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The Potential Impact of Changing Vegetation on Thawing Permafrost:

Effects of manipulated vegetation on summer ground temperatures and soil moisture in Abisko, Sweden

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Cover picture: Storflaket mire, Abisko (Photo: Martin Thysell)

Preface

We have been given the opportunity to work with data from a vegetation manipulation experiment conducted at Storflaket mire in northernmost Sweden, a project that has been ongoing since 2007 by Dr. Margareta Johansson at the Department of Physical Geography and Ecosystems Science, Lund University. The experiment focuses on identifying how different plant species categorized as plant functional types can impact on ground temperatures and soil moisture during the summer. Experiments like these are of great importance to increase the knowledge of how different factors can affect the permafrost. It is also important to link the results to further warming in the Arctic and how feedback processes can be affected with global climate implications as a result.

This bachelor thesis is based on statistical analysis of collected data at Storflaket mire, gathered during the summers of 2007, 2008, 2010 and 2011. This project has been performed in a group but the authors are responsible for different parts of the report:

John Bengtsson: 2.1, 2.2, 2.5, 4.2, 4.3, 5.1, 5.2, 6.2, 6.3

Eric Torkelsson: 1, 1.2, 2.3, 2.4, 2.6, 3, 4.1, 5.3, 5.4, 6.1, 6.4

Abstract

The Arctic region has experienced significant warming in the past decades and according to predictions further increases in air temperatures and precipitation will occur during the 21st century. Recent changes in climate have had widespread implications for the permafrost around the Arctic. Shorter periods of snow covering the Arctic regions significantly reduce the average annual albedo which dramatically increases the amount of energy being absorbed by the ground surface. In addition, the amount of snow has increased which results in even further warming of the ground through insulation during the winter. Warmer ground temperatures increase the available amount of organic material stored in the formerly frozen ground when the active layer (i.e. the upper layer that thaws and refreezes annually) becomes thicker. This can potentially lead to additional releases of greenhouse gases resulting in even further regional warming and permafrost degradation with implications for the global climate.

The Arctic vegetation has also changed due to higher air temperatures and altered precipitation patterns. Future predictions suggest more productive vegetation over the Arctic. This will likely increase the dominance of trees and shrubby vegetation leading to reductions in moss vegetation. Sub-arctic palsa mires in northern Sweden are experiencing a different shift in vegetation with higher graminoid abundance and declining shrub coverage due to increasing wetness. A change in the type of vegetation i.e. a change in plant functional types can alter the albedo together with the shading-, the evapotranspiration-, the snow trapping- and insulation potential. All these factors have the potential to change the ground temperature and the soil moisture content which affect the underlying permafrost. Changes like this have already been observed at the margin of where permafrost can exist, for example in the Abisko area in northernmost Sweden.

This report presents results from an experiment where different plant functional types (dwarf shrubs, graminoids, mosses and lichens) have been removed at the Storflaket mire in the Abisko area. During a five year period the vegetation has been manipulated in different plots to extract information on how soil moisture content and ground temperature (10 cm depth) respond to changes in vegetation. Ground temperatures were significantly warmer (0.2°C) where dwarf shrubs had been removed compared to the control plots. Removal of mosses and lichens significantly decreased the ground temperature by 0.7°C. Soil moisture was only significantly higher (6.6%) where mosses and lichens had been removed.

It is likely that ongoing vegetation changes on the mires i.e. a shift from dwarf-shrub dominated to graminoids dominated vegetation in the Abisko area will continue also in the future. The results suggest that the potential decrease of dwarf shrubs on the mires will lead to an additional increase in ground temperatures making the permafrost more sensitive to additional future changes in climate.

Keywords: *Physical geography, geography, climate change, permafrost, vegetation manipulation experiment, Abisko, sub-arctic*

Sammanfattning

Arktis har under de senaste årtiondena upplevt betydande uppvärmning och enligt prognoser förväntas ytterligare höjningar av både lufttemperatur och nederbörd under det kommande århundradet. Det förändrade klimatet har haft omfattande konsekvenser för permafrosten (ständigt frusen mark) som format och kraftigt präglar stora delar av det arktiska landskapet. Med ökande temperaturer förkortas den period avsevärt under vilken marken är täckt av snö. Detta medför att markens genomsnittliga förmåga att reflektera solljus drastiskt minskar. Sett över året resulterar det i att marken blir varmare samtidigt som lufttemperaturen fortsatt stiger. Ökande nederbörd gör att snötäcket under vintern blir tjockare vilket också bidrar till en uppvärmning av marken genom att isolera och skydda markytan från låga lufttemperaturer under vintern. I kombination leder konsekvenserna av ett varmare Arktis till att temperaturökningen i regionen idag sker mycket snabbare än den förändring som ses globalt. Efterhand som permafrosten tinar och marktemperaturen blir högre ökar även den mikrobiologiska aktiviteten och nedbrytningen av det organiska materialet som tidigare varit otillgängligt i den frusna marken. Detta kommer troligen leda till ökade utsläpp av växthusgaser vilket på sikt kan påverka det globala klimatet.

Förändringar i det arktiska klimatet har också påverkat vegetationen genom förändringar i temperatur, samt påverkat tillgången till vatten och näring. Vegetationen i Arktis förväntas bli allt mer produktiv med fler träd och buskar, samtidigt som utbredningen av mossor förväntas minska. Palsamyrar i norra Sverige genomgår en förändring där arealer som domineras av risbuskar minskar på grund av allt fuktigare miljö som istället gynnar gräsdominans. Förändringar i artsammansättningen kan påverka den arktiska energibalansen på flera sätt. Ett skifte i vegetationen innebär förändringar i reflektionsförmåga, skuggningsegenskaper, evpotranspiration och isolering både sommar- och vintertid. Alla dessa faktorer påverkar hur en förändring i klimatet kan ha inverkan på vegetationen och markvatten som i sin tur avgör vad som händer med permafrosten.

För att undersöka hur permafrosten kan påverkas av vegetationen startades ett experiment på Storflaket, en palsmyr utanför Abisko, där olika typer av vegetation (risbuskar, mossor och lavar samt gräsväxter) togs bort på olika platser för att se effekten av dessa vegetationstypers frånvaro på markens temperatur och fuktighet. Under en femårsperiod manipulerades vegetationen och mätningar gjordes på marktemperatur och markfuktighet under sommaren. Det fastställdes att temperaturen ökar med 0.2°C när risbuskar tagits bort och att temperaturen sjunker med 0.7°C där mossor och lavar tagits bort. Markfuktigheten ökar med 6.6 procentenheter där mossor och lavar tagits bort.

Det är troligt att de pågående vegetationsförändringar på myrarna, det vill säga en övergång från risbuskar till gräsdominerad vegetation på myrarna kring Abisko kommer att fortsätta i framtiden. Resultaten från denna studie tyder på att den potentiella minskningen av risbuskar kan leda till ytterligare ökade marktemperaturer vilket kan leda till att permafrosten i området blir ännu mer känslig för framtida förändringar i klimatet.

Nyckelord: *Naturgeografi, geografi, klimatförändring, permafrost, manipulation av vegetation, Abisko, subarktis*

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1. Introduction

The Arctic region experiences the most rapid climate change compared with other regions on earth. In the past decade, increases in mean annual air temperature in the Arctic was almost twice the global average, and since 2005 until 2010 air temperatures have been higher than for any other five-year period since measurements started around 1880 (IPCC, 2007; Walsh et al., 2011). Predictions for the 21st century based on atmosphere-ice-ocean general circulation models suggest a general increase in autumn and winter surface air temperatures of 3 to 6°C by 2080 in the Arctic (Overland et al., 2011). Simulations of precipitation show an increasing trend of both rainfall in summer and snow fall during winter, with the largest increase in winter (Christensen et al., 2007). In Abisko, sub-arctic Sweden, regional simulation models predict an increased air temperature of 2.7 to 3.6°C by 2080 and a mean increase in precipitation by 13.5-27% for the same period (Sælthun and Barkved, 2003). Changes of this magnitude, will impact cryospheric components such as permafrost (sediment, rock or soil that stay at or below freezing degrees for two or more consecutive years) which has already experienced increased temperatures by up to 2°C over the past two to three decades in the Arctic (Callaghan et al., 2011b).

24% of the land surface in the northern hemisphere is underlain by permafrost. Continuous permafrost (> 90%) is widespread at high latitudes over the terrestrial surface in the Arctic. At lower latitudes, permafrost is still present as discontinuous permafrost (50-90%). Perennial frozen ground can also exist as sporadic permafrost (10-50%) and in isolated patches (0-10%) mainly at the southern margins of the Arctic region (Fig. 1) (Zhang et al., 1999).

Source: International Permafrost Association, 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

Figure 1. Distribution of permafrost in the northern hemisphere with the location of the study site situated in the sub-arctic Sweden (Philippe Rekacewicz, UNEP/GRID-Arendal. http://www.grida.no/graphicslib/detail/permafrost-distribution-in-the-arctic_3823).

Discontinuous permafrost is widespread in northern Fennoscandia (Nelson et al., 2002). Outside the discontinuous zone where the regional climate is not favorable, sporadic permafrost exists due to local variations in geomorphology and topography (Johansson et al., 2006). In the Abisko area, permafrost exist in the lowlands under peat plateaus and palsas (hummock with a frozen core) due to their exposure to wind action and therefore a thin snow cover during winter in addition to the insulating layer of peat preserving low ground temperatures during summer (Johansson, 2009). These permafrost patches exists due to very specific conditions at the southern boundary of the permafrost zone and are therefore more sensitive to climate and environmental changes. Slightly warmer air temperatures in summer can result in a mean annual temperature above freezing. Thicker snow cover can result in increased ground temperatures during winter preventing permafrost from developing and being preserved (Fronzek et al., 2006). The Abisko area has experienced increased air temperatures and increased precipitation during the last three decades (Callaghan et al., 2010). As a result the Abisko region has experienced degrading permafrost during this period (Johansson et al., 2006; Åkerman and Johansson, 2008). With the on-going climate change and predicted future change, permafrost features such as peat plateaus and palsas are expected to decrease dramatically in northern Fennoscandia over the next 100 years (Fronzek et al., 2006). However, uncertainties remain of how these permafrost features will develop in the future and how a change in the active layer thickness due to changes in ground temperatures can affect the emissions of greenhouse gases. In the Abisko region, several studies have been conducted on the effects of thawing permafrost under peat plateaus and palsas with feedbacks to the climate change by increased emissions of greenhouse gases (Christensen et al., 2004; Malmer et al., 2005; Bosiö et al., 2012). These studies have focused on changes in wetness and species composition and its impacts to the regional climate. They show a general increase in wetness, a decrease in shrub coverage in favor of graminoids and a landscape scale increase in methane emissions on the palsa mires in the Abisko region.

