-positions are in decimal degrees.

Region	Plot	Geographic area	Location	Year of investigation	Inside Exclosure	Pair with no.	Est.	Northern latitude	Western longitude
West Greenland	1	Akia	Qussuq	2004, 2009	YES	4	2004	64,674	-51,3415
	2	**Akia**	**Qussuq**	**2005, 2009**	**YES**	**5**	**2004**	**64,729861**	**-51,3518**
	3	Akia	Qussuq	2004, 2009	YES	6	2004	64,713583	-51,3675
	4	Akia	Qussuq	2004, 2009	NO	1	2004	64,673667	-51,3431
	5	**Akia**	**Qussuq**	**2004, 2009**	**NO**	**2**	**2004**	**64,730306**	**-51,3519**
	6	Akia	Qussuq	2004, 2009	NO	3	2004	64,713194	-51,3677
South Greenland	38	Vatnahverfi	Qanisartut	2004, 2009	NO	39	1984	60,83166	-45,4704
	39	Vatnahverfi	Qanisartut	2004, 2009	YES	38	1984	60,83167	-45,4679
	73	Vatnahverfi	Russit Kuuat	1997, 2009	NO	74	1984	60,84976	-45,3824
	74	Vatnahverfi	Russit Kuuat	1997, 2009	YES	73	1984	60,84543	-45,3649
	202	Upernaviarsuk	Arpatsivik	1986, 1989, 2012	YES	203	1986	60,7568	-45,9398
	203	Upernaviarsuk	Arpatsivik	1986, 1989, 2012	NO	202	1986	60,75717	-45,9299
	216	Qanisartuut	Tasikulooq	1986, 1989,2004, 2012	YES	217	1986	60,68728	-45,8027
	217	Qanisartuut	Tasikulooq	1986, 1989,2004, 2012	NO	216	1986	60,68705	-45,8031
	219	Akia	Akia	1986, 2012	NO	220	1986	60,68558	-46,0098
	220	Akia	Akia	1986, 2012	YES	219	1986	60,68556	-46,0096
	221	Vatnerhverfi	Eqaluit	1986, 1989, 2012	YES	319	1986	60,76797	-45,573
	226	Qinngua Kangilleq	Qinngua Kangilleq	1992, 1997, 2004, 2009	NO	321	1986	61,25941	-45,5
	227	Qassiarsuk	Sammissoq	1992, 1997, 2009	YES	320	1986	61,16518	-45,5177
	228	Ipiutaq	Ipiutaq	1986, 1989, 2012	YES	229	1986	60,97065	-45,7222
	229	Ipiutaq	Ipiutaq	1986, 1989, 2012	NO	228	1986	60,97751	-45,7134
	231	Itilleq	Tatsip Kitaa	1989, 2009	YES	232	1986	61,00406	-45,4476
	232	Itilleq	Tatsip Kitaa	1989,197, 2009	NO	231	1986	61,00431	-45,4476
	250	Vatnahverfi	Hestesporsø	1987, 1990, 1997, 2012	NO	251	1987	60,87824	-45,3211
	251	Vatnahverfi	Hestesporsø	1987, 1990, 1997, 2012	NO	250	1987	60,87605	-45,324
	256	Vatnahverfi	Skygge Sø	1987, 1990, 1997, 2012	-	-	1987	60,86754	-45,3026
	259	Ipiutaq	Ipiutaq	1987, 1989, 2012	NO	-	1987	60,97068	-45,7208
	300	Upernaviarsuk	Upernaviarsuk	1997, 2009	YES	302	1985	60,75613	-45,8879
	301	Upernaviarsuk	Upernaviarsuk	1997, 2009	YES	303	1985	60,75602	-45,8866
	302	Upernaviarsuk	Upernaviarsuk	1997, 2009	NO	300	1985	60,75664	-45,8901
	303	Upernaviarsuk	Upernaviarsuk	1997, 2009	NO	301	1985	60,75687	-45,8881
	319	Vatnerhverfi	Eqaluit	1985, 1989, 2012	NO	221	1985	60,76991	-45,577
	320	Qassiarsuk	Sammissoq	1992, 1997, 2009	NO	227	1985	61,16564	-45,5189
	321	Qinngua Kangilleq	Qinngua Kangilleq	1992, 1997, 2004, 2009	YES	226	1985	61,25957	-45,501
	323	**Narsarsuaq**	**Kiattuut**	**1985, 1988, 1992, 1997, 2009**	**YES**	**326**	**1985**	**61,18081**	**-45,4143**
	326	**Narsarsuaq**	**Kiattuut**	**1985, 1988, 1992, 1997, 2009**	**NO**	**323**	**1985**	**61,18085**	**-45,4131**
	822	Qassiarsuk	Road to Tasiusaq	1992, 1997,2009	NO	823	1992	61,15291	-45,5499
	823	Qassiarsuk	Road to Tasiusaq	1992, 1997, 2009	NO	822	1992	61,15382	-45,552
	824	Qassiarsuk	Qassiarsuk	1992, 1997, 2004, 2009	NO	825	1992	61,14876	-45,5337
	825	Qassiarsuk	Qassiarsuk	1992, 1997, 2004, 2009	NO	824	1992	61,14812	-45,5363

2.1 The main station at Kiattuut, South Greenland

During the mid-1980s botanists made several studies in South Greenland. These studies were initiated by a working group on the environment and sheep farming in Greenland ("Arbejdsgruppen vedrørende miljø og fåreavl i Grønland"). The main task of this group was to examine the possibility of developing profitable sheep farming and to evaluate the consequences of the farming on the vegetation. Hence, a number of fenced exclosures were established to study the vegetation succession in un-grazed plots compared to grazed plots (Feilberg 1997). These plots have been visited at irregular intervals since their establishment (Table 1). Data from these studies have been made available for the project and the Greenland Institute of Natural Resources by Jon Feilberg. Table 2 gives an overview of these data.

The main station, Kiattuut, is located ca. 2 km north of Narsarsuaq in South Greenland in an area grazed by sheep. The Kiattuut station consists of an un-grazed plot within an exclosure (Plot 323) and a grazed plot (Plot 326) ca. 70 m from the exclosure. The exclosure was originally set up in 1985 but a new and larger one was built in 2010. The original exclosure was constructed leaving a large corner of the plot outside the exclosure. Hence, when doing the vegetation analyses the Raunkiær circles no. 8, 9, 10, 15, 16, and 20 and pin-point frame D, where in the grazed area. The new fence includes the entire plot. The vegetation in Plot 323 was analysed in a square of 15x15 m (Figure 4) while the vegetation in Plot 326 was analysed along a 20 m transect (Figure 5).

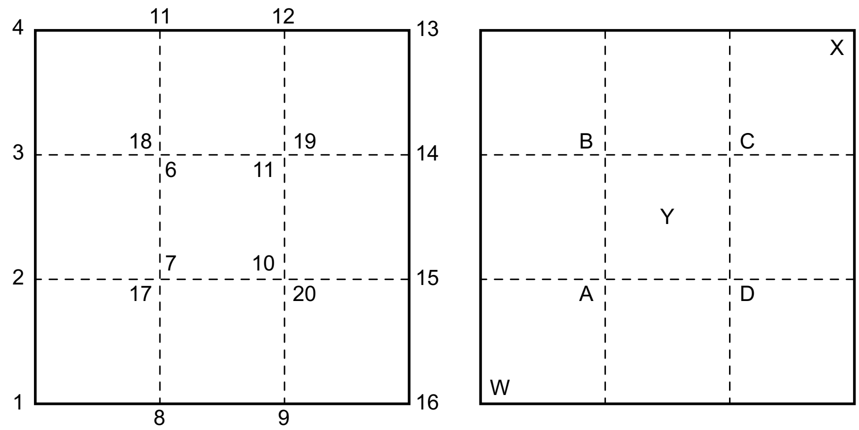


Figure 4. Placement of Raunkiær analysis (left; analysis done at each of the 20 markings) and frames for pin-point analysis (right) at 15x15 m plots (e.g. the main station plot 323 in Kiattuut). Each frame (marked with letters A, B, C, D, W, X, and Y) at the right hand side measures 0.9x0.9 m.

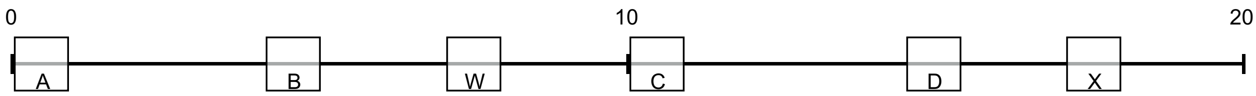


Figure 5. Placement of frames for pinpoint analysis at 20 m transect plots (e.g. Plot 326 in Kiattuut, 2 and 5 at Akia). Frame A: 0-0.9m, B: 5-5.9m, C: 10-10.9m, D: 15-15.9m, W: 7-7.9m, X: 17-17.9m. Each frame measures 0.9x0.9 m.

All four corners in the square are marked with metal pegs as are both ends of the transect.

2.2 The main station Akia, West Greenland

In West Greenland the caribou population fluctuates in numbers (Meldgaard 1986). It has been debated whether the fluctuations are primarily caused by overgrazing or by fluctuations in climatic conditions. The management of the caribou is currently based on the assumption that overgrazing should be avoided by keeping the population under a certain size allowing a sustainable harvest. In 2004 and 2005 the Greenland Institute of Natural Resources set up an experiment in Akia to get a better understanding of the relationship between caribou grazing and vegetation (Hassel 2005, Brobakk and Hassel 2006).

For this study one locality (Figure 3) was chosen in Akia. This report presents the first study after the exclosures were erected in 2004.

