Relationships between vegetation types and soil properties along a topographical gradient on the northern coast of the Brøgger Peninsula, Svalbard

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Abstract: Vegetation patterns in the high Arctic vary not only with proglacial chronosequence but also with a topographical gradient on older deglaciated areas which are covered by mature vegetation. A preliminary survey of local scale vegetation patterns along a topographical gradient with special reference to soil properties was conducted on the northern coast of the Brøgger Peninsula, Svalbard in the high Arctic. Three community types of vascular plants were distinguished by common dominants: *Cardamine* type, *Salix* type and *Oxyria/Luzula* type. Each community type was comprised of different habitat types. The *Cardamine* type was restricted to near the bottom of depressions, where there was high soil water content. The *Oxyria/Luzula* type was characterized by habitats belonging to upper slopes to ridges, having high gravel content soils. On the other hand, the habitat preference of the *Salix* type, which had higher vegetation cover and biomass of vascular plants compared to the other two types, was not clear. The core habitat of fertile/undisturbed area, as described by the centrifugal community organization model, might be dominated by *Salix polaris* in this area. The other species had a refugium from interspecific competition in their preferred peripheral habitats such as exposed ridge or wetland.

key words: Ny-Ålesund, *Salix polaris*, Svalbard, high Arctic vegetation, topographical gradient

Introduction

The plant distribution in the Arctic region is affected by the harsh environment, such as low temperature, low nutrient availability, and short duration of the growing season. These conditions generally result in species-poor communities (low α diversity) in Arctic vegetation zones compared to the other climate regions (Kleiden and Mooney, 2000). However, species with graminoid, deciduous shrub, evergreen shrub, bryophytes, and forbs growth forms typically co-occur at scales of less than 0.1 m^2 in the

Arctic tundra (McKane *et al*., 2002), and thus, local scale habitat heterogeneity creates high β diversity even in high Arctic vegetation.

    One of the main factors that create local habitat heterogeneity in the Arctic region is soil developmental gradient with primary succession of glacier foreland. There have been many studies of the chronosequence approach to vegetation patterns in the Arctic region (Chapin *et al*., 1994; Vetaas, 1994; Minami *et al*., 1996; Okitsu *et al*., 1998; Frenot *et al*., 1998; Kojima, 2002). Hodkinson *et al.* (2003) described the successional patterns along proglacial chronosequences representing glacial regression of up to 2000 years in the Ny-Ålesund area, Svalbard in the high Arctic. They suggested that the species richness of vascular plants increased only for *ca.* 100 years and then stabilized at around 10–13 species.

    Vegetation patterns in the high Arctic vary not only with chronosequence but also with the topographical gradient on older deglaciated areas which are covered by mature vegetation. Phytosociological studies (Nimis, 1985; Elvebakk, 1982; Kojima, 1994, 1999) have stressed the relationships between vegetation classification and habitat types in relatively well-developed soils. Elvebakk (1994) revealed that vegetation in Svalbard is greatly differentiated according to species preference of soil pH and/or topographical moisture conditions, though the whole area lies within the high Arctic *Dryas octopetala* zone (Brattbakk, 1986).

    East Brøgger Glacier is located near Ny-Ålesund in the northwestern part of Svalbard in the high Arctic. A few scattered vegetation patches of bryophytes (*e.g. Bryum cryophilum*, *Pottia heimii* and *Funaria arctica*) and vascular plants (*e.g. Saxifraga oppositifolia*) have occurred in a newly deglaciated moraine (Minami *et al*., 1996). In contrast, well developed vegetation of vascular plants with some bryophytes (*e.g.*, *Sanionia uncinata*) among topographical undulation is distributed in an older deglaciated area of the northern coast of the Brøgger Peninsula (Cannone *et al*., 2004; Nakatsubo *et al*., 2005). In this paper, we conducted a preliminary survey of local scale vegetation patterns along a topographical gradient with respect to soil environmental variables such as soil pH and water content.

