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Timothy Frederick Botting
Grand Valley State University

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Documenting Annual Differences in Vegetation Cover, Height and Diversity near Barrow, Alaska

Timothy Frederick Botting

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Abstract

Vegetation in the Arctic has been shown to respond to climate change. Documented changes have the potential to result in numerous ecosystem consequences. Therefore, understanding vegetation change is of great importance. This study documents changes in tundra vegetation with a focus on understanding the influence of annual differences in weather. Vegetation was sampled using a point frame method on 98 1-m^2 plots in 2010 and 2013 near Barrow, Alaska. A subset of 30 of these plots was also sampled in 2012 and 2014. Plant encounters were identified to species and grouped into one of the following functional groups: bryophytes, deciduous shrubs, forbs, graminoids, lichens, litter or standing dead. Plant height and species diversity metrics were also calculated. The following abiotic variables were used to quantify difference in weather between years: air temperature, precipitation, thawing degree days, thaw depth, soil temperature and soil moisture. For analysis, focus was on the 30 plots that were sampled over 4 years. The cover of all functional groups, the height of graminoids and alpha diversity changed significantly; the magnitude of changes was large. Significant correlations occurred between the following vegetation metrics and abiotic variables: the cover of forbs and soil temperature; the cover of graminoids and all abiotic variables except soil moisture; the cover of litter and air temperature, thawing degree days, soil temperature and soil moisture; the cover of standing dead and all measured abiotic variables; and the height of graminoids and soil moisture. The strongest correlations between abiotic variables and vegetation metrics varied between functional groups; this suggests multiple abiotic factors should be considered when attempting to explain observed changes. In summary, this study found large annual changes in vegetation cover, height and diversity that were presumably due to variability in weather of each year. While a longer consecutive time series is needed to better understand the relationship between the weather of a

given year and vegetation dynamics, caution should be used when interpreting the results of long-term vegetation monitoring that is sampled over a coarse time series because of large annual variability shown in this study.

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Introduction

Numerous global environmental changes are occurring and one especially important environmental change is climate warming. Arctic regions have been identified as one of the regions most susceptible to climate warming. As such, several research initiatives and projects have been implemented to document long-term changes in arctic regions, especially near Barrow, Alaska. Below is a brief discussion of the topics most closely related to this project. This thesis was completed as a subcomponent of a larger multi-university project aimed at documenting and understanding the vegetation changes and ecosystem consequences occurring in Northern Alaska. This project utilized an Arctic Systems Science Grid and was funded as part of the International Tundra Experiment and the Arctic Observing Network.

Global Environmental Changes

A host of environmental changes are occurring across the globe mainly as a result of anthropogenic activities. Nitrogen and phosphorus accumulation rates have increased substantially over time in terrestrial and aquatic ecosystems (Bennett et al. 2001; Galloway et al. 2004). Another observed change is the establishment of numerous exotic species in new regions through accidental or intentional relocation (Mills et al. 1993; Mack et al. 2000). Furthermore, the frequency and intensity of fire regimes is shifting mainly as a result of fire suppression or increased use of fires to alter the community composition of ecosystems (Veblen et al. 2000; Marlon et al. 2008). Likewise, numerous landscapes have become fragmented over time through activities such as deforestation which are known to alter the distributions of plant and animal species (Skole & Tucker 1993; Fahrig 2003). In addition, anthropogenic sources have substantially increased carbon dioxide and other greenhouse gas concentrations in the atmosphere well above preindustrial levels; those environmental changes are especially important in arctic regions which have been identified as particularly vulnerable to climate warming (IPCC 2013). Climate warming is expected to be an especially strong driver of environmental change in arctic regions due to the prevalence of cold-adapted species, short growing seasons and soil nitrogen limitations (Callaghan et al. 2005).

Research Initiatives Documenting Environmental Changes in Arctic Regions

Arctic Systems Science Grids

The Arctic Systems Science (ARCSS) Program was established as a funding initiative by the National Science Foundation (NSF) in the early 1990s. The goals of the program were to investigate how physical, chemical, biological and sociocultural processes are influenced by environmental changes in arctic regions and to identify ways to respond to such changes. One component of the program was to establish spatial grids, which typically span 1 ha to 1-km^2, allowing for numerous research projects to conduct landscape-level research related to the program goals. Currently this funding initiative supports interdisciplinary research at numerous sites in arctic regions (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13426).

International Tundra Experiment

The International Tundra Experiment (ITEX) was established in 1990 to investigate the response of vegetation and ecosystems to environmental change. The project mainly looked at plant responses to environmental change at the species-level and across moisture gradient extremes. Manipulated warming experiments occurred at each ITEX site to document the impacts of climate warming on plants. The most common warming manipulation was through the use of open-top chambers to passively warm the air 1-3°C consistent with future climate warming predictions (Henry & Molau 1997). Protocols for various measurements were developed to ensure consistent sampling at each site (Molau & Mølgaard 1996). Since all research sites within the network contained a warming experiment and data were collected using standardized protocols, syntheses that documented environmental change could be conducted across space and time with the option of including warming as another variable (Elmendorf et al. 2012a). Since its inception, the ITEX network includes numerous research sites in both arctic and alpine regions across more than 11 countries, and all arctic nations are currently represented (http://ibis.geog.ubc.ca/itex/about.php).

Arctic Observing Network

The Arctic Observing Network (AON) began in 2006 as a funding initiative by the NSF to encourage research proposals related to monitoring environmental change. The goals of AON were threefold: to better understand and inform about current environmental changes already occurring in the arctic, to predict future environmental changes and to develop ways to respond to observed or predicted environmental changes. Aided by interest in the International Polar Year (IPY), the NSF now funds 51 projects as part of AON including research into the atmosphere, ocean and sea ice, hydrology and the cryosphere, terrestrial ecosystems and human dimensions. ITEX projects in the United States and this project are currently funded through this initiative (http://www.arcus.org/search-program/aon).

Research in the Barrow Region

A considerable amount of research initiatives and projects have been established near Barrow, Alaska (a high arctic region) where this study took place. During the first IPY from 1882-1883, a weather station was built by explorers to monitor polar changes. The Naval Arctic Research Laboratory was established in 1947 to provide infrastructure to encourage scientific research in the region (Shelesnyak 1948). Research continued near Barrow and was especially prevalent during the involvement of the United States in the International Biological Program from 1964-1974 (USNC 1974). In 1973, the National Oceanic and Atmospheric Administration began the Barrow, Alaska Observatory monitoring weather patterns and processes as well as various aspects of the carbon cycle (http://www.esrl.noaa.gov/gmd/obop/brw/). In 1992, the Ukpeaġvik Iñupiat Corporation set aside some of their privately owned land to form the Barrow Environmental Observatory which was designated for research. This was rezoned as the Scientific Research District in 2003 by the North Slope Borough. Each year, Barrow hosts nearly 40 different research projects and has received national and international recognition for its cooperation with and fostering of scientific research (http://www.eu-interact.org/field-sites/alaska-2/barrow/).

The Importance of Vegetation

Individual Species

Documenting vegetation changes is critical as plants are important species in biological systems. They are primary producers exerting bottom up controls on successive trophic levels. As such, plant community composition especially impacts herbivore forage quantity and quality (Augustine & McNaughton 1998; Joly et al. 2009) as well as other plant-animal interactions (Tylianakis et al. 2008). Plants also help determine habitat suitability for animals ultimately influencing animal community composition (Orians & Wittenberger 1991; Rettie & Messier 2000). Plant species have also been shown to differ in resource allocation, impact nutrient cycles and alter soil organic matter accumulation (Vinton & Burke 1995). Therefore, shifts in vegetation species composition could have significant ecosystem consequences.

Functional Groups

Plant functional groups are used in ecological studies to serve as a reasonably accurate representation of the traits and characteristics of individual species to describe functional community composition. While some studies note that plant functional groups are not always accurate representations of individual species (Chapin & Shaver 1985; Hollister et al. 2015), benefits of using these groupings includes saving time when sampling vegetation and mapping large-scale vegetation patterns, as well as allowing for useful coarse-grained modeling of vegetation composition or plant traits (Lavorel et al. 2007; Ustin & Gamon 2010). Plant functional groups are also commonly used in climate warming studies to predict future consequences of environmental change, community structure and ecosystem function (Lavorel & Garnier 2002; Walker et al. 2006; Dorrepaal 2007). Thus, the use of plant functional types as a representation of several individual species has numerous benefits.

Cover and Height

Plant cover and height are important metrics for several reasons. Both impact competitive interactions between species. For example, shading from taller or larger plants especially impacts growth forms such as mosses and lichens due to their short stature (Cornelissen et al. 2001; Zona et al. 2011). Cover and height also alter albedo by reducing the extent of snow cover, shifting the timing of snow melt and scattering rather than reflecting short-wave radiation which has implications for modifying the transfer of energy through ecosystems and enhancing climate warming (Betts 2000; Loranty et al. 2011). Vegetation structure is important for the habitat selection of a variety of animals such as birds and small mammals which rely on the cover and height of vegetation for nesting and protection from predators (Cody 1981; Batzli & Pitelka

1983). Thus, vegetation cover and height are important metrics to consider when documenting vegetation changes.

Diversity

Vegetation diversity is a valuable component of biological systems. It has been shown to influence ecosystem function and the provision of ecosystem services such as food and timber supply, erosion control, invasion resistance and pathogen regulation (Quijas et al. 2010). In addition, plant diversity is linked to the productivity of ecosystems as the number of species present at a site is related to biomass production (Cadotte et al. 2008; Marquard et al. 2009). Likewise, plant diversity is associated with the stability of ecosystems as diverse systems can continue to remain productive even when a few plant species are lost (Hector et al. 2010). However, beyond a certain threshold, accumulated species losses lead to increased rates of change within ecosystems (Cardinale et al. 2011; Reich et al. 2012). Furthermore, a loss of vegetation diversity can strongly impact other trophic levels through bottom up controls (Scherber et al. 2010). Finally, diversity metrics can help predict future plant and animal assemblages which is imperative for ecosystem monitoring and management (Kessler et al. 2009; Cingolani et al. 2010). Therefore, monitoring vegetation diversity is critical.

Documenting Vegetation Changes in Arctic Regions

Climate Warming

Documenting vegetation changes in arctic regions is imperative. Northern regions have been identified as the most vulnerable to increased climate warming (IPCC 2013) and vegetation changes due to climate warming (either observational or experimental) have been well documented. Studies have shown that arctic plants typically respond to warming with initial responses of increased growth and reproduction, but this effect seems to lessen over time (Arft et al. 1999; Kremers et al. 2015). Warming induced changes, such as alteration of the timing of snow melt and the lengthening of the growing season are impacting the phenological activity of plants (Walther 2010; Oberbauer et al. 2013). Vegetation community composition changes, especially increased abundance and growth of shrubs have been linked with changes in albedo which could serve as a positive feedback to climate warming (Chapin et al. 2005; Sturm et al. 2005). In addition, vegetation changes will likely impact the carbon storage of plants and the release of carbon stored in soils due to increased microbial activity ultimately altering feedbacks to climate change (Melillo et al. 2002; Davidson & Janssens 2006) and may turn tundra regions into a carbon source instead of a carbon sink (Oechel et al. 1993).

Multiple Community Types

How vegetation is changing within multiple community types across the Barrow landscape remains poorly understood. Most recent vegetation change studies already conducted were investigated within one or two community types, typically dry heath tundra, wet meadow tundra or both (as part of ITEX climate warming experiments). The study designs utilized moisture gradient extremes to contrast changes between drier and wetter community types (e.g. Hollister et al. 2005a; Hollister et al. 2005b). However, it is well known that more than just two community types are prevalent across the landscape (Villarreal et al. 2012) and those communities function differently (Lara et al. 2012). Thus, changes within the two commonly used vegetation communities may not be representative of the landscape and vegetation changes may be different when multiple communities are considered. Therefore, more research studies are needed to better understand how vegetation is changing across the landscape within multiple vegetation community types.

Influence of Abiotic Factors on Vegetation

Multiple abiotic factors can also influence vegetation community composition and the diversity of ecosystems. Soil temperature is correlated with plant phenology (Oberbauer et al. 1998), net primary productivity (Natali et al. 2012) and nutrient availability (Melillo et al. 2002), and may help direct community composition (Brooker & van der Wal 2003). Likewise, precipitation and soil moisture is associated with plant growth (Phoenix et al. 2001), species composition and species interactions (Gornall et al. 2007) as well as net primary productivity and diversity (Weltzin et al. 2003; Douma et al. 2007). Together, both soil temperature and soil moisture are important factors controlling litter decomposition rates which will impact processes such as soil carbon storage and release (Hobbie 1996; Shaver et al. 2006). In addition, air temperature is linked with changes in the phenology (Oberbauer et al. 2013), growth (Hollister & Flaherty 2010) reproductive success (Myers-Smith et al. 2011) and distributions of plants (Parmesan & Yohe 2003). Likewise, thaw depth influences vegetation growth rates and community composition (Anisimov & Reneva 2006; Schuur et al. 2007). Therefore, identifying how various abiotic factors influence vegetation community composition is critical.

