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The relationship between phytomass, NDVI and vegetation communities on Svalbard

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ABSTRACT

Several studies have shown a close relationship between vegetation fertility and different vegetation indices extracted from satellite data. The vegetation fertility in Arctic is at overall scales highly related to temperature. At lower scales surface material, snow cover, hydrology and anthropogenic effects (geese, reindeer) are determinant in constituting the different vegetation communities. The extent and occurrence of different vegetation communities are expressed in vegetation maps. On Svalbard a vegetation map covering the entire archipelago has recently been developed. The map is differentiated into 18 map units showing large areas of non- and sparsely vegetated ground. The most favorable vegetation is seen as productive marshes and moss tundra communities in the lowland. Various mathematical combinations of spectral channels in satellite images have been applied as sensitive indicators of the presence and condition of green vegetation. Today the normalized difference vegetation index (NDVI) is mostly used to display this information. NDVI is an indicator of the density of chlorophyll in leaf tissue calculated from the red and near infrared bands: NDVI = (NIR − RED)/(NIR + RED). NDVI gives values between −1 and +1 where vegetated areas in general yield high positive values, while non-vegetated ground is found on the negative side.

The overall aim of the present study was to test the correlation between NDVI and field-recorded phytomass on Svalbard, Arctic Norway. During the field study the clip-harvest method was conducted on 104 plot sites in the areas of Adventdalen and at Kapp Linné. Every sites recorded was geo-located using GPS. In the image processing part, the available Landsat 7/ETM+ image from 17th of August 2000, was converted into an NDVI-image. From this image NDVI data at the plot sites were recorded. The NDVI data were recorded inside a circle of 100 m around the measurement center. The correspondence between the point-recorded phytomass and correspondent NDVI data show a correlation of $R^2 = 0.68$. Comparable comparison of NDVI extracted from vegetation communities and recorded phytomass show a correlation of $R^2 = 0.74$. The recorded correlation of community based NDVI and the plant phytomass were used to estimate the total plant phytomass for the entire Nordenskjöld peninsula. The overall phytomass for the entire Nordenskjöld peninsula (3972 km^2) is estimated to 604.4 ton × 103 giving an average amount of 152 ton/km^2 or 152 g/m^2. Correspondent values for lowland and upland areas are 239 ton/km^2 (239 g/m^2) and 94 ton/km^2 (94 g/m^2), respectively. Svalbard Miljøfond has funded the project with some support from the NCoE/Tundra project.

1. Introduction

Several studies have observed and predicted an increase in temperature for Arctic and northern areas (Beck and Goetz, 2011; Serreze and Barry, 2011; Xu et al., 2013). This will affect plant growth in terms of increased photosynthetic activity, respiration and transpiration (Billings, 1987; Xu et al., 2013). Further flowering of several plant species are triggered by specific temperature conditions. Buds of plants require exposure to certain number of days above a critical temperature before resuming growth in the spring (Wielgolaski and Nordli, 2011). Finally temperature affects the length of the growing season for several plant species (Wielgolaski and Nordli, 2011) and vegetation communities (Xu et al., 2013). A rise in temperature in northern areas will have dramatic effects on the composition of vegetation communities, as well as on the distribution of the local flora. The ability of species to track their ecological niche after climate change is a major source of uncertainty in predicting their future distribution (Alsos et al., 2007; Beck and Goetz, 2011; Xu et al., 2013).

In addition to affect plant occurrence and distribution increases in temperature will affect the net primary production in northern latitudes, significantly. Primary production is a fundamental

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aspect of ecosystem functioning that sets the energy available for other trophic levels (McNaughton et al., 1989). It is particularly important for the management of arid and tundra ecosystems to understand the factors controlling phytomass production. Several studies state that the mean aboveground net primary production (ANPP) of arid systems is strongly correlated with mean annual precipitation (Wiegand et al., 2004), while temperature is the main controlling factor for northern and Arctic systems (Keeling et al., 1996).

When sunlight falls on green vegetation, red wavelengths are absorbed by chloroplasts, while near-infrared (NIR) wavelengths are reflected. Because this spectrum is unique to vegetation, one way to infer the amount of vegetation existing in a pixel of a multispectral reflectance image has been to compare the reflectance for that pixel at red wavelengths to the reflectance at near-infrared. If the NIR reflectance is much larger than the red reflectance, then presumably there is a considerable amount of green vegetation present. The use of a ratio of near-infrared to red light for estimating vegetation amount was first reported by Jordan (1969). Later studies by Colwell (1974) concluded that the ratio of reflected infrared light to reflected red light was useful for estimating biomass of grass vegetation. This ratio is today referred to as the simple vegetation index (VI) or simple ratio. Many other variations of the vegetation index have been developed over years, and the index mostly used today is the normalized difference vegetation index (NDVI), which is the difference between near-infrared and red reflectance divided by their sum. The index operates in the range from (−1) to (+1). In general negative values indicate non- to sparse vegetation cover, while high positive NDVI values show productive green vegetation.

Satellite data analyses have proven the relationship between the NDVI and vegetation productivity. Further the link between this index and the fraction of absorbed photosynthetic active radiation intercepted (fAPAR) has been well documented, both theoretically and empirically. Data analysis based on the new GIMMS NDVI3g dataset from 1982 to 2011 suggests that phytosynthetic activity period of the terrestrial vegetation in Arctic has increased significantly (Xu et al., 2013). About 88% of the Arctic area and 81% of the boreal area showed an increase in the length of the growth season of more than 3 days for each decade, aggregated to 9 days in the period of 1982–2011 (Xu et al., 2013). Corresponding trends are detected for arctic Alaska (Walker et al., 2003) stating elevated values for the temperature sum during the growing season and a subsequent increase in phytomass. Walker further revealed that an increase of 5 °C in the annual temperature sum highly correlate with a phytomass increase of 120 g/m^2.

The objective of this study has been to investigate the feasibility of deriving variables of ecological interest from multispectral satellite reflectance images of Arctic tundra. In the study we want to obtain a better understanding of the variation of vegetation communities along present-day climate gradients and derive how these relate to satellite-derived vegetation indices and vegetation communities. The project aims to estimate, map and model the overall phytomass for the entire peninsula of Nordenskiöld Land, Arctic Norway.

2. Material and methods

In the first stage of the project phytomass measurements will be performed along two local climate gradients: (a) – from the "warmer" inner Isfjord area to the "colder" coastal regions (Isfjord Radio) and (b) – from lowland to mountain areas (altitudinal gradient). In the second stage the relationships from the local findings will be combined with a recently developed vegetation map in order to compute the above ground phytomass for the entire peninsula of Nordenskiöld Land. This area is the most productive part of the Svalbard archipelago.