The main station (plot 2 and plot 5) is located close to Qussuk ca. 63 km North-east of Nuuk in West Greenland. The area is grazed by caribou with a density of 1-3 animals per km^2 (Cuyler et al. 2005).

The Akia main station embraces an un-grazed plot within an exclosure, and a grazed plot outside the exclosure. The vegetation both inside and outside the exclosure was analysed along a 20 m transect (Figure 5). The vegetation transects are marked with a metal peg at the 0 m mark and a white plastic peg at the 20 m mark. The exclosure is fenced with 2 m high steel fences and the plot outside exclosure is marked with 1.5m high, 10x10 cm wooden poles. The size of the exclosure and the grazed area are larger than previously stated (Hassel 2005) and measures ca. 21x21 m.

3 Methods

3.1 Vegetation analysis – Frequency analysis

We used the Raunkiær Circle method (Böcher and Bentzon 1958) for frequency analysis (shoot density analysis) of the vegetation. We used a bent bike spoke with markings equalling a circle of respectively 1/1000 m^2 (mark at 1.77 cm from the bend), 1/100 m^2 (mark at 5.60 cm), and 1/10 m^2 (mark at 17.70 cm). All species rooted in the inner (closest to the bend), middle and outer circle were given a score of 3, 2 and 1 respectively. The frequency analysis consisted of 20 Raunkiær circles (numbered 1-20). Frequency analyses along transects were conducted at points one meter apart starting at 1 m. In plots with squares of 15x15 m the sampling points were distributed as shown in Figure 4.

Lichens and mosses were not determined to species level in the field. Samples of the different species were collected and lichens were determined by Eric Steen Hansen (Natural History Museum of Denmark), while mosses were determined by Kristian Hassel (Norwegian University of Science and Technology).

3.2 Vegetation analysis – Pin-point analysis

We used the pin-point method (Jonasson 1988) for the cover ratio analysis. A 90x90 cm frame with nylon strings gave 10x10 = 100 points of measurements (including the inner frame edges). A knitting pin (or the like) was used to pin-point species. At the main station lichens and mosses were identified to species level and analysed separately from the layer of vascular plants. At all other stations the lichens and mosses were only included in the analyses as either "Lichen" or "Moss". When vegetation was higher than knee-level the cover of this upper canopy was not included in the pin-point analysis. Instead, we estimated the cover of the canopy in percentages before the analyses.

Six frames (A-D, W, and X) were analysed in each plot in 2009[1]. The previous studies (Feilberg 1984, 1997, 2004) only included frame A-D. Pin-point frames were distributed as shown in Figure 4 and 5.

3.3 Nutrient probes, temperature loggers, and litterbags

Soil nutrient availability was measured at the main stations by PRS™-probes (Plant Root Simulator – probe, Western Ag Innovations Inc., Saskatoon, SK, Canada). The probes have an ion exchange membrane fitted into a plastic probe which could be inserted in the soil. The probes acted as a normal plant root surface with a surface area of 17.5 cm^2, hence nutrient supply rates could be studied since the probes adsorb charged ions continuously during the burial time. A total of 80 PRS™-probes were buried in pairs: one cation and one anion (40 at each main station, thus giving 10 pairs inside and 10 pairs outside exclosure at each location). The PRS™-probes were buried at a depth of 5 cm for 1 year at both main stations. For further information on the handling of PRS™-probes at layout and upon retrieval please consult the

[1]A seventh frame Y was added at the main station in Kiattuut

Plant Root Simulator (PRS™) Operations Manual (Western Ag Innovations Inc. 2010).

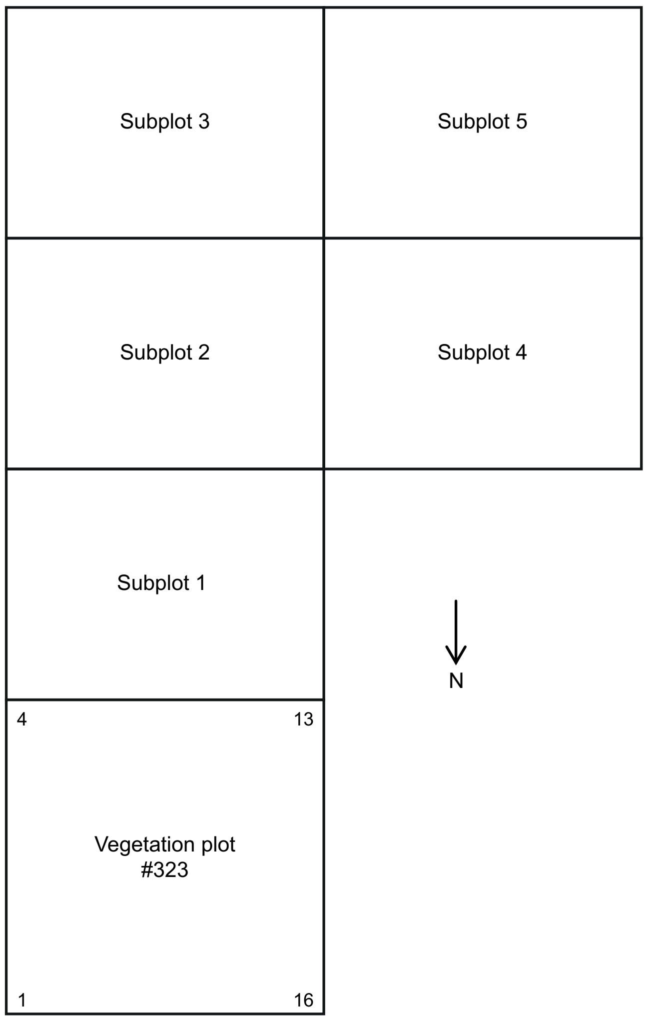
Soil temperatures were measured at a depth of approximately 5 cm using wireless GeoPrecision mini data loggers. The data loggers were programmed to record temperature every hour during the burial period of one year.

Decomposition was studied by measuring degradation of filter paper in litterbags deposited at a depth of 5 cm. The litterbags had a mesh size of 5x5 mm and contained 4 pieces of filter paper (VWR European Cat. No. 516-0814, Ø = 90 mm). A thorough description of the methodology can be found in Aastrup et al. 2009.

After 1 year litterbags were retrieved and brought to the laboratory, and then cleaned for roots, organic matter, soil particles etc., dried at 60 degrees and weighed.

PRS™-probes, temperature loggers, and litterbags were buried in 10 subplots (Subplots 1-10) adjacent to the vegetation monitoring plots. The layout depended on whether the vegetation plot was a 15x15 m square (Plot 323, Figure 6) or a 20 m transect (Plot 326, Plot 2 and Plot 5, Figure 7). Subplots within the exclosure were numbered 1-5 while subplots outside the exclosure were numbered 6-10.

Figure 6. Location of subplots with nutrient probes (in subplot 1 only), temperature loggers (in subplot 1 only), and litterbags (in each of the 5 subplots) in relation to the vegetation plot 323.



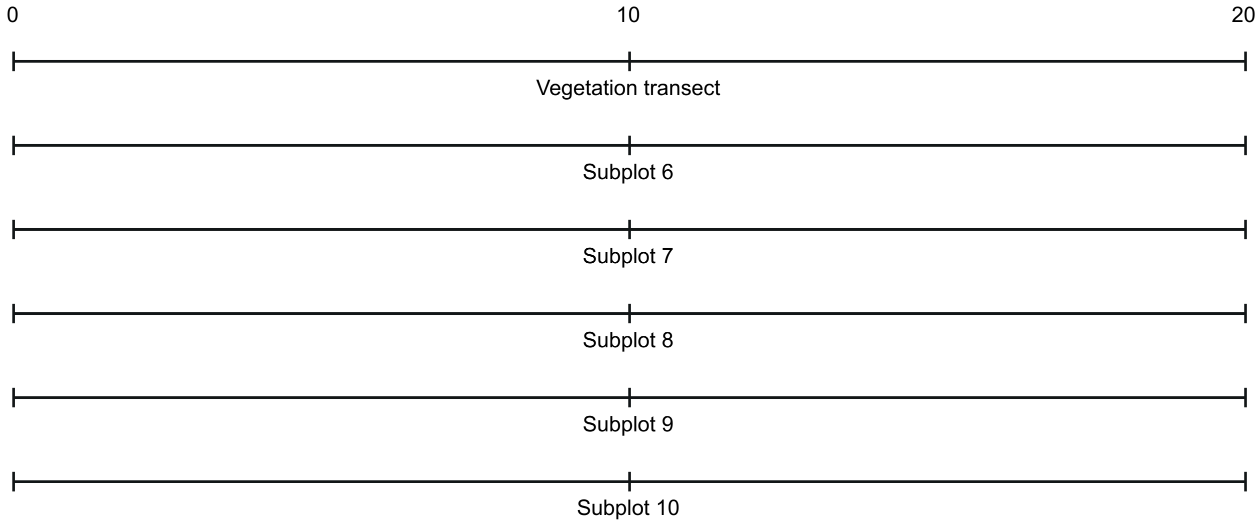


Figure 7. Location of subplots with nutrient probes (in subplot 6 only), temperature loggers (in subplot 6 only), and litterbags (in each of the 5 subplots) in relation to the vegetation plots 326 (outside exclosure), 2 and 5 (both inside and outside exclosure).

Ten litterbags were buried 1 m apart in each of the subplots 1-5 and 6-10 giving a total of one hundred litter bags at each main station. All litterbags were marked with either white plastic sticks or wooden sticks with yellow tape.

The locations of PRS™-probes, temperature loggers and litterbags are shown in Figure 8.