Rationale for Study and Research Questions

Continued research in the arctic is imperative as the region is particularly susceptible to climate warming due to factors such as the prevalence of cold-adapted species, the short growing season and soil nutrient limitations. Identifying vegetation changes in arctic regions warrants further investigation at the plant species level, as plant species exert bottom-up controls on successive trophic levels, determine habitat suitability for animals and influence soil processes; as well as at the functional group level, as utilizing functional groups saves time when sampling vegetation, simplifies vegetation modeling and mapping and has predictive power regarding future environmental, community structure and ecosystem function changes. Specifically, changes in the cover and height of vegetation should be documented as both metrics influence competitive interactions between species, alter albedo and provide nesting habitat and protection from predators for various animals. In addition, research into vegetation diversity is critical as it has been linked to the productivity, stability and function of ecosystems and vegetation diversity controls the diversity of successive trophic levels. Likewise, investigating the relationships between vegetation metrics and abiotic variables is warranted to explain why changes in vegetation metrics are occurring. Finally, there is a continued need to identify landscape level vegetation changes within multiple vegetation community types, especially in the Barrow region. This study addresses those critical research needs by documenting vegetation changes near Barrow, Alaska. Specifically, the following research questions were addressed:

1) *How has the vegetation metrics of cover, height and diversity changed over time?*
2) *What abiotic factors help explain the observed changes?*
3) *Are observed changes over time consistent across community types?*

Methods

Study Area

Permanent sampling locations were established by other researchers in the early 1990s at approximately 100 points forming an Arctic Systems Science spatial grid (Brown et al. 2000). In 2010, 98 vegetation plots were implemented near those points and were utilized for this study (Figure 1). The 1-m^2 vegetation plots were spaced 100 m apart and spanned approximately 1 km^2. No treatment was assigned and the plots were distributed across multiple vegetation community types. The mean July temperature at Barrow was ~4^{o}C (Brown et al. 1980). Plots were usually snow free in early to mid-June and maximum thaw depth was typically between 20 and 80cm. Topography varied across the landscape and included a drained thaw lake, a well-drained ridge, various ponds and polygonized tundra. Dominant vegetation varied across the grid but generally includes *Carex stans*, *Dupontia fisheri*, *Eriophorum triste*, *Eriophorum russeolum* and *Poa arctica*.

Data Collection

Vegetation cover, height and diversity metrics were estimated using a point frame method (standardized in Walker 1996). The frame was 75-cm^2 and utilized 100 string intersections spaced 7.5 cm apart. The frame was leveled and aligned with permanent markers which were placed at the four corners and at three points in each plot to allow for reasonably consistent re-sampling between years. A graduated ruler was used to measure the height of each encounter relative to the ground measurement at each point. All plants were identified to species and the live or dead status was recorded. In 2010 and 2013, 98 vegetation plots were sampled; in 2012 and 2014, only 30 of these plots were sampled. Sampling was done near peak season in July and August within seven calendar days of previous years to minimize the difference in development between samplings. For all analyses, ‘site’ refers to the 30 vegetation plots sampled in 2010, 2012, 2013 and 2014 while ‘grid’ refers to all the 98 vegetation plots which were sampled in 2010 and 2013. Therefore, the grid includes the 30 site plots and includes the 68 plots which extend beyond the site (n=98).

Air temperature (°C) was collected from a Model 107 Temperature Probe and precipitation (cm) from a TE525 tipping bucket rain gage located within the Arctic Systems Science Grid. Readings were taken every 15 minutes and averaged hourly (temperature) or summed (precipitation) using a CR10X Datalogger (Campbell Scientific, Logan, Utah USA). Thaw depth (cm) was recorded for each plot near the end of the field seasons by inserting a stainless steel graduated rod into the ground until the frozen surface was reached. Soil moisture and soil temperature were measured repeatedly during the summer using a FieldScout TDR 300 soil moisture meter and a standard household-grade thermometer, respectively.

Data Analyses

Site

Cover was calculated as the sum of the plant encounters in each plot. Prior to analyses, plant encounters were grouped as follows: functional groups of bryophytes, deciduous shrubs, forbs, graminoids, lichens, litter or standing dead; species within functional groups; and the most abundant taxa. All encounters were included in the analysis; however, information on a species is only presented if it was found on more than five plots each year. Due to difficulty identifying plants in the field, bryophytes and lichens were grouped by narrow functional groups and pleurocarpous mosses included leafy liverworts. Taxa were considered abundant if they were found on at least half of the plots each year. A cover value of 0 was assigned for analysis if a functional group or species was not present in a particular plot. For the analyses involving abundant taxa, if taxa were not found on a particular plot each year the plot was excluded from analysis (a value of 0 was not assigned).

The height (cm) of vascular plants was calculated by subtracting the ground measurement from the height of the vegetation encounter at each point. Only the maximum height per plot was used for analysis.

Alpha diversity was calculated as the total number of vascular species present per plot. Beta diversity was determined by dividing gamma diversity (the total number of vascular plant species at the site each year) by alpha diversity for each plot. Equitability was determined by calculating Shannon's equitability (E_H) for each plot.

Air temperature values were obtained by averaging daily summer air temperatures each year. Precipitation was calculated as the sum of daily summer precipitation values. Thawing degree days were calculated as the sum of the departures of daily temperatures above 0 degrees Celsius. Thaw depth, soil temperature and soil moisture measurements from each plot collected during the summers were averaged each year. The summer was defined as the period from when the plots were snow free until August 15.

Grid

Plots were grouped into generalized vegetation communities based on a land cover classification map developed from 2002 QuickBird satellite imagery (Tweedie et al. 2005, unpublished work) which was modified based on field observations of each plot collected during the 2010-2014 field seasons (Figure 2). Four vegetation communities were apparent: dry dwarf shrub-graminoid tundra (dry, n=24), dry-moist dwarf shrub-graminoid tundra (dry-moist, n=26), moist graminoid tundra (moist, n=21) and wet graminoid tundra (wet, n=27). Vegetation cover was calculated with the same groups as described above, however, change in cover of species within functional groups was not investigated. Analysis of similarities (ANOSIM) after nonmetric multidimensional scaling (NMDS) showed that the vegetation communities were significantly different from each other in years 2010 and 2013 (Figure 3).

Statistical Tests Performed

Data was checked for a normal distribution using the Shapiro-Wilk normality test and for equal variance using Bartlett's test before analyses were conducted. If necessary, data were square root or log transformed to approximate normality. If normality could not be approximated, non-parametric statistical tests were used. Post hoc analyses were completed using paired t-tests or paired Mann-Whitney U tests. The Holm method was used to correct for multiple comparisons. For all analyses, an alpha level of 0.05 was used to determine significance. All statistical analyses were performed in R Software for Statistical Computing v. 3.1.1 (R Development Core Team 2014). The R package 'vegan' was used to calculate Shannon's equitability values (Oksanen et al. 2013).

The change in cover of functional groups, species within functional groups, abundant taxa and the change in height of vascular functional groups as well as changes in alpha diversity, beta diversity and equitability over time at the site were analyzed using 1-way repeated measures ANOVAs or Friedman tests. Changes in the cover of functional groups and abundant taxa over time, across community types and the interaction between year and community type across the grid were analyzed using a 2 way ANOVA.

Spearman Rank correlations were used to investigate relationships between vegetation metrics and abiotic variables, relationships between vegetation metrics and year, relationships between all possible pairs of abiotic variables, as well as relationships between abiotic variables and year.

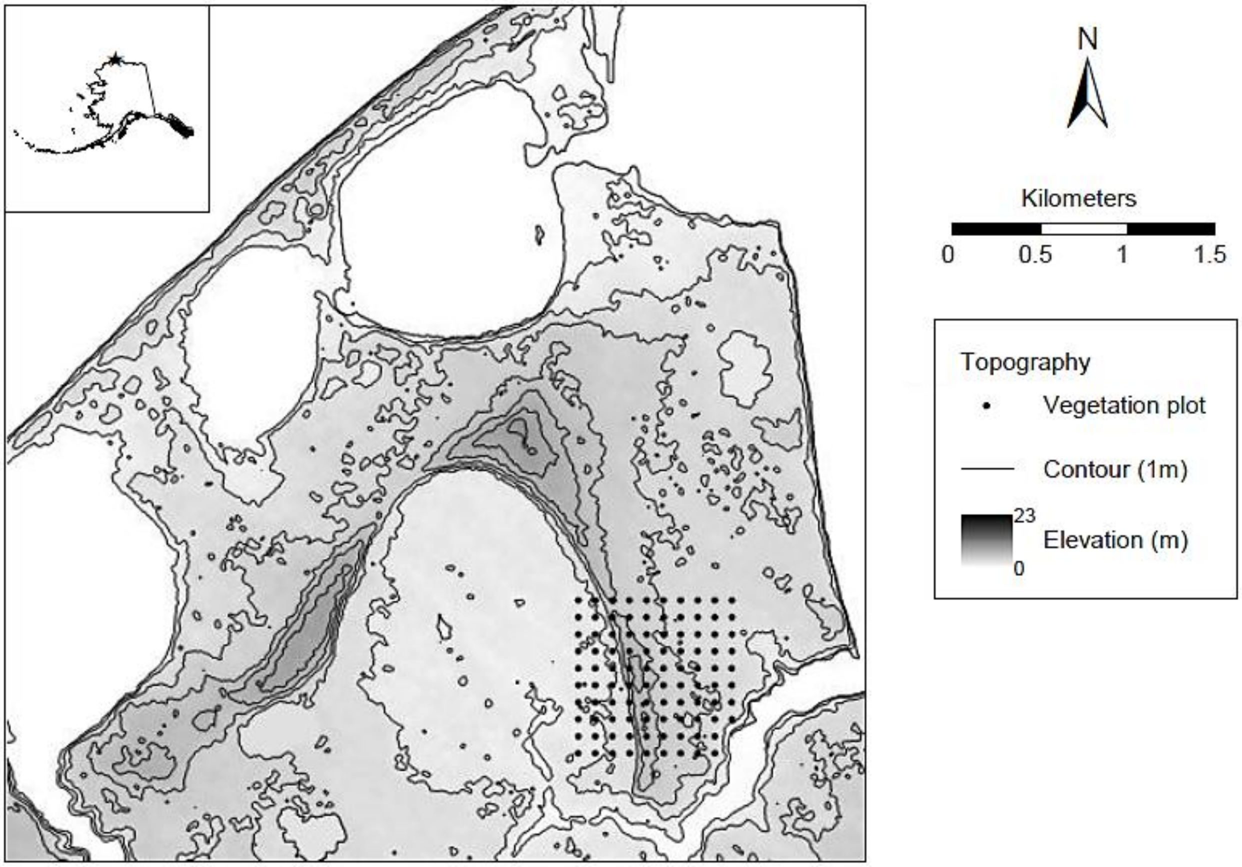

Figure 1: Maps of the study location (inset) and study vegetation plots near Barrow, Alaska. Imagery was from Tweedie & Gaylord 2003, Manley et al. 2005 and the National Atlas of the United States (http://nationalmap.gov).