Materials and methods

Study site

    The study was carried out on the northern coast of the Brøgger Peninsula, close to Ny-Ålesund (78°55′N, 11°51′E), north-west Spitsbergen, Svalbard. The study site was the glacier foreland of the East Brøgger Glacier. The northern coast of the Brøgger Peninsula was deglaciated *ca.* 11–13000 years ago (Cannone *et al*., 2004). A mixed community of bryophytes (*e.g.*, *Sanionia uncinata, Aulacomnium turgidum* and *Dicranoweissia* sp.) and vascular plants (*e.g. Salix polaris*, *Saxifraga oppositifolia*, *Oxyria digyna* and *Dryas octopetala*) covered the well developed vegetation among topographical undulation (Cannone *et al*., 2004).

    The study area lies within the polar semi-desert vegetation zone of the high Arctic (Longton, 1997). Climatological data from the Ny-Ålesund meteorological station (1975–96) indicated that the annual mean temperature is −6.3°C, with a minimum monthly mean temperature of −14.6°C in February and maximum monthly mean

temperature of 4.9°C in July.   Annual rainfall is 403 mm.   Snowmelt occurs in July.

Vegetation description

North facing slopes *ca.* 600 m from the Arctic Ocean near Ny-Ålesund airport were selected for survey in the study area.   Two line transects (Lines A and B) of 260 m length each with *ca.* 20 m relative height were set on the slopes in August 2004. Fourteen *ca.* 350 cm^2 circular (21 cm diameter) plots were selected on each transect at 20 m intervals.   Floristic composition and community structure were investigated in each plot.   Coverage (%) of all the higher plants by species was measured in each plot. Coverage of all bryophytes was also measured.   After the measurements of community attributes, all plants including bryophytes in each plot were clipped at ground levels. They were oven-dried at 70°C for more than 24 h and weighed for plant biomass.

Soil sampling and analysis

Volumetric water content was measured in each plot using TDR soil moisture sensor (Hydrosense TM, Campbell Scientific Australia Pty.).   A 50 m*l* cylindrical soil core ($\varphi = 5$ cm, height $= 2.5$ cm) was used to correct the soil samples of topsoil beneath the litter in each plot.   Fresh soil samples were brought to the laboratory in Ny-Ålesund and their fresh weight measured.   Subsamples of fresh soil were used to measure soil pH [soil: water ratio of 1 : 2.5 (g/g)] and the remains were air dried.   The air dried soils were passed through a 2 mm-mesh sieve and gravel content measured.   Total soil carbon and nitrogen content were measured with a CN-analyzer (Sumigraph NC-800, Sumika Chemical Analysis Service, Ltd.).

Data analysis

The relative dominance (D) of each vascular species was calculated using: D＝C of the species/total sum of C of all vascular species in each plot.   The number of dominant species in each plot was determined by dominance analysis using D (Ohtsuka, 1999). The floristic similarity of species composition (except for bryophytes) among all plots except for the plots that had no vascular plants was subjected to cluster analysis using the Sorensen similarity index (SI):

$$SI = \sum_{i=1}^{n} \min(X_i, Y_i),$$

where X_i and Y_i are the D of species i in plots X and Y, n is number of species.

Canonical correspondence analysis (CCA; Jongman *et al.*, 1995) was applied to all plots to assess the vegetation pattern along a topographical gradient with respect to environmental variables.   Cluster analysis and CCA computations were performed using PC-ORD ver. 4 (MjM Software Design, 1999).