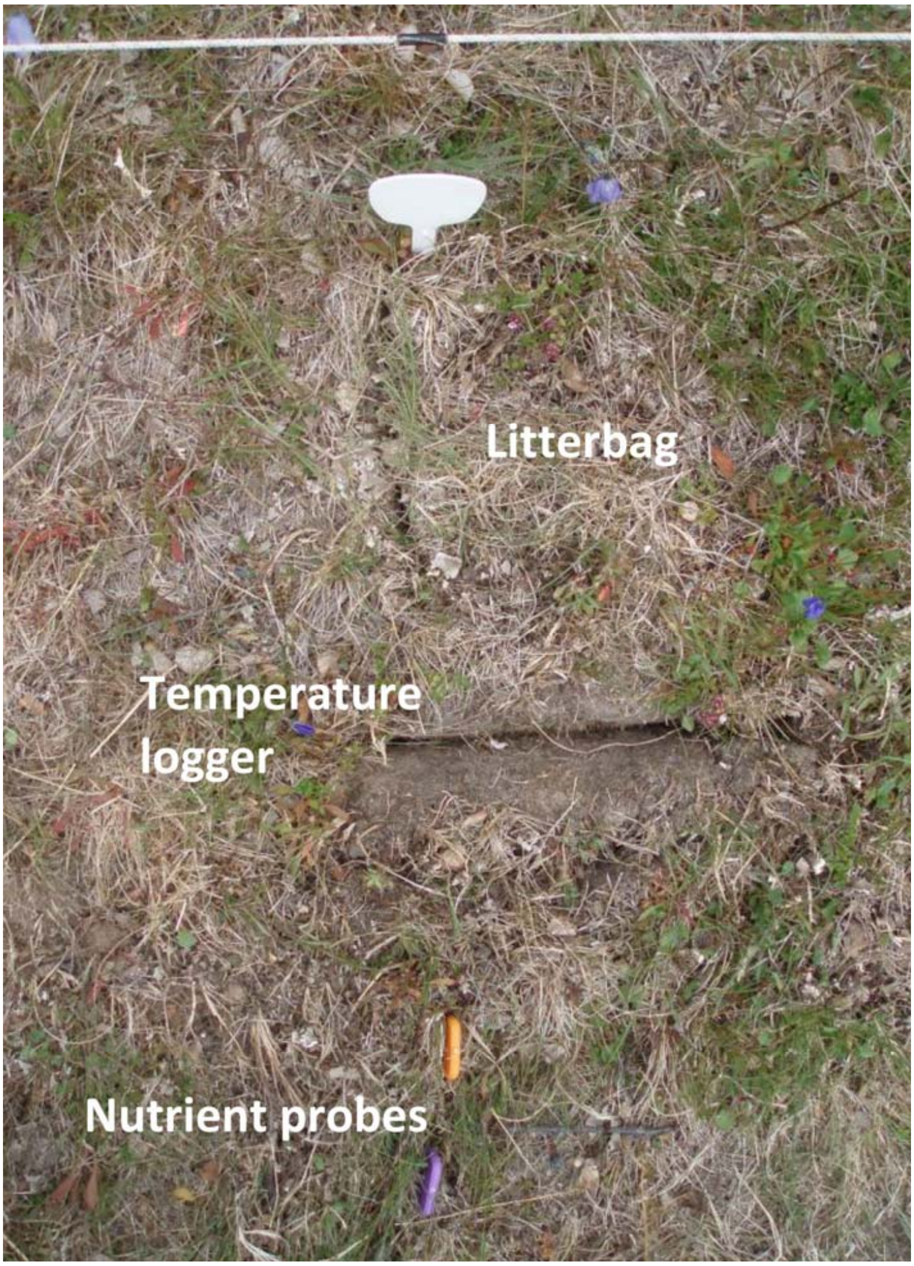
3.4 Soil samples for microarthropod extraction

We collected soil samples for microarthropod (collembolans and mites) extraction from each of the main stations. Samples were collected both inside and outside exclosures.

The following samples were collected: 2 samples, consisting of blocks of 20x30x10 cm, for bulk extraction of microarthropods at subplots 1-4 and 6-9 (totaling 16 samples at each location), and 4 samples with a soil auger (Ø = 6 cm, depth = 5.5 cm) at subplots 1-5 and 6-10 totaling 40 samples at each location. All samples were marked with date, locality and transect number (subplot number). Samples were sent to P.H. Krogh at Department of Bioscience, Aarhus University for further processing and analysis according to Aastrup et al. 2009.

Compression of the soil and litter was avoided at all stages of handling. The samples were stored as cold as possible (preferably between 0 to 10 °C) until processing.

Figure 8. The instruments were buried in the same manner at both Kiattuut, and at Qussuk, Akia. The 10x10 cm litterbag was buried closest to the transect line (vertical slot in soil), temperature logger in the middle (horizontal slot in soil) and nutrient probes (orange and purple plastic tops) furthest away from the line. The white plastic stick marks the litterbag (buried with 1 meter intervals). For further explanation please see the text.



3.5 Soil samples for physico-chemical soil characterisation

From each plot at the main stations we collected ca. 1 kg soil in a plastic bag for physico-chemical soil characterization.

3.6 Isotope composition and food-web structure

Isotope analyses are used to investigate the structure of food webs by providing time- and space-integrated insights into trophic relations between organisms (Fry 2006; Layman et al. 2011). The theory behind the application of isotopic signatures in ecological investigations is briefly that the larger the difference in content of $\delta^{15}N$ and $\delta^{13}C$ between two organisms or sources of organic matter, the more steps have been involved in the transfer of nitrogen through the food chain. This difference in content of of $\delta^{15}N$ and $\delta^{13}C$ is denoted the fractionation factor. The essential mechanism is the fractionation, which for each biochemical processing of ^{15}N increases the ^{15}N body content. An organism increases its body content of ^{15}N and ^{13}C compared to its food source, so it will always have an isotopic signature larger than its food source. A difference between two isotopic δ signatures of $\Delta \approx 3$ normally indicate a shift in one trophic level (Fry 2006).

Main types of dead and alive organic matter sources were visually identified from blocks of turf including bottom mineral soil cut from all the plots. Microarthropods were collected alive on plaster of Paris substrate during the extraction using a MacFadyen type of high temperature gradient equipment for the turf samples (Petersen 1978, Aastrup et al. 2009). To preserve the biomass for whole body determination of ^{15}N and ^{13}C live animals are needed to avoid loss of body content into the liquids that are usually used to fixate the extracted animals. Collembolans were sorted into species and mites into orders. A few individuals of dominant invertebrates were also included for reference and in their own right to characterise their trophic position.

3.7 Statistical analysis

To visualise the similarity between species inside and outside exclosures a similarity index, QS, (Sørensen, 1948) was calculated using data from the pin point analysis. The index is calculated as $QS = 2C/(A+B)$, where A and B are the number of species in samples A and B, respectively, and C is the number of species shared by the two samples. The index ranges from 1 to 100. A higher index equals a higher similarity.

Differences in nutrient content in the soil was tested using Kruskall-Wallis test.

Soil temperature differences were tested using the t-test.

Differences in the ratio of stable isotope ^{15}N ($\delta^{15}N$) for *Folsomia quadrioculata* between inside and outside exclosure was tested using a one-way ANOVA (F-test, $P<0.05$).

A Principal Component Analysis (PCA) of log (x+1) transformed population densities and diversity, S (species richness), H (diversity index) and E (evenness) was used to assess the microarthropod spatial and diversity distribution inside and outside exclosure.

Differences in litter bag weight was tested using a one-way ANOVA.

4 Results

This chapter presents a selection of the most significant results from each main station.

All the databases that were created as an outcome of the project are presented in Table 2. The databases from 2009 and 2012 are available at www.natur.gl.

Table 2. List of databases with data generated during the field work in 2009 and 2012 and the data made available by Jon Feilberg.

Vegetation composition	Database. Pin point analyses in Akia and South Greenland. Database. Raunkiær analyses in Akia and South Greenland. Data from 1984-2002 in South Greenland provided by Jon Feilberg.
Nutrient analyses	Results of nutrient analyses in soil in Akia and Kiattuut
Temperature	Temperatures measured at Kiattuut and Akia from July 2009 to July 2010.
Decomposition - Litter bags	Weights of litterbags in Akia and Kiattuut at lay-out in July 2009 and after app. one year in the field.
Microarthropods	Data related to microarthropod sampling are summarised in a database including the parameters summarised in Table 4.6.

4.1 Vegetation composition

4.1.1 The main station at Kiattuut in South Greenland

In total we recorded 39 species (29 vascular plants, 7 lichens, and 3 mosses (Table 3).

In the pin point analysis we recorded 22 plant species (plus soil and rock surfaces) at Kiattuut. Seventeen of these occurred inside as well as outside the exclosure, seven were only recorded outside the exclosure, and three were only found inside the exclosure.

Kiattuut is characterised by *Deschampsia flexuosa, Agrostis stricta, Betula pubescens,* and litter) (Figure 9). The cover of *Anthoxanthum odoratum* and *Campanula gieseckiana* is significantly higher inside the exclosure compared to outside the exclosure. *Betula pubescens* appear to be more abundant inside the exclosure, though this is not significant.

Four species did not occur inside the exclosure, and four species of herbs and graminoids only occurred inside the exclosure (Table 3). Outside the exclosure bare soil comprise almost five per cent while it is almost non-existing inside the exclosure.

The similarity index, QS, (Sørensen 1948) between species inside and outside the exclosure was 77.8. Increased cover in the non-grazed plots is very distinctive for shrubs, herbs, and litter, while graminoids and lichens decrease inside the exclosures (Figure 10).