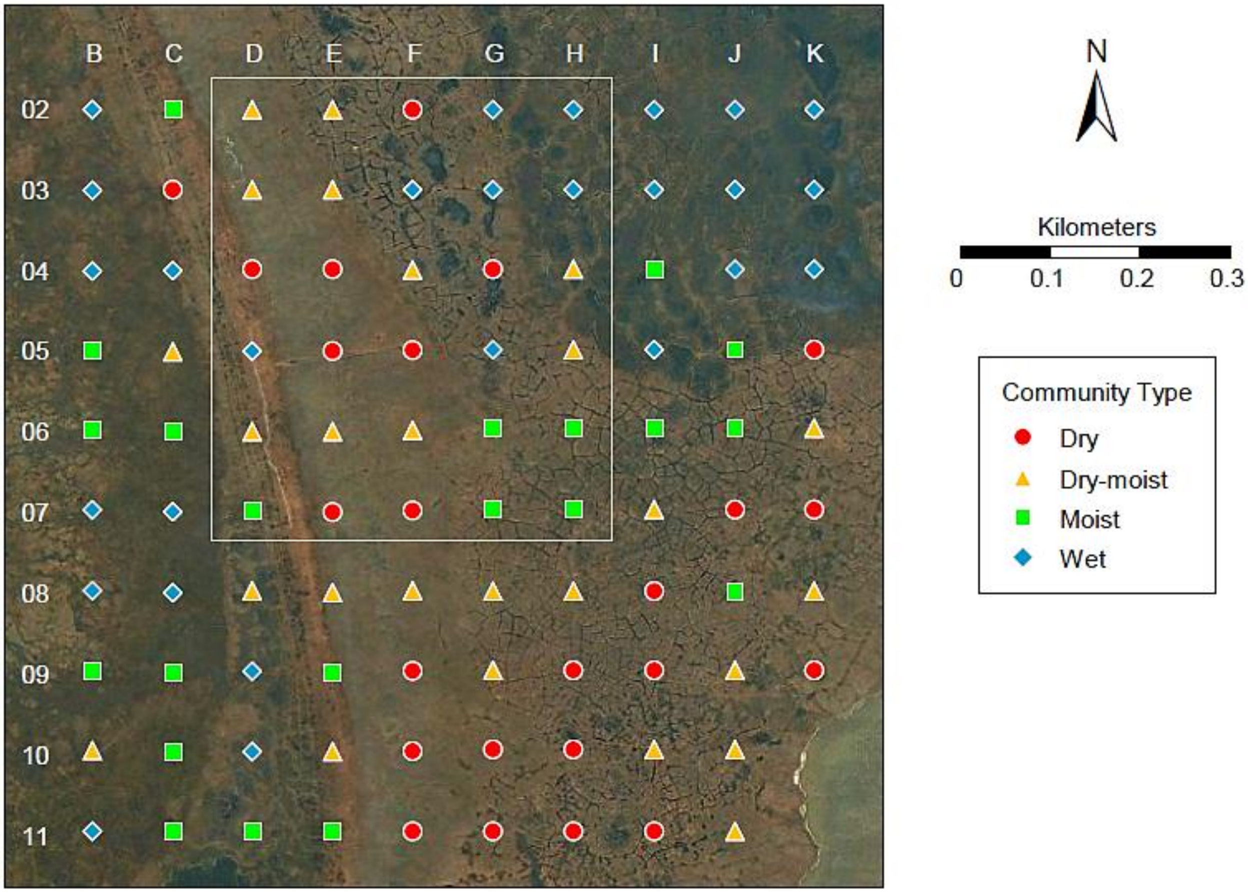

Figure 2: Map of the vegetation plots at the site (symbols within the rectangle) and the Arctic Systems Science grid which both included and extended beyond the site. Symbols represent the four generalized community types represented by each plot while letters (B-K) and numbers (02-11) identify the location of each plot within the grid. Generalized vegetation community types were obtained from a land cover classification map in Tweedie et al. 2005, unpublished work while imagery was from Tweedie & Gaylord 2003.

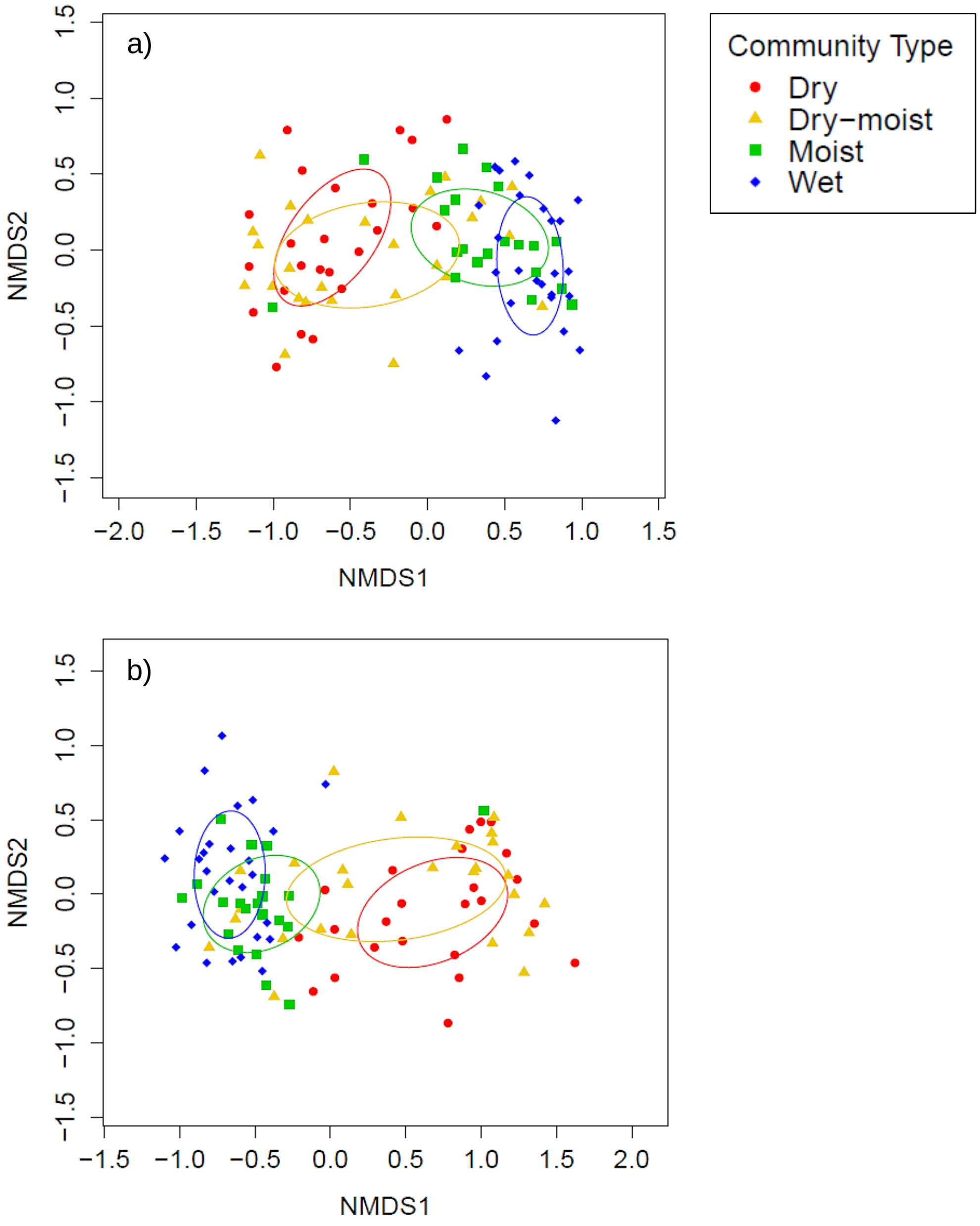

Figure 3: Nonmetric multidimensional scaling (NMDS) of the four generalized vegetation communities across the Arctic Systems Science grid in a) 2010 and b) 2013. The community types were significantly different from each other in both years based on analysis of similarities (ANOSIM). The sample size was 24 for dry plots, 26 for dry-moist plots, 21 for moist plots and 27 for wet plots each year.

Results

Site

Abiotic Correlations with Year and Correlations between Abiotic Variables

No abiotic variable was correlated significantly with year (Figure 4). When correlations between all possible pairs of abiotic variables were investigated, only mean summer air temperature and the sum of thawing degree days were significantly correlated (Table 1).

Vegetation Change over Time

The cover of all functional groups and most species within functional groups changed significantly over time. Most notably, the mean cover of graminoids more than doubled from 44.4% to 92.1% from years 2010 to 2013 followed by an approximate halving of cover to 50.1% in the year 2014. In addition, the mean cover of standing dead more than doubled from 49.6% to 105.8% between years 2010 and 2012 but declined sharply to 29.5% in the year 2013. Likewise, the cover of *Carex stans* more than doubled from 17.7% to 40.0% in years 2010 to 2013, but was reduced to 17.2% in the year 2014. (Table 2, Figure 5). The cover of the abundant taxa of pleurocarpous mosses and *Carex stans* changed significantly over time. The change in mean cover of *Carex stans* was notable as it more than doubled from 24.1% to 54.0% between years 2010 and 2013. By the year 2014, the mean cover of *Carex stans* was reduced to 23.1% (Table 3). There was a significant correlation between cover and year for standing dead but no significant correlations between cover and year for any of the other functional groups, all species within functional groups or all abundant taxa (Table 2, Table 3, Figure 6).

The height of graminoids changed significantly while deciduous shrub and forb height did not change significantly over time. Of particular interest was the mean height of graminoids increased by 3.2 cm from the years 2010 to 2012. There were no significant correlations between height and year for any of the three functional groups (Table 3).

Alpha diversity changed significantly but beta diversity and equitability did not change significantly over time. The largest change in alpha diversity was a shift from an average of 6.7 to 8.1 vascular plant species per plot between years 2012 and 2013. None of the three diversity metrics showed significant correlations with year (Table 2).

Relation between Vegetation Change and Abiotic Factors

There was a significant correlation between the cover of forbs and mean summer soil temperature (Table 4, Figure 7). The cover of graminoids was correlated significantly with all abiotic variables except mean summer soil moisture but was most strongly correlated with mean summer soil temperature (Table 4, Figure 8). There were significant correlations between the cover of litter and mean summer air temperature, the sum of thawing degree days, mean summer soil temperature and mean summer soil moisture. The cover of litter was most strongly correlated with mean summer soil temperature (Table 4, Figure 9). The cover of standing dead was correlated significantly with all measured abiotic variables and most strongly correlated with total summer precipitation (Table 4, Figure 10). The cover of bryophytes, deciduous shrubs and lichens were not correlated significantly with any of the measured abiotic variables (Table 4). There were significant correlations between the cover of the abundant taxa *Carex stans* and all measured abiotic variables except mean summer soil moisture but was most strongly correlated with mean summer soil temperature (Table 5, Figure 11). In addition, the cover of the abundant taxa *Dupontia fisheri* was significantly correlated with mean summer air temperature, the sum of thawing degree days, and mean summer soil temperature but the most strongly correlated with mean summer air temperature and the sum of thawing degree days (Table 5, Figure 12). The cover of all other abundant taxa was not correlated significantly with any of the measured abiotic variables (Table 5).

The height of graminoids was correlated significantly with mean summer soil moisture. The height of deciduous shrubs and forbs were not correlated significantly with any of the measured abiotic variables (Table 5, Figure 13).

All three diversity metrics were not correlated significantly with any of the measured abiotic variables (Table 4).

Grid

Comparison between Community Types

Although there were significant changes in cover over time and differences in cover within community types for most of the functional groups and the abundant taxa, there was no interaction between year and community type for any of the functional groups or the abundant taxa (Table 6, Table 7, Figure 14, Figure 15).

Table 1: Correlations between mean summer air temperature (°C), total summer precipitation (cm), the sum of thawing degree days (TDD), mean summer thaw depth (cm), mean summer soil temperature (°C) and mean summer soil moisture (VWC %) during years 2010, 2012, 2013 and 2014 at the site. Bold values represent significant associations and r_s values represent correlation coefficients from Spearman Rank correlations.

	Precipitation		TDD (sum)		Thaw depth		Soil temperature		Soil moisture	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Air temperature	-0.40	0.75	**0.99**	**0.01**	0.40	0.75	0.80	0.33	-0.45	0.75
Precipitation	—	—	-0.40	0.75	0.40	0.75	0.20	0.92	0.40	0.75
TDD (sum)	—	—	—	—	0.40	0.75	0.80	0.33	-0.40	0.75
Thaw depth	—	—	—	—	—	—	0.80	0.33	0.60	0.42
Soil temperature	—	—	—	—	—	—	—	—	<0.01	0.99

Table 2: Change in cover and diversity metrics over time at the site. A species within a functional group was included if the species was found on at least 5 plots. Due to difficulty identifying plants in the field, bryophytes and lichens were grouped by narrow growth form rather than by species and pleurocarpous mosses included leafy liverworts. Values for change over time represent the mean and standard error of the mean for each year. Bold p values represent significant changes from analyses which included 1-way repeated measures ANOVAs or Friedman tests and r_s represents correlation coefficients from Spearman Rank correlations. The sample size was 30 plots for each year.