Results

Topographical gradient and environmental changes

The two transects had a topographical gradient, rising from nearly 0 m a.s.l. at the bottom of the depression to 20 m on the exposed ridge.   Figure 1 illustrates the topographical profile and environmental changes along the two transects.   Most of the
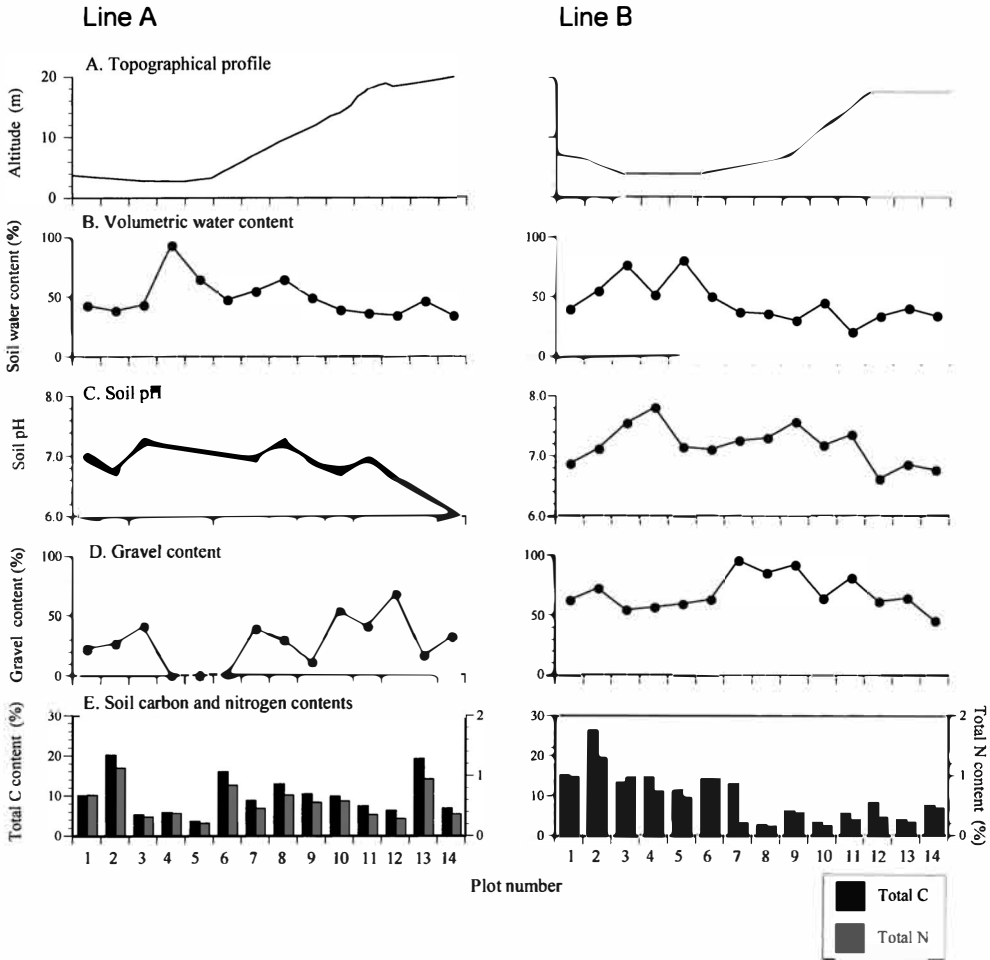
Fig. 1. Topographical profiles of the two line transects.   Changes of soil properties along topograph-
          ical gradient are also shown.

plots had moderate soil water content *ca.* 30 to 50%, though some plots near the bottom
of the depression (A4, E3 and E5) had higher soil water content, where small streams
flow in summer.   The soil pH along Line A gradually decreased toward the ridge, and
that along Line B was neutral to slightly alkaline.   Gravel content of surface soils
varied greatly between 0 and 100% irrespective of topographical gradient.   The gravel
content along Line B was higher than that along Line A.

Total carbon and nitrogen contents of surface soils varied between 2.8 and 26.5%,
and 0.14 to 1.31%, respectively.   Total carbon and nitrogen contents gradually
decreased moving up to the ridge along Line B, though no clear trend was found along
Line A.   The mean C/N ratio ($\pm$SE) of Lines A and B were 18.6$\pm$0.55 and 21.0$\pm$
3.37 respectively.