2.1. The study area of Nordenskiöld land

The archipelago of Svalbard is located to Arctic Norway extending roughly from 74 to 81 degrees northern latitude, and from 10 to 35 degrees eastern longitude (Fig. 1). The archipelago consists of more than 500 islands were the islands of Spitsbergen, Nordaustlandet, Edgeøya and Barentsøya are the largest in extent. Large parts of the area are mountainous with summits above 1500 m (Newtontoppen 1717 m). The coastal areas in north and west are deeply indented by fjords. Glaciers are the most characteristic landscape feature on the islands covering more than 60% of the land area.

Despite its northern location, Svalbard has a relatively mild climate compared to other areas at similar latitudes. On the archipelago the climates shift from typically humid, oceanic climate in the west to colder and drier conditions in other parts of the archipelago. This shift is mainly explained by the Gulf Stream affecting the western areas, while cold northern sea currents highly affect the northern and eastern regions (Aagaard et al., 1987). The temperatures in July are usually somewhat lower along the coast compared to the fjord regions. On Kapp Linné the average temperature in July is 4.8 °C, while corresponding temperatures at Longyearbyen show 5.9 °C. In winter the mean temperatures are generally low, with an average of −12.4 °C in February at Kapp Linné. In the fjord zone the winter temperature is even lower expressed by an average in February of −16.2 °C for Longyearbyen.

The amount of precipitation on the entire archipelago is generally low with averages along the western coast between 400 and 500 mm (Isfjord Radio – 480 mm). The fjord zone is extremely dry with annual means for Longyearbyen showing only 190 mm. The geology of Svalbard is highly varied and all geological periods are represented here.

The peninsula of Nordenskiöld Land is located to the central part of West Spitsbergen between Bellsund and Van Mijenfjorden in the south and Isfjorden in the north (Fig. 2). The total area is in this project estimated to 3554 km^2. Glaciers constitute approximately 16% of the peninsula mostly located to the mountain areas. However, one glacier, Fridtjovbreen, is calving into the sea at Fridtjovhamna. Two permanent settlements are found on the peninsula, Longyearbyen with mainly Norwegian habitants and the Russian settlement, Barentsburg, in Grönfjorden.

The fauna of Nordenskiöld Land peninsula is characterized by reindeer and a high number of migratory birds breeding in the area during summer. The goose population has grown from around 10,000 in the 1970s to approximately 33,000 individuals at present (Mitchell et al., 2010). However according to Black et al. (2007) and Mitchell et al. (2010) the geese population in Nordenskiöld Land has been stable the last decade due to increased predation from Polar bears and Arctic foxes. Monitoring shows that the reindeer population in Nordenskiöld Land varies in size, mainly due to variations in temperature and precipitation in winter. Today the reindeer population on Svalbard is estimated to 10,000 animals, most of them located at Nordenskiöld Land. In 1974 the number here was estimated to 5400 animals (Reimers, 1977). The reindeer population in Nordenskiöld land has shown a moderate increase during the last decades and a recent estimate of the population size is significant higher than in the 1970 (Hansen et al., 2013).

2.2. Vegetation

Several studies have described the vegetation on Svalbard, particularly the areas of Isfjorden and Brøgger peninsula (Brattbakk, 1981, 1985, 1986a; Spjelkavik, 1995; Nilsen et al., 1999; Elvebakk, 2005). On regional level Brattbakk (1986b) separates the area of Svalbard into two overall regions, the Mid- and High Arctic, with a further division of both regions into subgroups of dominant species. A later proposal presented by Elvebakk (1999), suggests

Fig. 1. Svalbard archipelago – Arctic Norway (74-81° N, 10-35° E).

an overall division into three bioclimatic regions, the middle arctic tundra zone (MATZ), the northern arctic tundra zone (NATZ), and the arctic polar desert zone (APDZ).

Consulting the most recent vegetation map produced for the Svalbard archipelago (Johansen et al., 2009, 2012), the Arctic Polar Desert Zone (APDZ) is characterized by glaciers and non- to sparsely vegetated areas. The main vegetation differentiation is along the dry-moist gradient with cryptogam herb barrens on dry sites and moist cryptogam tundra in areas with long lasting snow cover. On Svalbard large parts of the northeastern and eastern Spitsbergen, Nordaustlandet and eastern parts of Barentsøya and Edgeøya definitely belong to this zone. Correspondent growing conditions are also recorded for large parts of NW-Spitsbergen.

The Northern Arctic Tundra Zone (NATZ) shows a much higher variation in community types, but still the glaciers and non- to sparsely vegetated areas constitute the main landscape feature. Community types of *Dryas octopetala* are frequent on ridges, terraces and in hill slopes. Pioneer vegetation associated to instable river fans is common due to melting effects from surrounding glaciers. Moderate snowbed and snowflush areas are most common along the coast, as well as *Deschampsia alpina* tundra mires. The coastal plains are characterized by *Saxifraga oppositifolia* combined with the lichen *Cetraria delisei*. Three geographical sub-regions can be differentiated for the NATZ area: (a) coastal regions along the western coast (b) continental areas, especially along Wijdefjorden, and (c) the western parts of the Barentsøya and Edgeøya islands.

The Middle Arctic Tundra Zone (MATZ) is mainly located to the central fjord area. The general picture of this sub-zone is a fairly dense vegetation cover in the lowland, but also vegetated areas in the mountain areas. The community types in the lowland are varied constituting productive marsh vegetation in the valley floors, swamp and moss tundra vegetation on wet habitats, densely vegetated heather tundra in the hill slopes often characterized by *Cassiope tetragona* and open *Dryas-Carex rupestris* communities on ridges. The river fans are partly established, partly exposed. A characteristic feature of the area is a high number of species, many of them locally warmth demanding.

The vegetation of the Nordenskiöld Land peninsula belongs to the MATZ region, except from the western areas along the coast (NATZ) and the mountain areas (APDZ) (Elvebakk, 2005). At local scale the areas can be stated as the most diverse and productive area of the Svalbard archipelago. The information of the vegetation communities within the area is in this study based on a recently produced vegetation map for the Svalbard archipelago (Johansen et al., 2012). A subsection from this map covering Nordenskiöld Land is used as one of the basis datasets in this study. Further map subsections are produced for the areas studied more intensively, the areas of Adventdalen/Bjørndalen and the areas of Kapp Linné/Isfjord Radio. In addition two conventional vegetation maps has been available – one covering the areas of Adventdalen (Brattbakk, 1984), a second from Lågnesflya (Brattbakk, 1985) in the south-eastern parts of Nordenskiöldkysten.