Table 3. Flora lists from the main stations at Kiattuut, South Greenland and Akia, West Greenland. The table is separated into vascular plants, lichens, and mosses and further divided to separate observations inside exclosures (In) and outside exclosures (Out).

	Kiattuut		Akia	
Vascular plants	**In**	**Out**	**In**	**Out**
Agrostis stricta	x	X		
Antennaria alpina	x	x		
Anthoxanthum odoratum	x	x		
Betula nana			x	x
Betula pubescens	x	x		
Botrychium lunaria	x	x		
Calamagrostis langsdorfii			x	x
Campanula gieseckiana	x	x		
Carex abdita	x	x		
Carex bigelowii			x	x
Carex capillaris			x	x
Carex praticola	x	x		
Carex scirpoidea			x	x
Carex supina	x	x		
Cerastium alpinum	x	x		
Deschampsia flexuosa	x	x		x
Empetrum nigrum			x	x
Erigeron uniflorus		x		
Euphrasia frigida	x			
Festuca rubra	x	x		
Hieracium nigrescentia	x	x		
Juniperus communis	x	x		
Ledum groenlandicum				x
Ledum palustre			x	x
Loiseleuria procumbens			x	x
Luzula multiflora		x		
Luzula spicata	x			
Lycopodium annotinum			x	x
Phyllodoce coerulea			x	x
Poa glauca	x	x		
Poa pratensis	x			
Polygonum viviparum			x	x
Potentilla tridentata	x	x	x	x
Rhinantus minor			x	
Rumex acetosella		x		
Salix arctophila			x	x
Salix glauca		x	x	x
Salix herbacea			x	x
Taraxacum sp.	x	x		
Thalictrum alpinum	x			
Thymus praecox	x	x		
Trisetum triflorum	x	x		
Vaccinium uliginosum			x	x
Veronica fruticans	x	x		
Viscaria alpina	x	x		
Total no. of vascular plants	29		19	

	Kiattuut		Akia	
Lichens	**In**	**Out**	**In**	**Out**
Cetraria delisei	x	x	x	
Cetraria islandica	x			
Cladina rangiferina	x	x		
Cladonia sp.			x	x
Cladonia chlorophaea	x	x		
Cladonia cyanipes			x	x
Cladonia stricta	x	x		
Cladonia stygia			x	x
Peltigera aphthosa				x
Peltigera neckeri			x	x
Peltigera rufescens	x			
Peltigera scabrosa			x	x
Stereocaulon alpinum	x		x	
Total no. of lichens	7		8	
	Kiattuut		**Akia**	
Mosses	**In**	**Out**	**In**	**Out**
Aulacomnium palustre			x	
Cephaloziella sp.	x	x		
Dicranum scoparium			x	x
Onchophorus wahlenbergii			x	
Pleurozium schreberii			x	x
Plytrichum hyperborean			x	
Polytricum affine		x		
Ptilidium ciliare	x	x		
Sphagnum sp.			x	x
Total no. of mosses	3		6	

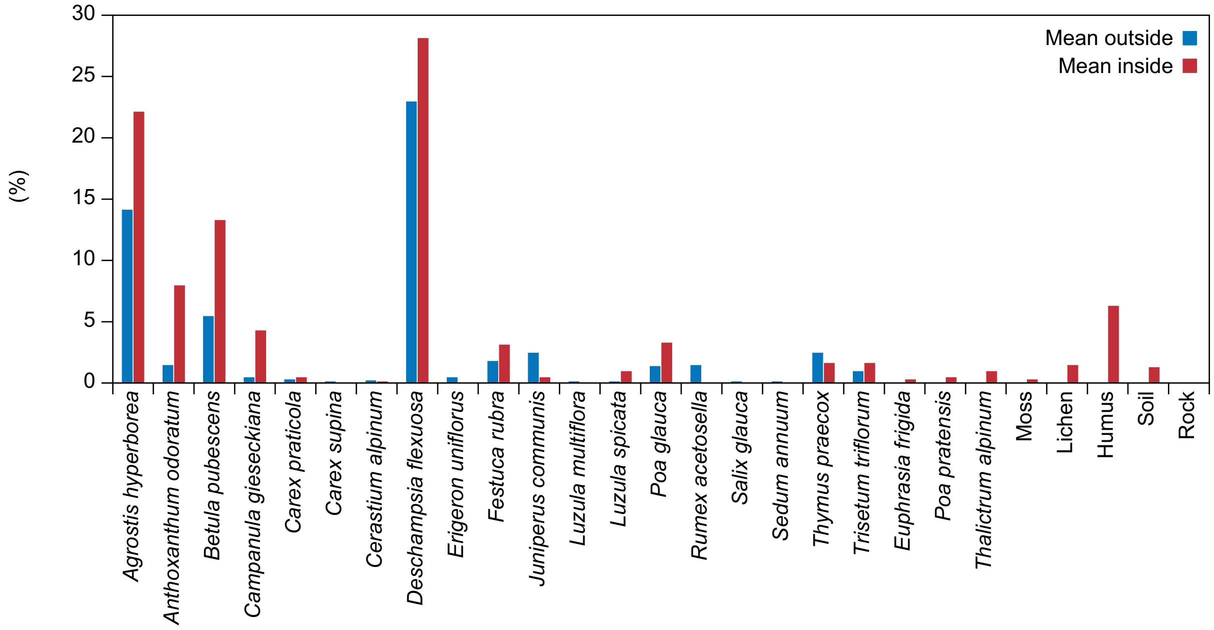


Figure 9. Vegetation composition by species at the main station in Kiattuut outside exclosure (blue) and inside exclosure (red). The differences in cover inside and outside the exclosure are significant for *Anthoxanthum odoratum* and *Campanula gieseckiana* (t-test) only.

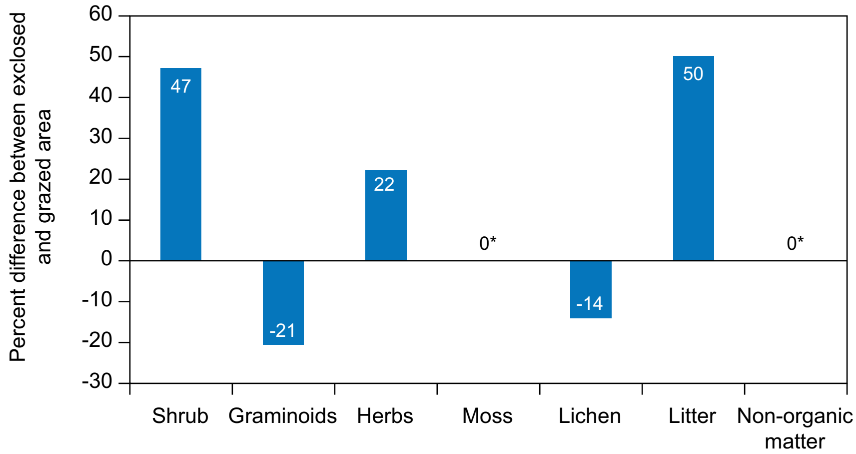


Figure 10. Changes in the cover of non-grazed and grazed areas in Kiattuut during 1985-2009. Calculations are based on the difference in cover between the grazed plot in 1985 and the non-grazed plot in 2009. A positive value indicates an increasing cover in the non-grazed area and a negative value indicates a decreased cover in the exclosure. (*) Mosses and non-organic matter were not present in 1985 when the exclosure was established.

4.1.2 Vegetation composition at the main station in Akia

In total we recorded 33 species (19 vascular plants, 8 lichens, and 6 mosses) beside rock and soil at Akia main station (Table 3). There was little visual difference between the area within the exclosure and the grazed area. Both areas are dominated by *Empetrum nigrum* and knee high shrubs (*Vaccinium uliginosum*, *Salix glauca*, and *Betula nana*).

Woody plants e.g. *Betula nana*, *Vaccinium uliginosum*, and *Salix glauca* characterise the main station in Akia (Figure 11).

Bare soil and two woody plants (*Ledum groenlandicum* and *Salix arctophila*), occurred only outside the exclosure. The herb *Rhinanthus minor* occurred only inside the exclosure (Table 3).

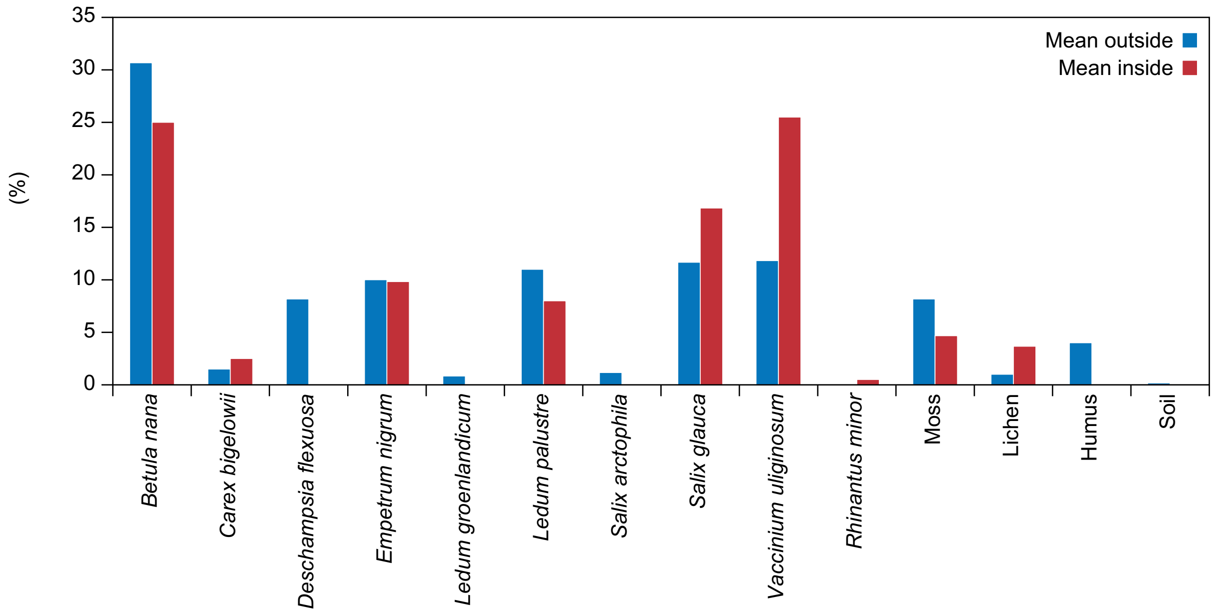


Figure 11. Species composition of the vegetation at the main station in Akia inside (red) and outside (blue) the exclosure. None of the differences are significant.