	Change Over Time				ANOVA	Correlation	
Metric	2010	2012	2013	2014	p	r_s	p
Vegetation cover							
Bryophytes	34.5 (3.2)	41.9 (4.8)	44.8 (4.1)	37.4 (3.3)	**0.05**	0.07	0.47
Acrocarpous mosses‡	17.6 (2.9)	14.1 (2.7)	19.1 (2.5)	13.6 (2.2)	0.88	-0.01	0.92
Pleurocarpous mosses‡	16.4 (3.8)	27.4 (5.2)	24.8 (4.3)	23.5 (3.9)	**<0.01**	0.16	0.08
Deciduous shrubs*	7.4 (2.4)	9.0 (3.1)	9.9 (3.2)	7.8 (2.6)	**<0.01**	0.05	0.58
*Salix rotundifolia**	5.8 (2.0)	6.4 (2.1)	7.9 (2.5)	6.6 (2.3)	**0.01**	0.03	0.74
Forbs*	6.7 (1.4)	11.0 (3.4)	14.0 (3.2)	6.7 (1.7)	**<0.01**	<0.01	0.97
*Petasites frigidus**	1.8 (0.7)	5.8 (3.1)	4.3 (2.1)	2.3 (1.2)	0.19	0.01	0.87
*Saxifraga cernua**	1.4 (0.5)	1.0 (0.4)	2.2 (0.6)	0.8 (0.2)	**0.01**	0.01	0.89
*Saxifraga foliolosa**	0.3 (0.2)	0.5 (0.3)	0.9 (0.3)	0.5 (0.3)	0.13	0.09	0.31
*Stellaria spp.**	1.9 (0.6)	1.6 (0.6)	2.7 (1.0)	1.5 (0.5)	0.20	0.01	0.89
Graminoids†	44.4 (4.0)	69.6 (7.6)	92.1 (7.5)	50.1 (4.6)	**<0.01**	0.13	0.17
*Arctagrostis latifolia**	2.0 (0.8)	2.6 (0.9)	3.2 (1.1)	1.8 (0.8)	**0.01**	<0.01	0.96
*Carex stans**	17.7 (2.9)	27.6 (4.5)	40.0 (6.1)	17.2 (2.7)	**<0.01**	0.04	0.68
*Dupontia fisheri**	6.8 (1.7)	9.9 (2.5)	10.2 (2.8)	6.2 (1.7)	**<0.01**	-0.04	0.69
*Eriophorum triste**	2.7 (0.9)	9.0 (3.0)	8.1 (2.8)	6.7 (2.3)	**<0.01**	0.12	0.18
*Eriophorum russeolum**	5.2 (1.0)	8.0 (2.7)	11.0 (2.9)	7.9 (2.1)	**0.02**	0.05	0.62
*Luzula arctica**	2.0 (0.9)	3.2 (1.2)	4.3 (1.9)	1.8 (1.0)	**<0.01**	<0.01	0.97
*Luzula confusa**	1.7 (0.5)	1.6 (0.5)	2.4 (0.8)	1.0 (0.4)	**0.03**	-0.12	0.21
*Poa spp.**	4.8 (1.4)	6.4 (2.9)	11.2 (3.8)	6.1 (2.0)	**<0.01**	0.07	0.45
Lichens*	12.8 (3.1)	15.2 (3.3)	19.6 (4.3)	15.3 (3.3)	**<0.01**	0.03	0.73
Foliose*	3.3 (0.9)	5.2 (1.4)	6.6 (1.7)	4.6 (1.3)	**0.01**	0.04	0.65
Fruticose*	9.4 (2.5)	9.8 (2.5)	12.5 (3.1)	10.3 (2.4)	**<0.01**	0.04	0.63
Litter‡	49.1 (3.9)	29.2 (3.9)	27.6 (3.7)	39.2 (3.2)	**<0.01**	-0.14	0.12
Standing dead*	49.6 (4.1)	105.8 (7.7)	29.5 (3.6)	53.3 (4.3)	**<0.01**	**-0.19**	**0.03**
Diversity							
Alpha	7.1 (0.4)	6.7 (0.4)	8.1 (0.5)	7.3 (0.5)	**<0.01**	0.04	0.69
Beta	0.26 (0.01)	0.26 (0.01)	0.27 (0.01)	0.26 (0.01)	0.56	-0.01	0.93
Equitability‡	0.43 (0.02)	0.40 (0.02)	0.41 (0.02)	0.41 (0.02)	0.80	-0.08	0.36

† = log transformed

‡ = square root transformed

* = non parametric test

Table 3: Change in cover and height metrics over time at the site. Note that this analysis is different from Table 2 because only plots where the plants were encountered are included therefore the sample size may be less than 30. Due to difficulty identifying plants in the field, bryophytes were grouped by narrow growth form rather than by species and pleurocarpous mosses included leafy liverworts. Height was determined using the maximum height per plot. Values for change over time represent the mean and standard error of the mean for each year. Bold p values represent significant changes from analyses which included 1-way repeated measures ANOVAs and r_s values represent correlation coefficients from Spearman Rank correlations.

	Change Over Time				ANOVA	Correlation		
Metric	2010	2012	2013	2014	p	r_s	p	n
Abundant taxa cover								
Acrocarpous mosses‡	21.9 (3.1)	16.1 (3.1)	21.4 (2.8)	16.1 (2.5)	0.13	-0.07	0.52	23
Pleurocarpous mosses‡	22.3 (4.6)	35.2 (6.2)	32.2 (5.0)	30.4 (4.3)	**<0.01**	0.16	0.14	22
Carex stans‡	24.1 (3.0)	37.2 (4.7)	54.0 (6.0)	23.1 (2.7)	**<0.01**	0.05	0.61	22
Dupontia fisheri†	11.4 (2.5)	16.9 (3.7)	17.4 (4.2)	10.7 (2.8)	0.98	-0.05	0.68	17
Eriophorum russeolum†	8.0 (1.3)	14.9 (4.5)	18.4 (4.4)	13.9 (3.3)	0.12	0.15	0.22	16
Height (cm)								
Deciduous shrubs	1.9 (0.4)	3.0 (0.6)	2.2 (0.4)	2.3 (0.4)	0.31	0.08	0.64	9
Forbs‡	5.1 (0.8)	6.2 (1.1)	4.7 (0.7)	3.7 (0.6)	0.14	-0.17	0.12	22
Graminoids‡	11.1 (0.7)	14.3 (0.9)	13.0 (0.9)	13.2 (1.0)	**0.01**	0.12	0.20	30

† = log transformed
‡ = square root transformed
n = the sample size for each year

Table 4: Correlations between cover or diversity metrics and mean summer air temperature (°C), total summer precipitation (cm), the sum of thawing degree days (TDD), mean summer thaw depth (cm), mean summer soil temperature (°C) and mean summer soil moisture (VWC %) during years 2010, 2012, 2013 and 2014 at the site. Bold values represent significant associations and r_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 30 plots for each year.

	Air temperature		Precipitation		TDD (sum)		Thaw depth		Soil temperature		Soil moisture	
Metric	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Vegetation cover												
Bryophytes	0.09	0.33	0.09	0.36	0.09	0.33	0.08	0.37	0.14	0.14	-0.04	0.63
Deciduous shrubs	0.02	0.82	0.04	0.65	0.02	0.82	0.01	0.89	0.04	0.66	-0.03	0.73
Forbs	0.12	0.20	0.09	0.34	0.12	0.20	0.15	0.09	**0.18**	**0.04**	0.01	0.88
Graminoids	**0.27**	**<0.01**	**0.22**	**0.02**	**0.27**	**<0.01**	**0.27**	**<0.01**	**0.40**	**<0.01**	-0.09	0.33
Lichens	0.03	0.74	0.03	0.73	0.03	0.74	0.02	0.80	0.05	0.61	-0.02	0.81
Litter	**-0.33**	**<0.01**	-0.07	0.46	**-0.33**	**<0.01**	-0.12	0.21	**-0.34**	**<0.01**	**0.26**	**<0.01**
Standing dead	**0.27**	**<0.01**	**-0.67**	**<0.01**	**0.27**	**<0.01**	**-0.45**	**<0.01**	**-0.18**	**0.05**	**-0.50**	**<0.01**
Diversity												
Alpha	-0.01	0.87	0.16	0.07	-0.01	0.87	0.14	0.11	0.10	0.28	0.11	0.23
Beta	0.04	0.69	0.03	0.78	0.04	0.69	0.05	0.56	0.06	0.53	0.01	0.88
Equitability	-0.04	0.66	0.01	0.96	-0.04	0.66	0.06	0.52	-0.02	0.86	0.12	0.19

Table 5: Correlations between cover or height metrics and mean summer air temperature (°C), total summer precipitation (cm), the sum of thawing degree days (TDD), mean summer thaw depth (cm), mean summer soil temperature (°C) and mean summer soil moisture (VWC %) during years 2010, 2012, 2013 and 2014 at the site. Due to difficulty identifying plants in the field, bryophytes were grouped by narrow growth form and pleurocarpous mosses included leafy liverworts. Height was determined using the maximum height per plot. Bold values represent significant associations and r_s values represent correlation coefficients from Spearman Rank correlations.

	Air temperature		Precipitation		TDD (sum)		Thaw Depth		Soil temperature		Soil moisture		
Metric	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p	n
Abundant taxa cover													
Acrocarpous mosses	-0.03	0.80	0.11	0.29	-0.03	0.80	0.17	0.10	0.07	0.48	0.19	0.07	23
Pleurocarpous mosses	0.05	0.61	0.06	0.59	0.05	0.61	-0.05	0.66	0.06	0.59	-0.16	0.15	22
Carex stans	**0.42**	**<0.01**	**0.22**	**0.04**	**0.42**	**<0.01**	**0.41**	**<0.01**	**0.57**	**<0.01**	-0.08	0.47	22
Dupontia fisheri	**0.25**	**0.05**	-0.01	0.92	**0.25**	**0.05**	0.15	0.21	**0.24**	**0.05**	-0.07	0.59	17
Eriophorum russeolum	0.04	0.75	0.12	0.32	0.04	0.75	0.03	0.82	0.10	0.45	-0.08	0.51	16
Height (cm)													
Deciduous shrubs	0.09	0.62	-0.08	0.66	0.09	0.62	-0.11	0.51	<0.01	0.96	-0.20	0.24	9
Forbs	0.17	0.11	-0.11	0.30	0.17	0.11	0.11	0.32	0.13	0.23	<0.01	0.95	22
Graminoids	0.15	0.11	-0.03	0.74	0.15	0.11	-0.06	0.49	0.09	0.30	**-0.23**	**0.01**	30

n = sample size each year

Table 6: Change in the cover of functional groups within four generalized plant communities (dry, dry-moist, moist and wet) between 2010 and 2013 within the Arctic Systems Science grid. The grid was comprised of 98 vegetation plots which both included and extended beyond the 30 vegetation plots at the site which were used for the prior analyses. Cover changes were analyzed over time (Y), across community types (C) and the interaction between them (I) using a 2-way ANOVA. Cover values represent the mean and standard error of the mean for each year. The sample size was 24 for dry plots, 26 for dry-moist plots, 21 for moist plots and 27 for wet plots.

	Dry		Dry-Moist		Moist		Wet		ANOVA (p Value)		
Metric	2010	2013	2010	2013	2010	2013	2010	2013	Y	C	I
Vegetation cover											
Bryophytes[‡]	28.0 (3.0)	42.4 (4.4)	34.2 (3.2)	44.1 (4.0)	38.1 (3.7)	60.6 (5.3)	40.9 (4.0)	67.2 (4.9)	**<0.01**	**<0.01**	0.37
Deciduous shrubs[‡]	6.7 (2.9)	7.3 (3.0)	6.5 (2.5)	10.3 (4.0)	—	—	—	—	0.54	**<0.01**	0.94
Forbs[‡]	12.2 (2.5)	20.2 (4.9)	8.1 (1.9)	14.7 (3.3)	10.3 (3.2)	20.3 (3.8)	5.2 (1.6)	10.2 (2.3)	**<0.01**	**0.01**	0.85
Graminoids[‡]	41.0 (4.8)	81.4 (6.6)	40.0 (4.5)	80.0 (7.1)	54.3 (6.4)	104.8 (9.3)	52.4 (5.3)	101.8 (8.1)	**<0.01**	**<0.01**	0.98
Lichens[‡]	19.9 (3.2)	29.0 (4.6)	16.7 (3.3)	28.4 (5.0)	—	—	—	—	0.11	**<0.01**	0.40
Litter[‡]	45.0 (3.1)	19.8 (1.8)	42.9 (3.2)	21.9 (2.3)	55.2 (3.9)	29.4 (3.1)	52.0 (4.1)	30.3 (4.2)	**<0.01**	**<0.01**	0.87
Standing dead[‡]	50.0 (2.5)	30.9 (3.3)	55.3 (3.6)	24.8 (2.1)	48.5 (6.0)	27.3 (2.4)	41.5 (4.8)	26.0 (4.0)	**<0.01**	0.08	0.21

[‡] = square root transformed

— = functional group was found in <5 plots and was subsequently excluded from analysis

Table 7: Change in the cover of the most abundant taxa within four generalized plant communities (dry, dry-moist, moist and wet) between 2010 and 2013 within the Arctic Systems Science grid. The grid was comprised of 98 vegetation plots which both included and extended beyond the 30 vegetation plots at the site which were used for the prior analyses. Due to difficulty identifying plants in the field, bryophytes were grouped by narrow growth form and pleurocarpous mosses included leafy liverworts. Cover changes were analyzed over time (Y), across community types (C) and the interaction between them (I) using a 2-way ANOVA. Cover values represent the mean and standard error of the mean for each year.