Floristic analysis and community types

    A total of 22 species appeared in the 28 plots, two of which (A4 and B12) had no vascular plants. Table 1 showed occurrence frequency (OF) and dominance frequency (DF) of 17 dominant species, which dominated at least once in the 28 plots. *Salix polaris*

Table 1. Dominance frequency (DF), occurrence frequency (OF) and mean cover (±SD) of dominant species in the 28 plots.

|	Total (n=28)		Line A (n=14)				Line B (n=14)			
	DF	OF	DF	OF	Mean cover (%)		DF	OF	Mean cover (%)	
Salix polaris	14	14	9	9	34.4 ±	11.3	5	5	22.6 ±	13.3
Oxyria digyna	4	11	1	5	2.3 ±	1.3	3	6	1.8 ±	1.8
Saxifraga oppositifoira	4	5	2	3	32.3 ±	26.4	2	2	5.5 ±	6.4
Luzula confusa	4	4	4	4	14.8 ±	9.5				
Saxifraga hyperborea	3	5		2	1.5 ±	0.7	3	3	3.0 ±	2.0
Sagina nivaris	2	6		3	0.7 ±	0.3	2	3	1.0 ±	1.3
Phippsia algida	2	5		2	6.0 ±	2.8	2	3	2.7 ±	1.2
Cardamine nymanii	2	4		2	2.0 ±	0.0	2	2	2.0 ±	0.0
Draba sp.	2	3	1	1	1.0		1	2	1.3 ±	1.1
Poa arctica	2	3	1	2	4.5 ±	0.7	1	1	2.0	
Juncus biglumis	1	6		4	1.0 ±	0.7	1	2	1.5 ±	0.7
Equisetum Scirpoides	1	5	1	2	1.0 ±	0.7		3	1.0 ±	1.0
Cerastium regerii	1	4	1	3	14.0 ±	22.5		1	0.1	
Saxifraga foliolosa	1	3		1	2.0		1	2	1.0 ±	0.0
Saxifraga cespitosa	1	2		1	0.5		1	1	2.0	
Saxifraga nivaris	1	2					1	2	1.3 ±	0.4
Ranunculus pygmaeus	1	1					1	1	1.0	
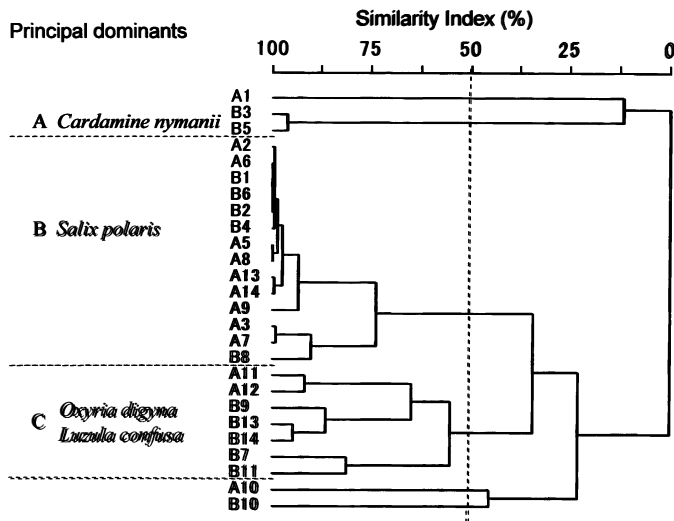
Fig. 2. A dendrogram showing similarity relationships among 26 plots. Plots having no vascular plants (A4 and B12) are excluded. Plots are indicated at left by line and plot number (Fig. 1). Principal dominants are the common dominant species in each cluster.
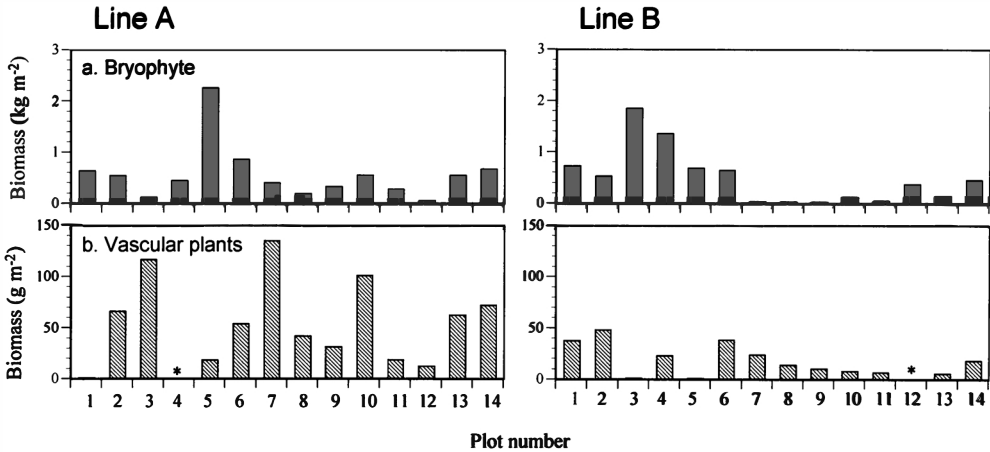
Fig. 3.   Biomass of bryophyte (a) and vascular plants (b) along the two line transects.   *Indicates no vascular plants.