In the bottom layer the cover of *Cladonia* sp. was higher inside the exclosure than outside the exclosure. Further, the lichens *Stereocaulon* sp. and *Cetrariella delisei* along with the mosses *Polytrichum hyperboreum*, *Onchophorus wahlenbergii*, and *Aulacomnium palustre* occurred only inside the exclosure.

The QS index (Sørensen, 1948) comparing the species inside and outside the exclosure was 87.2 (including species in the bottom layer). None of the changes in cover between 2004/05 and 2009 are significant. Looking at growth forms it appears that mosses and gramimoids became more dominant outside exclosure, while lichens increased inside the exclosure.

4.2 Soil nutrients and properties

Generally, soil nutrients were at the same level in Akia and Kiattuut except sulphur (S), which was about ten times higher in Akia than in Kiattuut, and calcium (Ca) which was about double as high in Kiattuut compared to Akia.

The difference in the content of soil nutrients inside and outside the exclosure is greater in Akia than in Kiattuut. Most important are Total nitrogen (N), nitrogen fixed in ammonium (NH_4-N), calcium (Ca), and iron (Fe) which were significantly higher outside the exclosure in Akia.

4.2.1 Kiattuut

The soil content of sulphur (S) was significantly higher outside the exclosure than inside the exclosure. There were no significant differences in the concentrations of any other element (Table 4).

Table 4. Nutrient content in soil at Kiattuut (µg nutrient/PRS probe/1 year). NH_4-N is nitrogen fixed in ammonium. Significances were tested by a non-parametric ANOVA. Only the difference in the content of sulphur was significant ($P<0.05$).

Variable	Mean - Inside exclosure	Std Dev	Minimum	Maximum	Mean - Outside exclosure	Std Dev	Minimum	Maximum	Kruskall-Wallis In/Out
Total N	9.80	6.45	3.00	30.60	8.24	6.14	1.40	29.60	0.2445
NH_4-N	6.99	5.99	2.40	29.60	5.19	3.61	0.00	14.40	0.2552
Ca	1582.38	295.53	1093.40	2128.00	1425.14	494.15	0.00	2156.00	0.3720
Mg	546.50	136.15	381.20	934.60	484.74	166.95	0.00	696.20	0.4614
K	326.65	161.51	86.00	580.00	224.61	134.22	0.00	594.80	0.0810
P	10.36	11.35	1.80	53.80	9.60	7.57	1.60	29.60	0.9353
Fe	12.93	8.70	4.00	39.20	13.10	9.20	6.40	44.40	0.7554
Mn	9.96	8.74	1.00	30.80	13.30	18.13	1.20	64.60	0.8181
Cu	0.27	0.12	0.20	0.60	0.32	0.18	0.20	0.80	n/a
Zn	4.25	2.79	0.60	10.80	6.32	3.92	1.20	16.20	0.0677
B	2.70	1.21	1.00	5.20	2.21	1.26	0.80	4.60	0.1974
S	9.55	5.03	1.00	18.80	12.91	5.19	6.00	23.00	0.0497
Pb	0.09	0.17	0.00	0.60	0.06	0.13	0.00	0.40	n/a
Al	42.48	8.47	31.80	63.40	34.80	10.12	10.40	47.80	0.0548
Cd	0.09	0.22	0.00	0.80	0.31	0.45	0.00	1.40	n/a

The soil properties (Table 5) were similar inside and outside the exclosure. The only exception was the higher content of coarse sand outside the exclosure compared to inside. Sand and fine-sand differed slightly between the grazing treatments within and outside exclosures.

Table 5. Soil texture in Kiattuut determined from a 1 kg sample of soil. Soil properties of the mineral soil below the organic layer with their 95% confidence limits. * Indicates a significant difference between parameters when performing ANOVA, (F-test, P<0.05).

	Inside exclosure		Outside exclosure	
Coarse sand, %	22*	[19-25]	25*	[23-28]
Fine sand, %	73	[70-76]	70	[67-73]
Silt, %	1.2	[0.7-1.7]	1.5	[0.8-2.2]
Clay, %	1.5	[1.3-1.7]	1.3	[1.0-1.6]
Humus, %	2.3	[1.8-2.8]	2.1	[1.3-2.9]
C, %	1.3	[1.0-1.6]	1.2	[0.9-1.6]
N, %	0.2	[0.1-0.3]	0.6	[-0.7-1.8]
C/N	8.0	[3.7-12]	17	[-11-44]
pH	5.4	[5.2-5.6]	5.2	[5.0-5.4]
P mg kg^{-1}	0.5	[0.4-0.7]	0.6	[0.5-0.6]
K mg kg^{-1}	2.1	[1.5-2.8]	2.2	[1.5-2.8]
Mg mg kg^{-1}	5.6	[4.2-6.9]	6.8	[4.9-8.6]
NO_3^- mg kg^{-1}	1.7	[-0.7-4.1]	0.6	[-0.1-1.2]
NH_4^+ mg kg^{-1}	2.5	[0.6-4.4]	1.4	[0.7-2.1]
N_{min} kg ha^{-1}	45.4	[12-79]	21.4	[13-30]

4.2.2 Akia

The concentrations of magnesium (Mg), potassium (K), and zink (Zn) were significantly higher inside the exclosure than outside the exclosure. Total nitrogen (N), nitrogen fixed in ammonium (NH_4-N), calcium (Ca), iron (Fe) were significantly higher outside the exclosure (Table 6).

Table 6. Nutrient content in soil in Akia (µg nutrient/PRS probe/1 year). NH_4-N is nitrogen fixed in ammonium. Significances were tested by a non-parametric ANOVA, (P<0.05).

Variable	Mean - Inside exclosure	Std Dev	Minimum	Maximum	Mean - Outside exclosure	Std Dev	Minimum	Maximum	Kruskall-Wallis In/Out
Total N	9.29	4.65	1.00	18.40	17.00	7.34	8.60	34.40	0.0003
NH_4-N	7.52	3.29	0.00	12.60	12.74	7.10	3.00	34.40	0.0047
Ca	777.96	304.11	73.60	1143.40	1615.06	240.28	1276.40	2208.00	<.0001
Mg	671.31	266.27	40.80	1009.20	600.92	127.84	410.20	944.60	0.0483
K	340.32	285.22	18.40	1074.60	62.36	66.90	8.00	243.40	0.0002
P	9.23	12.14	0.80	38.00	5.16	4.67	0.40	20.00	0.8180
Fe	3.82	3.17	0.60	11.60	10.29	10.25	0.80	42.40	0.0090
Mn	28.34	32.73	3.00	123.80	7.56	6.04	0.60	22.80	0.0003
Cu	0.15	0.09	0.00	0.20	0.38	0.34	0.00	1.20	n/a
Zn	4.58	2.32	0.00	10.40	1.57	0.92	0.40	3.80	<.0001
B	0.96	0.56	0.40	2.60	1.72	1.69	0.40	7.80	0.1406
S	82.70	60.98	5.20	222.00	116.89	61.42	10.00	229.00	0.0810
Pb	0.00	0.00	0.00	0.00	0.03	0.07	0.00	0.20	n/a
Al	33.18	14.86	12.40	62.60	39.47	15.94	15.40	81.20	0.2286
Cd	0.06	0.13	0.00	0.40	0.07	0.13	0.00	0.40	n/a

The soil properties (Table 7) were similar inside and outside the exclosure except for pH and ammonium (NH_4^+), which were significantly higher outside the exclosure, ANOVA, (F-test, $P<0.05$). The Akia locality had a clay type of soil with very high organic matter content, while the soil at Kiattuut was sandy with low organic matter content.

Table 7. Soil texture in Akia determined from a 1 kg sample of soil. Soil properties with their 95% confidence limits. * indicates a significant difference between parameters when performing ANOVA (F-test, P<0.05).