	Dry			Dry-Moist			Moist			Wet			ANOVA (p Value)		
Metric	2010	2013	n	2010	2013	n	2010	2013	n	2010	2013	n	Y	C	I
Abundant taxa cover															
Acrocarpous mosses[‡]	23.3 (3.0)	29.2 (3.8)	24	24.0 (2.8)	26.4 (3.2)	25	17.8 (3.8)	24.2 (4.0)	17	14.6 (3.0)	24.1 (3.0)	19	**0.01**	0.09	0.51
Pleurocarpous mosses[‡]	5.7 (1.1)	16.5 (3.1)	18	16.1 (3.9)	24.3 (5.3)	16	24.6 (4.0)	37.1 (4.4)	20	29.4 (3.7)	41.1 (4.1)	25	**<0.01**	**<0.01**	0.91
Carex stans[‡]	9.7 (2.2)	22.9 (5.6)	17	14.3 (2.9)	32.6 (6.5)	19	14.3 (3.4)	35.4 (6.5)	15	24.5 (3.8)	56.4 (7.6)	20	**<0.01**	**<0.01**	0.84
Dupontia fisheri[‡]	10.5 (2.1)	10.6 (2.7)	12	16.1 (3.8)	21.3 (5.2)	15	18.6 (3.1)	25.4 (3.5)	21	18.3 (3.9)	25.0 (4.8)	24	0.06	**0.03**	0.84
Eriophorum russeolum[†]	6.4 (1.2)	12.6 (3.0)	17	9.9 (1.7)	18.9 (4.9)	17	9.0 (2.7)	20.5 (4.3)	19	8.1 (1.4)	19.5 (3.5)	23	**<0.01**	**<0.01**	0.91

[†] = log transformed

[‡] = square root transformed

n = the sample size for each year

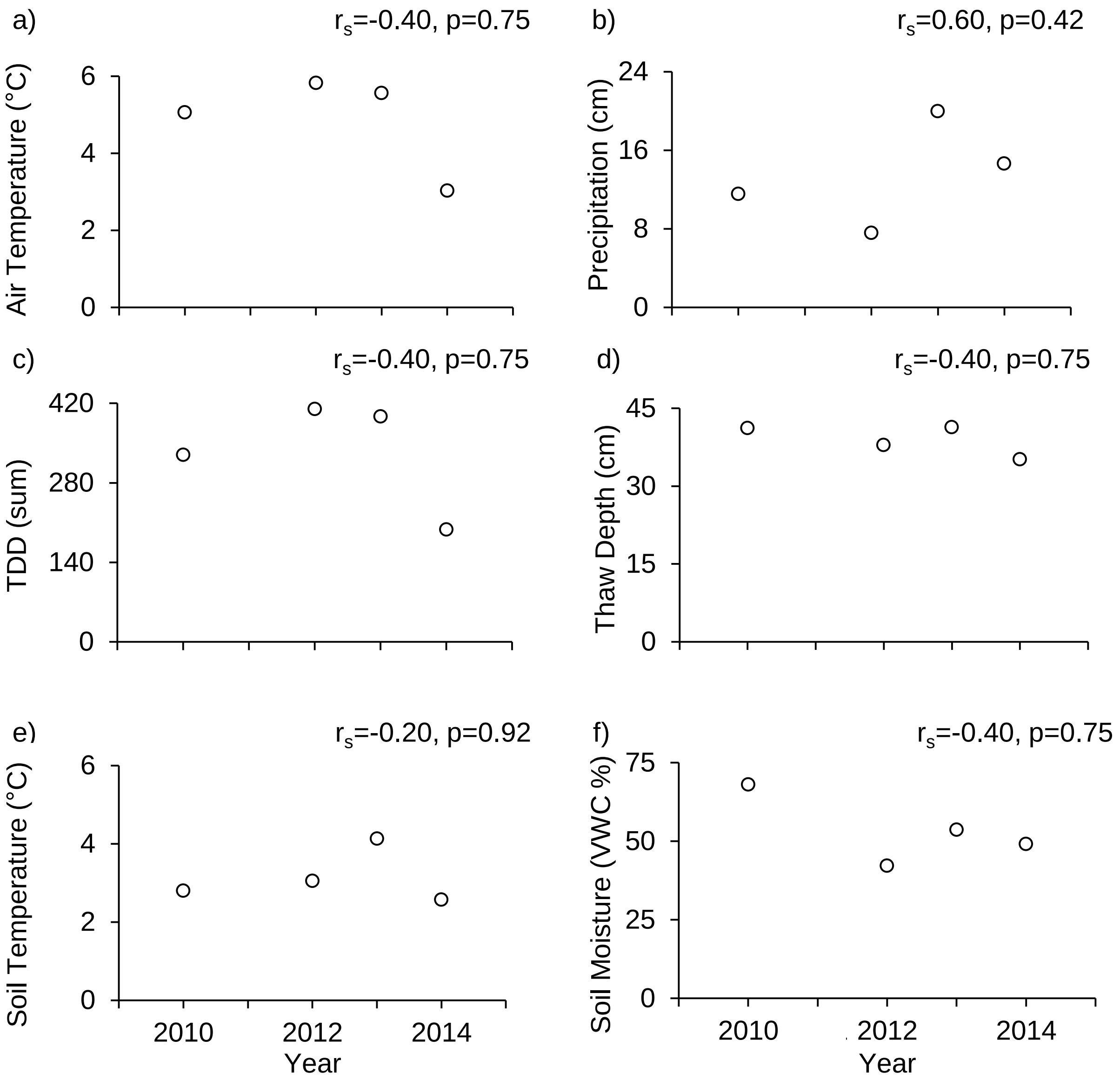

Figure 4: Correlations between year and a) mean summer air temperature, b) total summer precipitation, c) the sum of thawing degree days (TDD), d) mean summer thaw depth, e) mean summer soil temperature and f) summer mean soil moisture at the site. R_s values represent correlation coefficients from Spearman Rank correlations. Note the change in scale between abiotic variables.

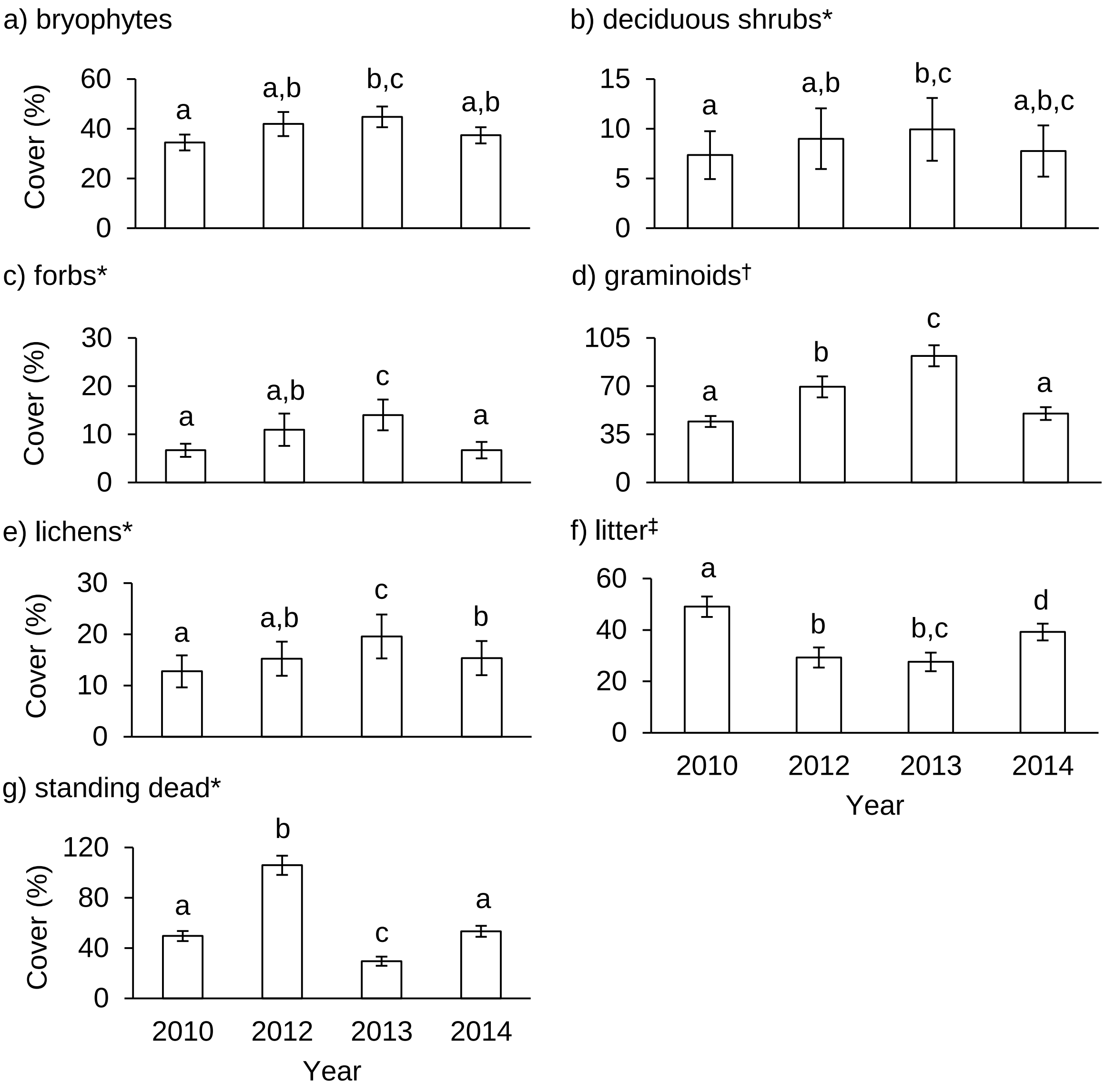

Figure 5: Mean cover of a) bryophytes, b) deciduous shrubs, c) forbs, d) graminoids, e) lichens, f) litter and g) standing dead over time at the site. Different letters indicate statistical significance between individual years. Statistical analyses were completed using 1-way repeated measures ANOVAs or Friedman tests. † = log transformed; ‡ = square root transformed; * = non parametric test. Error bars show standard error of the mean. The sample size was 30 plots for each year. Note the change in scale between functional groups.

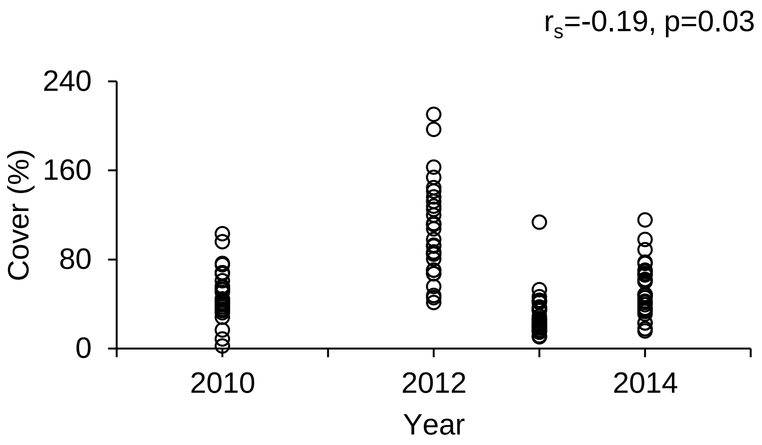

Figure 6: Significant correlation between year and the cover of standing dead at the site. R_s value represents correlation coefficient from a Spearman Rank correlation. The sample size was 30 plots for each year.

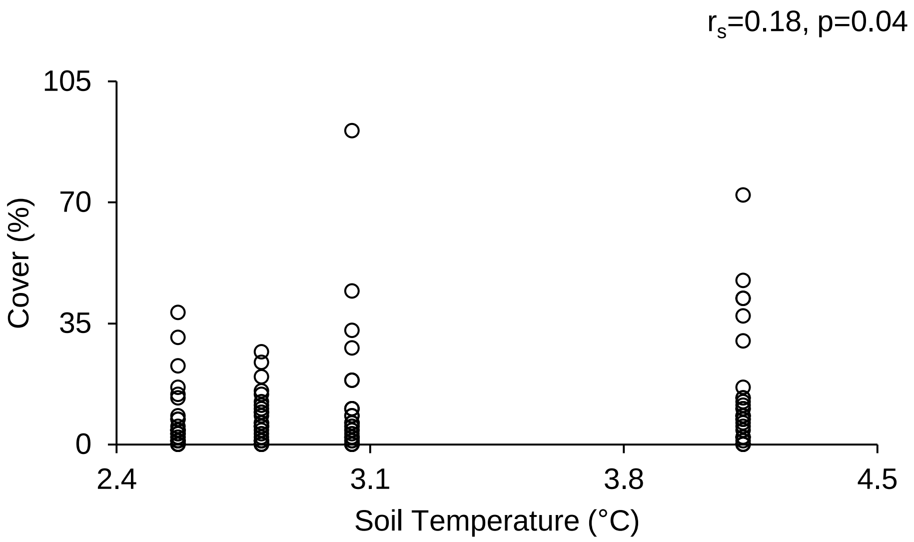

Figure 7: Significant correlation between the cover of forbs and mean summer soil temperature during years 2010, 2012, 2013 and 2014 at the site. R_s value represents correlation coefficient from a Spearman Rank correlation. The sample size was 30 plots for each year.