In addition to peat and snow depth as important parameters in relation to permafrost development, vegetation cover also constitutes an important factor as it impacts the permafrost through altering albedo, snow trapping, insulation and shading effects. Together with a shift in vegetation which is already occurring in the Arctic it can result in dramatic impacts on permafrost formation and degradation (Yi et al., 2007; Blok et al., 2010; Blok et al., 2011; Lawrence and Swenson., 2011). This has increased the necessity for local experiments, where the vegetation is manipulated to extract knowledge of the importance of the vegetation and its potential feedbacks to the ongoing permafrost degradation in a specific location. Therefore, an experimental study was set up at the Storflaket mire in the Abisko area, where the effects of different plant functional types (Dwarf shrubs, graminoids, mosses and lichens) on summer soil temperature and soil moisture were monitored.

1.2 Aim

The aim of this study is to evaluate the possible impact of different vegetation on summer ground temperature and soil moisture by vegetation manipulations at the Storflaket mire. To verify the aim, the following research questions have been formed:

- How is summer ground temperatures affected by a change in vegetation at the Storflaket mire, Abisko, Sweden?
- Can experimental manipulation of the vegetation have impacts on the soil moisture content in the top-soil layer at the Storflaket mire?
- How will the potential changes affect the energy balance?

2. Background

2.1 The importance of albedo in a changing climate

The proportion of the short-wave solar radiation that is directly reflected at the earth's surface is called albedo. The amount of radiation that is reflected is highly dependent on the reflective properties of the surface. For example, a vegetated surface (10-25% reflectance) has a lower albedo compared to a surface covered by snow (80-95% reflectance for fresh dry snow) (Holden, 2008). Different vegetation can also vary in albedo (e.g. mire 23%; tundra 17%; birch forest 11% reflectance) (Johansson et al., 2006). Radiation that is not directly reflected back into the atmosphere is absorbed, contributing to the heating of the surface. A large proportion of the absorbed heat is emitted back into the atmosphere as long-wave radiation, which can be absorbed and then reemitted by carbon dioxide, water vapor, methane and other greenhouse gases. This process is the main factor for the heating of the atmosphere. The surface heat is also transferred into the atmosphere by sensible and latent heat fluxes also contributing to the atmospheric heating. Lastly the heat can also transfer downward and heating up the soil or bedrock as ground heat flux (Fig. 2) (Holden., 2008).

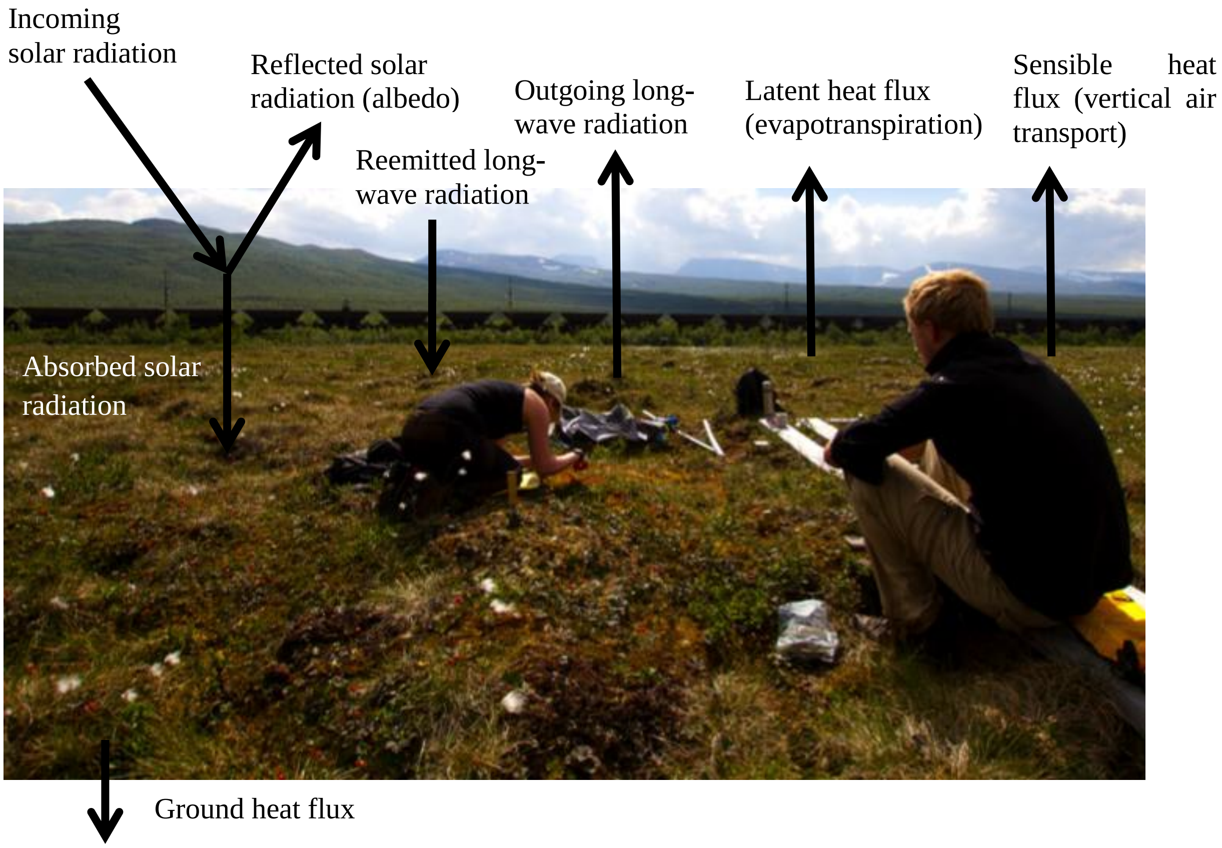

Figure 2. Simplified schematic picture of the energy balance of the Earth's surface in the sub-arctic and the involved energy and water fluxes. Photo: Martin Thysell.

With increased global warming, snow cover duration in northern Scandinavia is projected to decrease by 30-40% along with 10-20% for the Arctic region by 2050 (Callaghan et al., 2011a). A decrease in snow cover duration results in a longer period of time during the summer season with a vegetated or bare ground surface, which will significantly lower the albedo. The increase in absorbed solar radiation due to longer period with lower albedo will cause changes in surface heat fluxes and will thereby further increase both surface air temperatures and ground temperature in the Arctic. This leads to even shorter snow cover duration and a positive feedback on warming in the Arctic (Chapin et al., 2005).

Changes in vegetation have the potential to affect the reflective properties of the vegetation cover. This will have implications for the albedo in both summer and winter. In the summer the vegetation albedo varies depending on species composition. The winter albedo is dramatically affected if the vegetation is high enough to protrude through the snow cover, since the high albedo of pure snow is then being disturbed. This leads to an earlier snowmelt in spring, uncovering more bare ground with lower albedo (Sturm et al., 2005; Lawrence and Swenson, 2011).

2.2 Plant functional types

In order to evaluate responses and impacts of the vegetation in a changing arctic environment it is of great necessity to be able to group different species together and analyze the effects of them as a group instead of trying to evaluate the impact or response of all species individually. This can be done using the concept of plant functional types. Species that share mutual physical traits, or have similar responses to and similar effects on environmental factors and conditions fall under a common plant functional type. These groupings can be done on very different levels depending on what functions are of interest (Chapin et al., 1996). For example, plants can be divided in just tall vegetation (trees) and low vegetation (e.g. shrubs, grasses, herbs and mosses) to distinguish the ecosystem function of trees compared to other plants. Different species can also be grouped on a more detailed level such as dwarf shrubs, graminoids, mosses and lichens to be able to separate the functions of these groups on palsa mires (Fig. 3).

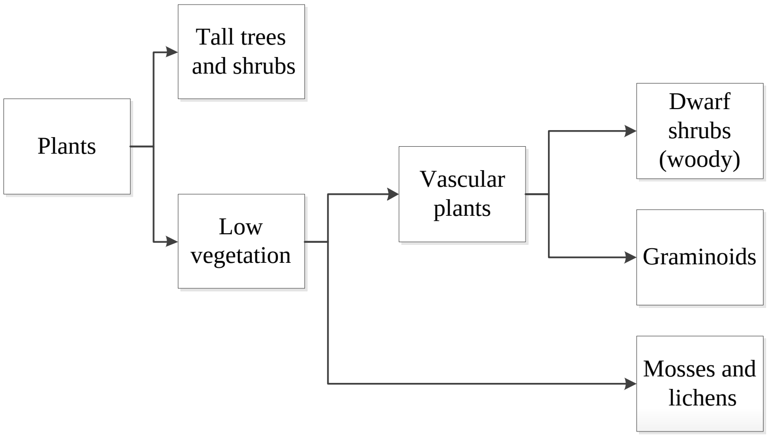

Figure 3. An example of a simple way to classify the plant functional types of a palsa mire ecosystem.

2.3 Vegetation in the Arctic

The vegetation in the Arctic region changes along a latitudinal gradient. In the southern boundaries of the Arctic, the terrestrial land is mainly covered by boreal forest (the taiga). The forest creates a closed canopy with an understory mainly consisting of mosses. Further north, the forest gets less dense along with a decreasing canopy height but with increasing patches of tundra and shrubs. At higher latitudes the tundra vegetation gets dominant due to constraints in climate which changes the landscape to a treeless wilderness generally covered by mosses and lichens. In the forest tundra, canopy height can reach up to 3 meters in several layers compared to only one decimeter in the polar desert where the mosses, herbs and lichens only colonizes 5% of the ground surface. The transition zone from taiga to tundra stretches around the earth but is relatively narrow (30-150 km). Species richness in the Arctic is low, approximately 3% of the global flora occurs in the region and it decreases towards the north (Callaghan et al., 2005).