	Inside exclosure		Outside exclosure	
Coarse sand, %	9.5	[-1.3-20]	9.9	[-2.0-22]
Fine sand, %	17.4	[2.8-32]	23	[4.1-42]
Silt, %	9.3	[6.5-12]	14	[8.5-19]
Clay, %	5.8	[1.5-10]	5.9	[1.9-10]
Humus, %	58	[32-84]	47	[10-84]
C, %	32	[19-45]	25	[5.2-44.8]
N, %	1.1	[0.2-2.0]	1.1	[-0.1-2.4]
C/N	45	[-9.1-98]	32	[14-51]
Ph	4.2*	[4.0-4.4]	4.8*	[4.2-5.4]
P mg kg^{-1}	1.0	[0.4-1.6]	0.9	[-0.0-1.8]
K mg kg^{-1}	6.2	[2.7-9.7]	4.3	[2.7-6.0]
Mg mg kg^{-1}	8.1	[4.0-12]	7.6	[4.5-11]
NO_3^- mg kg^{-1}	5.3	[2.4-8.3]	2.5	[-1.2-6.2]
NH_4^+ mg kg^{-1}	4.1*	[-2.2-10]	38*	[-11-87]
N_{min} kg ha^{-1}	102	[34-169]	436	[-84-956]

4.3 Soil Temperature

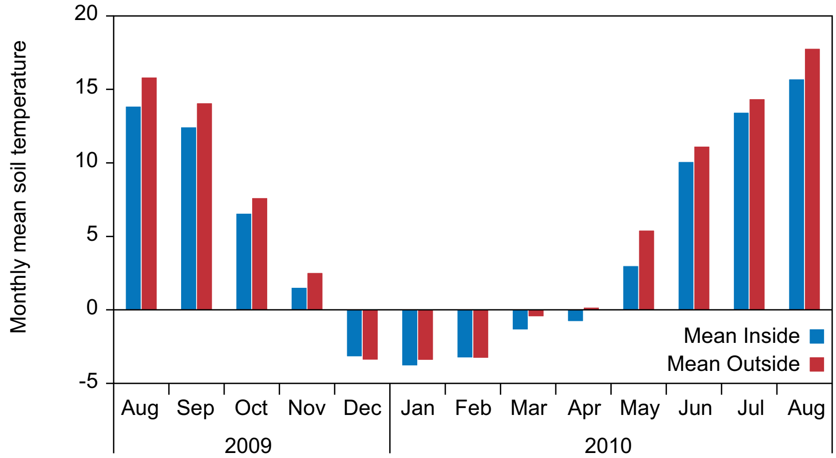
Generally, temperatures were higher outside the exclosure both in Akia and in Kiattuut. The lowest mean winter temperatures were similar at the two study sites in Akia and Kiattuut while the highest summer temperature in July in Kiattuut was more than 5°C higher than in Akia. The lowest winter temperature was recorded as early as December in Kiattuut while the minimum winter temperature appeared in March in Akia.

The period with temperatures below 0°C was longest in Akia lasting 7 months from October to April. In Kiattuut this period was only four months from November to March. Within the exclosure temperatures below zero were also recorded in March.

4.3.1 Kiattuut

The monthly mean temperatures were significantly higher outside the exclosure than inside the exclosure in all months except November 2009 (Figure 12). Temperatures were below 0°C in November-February and inside the exclosure also in March. The lowest average temperature, -3.8°C, was recorded in December 2009. The monthly mean temperatures were above 0°C the rest of the year. The highest mean monthly temperature, 15.8°C, was recorded in July 2010.

Figure 12. Monthly mean soil temperature in Kiattuut July 2009 to July 2010. The differences in average temperature inside and outside the exclosures are significant (P < 0.001) for all months except January 10.

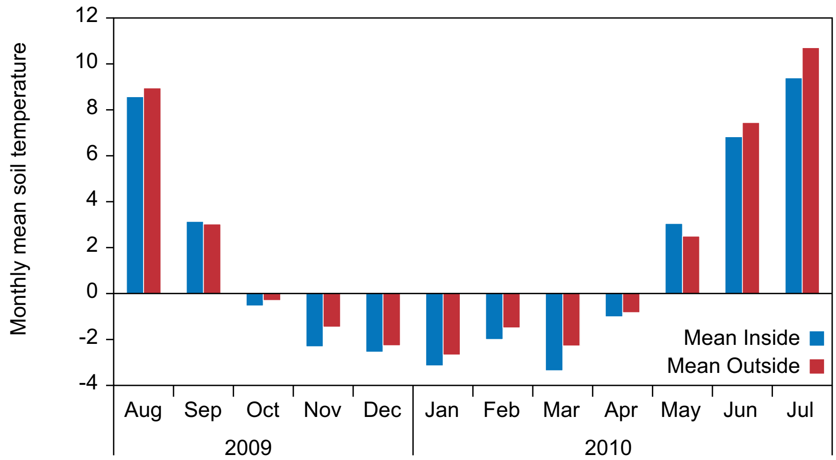


4.3.2 Akia

Average monthly temperatures were below 0°C from October through April and temperatures were significantly higher outside the exclosure than inside the exclosure except in September 2009 and May 2010 (Figure 13).

The lowest monthly mean temperature, -3.4°C, was recorded in March 2010, while the highest mean temperature, 10.7°C, was recorded in July 2010.

Figure 13. Monthly mean soil temperature in Akia July 2009 to July 2010. The differences in average temperature inside and outside the exclosures are significant (P< 0.001) for all months except September 09.



4.4 Microarthropod populations

Microarthropods were very abundant with app. 300,000 individuals per square meter in the upper 5.5 cm of the soil/turf layer (Table 8). The average diversity of the collembolan species and the four mite orders, we included in our assessment of population densities, was highest inside the enclosures. *Tetracanthella arctica* was most abundant inside the exclosure, while *Isotomiella minor* and *Mesaphorura* spp. were most abundant outside the exclosure at Akia.

Table 8. Soil microarthropods, common invertebrates, plant material, and organic matter encountered from heat extraction and during inspection of turf blocks collected in summer 2009 from the two locations. The isotopic composition of $^{13}C/^{14}C$ and $^{15}N/^{14}N$ was analysed for all the listed samples.

Taxon	Species/group/item
Acari	Gamasida
	Oribatida
	Actinedida
Collembola	*Isotoma caerulea cf. tolya*
	Desoria olivacea
	Friesea mirabilis
	Isotomiella minor
	Lepidocyrtus cyaneus
	Onychiurinae
	Folsomia quadrioculata
	Lepidocyrtus violaceus
	Neanura muscorum
	Tetracanthella arctica
Haplotaxida	Enchytraeid (potworm)
	Dendrobaena octaedra (earthworm)
Arachnida	*Haplodrassus signifer*
	Wolf spider, Lycosidae
Coleoptera	Rove beetle, Staphylinidae
	Curculionidae, *Otiorhynchus nodosus*
Hemiptera	Arctic-alpine seed bug, *Nysius groenlandicus*
	Scale bug, *Arctorthecia cataphracta*
Plant material	Moss, roots and shoots
	Decaying birch leaves
	Lichens
	Grass roots and leaves
	Litter/humus
	Herbs/scrubs/trees
Soil	Mineral soil layer

The principal component analysis depicts the overall community differences with no similarity between the two locations for the first two principal axes accounting for 40% of the variability (Figure 14). The first principal component axis is a diversity axis with low diversity to the left along with high population abundances of the mite groups Acaridida and Tarsonemidae often indicating stressed condition leaving room for opportunistic species. The second axis is a location axis discriminating the Akia and Kiattuut communities particularly determined by the dominant presence of *Tetracanthella arctica, Folsomia quadrioculata*, *Parisotoma ekmani*, and *Micranurida pygmaea* found only at the Akia location.

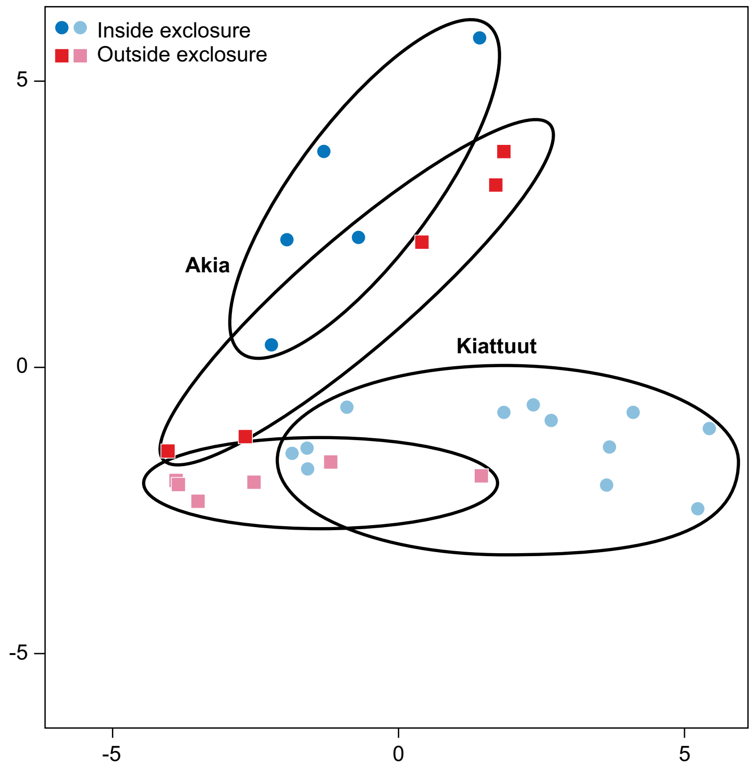


Figure 14. Principal Component Analysis (PCA) of log (x+1) transformed population densities and diversity, S (species richness), H (diversity index) and E (evenness). For each location, Akia and Kiattuut, the un-grazed, and grazed have been delineated. Light blue and light red symbols: Kiattuut; Blue and red symbols: Akia.

4.4.1 Isotopic composition and food-web structure

Table 9 lists all invertebrates, plants, roots and shoots encountered in the turf blocks and for which the natural abundance of ^{15}N and ^{13}C was obtained to calculate the isotopic signatures $\delta^{15}N$ and $\delta^{13}C$.

Figure 15 presents the trophic grouping as revealed by the isotopic signatures. The predators, decomposers, and primary producers forming three clusters for both study sites are also outlined in the figure. The position of predators along the $\delta^{15}N$ axis is roughly 4 units from the detrivores, when comparing the two right-most encircled groups in Figure 15.