2.3. Vegetation indices

Various mathematical combinations of spectral channels have been applied as sensitive indicators of the presence and condition

Fig. 2. Topographic map of Nordenskiöld land peninsula. Areas in white display glaciated areas, while areas in green are non-glaciated.

of green vegetation (Justice et al., 1985; Tucker and Sellers, 1986). Most simple of the vegetation indices is the vegetation index (VI), defined as "the ratio between the near-infrared channel and the red channel". The Normalized Difference Vegetation Index (NDVI) was found (Sellers, 1985; Tucker and Sellers, 1986; Prince, 1991) to be a representative of plant assimilation condition and of its photosynthetic efficiency. NDVI is an indicator of the density of chlorophyll and leaf tissue calculated from the red and near infrared bands:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

In this equation NIR represents the Near Infrared band 4 (0.76–0.90 μm) of Landsat 5 and 7 and RED the corresponding band 3 (0.63–0.69 μm). NDVI gives values between −1 and +1. Vegetated areas in general yield high values for these indices due to their high near infrared reflectance and low visible reflectance. Reflectance of cloud, snow and water is larger in the red than near infrared. Clouds and snowfields yield negative values while water has very low or slightly negative values. Rock and bare soil have approximately similar reflectance values in the red and near infrared channels, and results in indices near zero. A zero or close to zero means no vegetation (Myneni et al., 1995; Slayback et al., 2003; Delbart et al., 2006). The NDVI is further used for deducing temporal changes in the vegetation cover. Temporal changes in NDVI are related to the seasonal changes in the amount of photosynthetic tissues; typically NDVI increases in spring, saturates at a certain point of greenness in summer and then declines in autumn, at mid to high latitudes. The NDVI equation has a simple, open loop structure. This renders the NDVI susceptible to large sources of error and uncertainty over variable atmospheric and soil background conditions, wetness, imaging geometry, and with changes within the canopy itself (Liu et al., 1995; Jackson and Pinter, 1986).

In this project a Landsat ETM+ image acquired at 17th of August 2000 is used as basis for calculation of NDVI values. This is one of very few cloud free images available from Spitsbergen area during the last decades. The selected image was geo-corrected to a UTM map projection, zone 33, and converted into a NDVI map. This map projection corresponds to the recently produced vegetation map available for the study area (Johansen et al., 2009, 2012). NDVI values for different vegetation classes were recorded by superimposing classes from the vegetation map to the NDVI map.

2.4. Field study and map evaluation

During the field study biomass data at plot level were collected within the study areas. A total number of 104 sites were visited during the last week of July in the years 2010–2011. A number of 87 sites were recorded in Adventdalen/Bjørndalen and 17 sites at Kapp Linné. Each of the sites visited were recorded for biomass content using the clip-harvest method (Raynolds. et al., 2006). The harvesting was performed inside a square of 25 cm × 40 cm (0.1 m^2). Each of the plots recorded were geo-located using GPS equipment (Garmin Oregon 550) in order to establish the geographic link to the produced NDVI map. The relationship between recorded phytomass and corresponding NDVI data was studied by superimposing the phytomass data into the produced NDVI map. Satellite based NDVI data were recorded inside a circle of 100 m around the measurement center.

3. Results

3.1. Vegetation data from Adventdalen and Kapp Linné

In order to evaluate the relationship between vegetation communities, biomass and recorded NDVI from satellite data, the knowledge of the occurrence and distribution of different vegetation communities in the landscape is needed. This information is extracted from the vegetation map for Svalbard (Johansen et al., 2012). Subsections from this map are used to portray the diversity of vegetation communities in the study areas of Adventdalen/Bjørndalen and on Kapp Linné. The map subsections are viewed in Fig. 3. Areal statistics for the given areas are displayed in Table 1.

By inspecting the areal statistics of the two study areas it is easily stated that non-vegetated classes like sea, inland water, rivers and glaciers constitute approximately 30% of the area in both map subsections. Further areas affected by shade, mainly located to northern slopes, comprise respectively 16.9% of the Adventdalen area, and 11.9% at Kapp Linné. The remaining map units (5–18) are regarded as vegetated. At overall level it is reasonable to aggregate the community types into five overall groups of vegetation: (a) sparsely vegetated areas on dry subsoil; (b) sparsely vegetated areas on moist substrate; (c) densely vegetated areas on dry substrate; (d) densely vegetated areas on moist substrate and finally (e) areas of organic material.