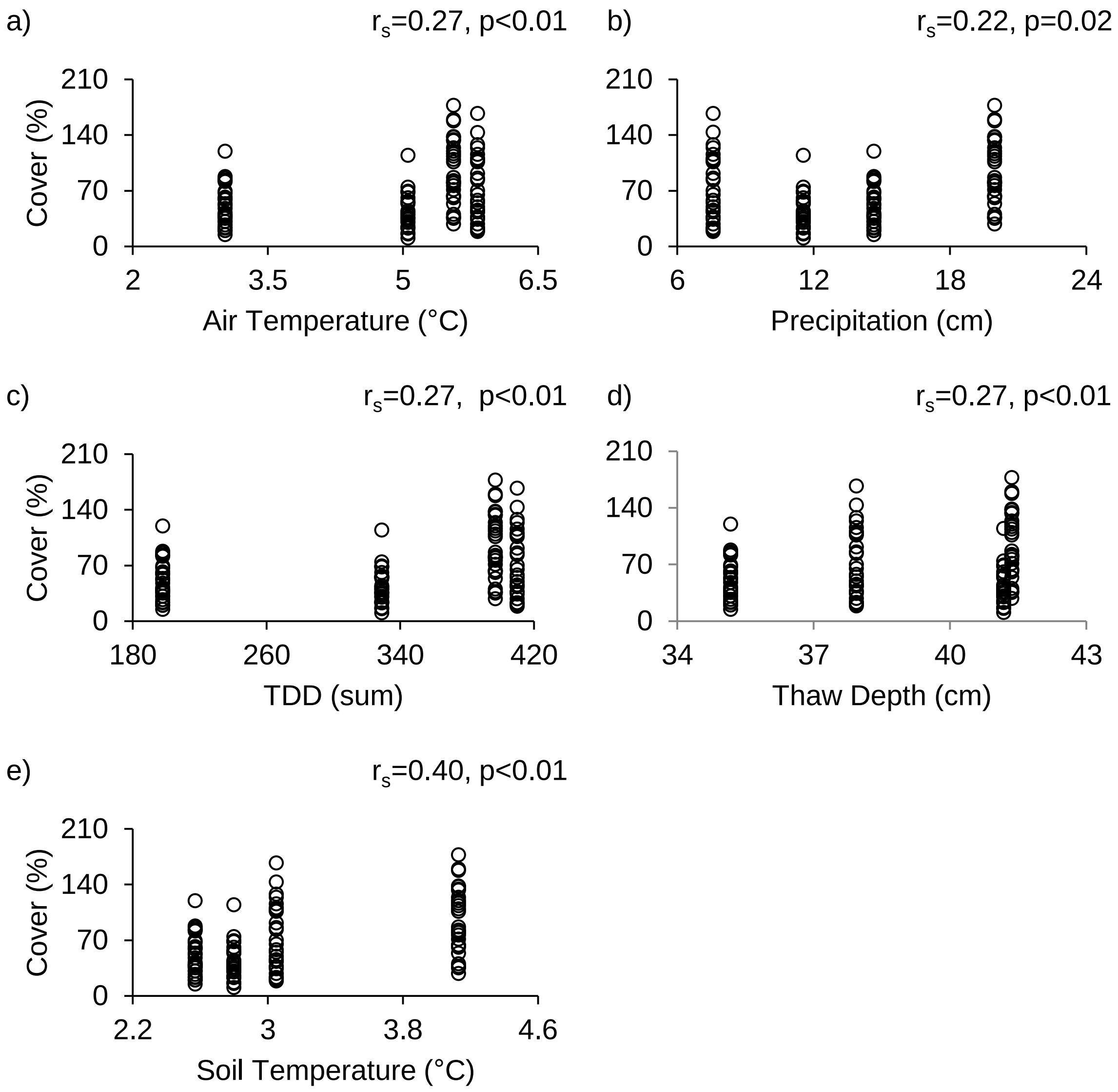

Figure 8: Significant correlations between the cover of graminoids and a) mean summer air temperature, b) total summer precipitation, c) the sum of thawing degree days (TDD), d) mean summer thaw depth and e) mean summer soil temperature during years 2010, 2012, 2013 and 2014 at the site. R_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 30 plots for each year.

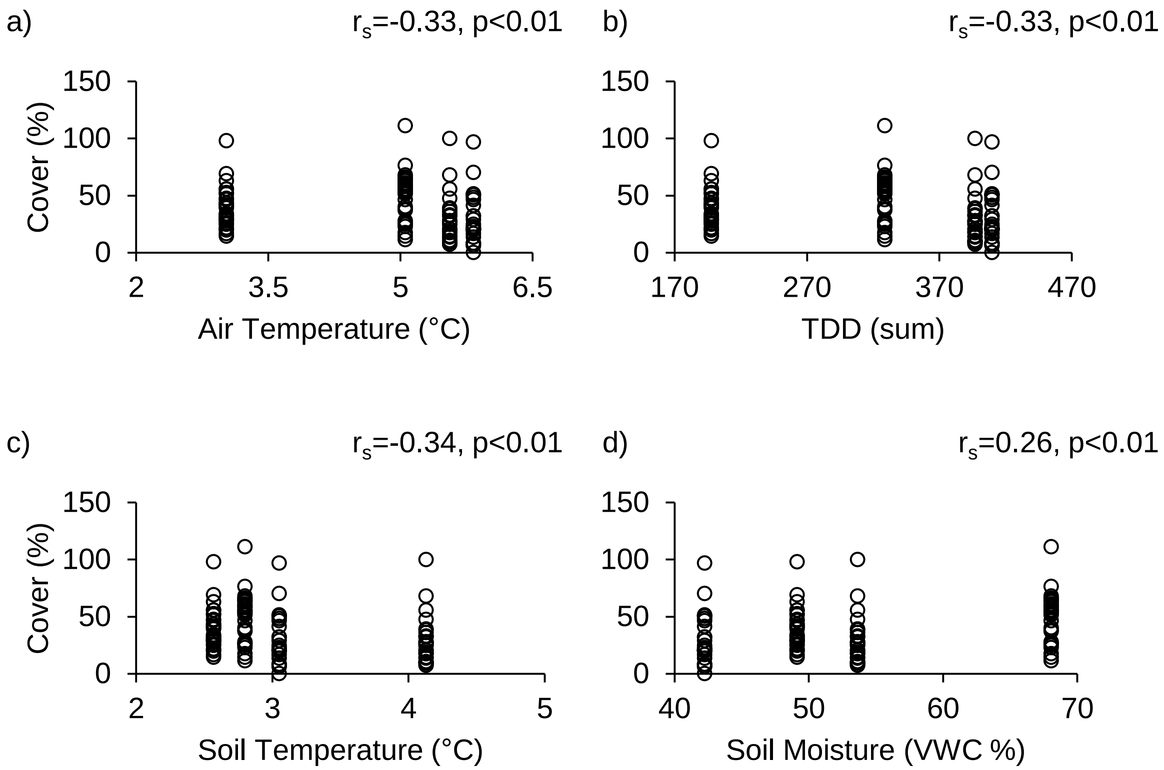

Figure 9: Significant correlations between the cover of litter and a) mean summer air temperature, b) the sum of thawing degree days (TDD), c) mean summer soil temperature and d) mean summer soil moisture during years 2010, 2012, 2013 and 2014 at the site. R_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 30 plots for each year.

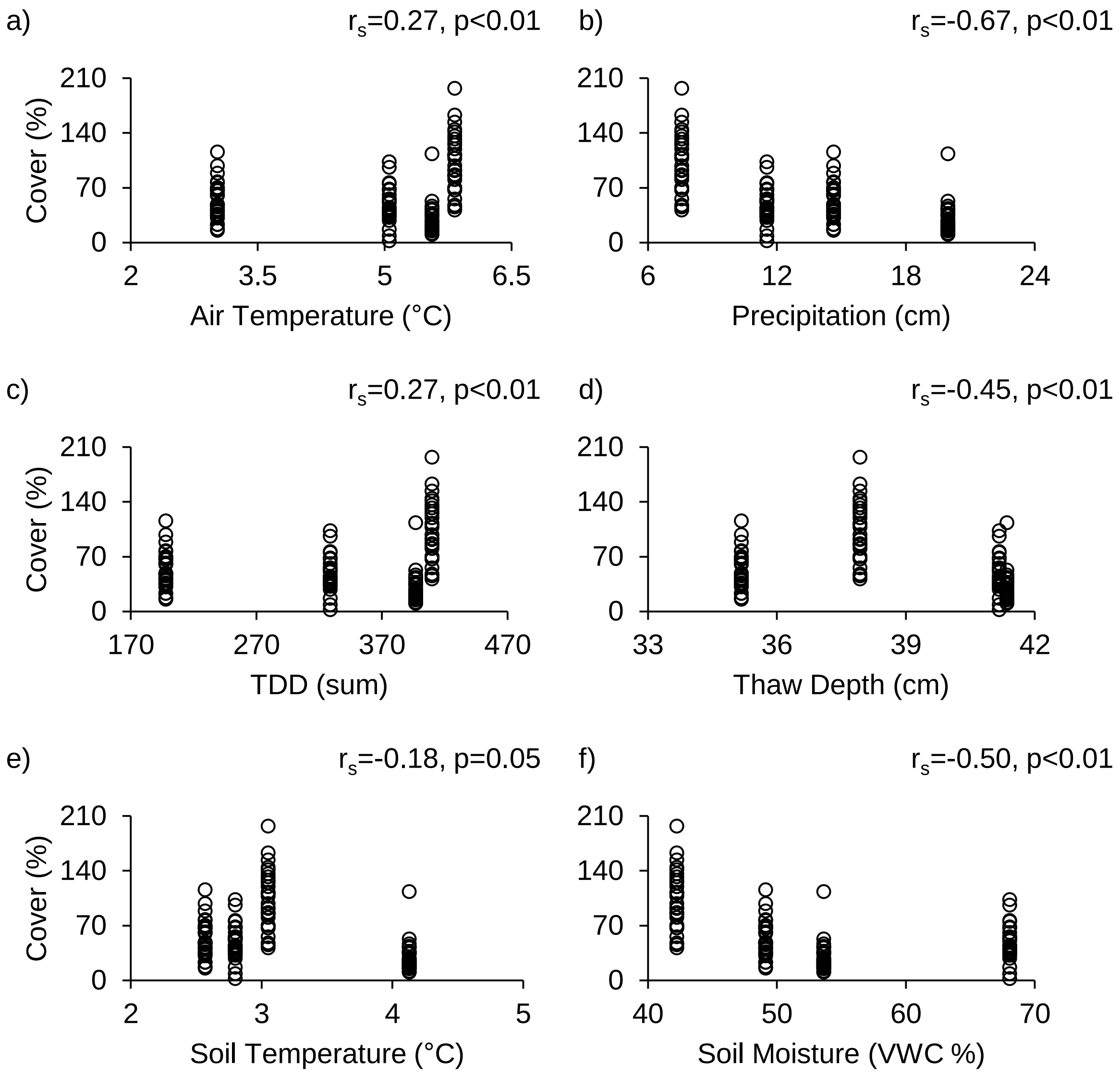

Figure 10: Significant correlations between the cover of standing dead and a) mean summer air temperature, b) total summer precipitation, c) the sum of thawing degree days (TDD), d) mean summer thaw depth, e) mean summer soil temperature and f) mean summer soil moisture during years 2010, 2012, 2013 and 2014 at the site. R_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 30 plots for each year.