The collembolan species *F. quadrioculata* had abundances high enough to obtain sufficient biomass for isotopic analysis from 8 replicates. We determined a mean $\delta^{15}N$ for *F. quadrioculata* of 1.3 (95% C.L.: 0.7 – 1.8) within the Akia exclosure and 0.4 (95% C.L.: 0.2 – 0.7) outside the exclosure which was significantly different (one-way ANOVA, $P<0.01$). Hence, the change in $\delta^{15}N$ from the un-grazed to the grazed habitat was $\Delta \approx -1$.

Table 9. Soil microarthropod population means in units of 1,000 individuals m^{-2} in the upper 5.5 cm of the soil/turf. Bold figures indicate a significant difference between un-grazed exclosures (In) and the surrounding grazed habitat (Out). Empty cells indicate absence of species from samples, if a mean abundance is significant from nil a bold zero is retained.

	Taxonomic groups	**Kiattuut**		**Akia**	
		In	**Out**	**In**	**Out**
Total microarthropods		275	259	248	328
Collembola		58	**6.5**	93	133
Acarina		217	253	155	195
	Actinedida	109	161	80	111
	Oribatida	100	81	72	78
Acari	Acaridida	0.06	**5.5**	0.06	
	Gamasida	8.4	4.7	3.0	5.7
	Tarsonemidae	0.4	**3.6**		
	Pygmephoridae	15	**1.1**	3.2	7.3
	Mesaphorura sp.	12	**1.7**	0.06	33
	Lepidocyrtus violaceus	0.7	1.0	0.8	
	Willemia sp.	3.0	0.9	4.6	12
	Isotoma caerulea	0.9	0.8		
	Folsomia bisetosa	9.7	0.7		
	Folsomia nivalis	9.8	0.3		
	Friesea truncata	4.8	0.3		
	Isotomiella minor	1.5	0.3	3.2	22
	Protaphorura cf. campata	11	**0.3**		
	Micranurida pygmaea	0.3		2.6	2.8
	Desoria olivacea			1.7	**0**
	Desoria tolya	3.1		0.9	0.8
Collembola	*Folsomia coeruleogrisea (alpha)*			1.7	0
	Folsomia fimetaria			0	1.2
	Folsomia sp.			0.6	
	Folsomia quadrioculata			51	58
	Folsomia spinosa			0.4	
	Ceratophysella denticulata	0.7			
	Isotoma anglicana			0.06	
	Isotoma notabilis	0.2			
	Parisotoma ekmani			3.6	2.0
	Protaphorura pannonica			0.4	**0**
	Sminthuridae sp.			0.06	0.08
	Sphaeridia pumilis	0.5			
	Tetracanthella arctica			22	**0.8**
Collembolan species richness		14	9	16	10
Average species richness incl. mite orders		11.3	**7.7**	11.2	7.6
H, $-\sum p_i \log_2 p_i$		2.1	**1.3**	2.1	1.9
E, equitability		0.62	**0.44**	0.60	0.66

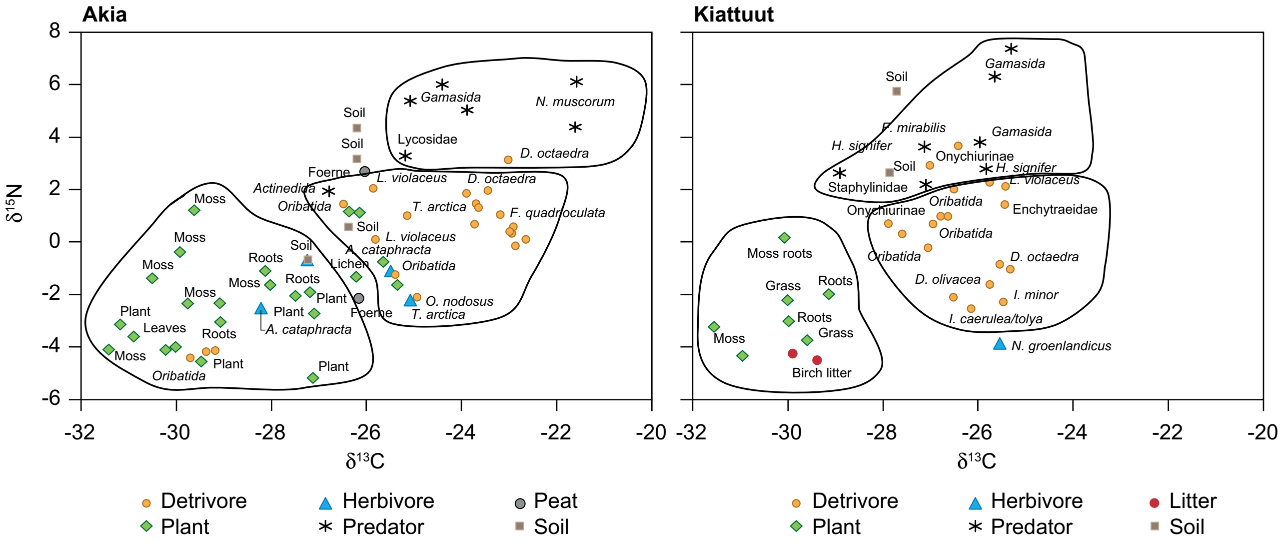


Figure 15. Isotopic signatures of the invertebrates, plants, and selected soil organic components.

4.5 Decomposition (litter bags)

The rate of decomposition is significantly (ANOVA P<0.00001) higher in Kiattuut (ca. 58% in average) than in Akia (ca. 27% in average). The differences in decomposition rate between grazed and un-grazed plots were not significant (Table 10), neither in Akia nor in Kiattuut.

Table 10. Weight loss in litter bags in Akia and Kiattuut.

	Litterbags laid out	Litterbags collected	Mean weight loss (g)	Mean weight loss %
Kiattuut				
Inside	50	43	11.803	62
Outside	50	45	11.182	59
Akia				
Inside	50	49	0.4960	26
Outside	50	47	0.5680	30

5 Discussion

Grazing may have several types of impact on vegetation. Biomass is removed and the physical environment is altered (e.g. Post & Klein 1996, Bråthen & Oksanen 2001). Hence, the balance of competition between plants may also be altered. This may have greater importance in the arctic than at lower latitudes because of relatively greater changes in resource availability and physical environment (Mulder 1999).

High similarity in plant species composition in grazed and un-grazed plots – even after more than 25 years

There was a high similarity between grazed and un-grazed plots both on the low arctic site in Akia (QS 87.2) and at Kiattuut (QS 77.8) in South Greenland. With the exception of two herbs in South Greenland, that probably benefitted from not being grazed, none of the differences in cover were significant.

The similarity was highest in Akia, probably because the plot there had only been fenced in 5 years while the plot in South Greenland have been fenced for more than 24 years. Chapin et al. (1995) found that short-term (3-years) responses were poor predictors of longer-term changes in plant community composition.

Austrheim et al. (2008) found that changes in abundance of plants mainly occurred in un-grazed and heavily grazed plots, and that low grazing intensities had almost no effect on plants. Austrheim et al. (2008) found that the effects of herbivory on plants are non-linearly related to herbivore density, and that the speed of plant responses depend both on plant properties and grazing pressure. Unfortunately, we have no data on grazing pressure, but our results indicate that grazing pressure had an effect.

A few species only appeared inside *or* outside the exclosures

Few species only appeared inside or outside the exclosures, might indicate that grazing could have effects on the species composition. Such species in Kiattuut were *Luzula multiflora* and *Carex supina*, and the herbs *Erigeron uniflorus, Rumex acetosella*, and *Sedum annuum*. In Akia the woody plant *Ledum groenlandicum*, the graminoid *Deschampsia flexuosa* and the lichen *Peltigera aphtosa* only occurred in the grazed plots.

Inside the exclosure it was expected that species sensitive to grazing would be found in higher frequencies.

In Kiattuut the herbs *Thalictrum alpinum* and *Euphrasia frigida* appeared to benefit from protection from grazing.

In Akia the herb *Rhinanthus minor*, the lichens *Cetrariella delisei* and *Stereocaulon* sp. and the mosses *Polytrichum hyperboreum*, *Onchoperus wahlenbergii*, and *Aulacomnium palustre* benefit by not being grazed.

In the sheep farming district in southern Greenland Meyhoff (2004) suggested that the absence or decrease of *Alchemilla vulgaris*, *Phleum commutatum*, and *Agrostis hyperborea* could be used as indicators of overgrazing. Furthermore, *Alchemilla alpina*, *Anthoxanthum odoratum*, *Achillea milleflorum* and mosses all increased under grazing conditions. Those species along with other herbs are generally thought of as not being preferred by sheep (Meyhoff 2004). When preferred species are being grazed (ultimately over-grazed) it creates space for new and/or other species to grow – species that might have been precluded from growing due to e.g. competition with the preferred species. The new species are not necessarily preferred by the sheep thus their density increases.

The cover of shrubs, herbs, and litter appeared to be favoured by not being grazed

Although not being significant there was a clear tendency that the cover of shrubs, herbs, and litter increased in un-grazed plots, while lichens and graminoids decreased. The increase of shrubs agrees with results by Zamin and Grogan (2013) who concluded that exclusion of grazing by caribou, even at a low population density, favoured shrubs like *Betula glandulosa*, *Vaccicnium vitis-idea*, and *Rhododendron subarcticum*.

The increase in litter is probably a result of the increase of decidous shrubs that have increased inside the exclosure. The decrease of lichens and graminoids is probably caused by the competition with the increasing shrubs. The lichen layer in Akia appeared disturbed outside the exclosure, having a lower cover outside than inside the exclosure. This disturbance is no doubt a result of grazing or trampling by caribou. The bare soil surfaces outside the exclosure in Kiattuut and in Akia are probably a result of grazing or trampling by sheep or caribou.