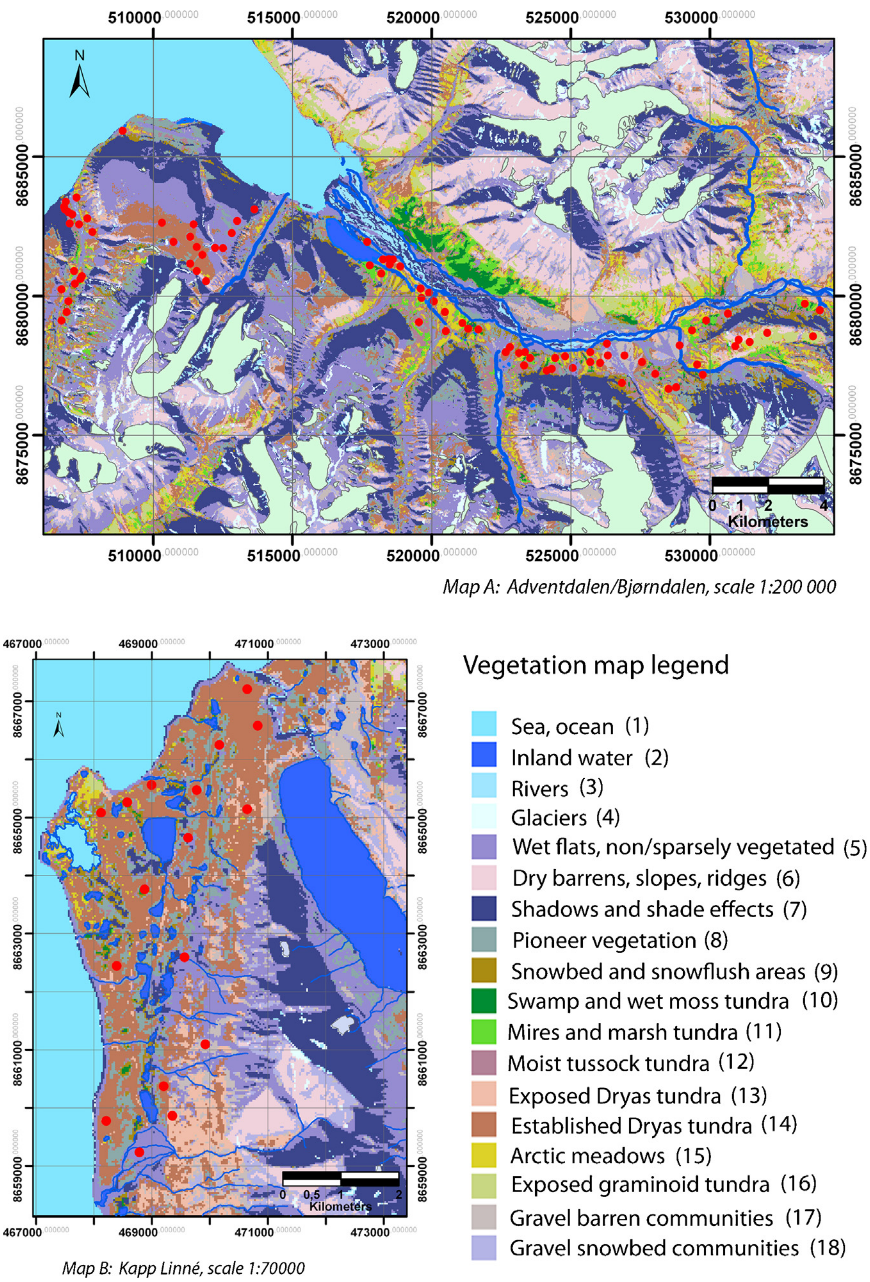

Fig. 3. Vegetation map for the areas of Adventdalen/Bjørndalen (A) and Kapp Linné (B). The map is differentiated into 18 map units. The legend to the map is displayed in the figure. Sites for biomass recordings are given in the figure as red spots.

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Table 1
Areal statistics for the study areas of Adventdalen/Bjørndalen and Kapp Linné.

Nr.	Vegetation units	Adventdalen/Bjørndalen		Kapp Linné	
		km^2	%	km^2	%
1	Sea, ocean	75.5	10.6	13.0	20.6
2	Inland water	1.5	0.2	5.3	8.4
3	Rivers	10.9	1.5	0.2	0.3
4	Glaciers	123.5	17.4	0.3	0.6
5	Wet flats, non/sparsely veg.	105.6	14.8	9.5	15.0
6	Dry barrens, slopes, ridges	57.7	8.1	2.2	3.6
7	Shadows and shade effects	120.5	16.9	7.5	11.9
8	Pioneer vegetation	34.1	4.8	4.2	6.7
9	Snowbed and snowflush areas	8.9	1.3	1.0	1.5
10	Swamp and wet moss tundra	4.0	0.6	0.1	0.2
11	Mires and marsh tundra	7.8	1.1	0.0	0.1
12	Moist tussock tundra	19.1	2.7	0.3	0.5
13	Exposed Dryas tundra	15.6	2.2	2.7	4.4
14	Established Dryas tundra	35.7	5.0	11.0	17.5
15	Arctic meadows	21.3	3.0	0.4	0.7
16	Exposed graminoid tundra	19.1	2.7	0.2	0.3
17	Gravel barren communities	23.7	3.3	2.8	4.5
18	Gravel snowbed communities	27.4	3.8	2.0	3.2
		711.9	100.0	63.1	100.0

(a) The sparsely vegetated areas on dry substrate are in both subareas displayed in the classes 6, and 17. Due to the sparse vegetation cover it is difficult to define the areas based on botanical criteria's. Different landscape elements are associated to this type of subsoil with gravel plateaus in the mountains, gravel hill slopes and gravelly river fans occupying the largest areas. The largest proportion of these landscape elements are found in the mountains and in the Arctic polar desert zone. In addition the exposed graminoid communities associated to map unit #16 are to be placed in this group.

(b) Sparsely vegetated areas on moist substrate are in both areas associated to the map units 5, 8 and 18. These classes are in the lowland characterized by sterile, loamy flats often found along flooding rivers, in the instable part of river fan mosaic and on seashores. Further different types of pioneer vegetation both in the lowland and in the mountains are found here. Finally different types of late snowbed communities often bounding recent moraines near glaciers are one of the main landscape elements within this unit. The unit is characterized by single species demanding wet growing conditions.

(c) The densely vegetated areas on dry substrate are in Adventdalen mainly associated to the established *Dryas* vegetation. The *Dryas* communities on Svalbard has been surveyed by Rønning (1965) and differentiated into four associations. Two of the associations, characterized by the species *Carex nardina* and *Carex rupestris* are located to exposed ridges with minor snow protection during winter. These stands are associated to map unit #13 in the vegetation maps. The two remaining associations Cassiopo tetragonae-Dryadetum octopetalae Rønning (1965) and Dryadetum minoris Hadac 1946 are found on areas with some snow protection during winter. The overall distribution is mainly located to the inner fjord zone. Here the communities are developed on terraces, hill slopes and in small depressions in the terrain. The most common variant of Dryas communities is characterized by few species, quite often more or less pure stands of either *Dryas octopetala* or *Cassiope tetragona*. The established stands of *Dryas* are in the vegetation map associated to vegetation unit #14. The stands of *Cassiope* are developed both on dry and moist substrate. The moist community types are mainly found in map unit #12 in the vegetation map. In the mountain areas, as well as in the most northern and easternmost parts of the Svalbard archipelago *Dryas* stands with *Papaver dahlianum* are quite common.At Kapp Linné the occurrence of *Dryas octopetalae* is rare, while *Cassiope tetragona* is fully absent (Rønning, 1996). Here community types of *Luzula-Saxifraga oppositifolia*, partly with lichens, constitute large areas on the dry and gravel costal plains. In areas with more heavy snow protection the lichen *Cetrariella delisei* is common. The ubiquitous *Salix polaris* is also a common species of this community type. Among other species associated to this community are *Bistorta vivipara, Cerastium arcticum*, *Saxifraga caespitosa*, *Pedicularis hirsuta* and *Silene uralensis*. This important vegetation community lacks a validly published phytosociological name, but probably belong to the alliance Luzulion nivalis Nordhagen 1936 (Elvebakk, 1994).

(d) Densely vegetated areas on moist substrate are in Adventdalen associated to the classes 9, 12 and 15. These community types are mainly found in the lowland regions with the largest areal extent in the inner fjord zone. At the northern parts of Kapp Linné only minor stands of these classes are recorded, while more to the south, at Lågnesflya, the communities are more frequent.

The three classes here aggregated represent vegetation communities with differences in moisture content. The moisture supply may vary between areas, but the snowmelt in the spring and early summer period plays an important part of this supply. The map unit #9 is located to areas with the most heavy snow cover. The unit is characterized by moss-rich stands with few vascular species apart from the species *Oxyria digynae*, *Ranunculus pygmaeus* and *Saxifraga cernua*. To some extent grass-rich variants are developed with *Poa alpina* as one of the characterizing species. Another type of vegetation associated to wet areas or areas that are water-logged early in the summer is *the Deschampsia alpina* communities. It is regarded that these communities are not climatologically favorable enough to permit peat production. *Deschampsia* stands are often found along drainage grooves and in areas with irrigating water during most of the growing season. The large tussocks of *Deschampsia*, often with liverworts and spots of open gravel in between easily recognize this community. At Kapp Linné the unit is most commonly developed in the lower parts of hill-slopes. The community seems to be most common in coastal areas. In areas with a more moderate snow protection the variation in species composition is higher. At general level formations comprising a mixture of heather and snowbed species are developed here. Characterizing spieces are *Salix polaris*, *Dryas octopetalae*, *Equisetum arvense*, *Saxifraga oppositifolia* and *Silene acaulis*. The moss layer is generally moderately developed.