Vegetation changes are ongoing in the Arctic region. A widespread increase in shrub abundance has been observed during the past 50 years in Alaska. Human and natural disturbances are low in the region which led to the conclusion that more prominent shrubby vegetation and biological productivity were linked to recent changes in climate (Sturm et al., 2001b). Similar shrub expansion has also been observed over northern Canada, in Scandinavia and in Siberia (Tape et al., 2006). Experimental warming has also resulted in increased growth of dominant vascular plants. However, growth of mosses decreased with a warming climate (Rixen and Mulder, 2009). Another experimental warming conducted by Chapin et al. (1995) resulted in the same change in vegetation as mentioned above but warming and nutrient treatments also decreased species richness by 30-50%. The explanation to shrub expansion over the Arctic is the fact that they respond faster than other plant functional types to higher air temperatures which increase their height and cover (Walker et al., 2006). Higher temperatures and increased snow thickness promote higher soil temperatures which increases the microbial activity in the soil. Higher microbial activity increases the amount of available nutrients in the soil which favors further shrub dominance as they are better at utilizing nutrients than competing plant functional types (Chapin et al., 1995; Walker et al., 2006).

Generally, the future predictions of vegetation changes over the Arctic region include northward movement of the tree line and an overall more shrubby and productive vegetation. However, species response to increased temperature and other environmental factors is complex and different local specific responses can exist (Callaghan et al., 2005).

2.4 Vegetation in the Abisko area

In the Torneträsk region, sub-arctic Sweden the vegetation mainly consists of mountain birch forest (*Betula pubescens ssp. czerepanovii*) that covers an area if 1200 km^2 (~25% of the total area of the Torneträsk catchment) together with patches of boreal pine forest. In the lowland areas mountain birch is still present around the palsa mires on which the vegetation is dominated by low statured vascular plants such as dwarf shrubs and graminoids (sedges) together with an understory dominated by mosses and lichens (Johansson, 2009).

A comparative study on the vegetation and the effect of changing environmental factors has been conducted at the Stordalen mire, approximately 10 km east of Abisko and 4 km northeast of Storflaket mire. The study concluded that, between 1970 and 2000 thawing permafrost had changed the vegetation at the mire and that more wetter conditions had been created due to poor drainage. It was observed that the area coverage of tall graminoids had increased by 46.5% along with a decrease in shrubs by 33.9% at the Stordalen mire from 1970-2000 (Fig. 4) (Malmer et al., 2005). Christensen et al. (2004) established that the changes in hydrology and vegetation associated with the degradation of palsa mires have increased the landscape scale methane emissions by 22-66% between 1970 and 2000. According to simulations by Bosiö et al. (2012) the dry hummock areas on Fennoscandian palsa mires will have decreased by 97% and be replaced mainly with moist hummock formations by 2060.

Figure 4. The proportion of wet areas has increased at the Stordalen mire, 4 km east of the Storflaket mire, Abisko. Photo: Margareta Johansson.

Wolf et al. (2008) modeled future changes in vegetation and ecosystem function in the Barents region, including subarctic Sweden. The model predicted over the next hundred years that boreal needle leaved evergreen forest and broadleaved summer green forest would advance further north and upwards in mountainous areas around the Barents region. In Scandinavia this would lead to a decrease in shrublands and a widespread disappearance of open ground vegetation over the next hundred years. However, a dendrochronological study conducted in Abisko showed increased radial and vertical growth of shrubs during recent decades (Hallinger et al., 2010). They concluded that shrub growth is correlated to warm summers and snow cover which likely will increase future shrub expansion with changes in climate.

2.5 The effects of vegetation change on permafrost

Different kinds of vegetation affect the permafrost in different ways. As previously mentioned, vegetation composition can have impacts on both summer and winter albedo depending on reflective properties and height (Callaghan et al., 2011b). The predicted increase of tree vegetation in the Barents region would lead to lower summer albedo of 3% and a decrease by 6% in winter. However, for Scandinavia, the predicted future changes in vegetation would result in decreased albedo by 12% in winter and 18% in summer (Wolf et al., 2008). Vegetation can directly insulate the ground by keeping it warmer in the winter and cooler in the summer. Also indirect insulation can take place in winter depending on the snow trapping capabilities of the vegetation (Callaghan et al., 2011b).

Mosses cover large areas in high northern latitudes and play an important part in the thermal and hydrological regime of arctic soils. A decline in moss cover may have major impacts on the energy and water exchange between the surface and atmosphere. Mosses act as insulators for the soil reducing summer soil temperatures and increasing the soil temperature during winter. This way mosses help reducing summer thaw of the permafrost (Beringer et al., 2001; Blok et al., 2011). Mosses also contribute to greater surface infiltration and a lower surface runoff. The insulating qualities of mosses also reduce ground heat flux, which results in a greater amount of latent and sensible heat exchange with the atmosphere (Beringer et al., 2001). A removal experiment conducted in the Siberian tundra showed that removal of mosses resulted in an increase in evapotranspiration and ground heat flux (Blok et al., 2011).

An increase in tall shrubs in areas formerly occupied by low statured herbs and mosses may lead to snow trapping effects and regional increase in snow depth. The low thermal conductivity of snow makes the snow cover thickness an important factor on winter soil temperature, as it will separate the soil from the cold air temperatures, increasing soil temperature during the winter (Yi et al., 2007; Callaghan et al., 2011b). The effect on soil temperature from increased snow depth was tested using snow fence manipulation at the Storflaket mire, and an increase in winter soil temperature by 0.5-1.0^{o}C at 15cm depth was verified (Johansson, 2009). A study was conducted in Alaska by Sturm et al. (2001a), showing that shrub-snow interactions could lead to a substantial increase in snow depth (10-25%) in patches with shrubs. This will result in an increase in winter soil temperatures and promotion of nitrogen mineralization, which in turn promotes shrub growth (Chapin et al., 2005).

The canopy effect of the vegetation is important for the preservation of permafrost since it affects how much of the incoming solar radiation that reaches the ground. Shrubs generally have a high leaf area index, resulting in a shading effect since a higher proportion of the short-wave solar radiation is absorbed in the shrubs canopy preventing it from reaching the ground beneath it, hence cooling the soil during the summer and contributing to the preservation of permafrost (Johansson et al., 2006). A study on the effect of dwarf shrubs (*Betula nana*) on active layer thickness in the Siberian tundra showed that the removal of shrubs resulted in a thicker active layer thickness compared to the non-manipulated control plots. This indicates that shrubs have the potential to reduce soil temperature through shading, hence protecting the underlying permafrost from incoming solar radiation in the summer (Blok et al., 2010). Simulations have been done, arguing that in the most northern regions shading from vegetation and insulation from dry peat is sufficient to preserve the permafrost also under projected future warming scenarios (Yi et al., 2007). Although, when considering winter insulation caused by snow trapping and the increase in winter albedo due to protrusion of shrub stems above snow cover, the net impact on the permafrost from an increase in shrubs may still be of a degrading nature (Lawrence and Swenson, 2011).

Some graminoids, such as *Eriophorum sp*., have the potential to impact the dynamics of methane emissions through stimulation of methane production by increasing carbon substrate availability (Ström et al., 2005; Jackowicz-Korczynski et al., 2010). Malmer et al. (2005) predicted an increase of such graminoids, as palsa mires in the subarctic becomes wetter due to thawing of the underlying permafrost. This will potentially cause further increase in emissions of methane as a combined effect of more carbon available for decomposition as permafrost thaws, and a shift of vegetation to more graminoids such as *Eriophorum sp*.

2.6 The relationship between peat and permafrost

The soil type and amount of organic material are of great importance for the ground temperature as they affect heat flows from the surface to the ground. In general, soils with high organic content e.g. peat has a lower thermal conductivity compared to mineral soils. This is a very important factor for the preservation of permafrost in the Torneträsk region where peat creates an insulating layer (Johansson et al., 2006). During summer the peat layer is usually dry and contains a large amount of air, which decreases the thermal conductivity and therefore affects the heat flow from the surface to the ground (Yi et al., 2007). However, during autumn the water content generally increases in the peat layer leading to higher thermal conductivity and therefore making it easier for colder temperatures to affect the ground. Peat lands and palsa mires are therefore often seen as hosts for the southernmost occurrence of permafrost in the sub-arctic (Johansson et al., 2006).

3. Site description

The experiments in this study were conducted at the Storflaket peat mire (68°20’47’’N, 18°58’16’’E) in the Torneträsk region, 6 km east of Abisko in the northernmost Sweden (Fig. 5). The peat plateau measures approximately 900 meters in length and 400 meters in width with a depression of standing water dividing the mire in an eastern and western part. The field experiments were conducted at the western part. Storflaket is located in between the main road E 10 in the north, a railway in the south and by the west- and east facing borders of a sparse birch forest (*Betula pubescens* spp. *czerepanovi*). The vegetation covering the peat mire consists of a mixture of dwarf shrubs (*Andromeda polifolia*, *Vaccinium uliginosum*, *Empetrum nigrum* and *Betula nana*), mosses (*Dicranum scoparium*, *Sphagnum fuscum* and *Sphagnum balticum*) and lichens (*Cetraria cucullata*, *Cetraria nivalis* and *Cladonia* spp.) in the drier parts and graminoids (*Eriophorum vaginatum*) in the wetter parts (Johansson, 2009).