The grazing pressure is not monitored at the study sites. The higher proportion of bare soil at grazed plots at both sites indicates, however, that both sites actually are grazed. At Kiattuut the amount of litter has increased considerably in the exclosure (Figure 10) compared to outside the exclosure during the past more than two decades. This is in correspondence with the increasing amount of deciduous shrubs.

The cover of mosses and graminoids appeared to be favoured by grazing in Kiattuut, while lichens decreased in the caribou range Akia in West Greenland

Grazing can promote transition of moss-rich heath into steppe-like vegetation dominated by graminoids (Olofsson et al. 2001, van der Wal 2006, Meyhoff 2004). This agrees with our findings at Kiattuut, where the percentage of shrubs and graminoids in the exclosure increased by 47% and decreased by 21%, respectively, compared to the grazed areas. Sheep grazing in South Greenland thus promotes the transition from shrubs and heath into a vegetation which is more dominated by graminoids.

In Akia the cover of the lichens *Cladonia* sp. was higher inside the exclosure than outside the exclosure and *Stereocaulon* sp. and *Cetrariella delisei* only occurred inside the exclosure. These findings are most probably a result of caribou grazing.

The mosses *Aulacomnium palustre, Polytrichum hyperboreum*, and *Onchophorus wahlenbergii* were only found inside the exclosure, whereas the opposite of what was found in Kiattuut and many other places as mentioned above.

The nutrient content in soil was similar in grazed and un-grazed plots

Generally, soil nutrients were at the same level in Akia and Kiattuut except sulphur (S), which was highest in Akia, and calcium (Ca) which was highest in Kiattuut. The difference in the content of soil nutrients inside and outside the exclosure is greater in Akia than in Kiattuut. Most important are the higher content of Total N, NH_4-N (nitrogen fixed in ammonium), Ca, and Fe outside the exclosure in Akia. This may be a result of caribou activity.

It is surprising that differences in soil nutrients between grazed and un-grazed plots were higher in Akia than in Kiattuut, as the exclosures at Akia were established 20 years later than in Kiattuut. The reason may be that more of the nutrient pool is in the standing crop in the warmer south Greenland than in Akia where temperatures are lower and the season with temperatures above zero is shorter. Also the local geology may be important for differences between Akia and Kiattuut.

The higher levels of nutrients in grazed plots can be a result of supply of faecal pellets and urine from sheep or caribou, respectively as has been found in other arctic tundra systems (Stark 2002, van der Wal et al. 2003). The effect of faecal pellets and urination by the large herbivores are suspected to be important only during summer since snow or ice might impede the additional nutrients to reach the soil during the winter season (Pastor et al. 2006). N-cycling is very dynamic and dependent on temperatures above ca. 10 °C (Nadelhoffer et al. 1991). At Akia average temperatures are only above the 10 °C limit in July, while temperatures can be above 10 °C for several months at Kiattuut. Thus, N mineralization must be much faster in Kiattuut compared to Akia.

Our results show that the amount of Total N in the soil is more than twice as high in Akia compared to Kiattuut. But as stated above this might be attributed to the fact that more of the available nutrients are already in the standing crop in the lush vegetation at the location in South Greenland. Our results also show that the decomposition rate is much higher in South Greenland than in Akia.

Results from the International Tundra Experiment (ITEX) indicate that the effect of elevated temperatures in the short term are increased height and cover of shrubs and graminoids, decreased cover of lichens and mosses and decreased species diversity and evenness (Arft et al. 1999, Walker et al. 2006). However, this effect, seems to change towards more investment in reproduction after the first initial experimental years. It is hypothesized that this change is a result of limitation of nutrients after the first “explosion” of growth where the vegetation exploits all available nutrients.

Our study confirms these trends. The differences between nutrients inside and outside exclosure was most pronounced in Akia, while there were only minor differences in Kiattuut which has been fenced almost five times as long.

The soil temperatures were highest in the grazed plots year round

Generally temperatures were highest outside the exclosures and the cold season with temperatures below 0°C was longer in Akia than in Kiattuut.

Especially the thickness of the moss layer plays an important role in the temperature difference (van der Wal et al. 2001, van der Wal and Brooker

2004). A thick layer of moss insolates the soil and impedes the heating of the soil during summer. Herbivores are able to reduce the moss layer both by trampling and to a lesser degree by foraging. This results in a thinner layer of the moss resulting in warmer temperatures in the soil. Our results are in perfect line with this theory since temperatures in un-grazed plots are lower compared to grazed plots.

It is a bit more difficult to say the same for the station in Akia. There are hardly any differences in the amount of mosses between the exclosure and the surroundings. This might be due to the relatively short period of time since the fences were established.

Studies of responses of high arctic plants (grasses, sedges/rushes, and non-graminoids) to experimentally controlled soil temperatures showed that total biomass increased with temperature, as did the ratio of above-ground live mass to total live mass and the mass of root tissue (Brooker & van der Wal 2003). In all growth forms grasses had the strongest response. We have no data to support this at our study plots. It is interesting to note, however, that if the same effects occur at our study sites in Greenland, then the plant production may indirectly be increased by grazing through the effect on soil temperature.

The rate of decomposition was much higher in South Greenland than in West Greenland

The rate of decomposition was significantly higher in Kiattuut (ca. 58% in average) than in Akia (ca. 27% in average). The differences in decomposition rate between grazed and un-grazed plots were non-significant in both Akia and Kiattuut. The higher decomposition rate in South Greenland was caused by the overall higher temperatures and a longer period with temperatures above 0 °C.

The average diversity of microarthropods was highest in plots not grazed

Grazing had only a negative effect on Collembola and only in Kiattuut. This may indicate a generally higher level of grazing at Kiattuut compared to Akia combined with the lower content of organic matter in the soil. The lower organic content in the soil might be a result of grazing.

Intense grazing favours smaller species at the expense of larger surface-living species. However, as such a pattern was not identified in the collembolan community, the grazing does not seem to be very intense with respect to this group of organisms. Nevertheless, the 6 collembolan species were found less in the grazing area compared to the un-grazed area and the presence of some mite groups indicating disturbance, and therefore still confirm the rather different environmental conditions created by grazing.

The isotopic signatures reflect the different structural properties of the ecosystem compartments: plants, detritus, herbivores, detrivores, and predators. A difference between two isotopic $\delta^{15}N$ signatures of $\Delta \approx 3‰$ normally indicates a shift in one trophic level, so some re-assimilation may occur resulting in more than one trophic level, or in other words a more complex food-web involving more than one trophic level in the cases where we observed trophic shifts larger than 3‰. The group of detrivores such as *T. arctica* and Oribatida that have the lowest ^{15}N enrichment may actually be herbivores, similar to the known non-microarthropod insect herbivores *Otiorhynchus nodosus* (Curculionidae), *Arctorthecia cataphracta* and *Nysius groen-*

landicus. The collembolan *Friesea mirabilis* is already known to be a predator, but *Neanura muscorum* has not really been reported as a predator although Chahartaghi et al. (2005) classified it as a secondary composer/predator.

The food-web structure as revealed by isotopic signatures generally agrees with our previous conception of the trophic positions of the species. For the Kiattuut site the primary production including decaying plant material has a narrow range of $\delta^{13}C$ of -32 to -29 and for Akia it was -32 to -26, cascading through the food-web resulting in decomposers and herbivores having higher $\delta^{13}C$ finally shifting predators 4 units to the right compared to predators from Kiattuut. Hence, the two locations have a basic difference in the trophic structure. This is indicated by the wider $\delta^{13}C$ range at Akia which is a result of a slightly longer food-chain. It remains to be further explored how these food-web structures may be employed for future monitoring of arctic ecosystem dynamics.

It was possible to investigate the impact of grazing only for one collembolan species, namely *F. quadrioculata*. The observed shift in $\delta^{15}N$ of one unit, Δ=-1, indicate a change in food selection from less decomposed material in the grazed area towards more decomposed material in the un-grazed areas. Indeed, such an interpretation would highly benefit from state-of-the-art compound specific stable isotope analyses (CSIA), that would reveal the origin of the food base by discrimination between, bacteria, fungi, and plant material (Larsen *et al.* 2009).

5.1 Perspectives

This technical report has been focused on presenting overviews of the results from the field season in 2009-10 and 2012. The results have clarified our first hand observations in the field – the herbivores have had a greater impact on the vegetation in Kiattuut than at Akia. This is mainly due to the longer timeframe of the exclosures in South Greenland compared to the ones at Akia, different foraging strategies, and differences in grazing pressure. Thus, it is expected that the effect of herbivores will increase at Akia in the coming years.

We have not focused on the density of herbivores at either locality within this report. This is a crucial factor when possible overgrazing is a potential effect of herbivory. At present the density of sheep in South Greenland is not decreasing and it might even be growing (A. Fredriksen, pers. comm.). The same is not true for the caribou in the Akia locality where numbers have been declining during the past years (Cuyler et al. 2011).

Our dataset offers unique possibilities for analysing the relations between grazing, climate change and biodiversity in the low Arctic. Further in depth analysis of the data collected will shed more light on the future effects of the large herbivores in Arctic.

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EFFECTS OF LARGE HERBIVORES ON BIODIVERSITY OF VEGETATION AND SOIL MICROARTHROPODS IN LOW ARCTIC GREENLAND

Akia, West Greenland and southern Greenland

This report summarizes the results of a project that aims at documenting long term effects of grazing by comparing baseline data inside and outside exclosures. We collected data on vascular plants, mosses, lichens, microarthropod abundance and food-web structure, soil nutrients, decomposition, and soil temperature. Data provide a significant basis for understanding the interaction between large herbivores and vegetation in Greenland. The report contains documentation of data collected in 2009 and 2012 as well as documentation of data from 1984-2004 made available by Jon Feilberg.

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