The final group of species being confined to areas with (#15) more slight moist conditions are the drier parts of Dupontia meadows. In Adventdalen they constitute large areas on lowland flats and in south- to southwest facing slopes with some supply, especially in the early part of the growing season. The community types are mainly distributed in the MATZ bioclimatic zone constituting large areas at Dickson Land, and in the valleys of the fjord zone. To some extent luxuriant bird cliff vegetation belong to this group, combined with established graminoid communities on river fans and vegetated plains with *Bistorta vivipara* as a characterizing species in the field layer.

(e) Areas on organic material are in the vegetation map associated to the classes 10 and 11. The areas are characterized by wet growing conditions constituting a peat layer and with ground water located at or in a short distance beneath the soil surface. This includes moist bog areas with poor drainage often located to depressions, flats and gentle slopes in the lowland. In peat land areas, permafrost is often found near the surface due to the good insulative properties of the peat layer. There is also a great deal of water and ice in the ground, and the spring is therefore delayed compared with well-drained sites, but the season may be prolonged in late summer. The moss layer is usually very well developed, while lichens are lacking. Woody plants are of small importance, while carpet-forming grasses, sedges, rushes, and many forbs are characteristic. All vegetation types are more or less marshy.

In Adventdalen these communities are well developed with the largest extent on the northern side of the main river. The species *Arctophila fulva* and *Carex subspathacea* are most common in areas of stagnant water. In areas with somewhat drier growing conditions the species *Eriophorum scheuzerii*, *Alopecurus alpinus*, *Dupontia fisherii, D. psilosanta* and different herb species are common. The moss layer is characterized by *Tomentypnum nitens*. The moss tundra communities at Kapp Linné have a restricted distribution, mainly located near ponds and watersheds in the inner parts of the coastal plain.

3.2. Biomass and NDVI measurements

One of the main challenges in this project has been to bridge the vegetation content associated to different units in the vegetation map with correspondent field recorded biomass data and NDVI data from satellite. The correspondence between point- recorded biomass data and NDVI data extracted at corresponding points are shown in Figs. 4 and 5, while the computed and aggregated values are summarized in Table 2. In the table column (1) refers to the class unit in the vegetation map. Column (2) shows the number of sites recorded for each vegetation unit and column (3) the average of the recorded biomass. The biomass for each vegetation unit varied from 16 g/m (dwt) for gravel barren communities to 551 g/m (dwt) for mires and marshlands. In column (4) and (5) the extracted NDVI values are summarized, while column (6) shows computed biomass values after a linear adjustment of the biomass values.

The values summarized in Table 2 are a result of a series of computations. In the first stage of this aggregation of the two data sets, correlation analysis between the point-recorded biomass and comparable NDVI values were carried out. The correlation plot is given in Fig. 4 with a correlation value of $R^2 = 0.68$ determined by linear regression. Comparable calculations are performed for the biomass values assigned to different vegetation units and NDVI values extracted from the units. The correlation plot is given in Fig. 5, with correlation coefficient of $R^2 = 0.74$. From the calculations

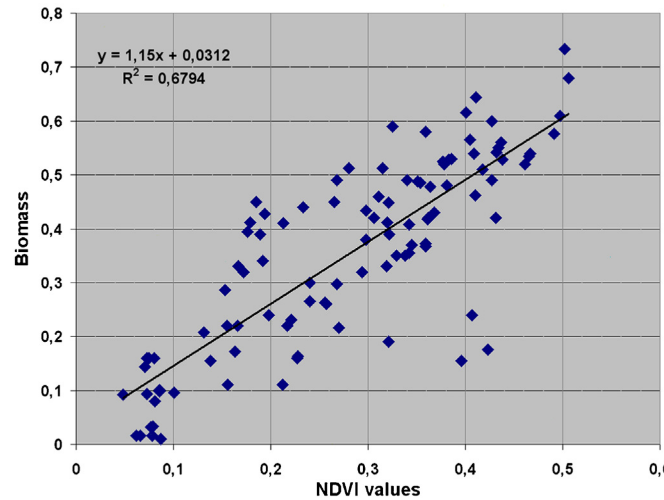

Fig. 4. Scatter plot illustrating the relationship between field recorded biomass and NDVI data extracted from available Landsat 7/ETM+ image. $R^2 = 0.68$.

performed, it is easily stated that there is a linear relationship between ground recorded biomass and belonging NDVI values extracted from the selected Landsat image. This relationship is expressed by the equation: biomass = $\alpha \times$ NDVI + β. For the dataset given in Fig. 5 the values for $\alpha = 1.06$ and $\beta = 0.04$. When the values for α and β are known we can use these values to compute adjusted values for the biomass. The adjusted values fit fully into a linear relationship for NDVI and biomass. The adjusted values are summarized in Table 2, column 6. By connecting the computed biomass values either to a produced NDVI-map for the Nordenskiöld Land peninsula (Fig. 6) or to the vegetation map for the area (Fig. 7), we are now able to compute the biomass for the entire study region. In our case the peninsula of Nordenskiöld Land is separated into lowland and upland regions. The 200 m contour line is used in this distraction. Areal statistics and computed biomass for Nordenskiöld Land peninsula with subsections are summarized in Table 3.

4. Discussion

The results concerning the biomass measurements showed a variety from 16 g dwt m^{-2} for sparsely vegetated areas to

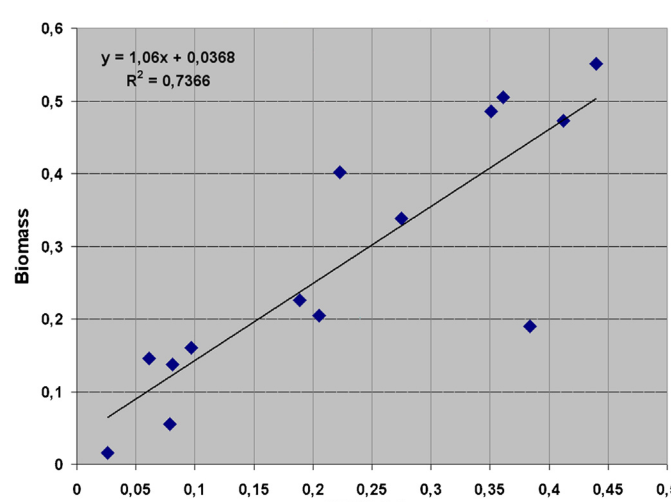

Fig. 5. Scatter plot illustrating the relationship between biomass data assigned to different vegetation unit and NDVI values extracted from available Landsat image. $R^2 = 0.74$.