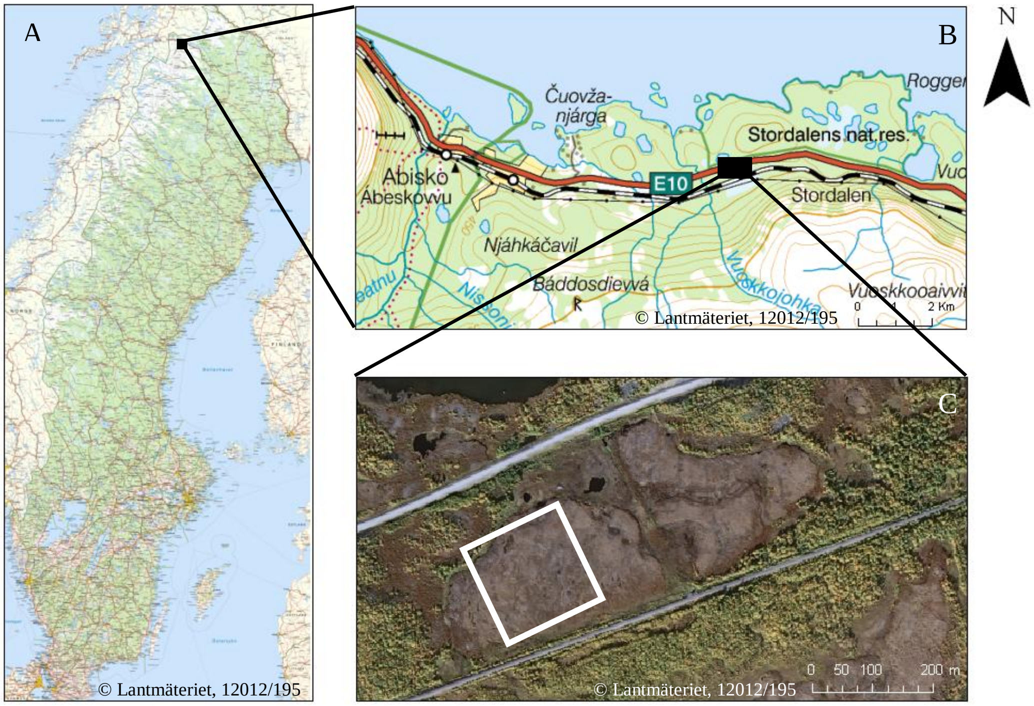

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Figure 5. A) Location of Abisko in the northernmost Sweden, B) Location of Storflaket mire and C) The relative location of the study area on the Storflaket mire. Coordinate system: SWEREF 99 TM.

Storflaket mire is located within the discontinuous permafrost zone in the subarctic region, where 50-90% of the area is underlain by permafrost (Johansson, 2009). Since 1978, the permafrost has been monitored and according to Åkerman and Johansson (2008) the active layer has increased by 0.7 cm yr^{-1} from 1978 to 2006 with an accelerated phase of thawing since the mid-1990s. The permafrost in the mire reaches a depth of approximately 14-30 meters (Åkerman and Johansson, 2008; Dobinski, 2010) and is considered as “Ecosystem protected permafrost”, which is common in climates where current annual mean temperature is approximately between 2°C to-2°C (Shur and Jorgenson, 2007). This type of permafrost can due to the insulating effects from peat persist as patches under a warmer climate (Shur and Jorgenson, 2007). The layer of protecting organic material (peat) on the Storflaket mire is relatively homogenous in thickness (~40 cm) and is underlain by a transition zone of silt and peat down to ~70 cm (Klaminder et al., 2008). The thick uppermost layer of organic material rests on a subsoil of glacial silt (Klaminder et al., 2008) and a bedrock of quartzite and slate (Kulling, 1963).

Regional climate data (from the Abisko Scientific Research Station's meteorological data, 1971-2000) show mean annual air temperature of -0.5°C and average July temperature of 11.3°C. The annual mean temperature at Storflaket mire for the period 2007-2010 was -0.2°C (Table 1). Summer mean temperature for the same years (June-August) was 11.1°C and the winter (December the preceding year - February) was -10.8°C.

Table 1. Annual (January - December), summer (June - August), autumn (September - November), winter (December the preceding year - February) and spring (March – May) mean temperature for the period 2007-2011 at Storflaket.

	2007	2008	2009	2010	2011	Mean 2007-2011
Annual temp (°C)	0.8	0.1	-0.1	-1.6	-	-0.2
Summer temp (°C)	11.6	10.6	11.4	9.5	12.1	11.1
Autumn temp (°C)	1.2	0.0	0.2	-0.9	-	0.1
Winter temp (°C)	-10.4	-6.3	-10.0	-13.4	-13.8	-10.8
Spring temp (°C)	0.5	-2.5	-0.8	-1.5	0.5	-0.8

In the Torneträsk region, the lowest precipitation is found in the Abisko area due to a rain shadow (Johansson, 2009). The mean annual precipitation for the period between 1961 and 1990 was 305 mm, mostly falling as rain during the summer months with July as the wettest month: average July precipitation is 54 mm (Alexandersson and Karlström, 2001). In contrast, between the period 1997 and 2007 the mean annual precipitation has increased to 362 mm (Data from Abisko Scientific Research Station). In 2007 and 2010, the years when soil moisture measurements were conducted at Storflaket mire, the mean precipitation from July until August for 2007 was ~116 mm and in 2010 ~73 mm (Fig. 6).

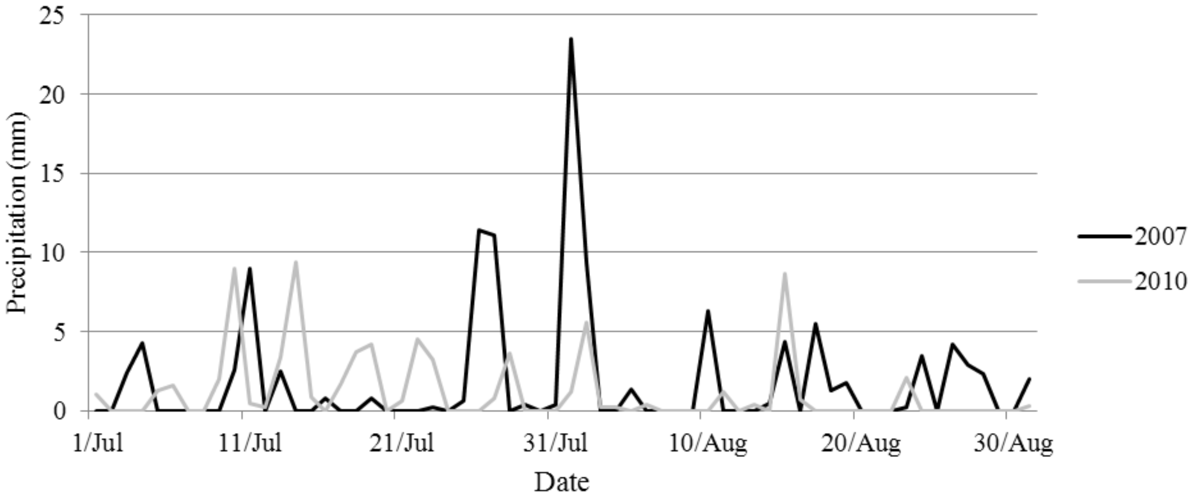

Figure 6. Mean daily precipitation measured from 1st of July until 31th of August in 2007 and 2010 at the Abisko Scientific Research Center.

4. Method

4.1 Experimental design

In 2005 an experiment was set up on the western part of Storflaket in order to investigate the effects of snow depth on active layer thickness. Twelve plots were established across the study site (Fig. 7A). Six plots were randomly chosen to be subject to simulated increase in snow depth using snow fences (Johansson, 2009). In 2007 the vegetation removal experiment used in this study was set up using the same plots to investigate the effects of different plant functional types on soil temperature and soil moisture. In each plot, three different 1×1m treatments were established, in which one specific plant functional type were removed in each of the treatments; 1) all mosses and lichens were removed 2) all graminoids were removed 3) all dwarf shrubs were removed (Fig. 7B).

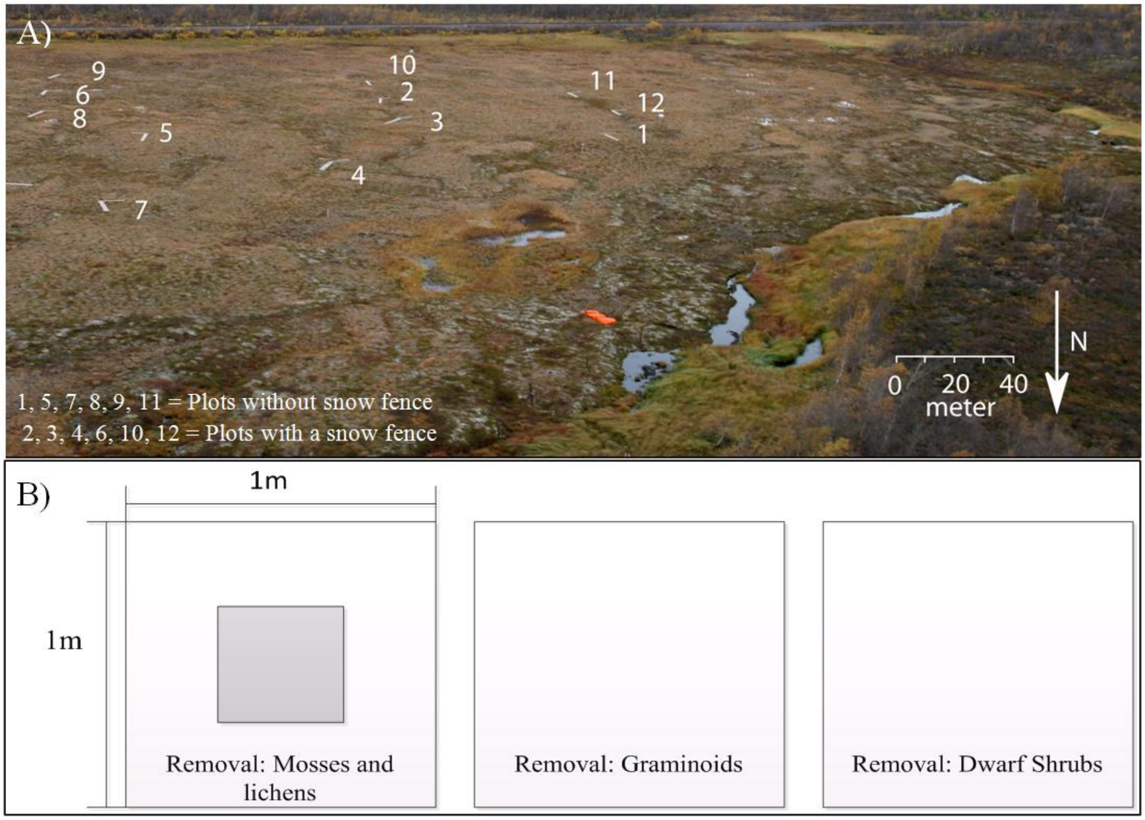

Figure 7. A) Aerial photography over the western part of Storflaket with plot positions. B) Schematic picture of the 1×1m treatments within a single plot. Mosses and lichens were only removed in a ~20×20cm square in the treatment (dark square). Aerial photo modified from (Johansson, 2009).