occurred in half of the plots (14 times), and dominated in all of the plots in which it occurred. *Oxyria digyna* also widely occurred (11 times) but dominated in only 4 plots. *Saxifraga oppositifolia* and *Luzula confusa* dominated in 4 plots. Figure 2 illustrates the floristic similarity among the 26 plots. Three clusters were distinguished by the common dominants: A, *Cardamine* type (2 plots); B, *Salix* type (14 plots); C, *Oxyria/Luzula* type (7 plots) except for the other non-classified plots. Each cluster consisted of different topographical habitat types. A type was restricted to near the bottom of the depression along Line B (B3 and B5), where soil water content was high (Fig. 1). B type was widely distributed irrespective of habitat type. C type was characterized by habitats belonging to upper slopes to ridges along both lines.

The biomass of the bryophyte (*e.g.*, *Sanionia uncinata* and *Aulacomnium turgidum*) varied with topographical undulation ranging from 0.03 to 2.26 kg m^{-2} (Fig. 3), and the habitat near the bottom of the depression had high biomass. The biomass of vascular plants was rather small compared to the bryophyte, and was only up to 0.14 kg m^{-2}. The mean biomasses ($\pm$SE) of vascular plants in the three community types (*Cardamine*, *Salix* and *Oxyria/Luzula* types) were 1.0$\pm$0.14 (g m^{-2}), 54.3$\pm$9.37 and 13.8$\pm$2.54 respectively.