Table 2
Biomass data, NDVI and adjusted biomass values. Aggregated data from the study areas of Adventdalen/Bjørndalen and Kapp Linné.

Vegetation map units 1 Nr	Number of sites recorded 2 (*n*)	Biomass – site recordings 3 kg/m^2	NDVI-values – site average 4 Index values	NDVI values – map unit averages 5 Index values	Adjusted biomass values 6 kg/m^2
5	7	0.146	0.10	0.06	0.105
6	1	0.160	0.23	0.10	0.143
7	1	0.016	0.00	0.03	0.068
8	7	0.205	0.21	0.21	0.257
9	9	0.338	0.30	0.28	0.332
10	6	0.473	0.42	0.41	0.477
11	12	0.551	0.44	0.44	0.506
12	13	0.486	0.36	0.35	0.412
13	3	0.226	0.21	0.19	0.240
14	16	0.402	0.21	0.22	0.276
15	11	0.505	0.36	0.36	0.423
16	4	0.190	0.41	0.38	0.447
17	7	0.055	0.07	0.08	0.124
18	7	0.137	0.19	0.08	0.126

551 g dwt m^{-2} for mires and marshlands (Table 2). If we compare our biomass measurements from established *Dryas* heath (map unit #14) with measurements done by Brattbakk and Rønning (1978) from Adventdalen, the recordings seems to be comparable, 427 g dwt m^{-2} versus 402 g dwt m^{-2} in our studies. For the moist tussock tundra (map unit 12), however, our measurements showed significant higher value, 486 g dwt m^{-2} versus 245 g dwt m^{-2} which could be a result of variation between years (Brattbakk and Rønning, 1978; Johansen et al., 2012) or variation in grazing of reindeer and geese (Speed et al., 2009; Stien et al., 2010), but also a result of increased growth due to warmer climate (Alsos et al., 2007; Epstein et al., 2012). The populations of geese and reindeer have

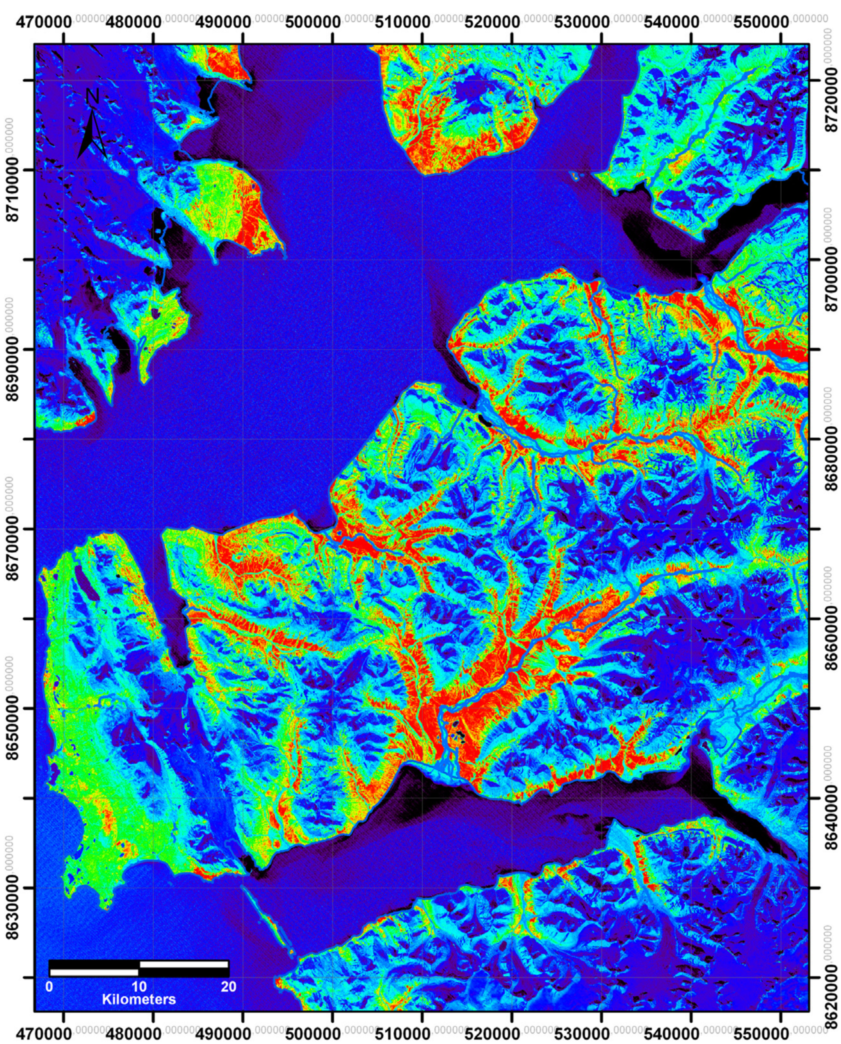

Fig. 6. NDVI-map for Nordenskiöld Land. Areas in red reflect regions of high NDVI values; green reflect medium height values, while blue and black areas reflect areas with low to negative NDVI values.