4.2 Removal of vegetation

Mosses and lichens were removed in a ~20×20 cm plot within the treatment (Fig. 8C). Approximately the upper 5 cm were removed, as it was the above ground living material that was removed. Removal of mosses and lichens were only done in 2007 since the plant functional type does not recover at the same rate as dwarf shrubs and graminoids. All above ground vegetation was removed for the two plant functional types, dwarf shrubs and graminoids in the whole 1×1m plot using scissors (Fig. 8A and Fig. 8B). The removal of dwarf shrubs and graminoids were done each following year to clear the treatments from regrowth. Table 2 lists the species that were removed from the plots.

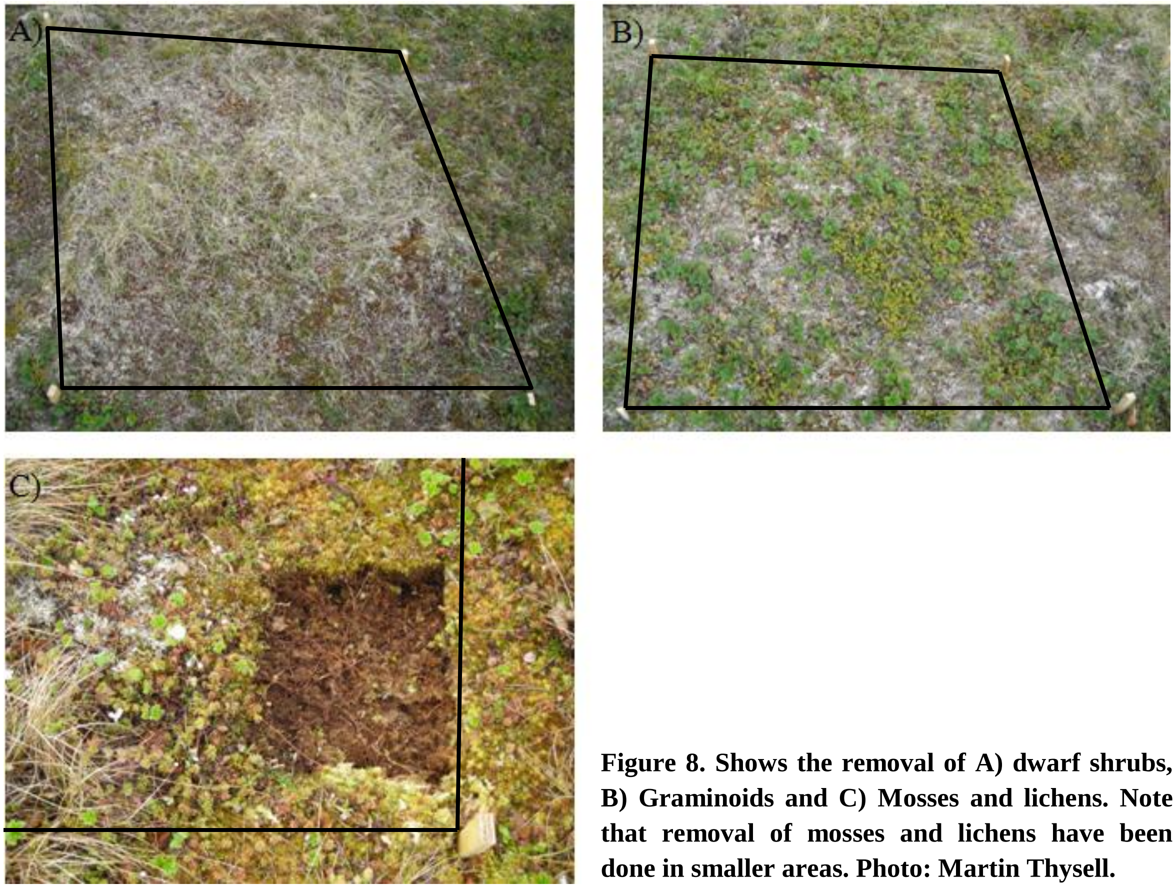

Figure 8. Shows the removal of A) dwarf shrubs, B) Graminoids and C) Mosses and lichens. Note that removal of mosses and lichens have been done in smaller areas. Photo: Martin Thysell.

Table 2. The species that were removed from the three different treatments.

Plant functional type	Species
Dwarf shrubs	*Andromeda polifolia*
	Betula nana
	Empetrum nigrum
	Vaccinium uliginosum
	Vaccinium vitis-idaea
	*Rubus chamaemorus**
Graminoids	*Eriophorum vaginatum*
Mosses and Lichens	*Sphagnum augustifolium*
	Sphagnum fuscum

* *Most like a dwarf shrub in terms of plant functional types*

The samples were prepared in laboratories after removal. As for dwarf shrubs the stems were separated from the leaves for *Andromeda polifolia*, *Betula nana*, *Vaccinium uliginosum*, *Vaccinium vitis-idaea* (not for *Empetrum nigrum* and *Rubus chamaemorus*). As for graminoids, the dead leaves and litter were separated from the living leaves. Lastly, for the samples of mosses and lichens, the mosses were separated from the other species. All samples were then dried in a drying oven for 48 hours in 70 ºC and then weighed.

The total amount of graminoids and dwarf shrub that were removed at each plot for each year was summed up to be able to compare the amount of each plant functional type that was removed. The regrowth of dwarf shrubs generally declined in 2009 compared to 2008 and then increased in 2010 whereas graminoids seem to decline in both 2009 and 2010. The dry mass of removed dwarf shrubs is generally much larger than the removed graminoids (Table 3).

Table 3. Vegetation that was removed from each treatment plot (dry weight) during the years of manipulating the vegetation cover at the Storflaket mire, Abisko.

	2008		2009		2010	
Plot	Dwarf shrubs (g)	Graminoids (g)	Dwarf shrubs (g)	Graminoids (g)	Dwarf shrubs (g)	Graminoids (g)
1	57.90	20.12	35.35	10.01	36.48	10.38
2	43.85	13.85	21.08	7.94	35.99	5.23
3	70.77	24.66	31.67	14.94	48.06	19.36
4	81.06	10.73	26.69	7.53	45.7	4.29
5	43.36	15.31	34.9	7.59	30.16	6.13
6	42.73	3.55	28.03	1.54	34.45	2.4
7	61.39	8.62	25.21	3.99	34.85	2.65
8	41.73	11.52	20.9	8.84	33.71	8.79
9	65.49	46.31	43.61	21.07	53.9	19.15
10	37.45	9.17	21.23	4.62	33.72	4.57
11	29.19	10.47	9.69	4.84	21.07	5.71
12	62.51	3.13	37.88	2.16	66.74	2.67

4.3 Measurements and data analysis of ground temperatures and soil moisture

Three measurements were done in each treatment to remove effects of e.g. micro-topography. Three additional measurements were taken outside the treatments as control. Temperature measurements were taken for a total of 30 days over a period of July through October during 2007, 2008, 2010 and 2011. The sampling frequency was determined by staff available at site. Soil moisture was only measured in total 16 days during 2007 and 2010 (the equipment was only available for these two years). The temperatures were recorded at 10cm depth using nameless thermistors and the soil moisture was monitored using Theta Probe soil moisture sensor (ML2x).

The mean value of the three measurements in each treatment and the control was calculated before doing any analysis in order not to use sub-samples as actual replicates. The use of sub-samples as replicates would result in pseudo replication, which would compromise the reliability of the statistical results (Quinn and Keough, 2002). Before the analysis was done, obvious data errors were removed, such as extremely high values (>1000 ^{o}C) and one date where measurements in plots 1-6 were identical to those taken in plots 7-12. This was considered a data entry error. Also measurements taken in October were removed because temperatures dropped below 0^{o}C resulting in ground freezing so that measurements could not be obtained at all plots. Plot 11 was excluded in the analysis of soil moisture since 2 out the 3 treatments in this plot were saturated during the summer of 2010. The dates of data that were used for the statistical tests are presented in table 4 and table 5.

Table 4. Dates used for the analysis of ground temperatures.

2007	2008	2010	2011
22.07.07	29.07.08	12.07.10	17.08.11
12.08.07	11.08.08	21.07.10	26.08.11
19.08.07	03.09.08	27.07.10	15.09.11
25.08.07	09.09.08	04.08.10	
		09.08.10	
		10.08.10	
		16.08.10	

Table 5. Dates used for the analysis of soil moisture.

2007	2010
12.07.07	12.07.10
22.07.07	27.07.10
30.07.07	12.08.10
12.08.07	23.08.10
25.08.07	

The data was analyzed statistically using SPSS ver. 19.0. Normal distribution was tested for each individual datasets using nonparametric test (one sample Kolmogorov-Smirnov). Dates with datasets that were not normally distributed were removed in order to be able to analyze the data with an analysis of variance (ANOVA).

Non-parametric Independent sample t-tests (Mann-Whitney U-test) were made to ensure that soil temperatures and soil moisture did not differ between plots with and without the influence of the snow fence manipulation (as the vegetation removal was made in an ongoing snow manipulation experiment, to ensure that any changes in soil moisture and ground temperatures were only due to the effect of vegetation removal). No significant differences were found as the vegetation removal plots were outside the range of the snow effect. Therefore both the snow fence plots and the control plots could be used in the analysis (Table 6).

Table 6. Statistics from Mann Whitney U-test on the effect of accumulated snow from snow fences around 6 out of 12 plots on the Storflaket mire. Individual tests have been conducted for soil moisture and ground temperature separated by the different plant functional types and if snow fences were mounted or not.

	Significance value	
Treatment (snow fence vs. no snow fence)	Ground temperature	Soil moisture
Control	0.338	0.070
Dwarf Shrubs	0.632	0.682
Graminoids	0.737	0.790
Mosses and lichens	0.334	0.570

The effects of plant functional type removal on soil temperature and soil moisture were tested using repeated measures analysis of variance (ANOVA) with date as between-subject factor. In this way all measurements were compared only with measurements from the same date. So that the variance that comes with a mean value of all measurements of a treatment, because of the seasonal differences, is bypassed with this method.