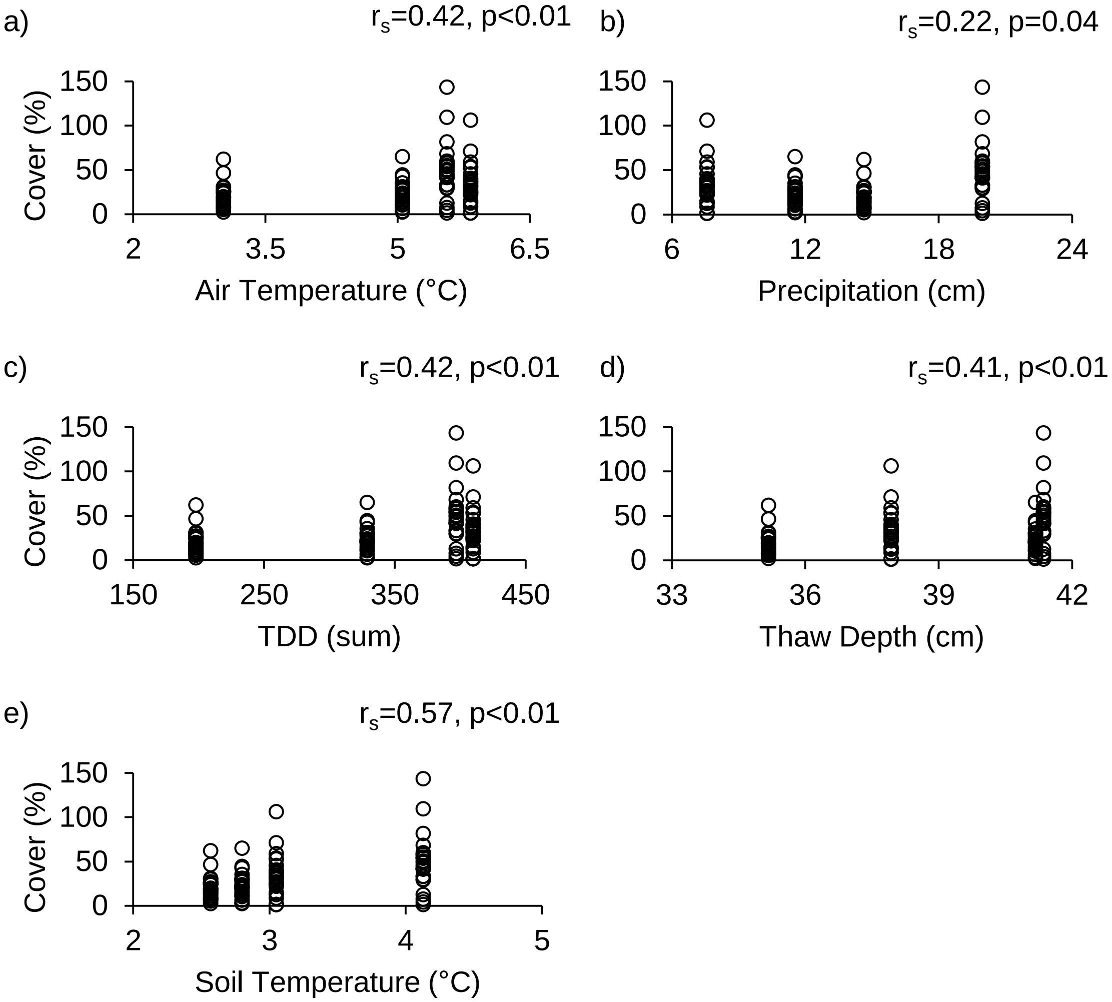

Figure 11: Significant correlations between cover of the abundant taxa *Carex stans* and a) mean summer air temperature, b) total summer precipitation, c) the sum of thawing degree days (TDD), d) mean summer thaw depth and e) mean summer soil temperature during years 2010, 2012, 2013 and 2014 at the site. R_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 22 plots for each year.

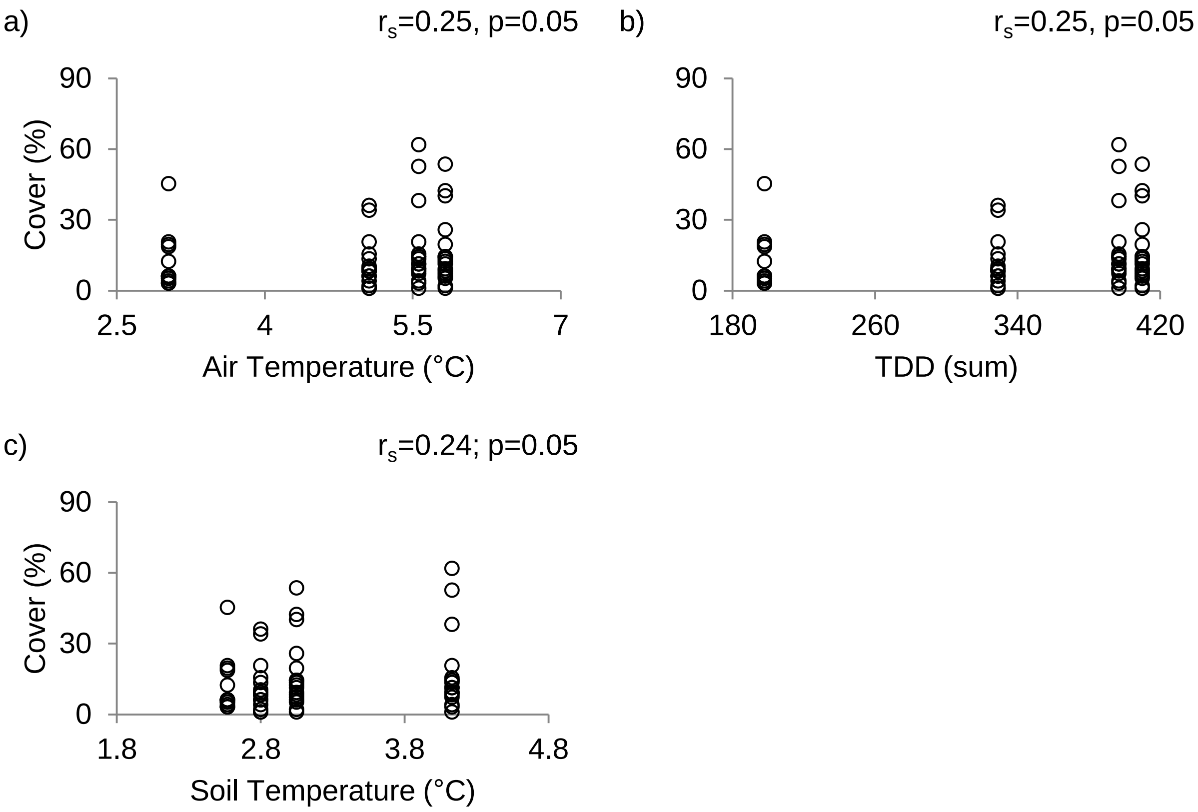

Figure 12: Significant correlations between cover of the abundant taxa *Dupontia fisheri* and a) mean summer air temperature, b) the sum of thawing degree days (TDD) and c) mean summer soil temperature during years 2010, 2012, 2013 and 2014 at the site. R_s values represent correlation coefficients from Spearman Rank correlations. The sample size was 17 plots for each year.

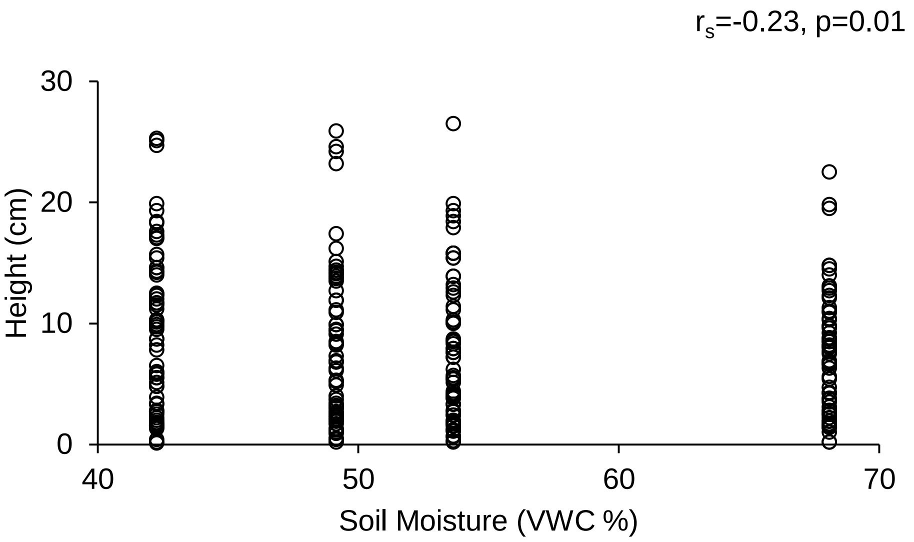

Figure 13: Significant correlation between height of graminoids and mean summer soil moisture during years 2010, 2012, 2013 and 2014 at the site. Height was determined using the maximum height per plot. R_s value represents correlation coefficient from a Spearman Rank correlation. The sample size was 30 plots for each year.

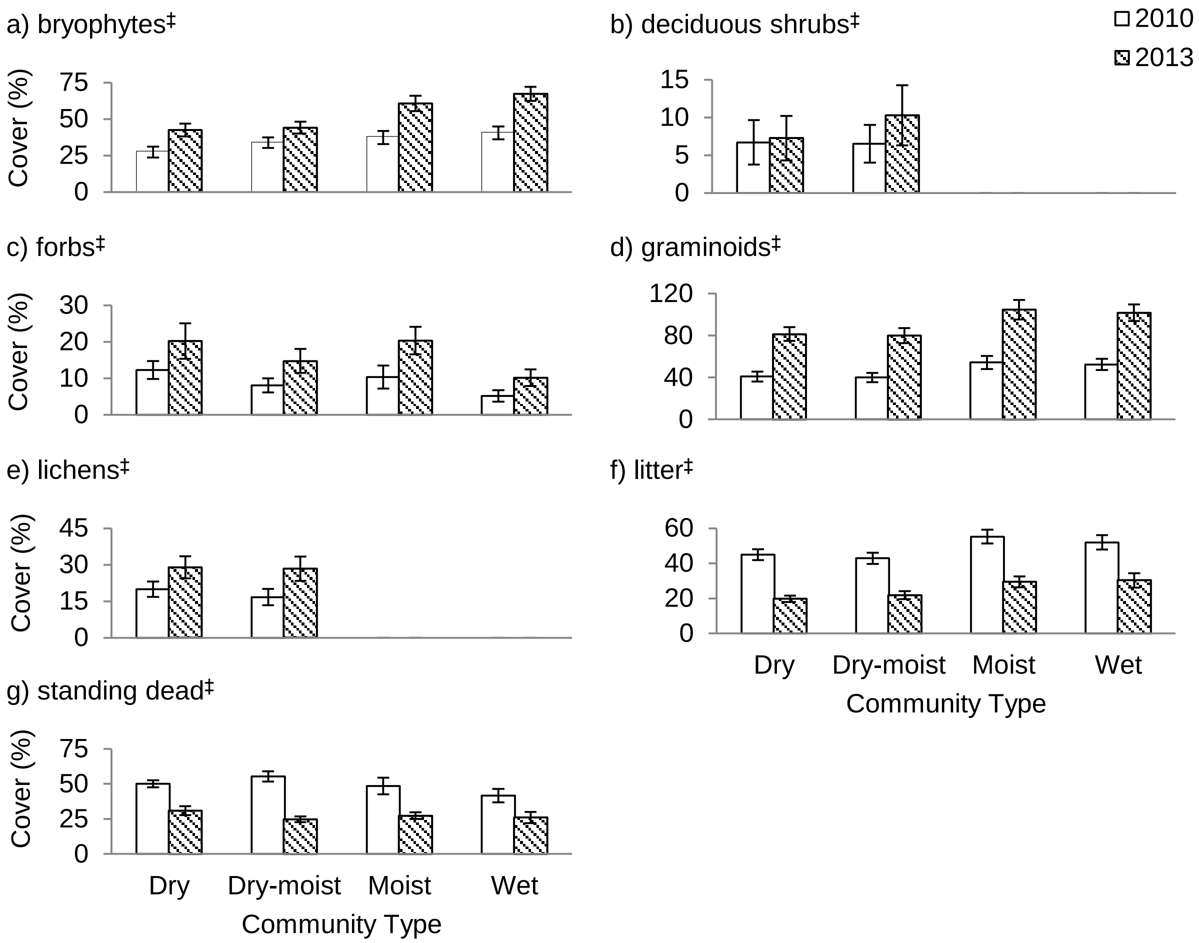

Figure 14: Mean cover of a) bryophytes, b) deciduous shrubs, c) forbs, d) graminoids, e) lichens, f) litter and g) standing dead within four generalized plant communities (dry, dry-moist, moist and wet) between 2010 and 2013 within the Arctic Systems Science grid. The grid was comprised of 98 vegetation plots which both included and extended beyond the 30 vegetation plots at the site which were used for the prior analyses. Cover changes were analyzed using a 2-way ANOVA. ‡ = square root transformed. Lack of comparisons indicate functional group was found in <5 plots and was subsequently excluded from analysis. Error bars show standard error of the mean. The sample size was 24 for dry plots, 26 for dry-moist plots, 21 for moist plots and 27 for wet plots. Note change in scale between the functional groups.