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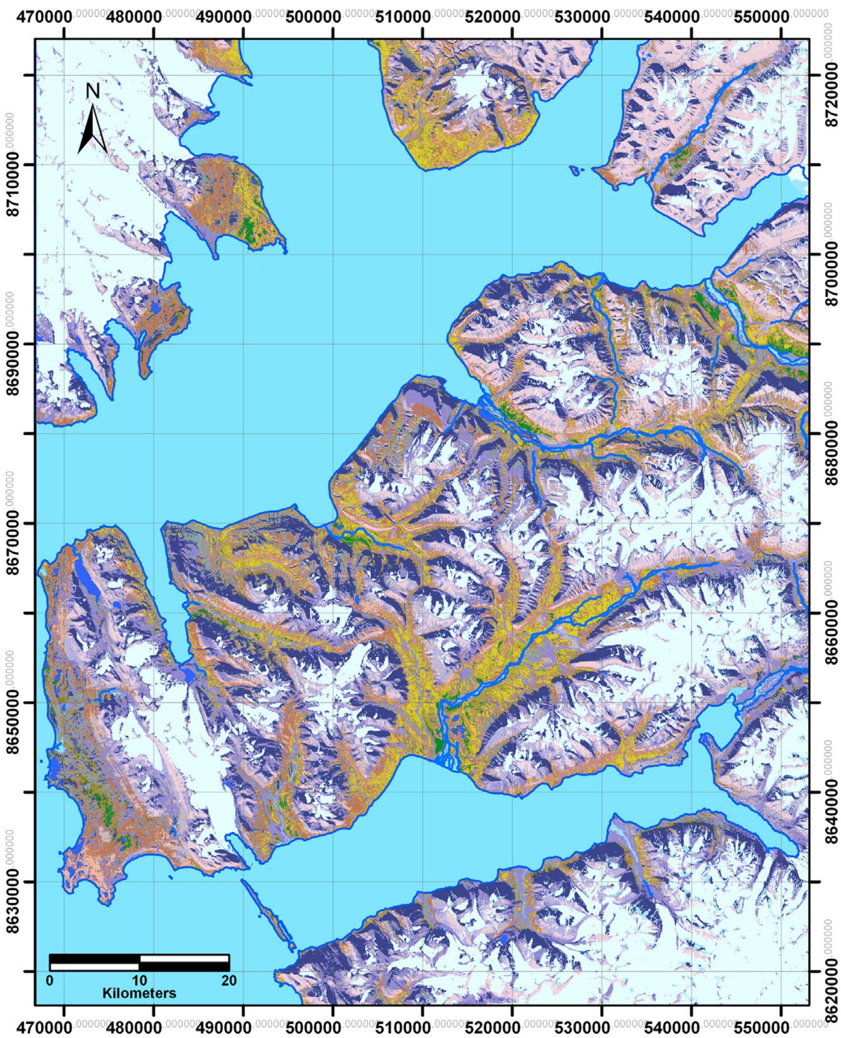

Fig. 7. Vegetation map for the peninsula of Nordenskiöld Land, Svalbard. The legend to the map is given in Fig. 3.

Table 3
Areal statistics and computed biomass values for the peninsula of Nordenskiöld Land.

Nr	Vegetation unit	Nordenskjöld land – lowland		Nordenskjöld land upland		Nordenskjöld land total	
		Area km^2	Biomass ton × 10^3	Area km^2	Biomass ton × 10^3	Area km^2	Biomass ton × 10^3
1	Sea, ocean	12.2	0.0	0.0	0.0	12.2	0.0
2	Inland water	23.2	0.0	1.5	0.0	24.6	0.0
3	Rivers	36.2	0.0	31.8	0.0	68.0	0.0
4	Glaciers	33.5	0.0	759.3	0.0	792.8	0.0
5	Wet flats, non/sparsely veg.	271.8	28.5	365.7	38.4	637.5	66.9
6	Dry barrens, slopes, ridges	37.7	5.4	233.1	33.3	270.8	38.7
7	Shadows and shade effects	173.0	11.8	466.6	31.7	639.6	43.5
8	Pioneer vegetation	168.3	43.3	62.8	16.1	231.1	59.4
9	Snowbed/snowflush areas	54.4	18.1	13.3	4.4	67.7	22.5
10	Swamp and wet moss tundra	31.4	15.0	0.6	0.3	32.0	15.3
11	Mires and marsh tundra	65.4	33.1	4.0	2.0	69.5	35.2
12	Moist tussock tundra	125.1	51.5	16.7	6.9	141.8	58.4
13	Exposed Dryas tundra	53.3	12.8	46.0	11.0	99.3	23.8
14	Established Dryas tundra	179.9	49.6	79.4	21.9	259.3	71.6
15	Arctic meadows	159.6	67.5	29.9	12.7	189.5	80.2
16	Exposed graminoid tundra	70.8	31.6	35.9	16.1	106.7	47.7
17	Gravel barren communities	57.8	7.2	97.4	12.1	155.2	19.2
18	Gravel snowbed communities	32.8	4.1	142.0	17.9	174.7	22.0
	Total	1586.5	379.5	2386.0	224.9	3972.5	604.4
	Average		0.239		0.094		0.152

varied a lot the last decade due to increased predation and severe winters and was on the same level in year 2010 compared with year 2000. Hill and Henry (2011), however, found a 158% increase in aboveground tundra biomass for wet sedge communities in Arctic Canada from 1981 to 2005. But long term monitoring of vegetation cover and biomass on Svalbard is rare or lacking (Hodkinson et al., 2003; Cannone et al., 2004) so these results have to be treated with care. However, our plots are GPS-positioned and can act as monitoring plots in future biomass studies.

Several researchers have shown linear relationships between NDVI and phytomass within arctic vegetation types (Hope et al., 1993; Spjelkavik, 1995; and Riedel et al., 2005; Epstein et al., 2012). Raynolds. et al. (2006) reported a robust relationship between biomass and NDVI of $R^2 = 0.89$. Our study also shows similar relationship between plot-recorded biomass and NDVI data. The correlation is estimated to $R^2 = 0.68$. If we compare the average NDVI for vegetation units in the compiled vegetation map for Svalbard (units 5–18) with average biomass for corresponding units, the relationship is estimated to $R^2 = 0.74$. The computed relationships show reliable values and seems to be in coincidence with previous satellite based NDVI-biomass relationships ($R = 0.72$ and $R = 0.91$) reported from Svalbard (Spjelkavik, 1995). Boelman et al. (2005) report that the relationship between NDVI and aboveground biomass was $R^2 = 0.59$ across all tussock experimental tundra treatments in Alaska and that the NDVI – biomass relationships for tussock and wet sedge tundra communities are community specific. This is also our experience in our study (Table 2). Epstein et al., 2012 report a relationship between aboveground biomass sampled in arctic areas of North America and Siberia and NDVI of $R^2 = 0.94$ ($p < 0.001$; $n = 90$) encompassing a variety of vegetation types from low Arctic to High Arctic. They used single AVHRR GIMMS3g pixels that encompassed each of their field locations for developing the relationship between NDVI and aboveground phytomass. Our analysis includes a limited number of biomass recordings from a variety of vegetation types ($n = 104$) which was related to NDVI. However, compared with the number of sites in the study of Epstein et al. (2012) encompassing Low Arctic to High Arctic zones we consider our results as satisfactory and the relationship found between biomass and NDVI is useful for discerning major patterns of biomass distribution in the central parts of Svalbard. Comparing the lowland and upland regions of the peninsula of Nordenskiöld Land, we can observe, not surprisingly, that the lowland areas have significant higher amount of biomass compared with the upland areas, but vegetation types like exposed and established *Dryas* tundra, vegetated snowbed communities and exposed graminoid tundra have significant amounts of biomass also in the upland areas. This may indicate significant resources of food for reindeer and other herbivores if the lowlands are blocked by icing events during winter (Stien et al., 2010). Tyler and Øritsland (1989) report: "Svalbard reindeer seem neither to undertake long migrations nor to be nomadic within seasons like mountain reindeer or barren-ground caribou. They appear instead to use small, traditional, seasonal home ranges more, for example, like red deer or wild sheep, and these ranges are mainly located below 150 m.a.s.l.". However, if the situation is severe (Stien et al., 2010) then the sedentary Svalbard reindeer is forced to migrate upwards (Tyler and Øritsland, 1989) in order to survive.