Community patterns with respect to environmental variables

Figure 4 illustrates the CCA ordination of the 26 plots based on species composition and environmental variables. Figure 5 shows the two dimensional ordination of CCA of the 26 plots demarcated with the relative dominance (D) of the four principal dominant species (Fig. 2) in each plot. Two plots of the *Cardamine* type (A in Fig. 4) were located on the lower right side, where soil water content and soil pH were high. Almost all the plots belonging to the *Salix* type (B in Fig. 4) were located on the center to the upper right side with relatively well developed soil (high C and N contents). Almost all the plots belonging to the *Oxyria/Luzula* type (C in Fig. 4) were located on
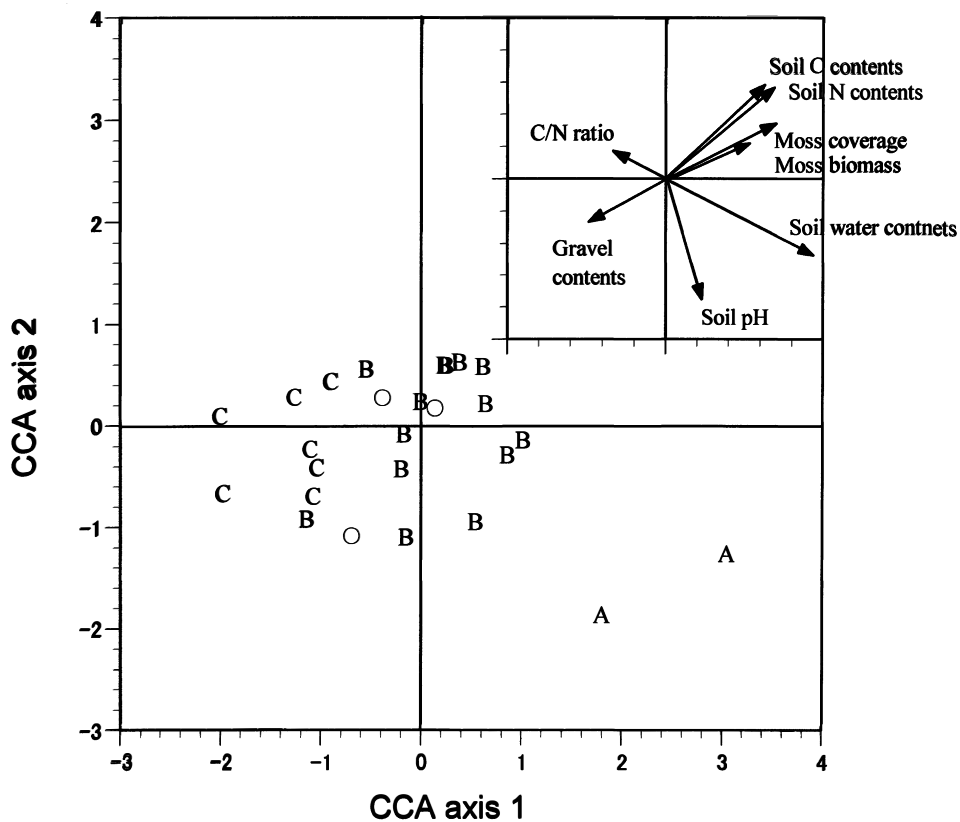
Fig. 4. CCA ordination diagram based on species composition for the 26 plots.   Weights of environmental variables are displayed as vectors.   Letters indicate the vegetation types in each plot clustered in Fig. 2: A, *Cardamine* type; B, *Salix* type; C, *Oxyria* and *Luzula* type; ○, non-classified plots.
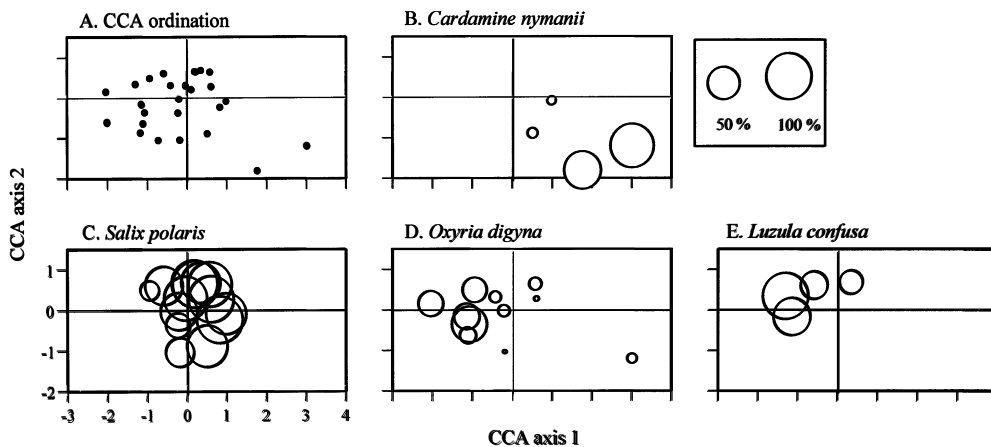

Fig. 5. CCA ordination for the 26 plots (A) demarcated with relative dominance (%) of the four principal dominant species (B–E) in each plot.

the left side with high gravel content of soils.