In order to do repeated measures ANOVA, either sphericity has to be assumed or an approximation has to be used that does not require assumption of sphericity. Sphericity is a term used to describe the combination of the usual ANOVA assumption of equality of variances and something called compound symmetry. To be able to assume compound symmetry, in this case, would mean that there would have to be equal correlation among pairs of treatments over time (Zar, 1996). According to the test for sphericity (Mauchly's test of Sphericity, P>0.05), it should not have been assumed for the data used in this analysis. Sphericity was assumed anyway on account that the p-value from the sphericity test was close to non-significant (P=0.032) and also the results from the repeated measures ANOVA were the same for the approximations and for assumed sphericity. According to Zar (1996) this is a common solution and is unlikely to cause any large errors. To make a pairwise comparison to see the significance in the difference between the mean values of the different treatments, Bonferroni correction had to be applied (Quinn and Keough, 2002).

5. Results

5.1 Ground temperatures – General description

The monitored ground temperatures indicate that the warmest month was July (9.1°C) under control plots (without any removal of different plant functional types) (Table 7). The ground temperatures in the control plots then decreased in August (8.0°C) until it reached its lowest temperature in September (6.1°C). Seasonal development of temperatures in the top-soil layer showed variation between the different years of the study, with 2010 and 2011 being generally warmer compared to 2007 and 2008 for all the plots including the control plots and plots with different vegetation manipulations (Fig. 9). The removal of dwarf shrubs increased the soil temperature of approximately 0.2°C from July-September compared with the temperature measured in the ground under the control plots. However, removals of the other two plant functional types lead to generally colder temperatures (graminoids -0.5°C; mosses and lichens -0.6°C) (Table 7).

Table 7. Mean ground temperatures from July to September in 2007, 2008, 2010 and 2011 at the Storflaket mire, Abisko.

Monthly mean values for period 2007, 2008, 2010 and 2011	Plant functional type removal						
	Dwarf shrubs	Diff. DS-C*	Graminoids	Diff. G-C**	Mosses and lichens	Diff. ML-C***	Control plots
Ground temperature (°C)							
July	9.2	0.1	8.5	-0.5	8.4	-0.7	9.1
August	8.2	0.2	7.5	-0.5	7.5	-0.5	8.0
September	6.2	0.1	5.6	-0.5	5.4	-0.7	6.1
July-September	8.2	0.2	7.5	-0.5	7.4	-0.6	8.0

**Diff. DS-C is the difference in ground temperature between dwarf shrubs removal plots and the control plots.*
***Diff. G-C is the difference in ground temperature between graminoid removal plots and control plots.*
****Diff. ML-C is the difference in ground temperature between mosses and lichens removal plots and the control plots.*

5.2 Ground temperatures – Statistical analysis

Monitored ground temperature in the plots between July-September showed a significant difference between the different dates of measurements during the season (date) ($P<0.05$). The mean ground temperature in the three different vegetation removal treatments (dwarf shrub, graminoids, mosses and lichens) and the control differed significantly (treatment) ($P<0.05$). The difference in ground temperature between the vegetation manipulations were also significantly different between dates (treatment×date) ($P<0.05$) (Table 8).

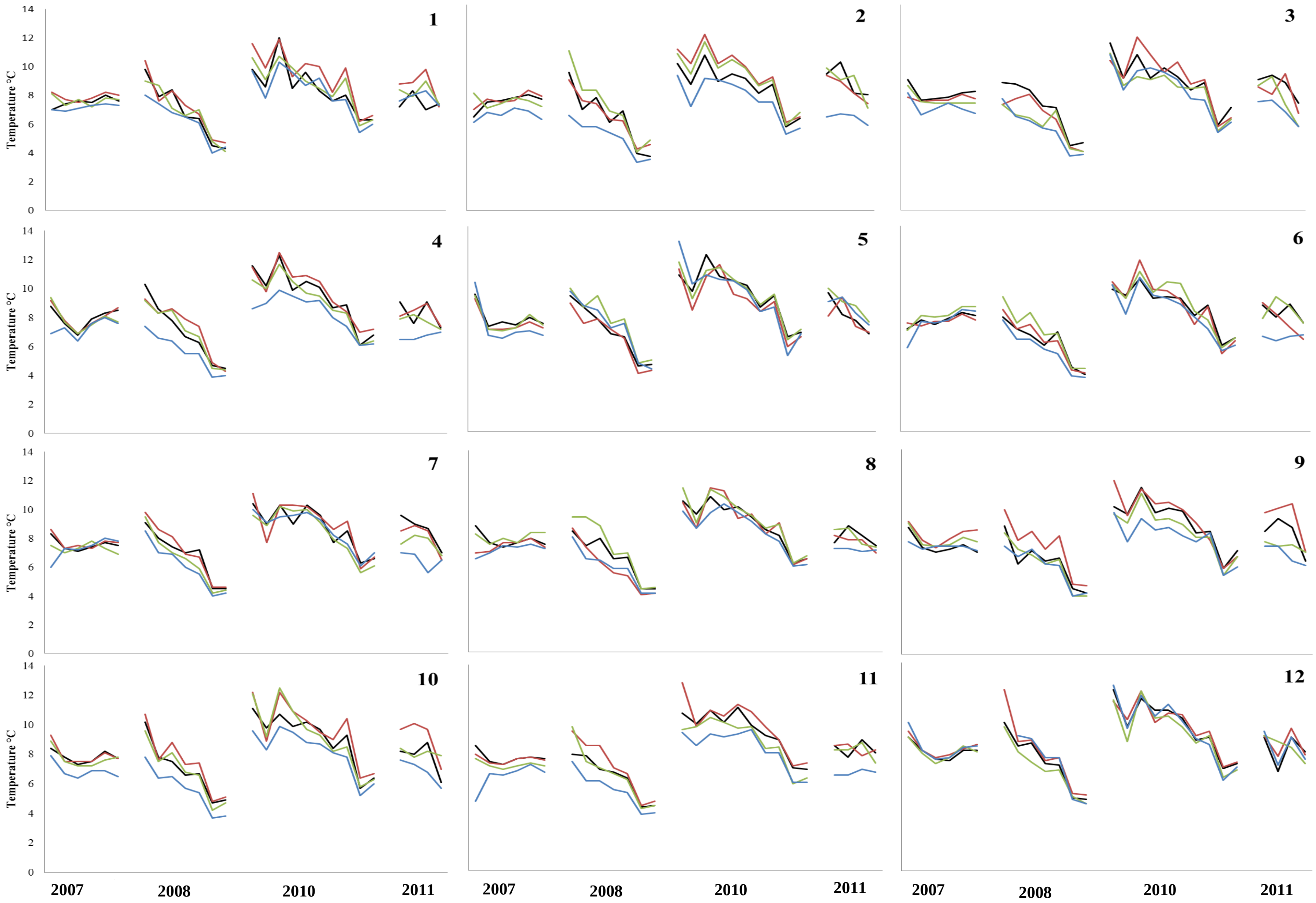

Figure 9. Mean ground temperature measured in the twelve plots with different manipulations; dwarf shrub removal plot (red line), graminoids removal plot (green line) and mosses and lichens removal plot (blue line) in comparison with the control plot (black line) for July - September 2007, 2008, 2010 and 2011.

Table 8. Results of repeated measures ANOVA, testing the effects of vegetation removal treatment, and difference between dates, on ground temperature. The significance values are presented with the degrees of freedom and the F-value.

Ground temperature	Type III Sum of Squares	df	F	Sig.
Between-subject effects				
Date	232	16	234	<0.001
Within-subject effects				
Treatment	91.4	3	103	<0.001
Treatment×date	27.2	48	1.92	<0.001

Where dwarf shrubs were absent from the plots, the ground temperature was significantly different (P<0.05) for all 4 years of monitoring compared to the plots where dwarf shrubs were still present (Table 9) The mean soil temperature (July-September) under the dwarf shrub removal plots was 8.4°C (Table 9 and Fig. 10). Compared to the control plots, removal of dwarf shrubs led to a mean increase of the soil temperature by 0.2°C. Furthermore, where mosses and lichens had been removed this resulted in a significant difference in ground temperature compared to the control plots (P<0.05). Instead of increasing the soil temperature, plots absent from mosses and lichens resulted in 0.7°C colder temperatures than in the control plots, and also approximately 1°C colder compared to the dwarf shrubs removal plots. Removal of graminoids from the peat plateau showed no significant difference compared with the control plot (P>0.05) (Table 9).

Table 9. Results of repeated measures ANOVA, pairwise comparison testing the statistical significance between ground temperatures under the vegetation removals and the control plots.

Treatment	Mean value	Mean difference (treatment-control)	Std. Error	Sig.
Ground temperature (°C)				
Dwarf shrub	8.4	0.2	0.05	0.001
Graminoids	8.2	-0.1	0.05	1
Mosses and lichens	7.5	-0.7	0.05	<0.001

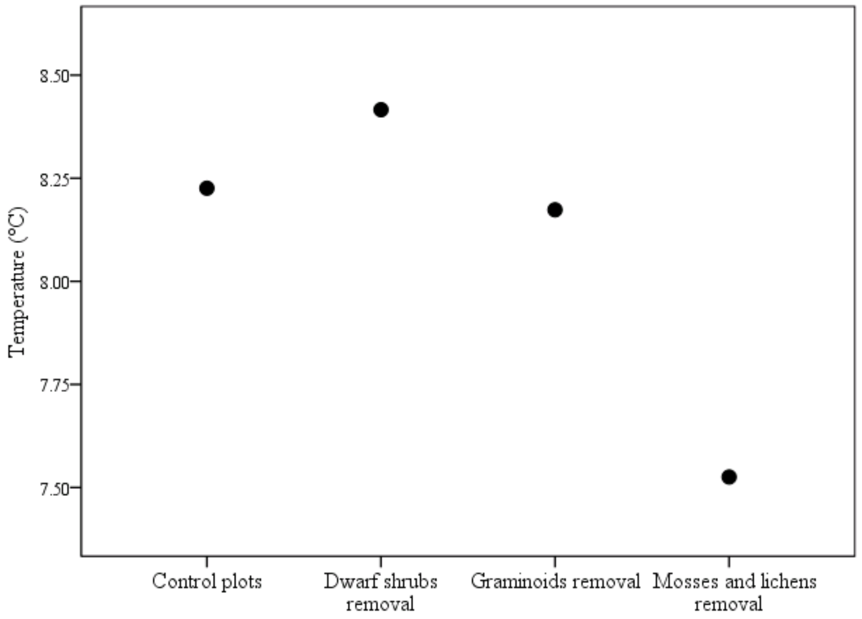

Figure 10. Plot from repeated measurements ANOVA of mean ground temperatures under removal of graminoids, mosses and lichens and dwarf shrubs together with control plots.