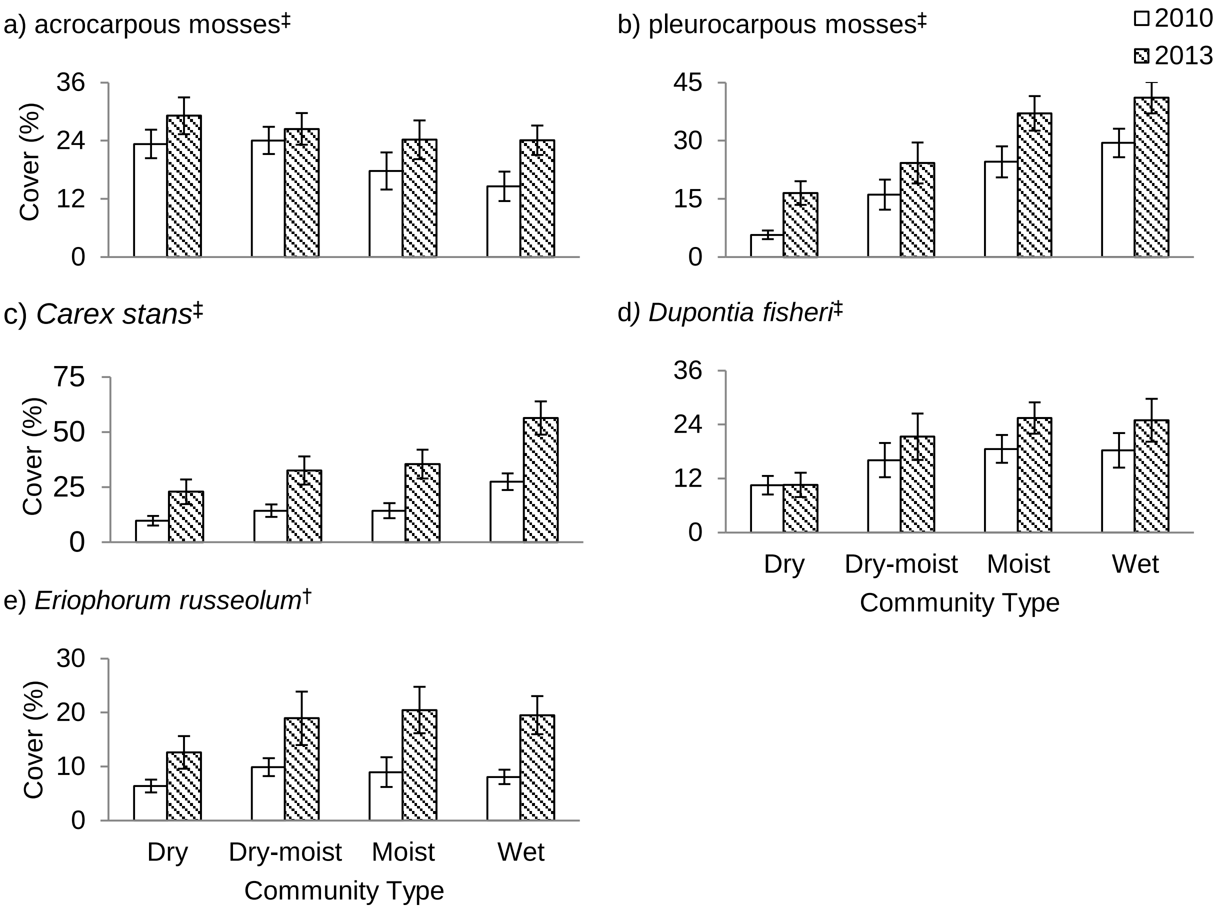

Figure 15: Mean cover of a) acrocarpous mosses, b) pleurocarpous mosses, c) *Carex stans,* d) *Dupontia fisheri* and e) *Eriophorum russeolum* within four generalized plant communities (dry, dry-moist, moist and wet) between 2010 and 2013 within the Arctic Systems Science grid. The grid was comprised of 98 vegetation plots which both included and extended beyond the 30 vegetation plots at the site which were used for the prior analyses. Cover changes were analyzed using a 2-way ANOVA. ‡ = square root transformed; † = log transformed. Error bars show standard error of the mean. The sample size was 24 for dry plots, 26 for dry-moist plots, 21 for moist plots and 27 for wet plots. Note change in scale between the abundant taxa.

Discussion

Due to the large differences observed between years with many of the vegetation metrics, caution should be exercised when utilizing the traditional method of documenting long-term vegetation changes over a coarse time series. Results from this study showed that the magnitude of vegetation changes at the site were dramatic over short time spans of just one to three years. For example, the cover of functional groups was shifting dramatically at the site, especially between years 2010 and 2013 when graminoids and forbs more than doubled in cover which was followed by nearly a halving of the cover of both functional groups just one year later from 2013 to 2014. In addition, even the cover of individual species changed drastically between years as *Carex stans* showed considerable increases in cover from years 2010 to 2013 in both the species within functional groups and the abundant taxa analyses. Likewise, plant height increased substantially over a two year time span as the height of graminoids increased by over three centimeters. Thus, by not considering intermediate years, a considerable amount of change of vegetation metrics may be missed likely as a function of the variability in weather between years. As such, conclusions reached over a coarse time series may be different than conclusions reached when interannual variation is considered. Therefore, long-term consecutive time series are needed when documenting vegetation changes to account for such variability. Other research studies also note the importance of considering interannual variability when investigating plant phenology (Iler et al. 2013) and net primary productivity (Knapp & Smith 2001).

To ensure the magnitude of observed vegetation changes were not the result of different researchers collecting data from year to year, additional analyses were conducted but not presented here. A simplified version of the point frame method where only top and bottom encounters are considered was validated by May & Hollister (2012), serving as a reasonably accurate alternative to using all vegetation encounters. This method was applied to all vegetation cover change over time analyses presented in this study and lesser but still significant changes were found similar to the results presented in this study. Since the top and bottom method includes only two vegetation encounters instead of multiple encounters per point, the likelihood of sampling differences between researchers was reduced considerably. Furthermore, changes in the height of functional groups over time were also analyzed with average height instead of maximum height per plot. Again, changes were less pronounced but consistent with the results presented here. Since changes observed with the different point frame methods and different vegetation height methods were similar, results presented in this study are unlikely to be the consequence of different researchers collecting data differently from year to year.

Regardless of the short time span of this study and the major differences in vegetation metrics between individual years, there was still a significant negative correlation between year and the cover of standing dead. Dead plant material has been shown to be accumulating in arctic regions over time (Elmendorf et al. 2012b) but this study shows an opposite pattern which was likely driven by the high standing dead cover documented in the year 2012 and dramatic declines observed in later years. The cover of standing dead often varies interannually as it is typically a function of how long plants retain dead leaves (Knapp & Seastedt 1986) and the large amount of change detected in this study may be a function of that retention time. Lemming herbivory may have also the influenced the initial cover of standing dead observed in the year 2010 as Villarreal et al. (2012) noted that lemming abundances were high during the summers of years 2007-2008 near the study site and significantly altered vegetation community composition in the region from 2007-2010.

The analyses in this study were limited due to sample size and non-consecutive time series sampling at the site and across the grid. Issues with sample size were apparent as only five taxa were found on at least half of the site plots and at least half of each of the grid community types. These five taxa included only mosses and graminoids which comprise merely a portion of the species composition at the site. Likewise, the site was not sampled in 2011 nor was the grid sampled in 2011, 2012 or 2014. Thus, only four time points were available for correlations at the site and only two time points were available for analyzing changes across the grid. Increased sample size and a longer consecutive time series would be beneficial to help understand observed changes in vegetation metrics over time.

Similarly, it was not determined whether the changes in cover were the result of changes in growth, shifts in abundance or a combination of both. For example, these factors were investigated for vascular growth forms and species at a study site in Atqasuk, Alaska which showed that changes in the cover of graminoids were explained mainly by individual plant growth, while changes in the cover of shrubs typically involved both plant growth and density (Gregory 2014). Similar measures outlined in that study could be applied to the Barrow site to better understand the mechanisms behind cover changes observed at the site.

Despite the short-term nature of this study, vegetation metrics were still significantly and the most strongly correlated with different abiotic variables. Other studies have linked soil temperature with the biomass of various functional groups and species in tundra regions (Hill & Henry 2011; Natali et al. 2012) and results from this study show similar findings especially as soil temperature was the most strongly correlated with the cover of forbs, graminoids, litter and *Carex stans*. In addition, the impact of of climate warming on the cover of graminoids, litter and standing dead (Walker et al. 2006; Elmendorf et al. 2012a) as well as *Carex stans* and *Dupontia* *fisheri* (Hollister et al. 2005a; Hollister et al. 2015) is well documented and similar results were presented in this study. Likewise, precipitation and soil moisture are associated with vegetation growth in tundra regions (Chapin et al. 1996; Blok et al. 2011) and results from this study mirror those studies as both abiotic factors were correlated significantly and the most strongly with the cover and height of certain functional groups. Finally, thaw depth is often correlated with vegetation growth and community composition in arctic regions (Schuur et al. 2007; Lantz et al. 2009) which was further observed in this study. Therefore, multiple abiotic factors should be considered when documenting vegetation changes in arctic regions.

Future work should involve identifying other factors, especially biotic ones that may correlate with vegetation metrics since not all of the vegetation metrics were correlated significantly with any of the measured abiotic variables. This is especially critical considering abiotic variables in this study were correlated independently with vegetation metrics as the variables were inherently related to each other. Leaf length or leaf area index of vascular plant species would be potential metrics to consider, since they impact point frame sampling and are related to greening trends in the Arctic (Zhou et al. 2001; Jia et al. 2003). Since each year of sampling in this study was considered a separate independent time point, winter and spring processes should also be included such as the timing of snowmelt, soil temperature and microbial activity which are known to be associated with vegetation composition in arctic regions (Sturm et al. 2005; Wahren et al. 2005; Aerts et al. 2006). Finally, quantifying herbivory at the sites to identify the direct impacts of herbivores such as caribou or lemmings on vegetation would also be useful. Impacts of multiple variables together (both measured in this study and proposed for future research), perhaps in a multiple regression analyses, could help illuminate observed vegetation changes.

Studies conducted in Barrow identifying vegetation changes within only one or two vegetation community types was representative of changes across the landscape as the vegetation communities in this study responded similarly over time. Although the community types identified in this study were significantly different from each other in years 2010 and 2013, there was still a considerable amount of overlap between species which blended together likely explaining the non-significant interactions between community type and year. In addition, results presented here may be due to using a land cover classification map which was developed with satellite imagery from 2002. Several times the land cover classifications assigned to the plots did not match field observations during the years of this study and required modification. A new land cover classification map of the area which contains imagery obtained during the study period outlined here is still being finalized elsewhere but would be more representative of the study area than the map derived from older satellite imagery. Thus, identifying vegetation changes within one or two vegetation community types serves as a reasonably accurate representation of the Barrow landscape. However, it is important to note that these results are site specific and results could be different at other sites across a different range of abiotic conditions.

Conclusion

Documenting vegetation changes are critical for numerous reasons. Individual plant species control energy transfer between trophic levels which is especially critical for herbivore forage quantity and quality. Functional groups are useful indicators of climate warming, help simplify vegetation models and maps and have predictive power. The vegetation metrics of cover and height influence competitive interactions, albedo and habitat suitability while diversity is linked to the productivity, stability and function of ecosystems. Identifying changes in arctic regions is especially important considering the numerous consequences associated with current and future climate warming. Research programs and funding initiatives have been implemented to document long-term changes in arctic regions such as ARCSS, ITEX and AON. Specifically the Barrow region, where this study took place, has a rich history of facilitating scientific research.

However, regardless of the many studies already conducted on vegetation changes in the Barrow region, knowledge gaps remain. The full consequences of changes in vegetation cover, height and diversity remain poorly understood but could have significant implications for ecosystem processes and ecosystem function, especially with future climate warming in arctic regions. Furthermore, most of the recent studies in the Barrow region as part of ITEX only utilized one or two vegetation community types (dry heath, wet meadow tundra or both) while numerous vegetation communities exist across the landscape and are known to function differently. Therefore, new studies are needed to ensure that changes identified within those recent studies accurately represent changes occurring across the landscape. This study addressed those knowledge gaps by investigating how vegetation cover, height and diversity changed over time, correlating observed changes with various abiotic factors, and identifying vegetation changes within generalized community types across the landscape.

Results from this study showed that the cover of all functional groups and many species within function groups changed significantly over time indicating that a considerable amount of change was occurring at the site even with the short duration of the study. This was further evident by the magnitude of changes observed across the site. The cover of certain functional groups such as graminoids, litter, standing dead and *Carex stans* approximately doubled or halved between individual years of this study and the height of graminoids increased by over three centimeters in just two years suggesting that caution should be used when documenting vegetation changes across coarse time series as variability of vegetation metrics in intermediate years could be missed. While these changes were large and the time span of the study was short, results still showed that the cover of standing dead was significantly correlated with year. This was likely a product of the length of time dead leaves are held by plants and lemming herbivory at the site. Results of this study also illustrated that vegetation metrics were significantly and the most strongly correlated with different abiotic factors showing that multiple abiotic factors such as air temperature, precipitation, thawing degree days, thaw depth, soil temperature and soil moisture should be considered when documenting vegetation changes. Finally, while the cover of functional groups and the abundant taxa significantly changed over time and cover differed between community types, the vegetation communities responded similarly over time likely due to the considerable amount of overlap in the vegetation composition across the grid. Thus, recent studies utilizing one or two community types to identify vegetation changes were representative of changes across the landscape.

Continued research and monitoring at the site and across the grid is needed. More vegetation metrics should be considered, especially biotic factors such as leaf length and herbivory while analyses should include multiple variables to identify how several factors are influencing vegetation metrics simultaneously rather than on an individual basis as was done with this study. Further research into the mechanisms influencing vegetation cover, such as growth, abundance or a combination of both would also be beneficial. Finally, a longer consecutive time series is needed to identify and understand vegetation changes at the site, the relationship between vegetation metrics and abiotic factors as well as changes within multiple vegetation community types over time.

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