Discussion

Topographical habitat types on the northern coast of the Brøgger Peninsula were defined by Elvebakk (1994): dry site habitats along the ridge—snow bed gradient, and wet site habitats around ponds and streams in depressions. Four major habitats were distributed along ridge—snow bed gradients related to the snow cover pattern (exposed ridge, mesic plain/slope, moderate snowbed and late snowbed). Phytosociological alliances of *Luzulion arcuatae* dominated on acidic exposed ridges. Wet sites were also characterized by four habitats, and phytosociological associations of *Cardamino nymanii—Saxifragion foliolosae* typically occurred in wetland habitat near ponds or streams.

In this study site, the *Cardamine* type was restricted to near the bottoms of depressions with high soil water content, and the *Oxyria/Luzula* type occurred on upper slopes and ridges with relatively high gravel content of soils. These results indicate that the line transects of our study might have nearly the same topographical gradient of exposed ridge to late snow bed, and in turn wetland beside streams, though the soil properties had no clear trend along the topographical profile (Fig. 1). Elvebakk (1994) stated that the soil properties along the topographical gradient varied not only with topographical position but also with bedrock substrate. For example, soil characteristics of exposed ridge habitats varied from alkaline calcareous substrate to acidic substrate, resulting in different community types within the same habitats.

Chemical and physical soil properties such as water content, nutrient availability and pH are not only environmental conditions that affect vegetation patterns. Substrate disturbance in periglacial regions is responsible for the microhabitat differentiation among landform types. Cannone *et al.* (2004) demonstrated that the small-scale vegetation patterns occurred on the deglaciated area on the Brøgger Peninsula with respect to periglacial landforms. They classified the different types of periglacial features into six main groups. For example, strong disturbance by frost heave results in sharp habitat differentiation within sorted circles, and thus, microtopography and substrate texture differed greatly among center, trough and stony borders of sorted circles. Stress-tolerant species such as *Oxyria digyna* and *Luzula confusa* were more abundant in the trough and the center of sorted circles. They concluded that the distributional patterns of vegetation were primarily affected by complex responses to micro-habitat conditions and substrate disturbances.

On the other hand, Cannone *et al.* (2004) neglected to classify some species that had high percentage frequencies irrespective of landform types, such as *Salix polaris* and common bryophytes *Sanionia uncinata* around our study area (Uchida *et al.*, 2002). The *Salix* type of our study site was also widely distributed irrespective of topographical habitat (Fig. 2, Fig. 4), and thus, the habitat preference of the species was still unclear. In this case, the centrifugal community organization model (Keddy, 1990) might be applied to these patterns. The centrifugal community organization model is based on the principle that plant communities are structured by competitive hierarchies. There is a central core habitat (fertile undisturbed sites) with species radiating out from it,

each responding to different kinds of stress or disturbances. The core habitat is dominated by a dense nearly monospecific community. In contrast, a vast array of life forms is found in disturbed and/or infertile peripheral habitats.

The core habitat of moderate water condition and high nutrient content in the study area was mono-dominated by the *Salix polaris* community that had dense vegetation (Table 1) and high biomass of vascular plants. The other species had a refugium from interspecific competition in their preferred peripheral habitats, such as xeric exposed ride or mesic wetland. However, small scale micro habitat differentiation resulted in small scale centrifugal organization patterns from core habitat to peripheral disturbed and/or infertile habitats, which are difficult to detect in the high Arctic region. Nimis (1985) revealed that the vegetation patterns fairly well reflect the microgeomorphological patterns induced by physical forces, which were detected using small sample sizes ($100\,\mathrm{cm}^2$) for the analysis in Svalbard. Therefore, we need further studies of micro-morphological patterns with special reference not only to soil properties but also to the substrate disturbance regime using small scale sampling plots.

Acknowledgments

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