5.3 Soil moisture – General description

Within the 12 manipulation plots, soil moisture varied greatly throughout the season and also between the two years of monitoring (Fig. 11). General trends in the dataset are hard to distinguish. However, in the plots where mosses and lichens had been removed an increase in the average soil moisture content under the treatment plots could be detected by 6.8% from July-August. Where mosses and lichens still were present in the treatment plots and dwarf shrubs and graminoids had been removed, the average soil moisture content decreased during the summer season (Table 10).

Table 10. Mean soil moisture from July to August in 2007 and 2010 at the Storflaket mire, Abisko.

	Plant functional type removal						
Monthly mean values for period 2007 and 2010	Dwarf shrubs	Diff. DS-C*	Graminoids	Diff. G-C**	Mosses and lichens	Diff. ML-C***	Control plots
Soil moisture (vol%)							
July	49.8	-0.4	46.6	-3.6	58.4	8.2	50.2
August	47.0	-2.4	45.8	-3.6	55.3	5.9	49.4
July-August	48.1	-1.6	46.1	-3.6	56.5	6.8	49.7

**Diff. DS-C is the difference in soil moisture between dwarf shrubs removal plots and the control.*

***Diff. G-C is the difference in soil moisture between graminoid removal plots and control.*

****Diff. ML-C is the difference in soil moisture between mosses and lichens removal plots and the control.*

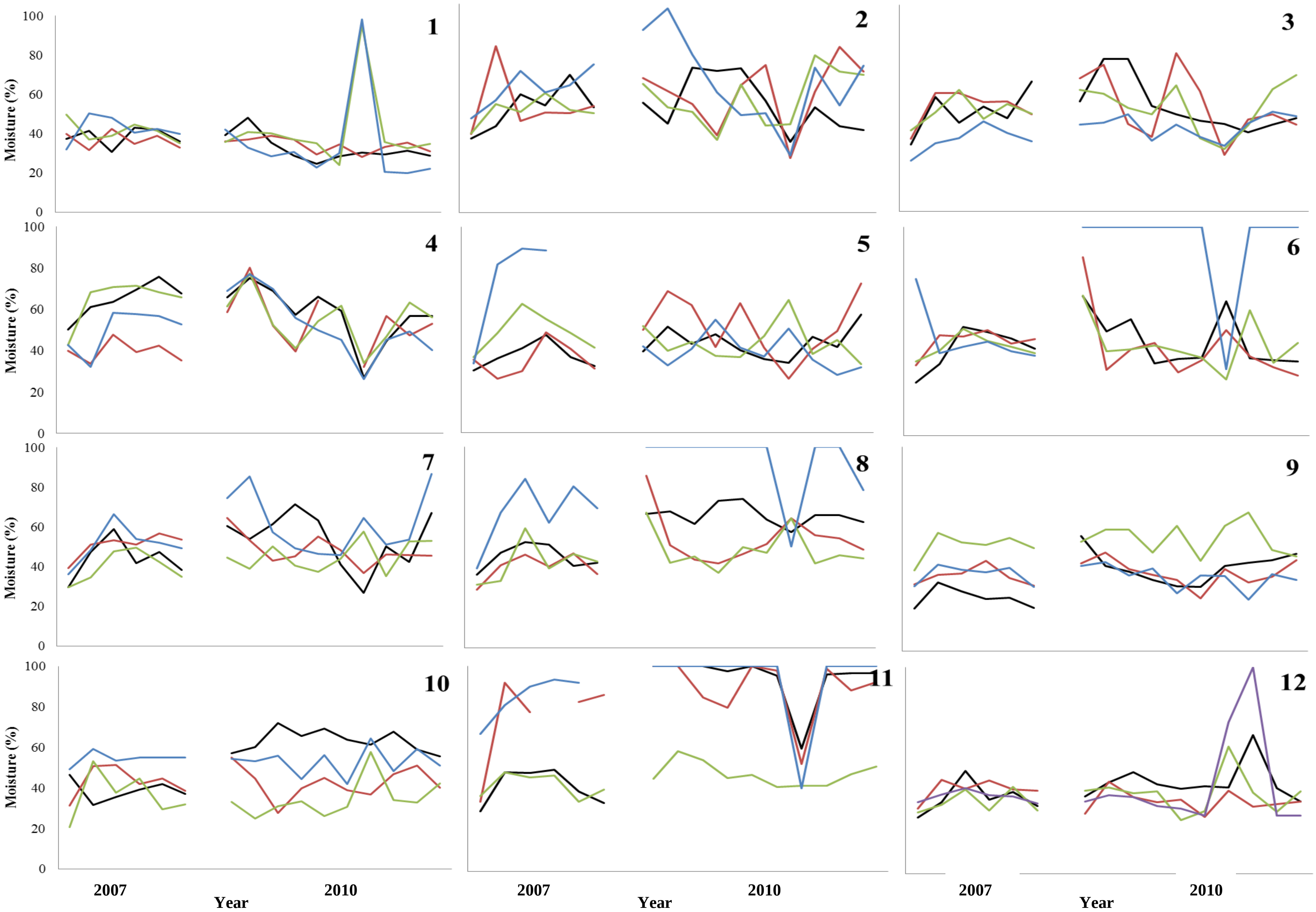

Figure 11. Mean soil moisture measured in the twelve plots with different manipulations; dwarf shrub removal plot (red line), graminoids removal plot (green line) and mosses and lichens removal plot (blue line) in comparison with the control plot (black line) for July - September 2007 and 2010.

5.4 Soil moisture – Statistical analysis

Significant differences were found in the monitored soil moisture in the plots between July to August between the different dates of measurements (P<0.05). The mean soil moisture in the three different vegetation removal treatments (dwarf shrub, graminoids, mosses and lichens) and the control differed significantly among them (treatment) (P<0.05). The difference in soil moisture between the vegetation manipulations were not significantly different between dates (treatment×date) (P>0.05) (Table 11).

Table 11. Results of repeated measures ANOVA testing soil moisture differences between dates, different vegetation manipulations and the effects of vegetation manipulations between dates. The significance values are presented with the degrees of freedom and the F-value.

Soil moisture	Type III Sum of Squares	df	F	Sig.
Between-subject effects				
Date	11254	8	4.11	<0.001
Within-subject effects				
Treatment	3831	3	8.24	<0.001
Treatment×date	3297	24	0.89	0.621

Removing mosses and lichens from the treatments lead to a significant increase (P<0.05) in soil moisture content by 6.6% compared to the control plots. Where dwarf shrubs and graminoids were removed no significant difference (P>0.05) was found compared to the control plots (Table 12 & Fig. 12).

Table 12. Results of repeated measures ANOVA, pairwise comparison testing the statistical significance between soil moisture under the vegetation removals and the control plots.

Treatment	Mean value	Mean difference (treatment-control)	Std. Error	Significance
Soil moisture (vol%)				
Dwarf shrub	44.3	-1.7	1.34	1.000
Graminoids	47.2	1.3	1.52	1.000
Mosses & lichens	52.6	6.6	2.06	0.011

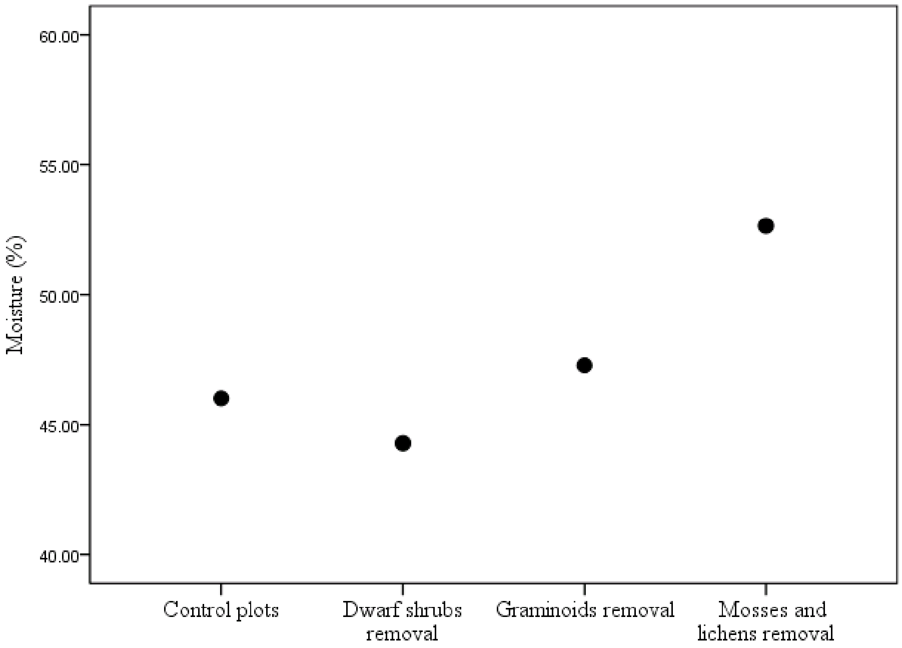

Figure 12. Plots from repeated measurements ANOVA of mean soil moisture variation in the different plots where plant functional types have been manipulated differently.

6. Discussion

6.1 Ground temperatures

When considering the general description of the ground temperature data, the mean ground temperature in the treatments where dwarf shrubs were absent was 0.2°C warmer compared to the control. The normal distributed data analyzed statistically revealed a significant warming of 0.2°C under the dwarf shrubs removal, so it is the same as the difference calculated before data were removed. In the analysis of mosses and lichens treatment the significant difference (-0.7°C) were also similar to the mean value in the general description (-0.6°C). This indicates that removal of non-normal distributed data did not severely impact the result of the statistical analysis of these treatments.

Where dwarf shrubs are still present in the study site, they decrease soil temperature during summer. This result is similar to what Blok et al. (2010) found, that an increase in dwarf shrub cover (*Betula nana)* reduced the thickness of the active layer. This is most likely an effect of the dwarf shrubs shading capabilities due to their high-stature characteristics combined with the canopy effect. It also indicates that the cooling effect of shrubs is strong enough to counter the heating that would come from the relatively low albedo of dwarf shrubs. In Stordalen, where Malmer et al. (2005) verified an increase in dominance of graminoids, the dwarf shrubs are likely to decline due to unfavorable conditions caused by the degrading permafrost and the poor drainage. With the results from this study the loss of the cooling effect of the shrubs could lead to further warming of the soil which will lead to increasing degradation of the permafrost. In a long term perspective more wet conditions will be created leading to further decline in dwarf shrub abundance. However, considering the vegetation removal the regrowth of dwarf shrubs in the plots were still generally higher compared to the graminoids. This indicates that Storflaket mire still offers suitable conditions for shrub growth. If the mire gets drained in the future resulting in more dry conditions it could be beneficial for the dwarf shrubs. However, considering results from Bosiö et al. (2012) it is not very likely that future conditions on palsa mires in norther Fennoscandia will be suitable for shrub expansion.

The cooling effect of shrubs during the summer suggests that the plant functional type can have a positive effect on the permafrost preservation in those locations where increased shrub growth and dominance is expected. However, to be able to evaluate the net effect of shrubs on the permafrost in the Arctic region, one has to consider how they impact winter soil temperatures and winter albedo. The simulations conducted by Yi et al. (2007) showed that future vegetation cover and insulating organic soil layers should actually be enough to protect the permafrost from degradation even with the projected increase in temperature. On the other hand, Lawrence and Swenson (2011) argues that shrub expansion around the Arctic, with resulting increase in both summer and winter albedo and the increase in winter soil temperatures from increased snow trapping, will lead to further permafrost thaw despite the shrubs capacity to decrease soil temperatures during summer. The effect of the projected shrub increase in the Arctic has both positive and negative aspects causing and preventing permafrost degradation. The net impact of shrubs is still unclear and the strength of the different effects of shrubs needs to be further studied to understand the final impact that the increase in shrub coverage will have on permafrost thaw in the Arctic region.

In the statistical analysis there is a significant difference in the impact of vegetation removal between the dates. How the impact differs throughout the season is not shown in the statistical analysis but this can be seen when considering the visualization in the general description of the ground temperature data. In the years 2008 and 2010 there is a pattern in most plots of decreasing differences towards the end of the period. This indicates a trend that the impacts of the vegetation removal is strongest in mid-summer and declines throughout the season, which can be explained by the intensity of the sun.

Based on the analysis from the plots where graminoids were removed it is difficult to draw any conclusions on how they affect summer soil temperatures. Removal of graminoids had no significant effect on the ground temperatures. However, when the total amount of data were evaluated the absence of graminoids resulted in a 0.5°C lower soil temperature. Only considering the descriptive evaluation of all the data there is a possible effect of warmer ground temperatures by increased dominance of graminoids at Storflaket. Combined with the significant increase of ground temperatures when dwarf shrubs are absent this can potentially lead to an increased active layer thickness at the mire. Further increase in active layer thickness will lead to higher amount of organic material available to be released to the atmosphere as greenhouse gases (Callaghan et al., 2011b). Increased dominance of graminoids also increases the production and emission of methane (Ström et al., 2005; Jackowicz-Korczynski et al., 2010; Bosiö et al., 2012). Increase in greenhouse gas emissions can result in further warming, permafrost degradation, increased soil water content and graminoid expansion on the mires. These results are highly insecure since they are based on the descriptive evaluation of the entire data, but is still worthy of discussing because more knowledge is required of how carbon stored in the frozen ground can affect the global climate through greenhouse gas emissions and how the vegetation can feedback to the process.

According to this analysis, the removal of mosses resulted in a significant decrease in soil temperature by 0.7°C, which also coincides with the descriptive analysis of the monitored ground temperatures. This would indicate that the presence of mosses and lichens has a warming effect on the soil during the summer, which is in contradiction to Blok et al. (2011) and Beringer et al. (2001). They both proposed that the insulating properties of the mosses would mitigate soil warming during the summer. So the removal of mosses should rather cause heating of the soil in the summer due to the absence of insulation. The results from this study indicate that future loss of mosses due to increased shrub abundance would be beneficial for the preservation of permafrost in the sub-arctic regions.

6.2 Soil moisture

Removal of dwarf shrubs and graminoids had no significant impact on soil moisture. This concludes that they are of less importance when it comes to changing the thermal conductivity of the underlying soil. The only treatment in the experiment that had a significant impact on soil moisture was the removal of mosses where soil moisture increased by 6.6%. A similar increase (6.8%) was also seen when all data were considered. The soil moisture data were checked against precipitation data to see if there were measurements taken at dates when soil moisture might have been heavily impacted by rainfall. Based on estimation, temporary peaks in the precipitation did not seem to coincide with any uniform increases in the soil moisture measurements in the data.

According to Beringer et al. (2001) the mosses ability to hold water prevents it from draining through the mosses and into the ground. This way the water evaporates from the mosses into the atmosphere instead. This indicates that the removal of mosses would potentially increase the amount of water in the underlying soil. More water in the insulating organic soil layers leads to less insulation and an increase in permafrost degradation. For Storflaket a decrease of mosses and lichens could lead to more wet conditions and therefore increasing the thermal conductivity of the peat layer. This will increase permafrost degradation during summer but increase the buildup of permafrost during autumn.

6.3 Sources of errors

Some of the collected data had to be excluded in order to do the repeated measure ANOVA. The majority of the data that was excluded from the original data was due to lack of normal distribution. All efforts to normalize the non-normal distributed data failed, mainly because no common pattern could be observed in the distribution of the different datasets. The main reason for the amount of non-normal distributed datasets was probably the number of measurements per dataset. With only 12 plots and the need to evaluate normal distribution for one day at a time there were only 12 values per dataset. If there were more plots it would probably result in a higher proportion of normal dirtributed datasets.

When comparing all of the collected data with the results of the statistical analysis the mean differences in ground temperature between treatment and control were similar for the dwarf shrub treatment and also for the mosses and lichens treatment. As stated earlier this might suggest that the exclusion of data that was done did not have any large impacts on the final results for these treatments. The graminoid treatments on the other hand, showed a mean difference of -0.5°C when considering all data but only a non-significant difference of 0.1°C in the statistical analysis. The reason for this shift in the data has not been resolved and is still unclear. Further analysis needs to be done to explain the difference in result of graminoids before and after exclusion of non-normal distributed data.

The lack of significance in the soil moisture analysis could be associated with the small amount of data that was analyzed in this study, since it has only been measured for two years. Additionally, some of the gathered data had to be excluded from the analysis due to non-normal distribution and saturation. It could also be that soil moisture has a higher spatial variance than temperature since it is more dependent on topography, which inevitably may vary both between and within plots. The combination of lack of data and a higher variance within the datasets could very well explain why there were so few significant differences in the soil moisture analysis.

In the process of removing the mosses, a 5cm deep depression was created. Measurements taken in these treatments may have been taken approximately 5cm deeper than in other treatments since measuring instructions stated to stick the thermometer “as deep as possible” into the ground. This can have effect on both temperature measurements and soil moisture measurements. These depressions also have the potential to accumulate water, which might increase soil moisture values measured in the moss removal sites. It can also cause shading of the surface in the depression. Depending on the solar angle a portion of the soil surface in the depression will be completely obscured from direct solar radiation. This might explain some of the impact on the cooling in the moss removal sites. When removing the mosses and lichens they were simply removed without replacing them with anything else, hence creating bare ground instead of any vegetation. In contrast, the mosses and lichens that are projected to decline due to vegetation changes will be replaced with shrubs or sedges. In the removal of shrubs and the removal of graminoids other functional groups were still present.

The accuracy of the measuring devices was one tenth of a degree for temperature and one tenth of a percent for soil moisture. So the accuracy of the results had to be considered the same. Therefore all results had to be rounded to a one decimal value. This could have effects on the accuracy of the results because the differences in ground temperature are below 1°C and therefore more accurate measuring devices would be preferred.

6.4 Future Studies

Since the analysis of these data needs to be done using a repeated measure ANOVA, comparing means for different treatments one day at a time, the only way to increase the sample size is to increase the number of plots. This would also make better ground for normal distribution of the datasets. Since this would increase the workload with both the manipulation and measuring, it might be worth considering putting more focus on the treatments that has shown to affect the ground temperature. It could be argued that one treatment to focus on in this specific study should be the dwarf shrub removal treatment. The effect of the graminoids on soil temperature and soil moisture needs to be studied but if the amount of graminoids removed is too small to make a measurable difference in soil properties, then maybe another site or experiment is needed in an environment where graminoids are plentiful enough to make a significant difference when removed. The removal of mosses is somewhat hard to compare with the other treatments since the removal process differs a lot from the others.

Since the differences that are of interest are not dependent of year to year changes and the fact that there is a significant difference in the effect of vegetation removal throughout the season it may be better to do more measurements over a shorter period of time in one season. This could increase the amount of data and minimize the between subject effect in the analysis. A good way to solve the problems with increased workload due to daily measurements would be to use some sort of logger equipment. With continuous measuring there is also the possibility to evaluate the vegetation removal effect on soil temperatures during the winter with differences in snow trapping and insulation.

7. Conclusions

- The absence of dwarf shrubs has a warming effect on the summer soil temperature at Storflaket. According to the results of this study the absence of mosses has a cooling impact on summer soil temperature.

- The absence of mosses and lichens increases the soil moisture in the summer.

- A decline in dwarf shrub vegetation at Storflaket mire would lead to increased ground temperatures and therefore further permafrost degradation resulting in increased dominance of graminoids. This can lead to increased emissions of methane possibly affecting the global climate.

- The cooling effect of shrubs during the summer may contribute to less permafrost degradation in those locations where increased shrub dominance is expected. However, further studies are required to evaluate the net impact of shrubs on permafrost thaw over the whole year.

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