If we compare the total biomass result from Nordenskiöld Land, with other regions on Svalbard, the biomass amounts seem comparable. Nordenskiöld Land areas shows amounted to a mean biomass of 152 tons dwt km^{-2}, with 239 and 94 tons dwt km^{-2} for the lowland and upland areas (Table 3). In the Kongsfjord area of north-western Svalbard, Brattbakk (1986a) and Spjelkavik (1995) reported biomass amounts of 268 and 299 tons dwt km^{-2}, respectively. The recordings here were mainly performed in the lowland areas. Our result concerning lowland areas of Nordenskiöld Land seem to be reliable showing highly equal amounts of biomass. For the island Edgeøya in the eastern part of Svalbard archipelago, the biomass was estimated by the Dutch Reindeer Environmental Expedition (REES-1977) to 121 tons dwt km^{-2} (Zonneveld et al., 2004), which is more comparable to the upland areas of Nordenskiöld Land. A circumpolar study based on in-situ measurements and GIMMS NDVI 3 g data (Epstein et al., 2012) reports a mean biomass for Svalbard of 127.3 tons dwt km^{-2} and 96.9 tons dwt km^{-2} for the areas of Greenland. On this background our result of 152 tons dwt km^{-2}, seem to be reasonable and is together with Greenland in the lower part of reported biomass data varying from 83.8 to 241.2 tons dwt km^{-2} for the High Arctic subzones of the circumpolar area (Epstein et al., 2012).

5. Conclusions

The approach described in this paper demonstrates one of several potential aspects of use for vegetation maps. The study is performed on the peninsula of Nordenskiöld Land on Svalbard, Arctic Norway. The region provides a unique opportunity for establishing a reliable relationship between ground-based biomass recordings and NDVI values extracted from satellite data. By combining these recordings to vegetation map units, the overall biomass for larger areas like Nordenskiöld Land can be compiled. The results from the project gives new input to discussions related to the concept of "Greening of the Arctic" (Walker et al., 2003; Xu et al., 2013). A rise in temperature in northern areas will affect the plant growth in terms of increased photosynthetic activity and length of growing season (Xu et al., 2013), with subsequent increase in phytomass production. At local scale this will affect other tropic levels in term of increased food for herbivores peculiar to the locality. At overall level the rise in the biomass amount will affect the amount of solar radiation absorbed by vegetation being converted to heat (Chapin et al., 2005). This type of question will in the years to come attract lots of attention, especially for the Arctic and northern areas.

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References

Aagaard, K., Foldvik, A., Hillman, S.R., 1987. The West Spitsbergen current: disposition and water mass transformation. J. Geophys. Res. 92, 3778–3784.
Alsos, I.G., Eidesen, P.B., Ehrich, D., Skrede, I., Westergaard, K., Jacobsen, G.H., Landvik, J.Y., Taberlet, P., Brochmann, C., 2007. Frequent longdistance colonization in the changing Arctic. Science 316, 1606–1609.
Beck, P.S.A., Goetz, S.J., 2011. Satellite observations of high northern latitude vegetation productivity changes between 1982 and 2008: ecological variability and regional differences. Environ. Res. Lett. 6, 045501.
Billings, W.D., 1987. Constraints to plant growth, reproduction, and establishment in Arctic regions. Arct. Alpine Res. 19, 357–365.
Black, J.M., Prop, J., Larsson, K., 2007. Wild goose dilemmas. Population consequences of individual decisions in barnacle geese. Branta Press, Groningen, The Netherlands, pp. 254p.
Boelman, N.T., Stieglitz, M., Griffin, K.L., Shaver, G.R., 2005. Inter-annual variability of NDVI in response to long-term warming and fertilization in wet sedge and tussock tundra. Oecologia 143 (606), 588–597.
Brattbakk, I., Rønning, O.I., 1978. Rikt planteliv langt mot nord. Forskningsnytt 23 (8), 44–51.
Brattbakk, I., 1981. Kvadehuksletta, Brøggerhalvøya, Svalbard. Vegetasjonskart 1:10.000. K. norske Vidensk. Selsk. Mus. Bot. Avd., Trondheim.
Brattbakk, I., 1984. Adventdalen, Svalbard, vegetasjonskart 1:50.000. K. norske Vidensk. Selsk. Mus. Bot. Avd., Trondheim.

Brattbakk, I., 1985. Vegetasjonskart Lågnesflya, Svalbard, 1: 20000. Universitetet i Trondheim, Mus., Bot. avd., Trondheim, 4 kartlblad.
Brattbakk, I., 1986a. Vegetasjonsregioner – Svalbard og Jan Mayen. In: Nasjonalatlas for Norge. Statens Kartverk 1986.
Brattbakk, I., 1986b. Flora og vegetasjon. In: Øritsland, A. (Ed.), Svalbardreinen og dens livsgrunnlag. Universitetsforlaget, Oslo, pp. 15–34.
Cannone, N., Guglielmin, M., Gerdol, R., 2004. Relationships between vegetation patterns and periglacial landforms in northwestern Svalbard. Polar Biol. 27, 562–571.
Colwell, J.E., 1974. Vegetation canopy reflectance. Remote Sens. Environ. 3, 175–183.
Chapin III, F.S., et al., 2005. Role of land-surface changes in arctic summer warming. Science 310, 657–660.
Delbart, N., Toan, T.L., Kerogoats, L., Fedotova, V., 2006. Remote sensing of spring phenology in boreal regions: a free of snow-effect method using NOAA-AVHRR and SPOT-VGT data (1982–2004). Remote Sens. Environ. 101, 52–62.
Elvebakk, A., 1994. A survey of plant associations and alliances from Svalbard. J. Veg. Sci. 5, 791–802.
Elvebakk, A., 1999. Bioclimatic delimitation and subdivision of the Arctic. Det Norske Vitenskaps-Akademi. I. Matematisk Naturvitenskapelig Klasse Skrifter, Ny serie 38, 81–112.
Elvebakk, A., 2005. A vegetation map of Svalbard on the scale 1:35 mill. Phytocoenlogia 35, 951–967.
Epstein, H.E., Raynolds, M.K., Walker, D.A., Bhatt, U.S., Tucker, C.J., Pinzon, J.E., 2012. Environ. Res. Lett. 7, 12 pp, http://dx.doi.org/10.1088/1748-9326/7/1/015506, 015506.
Hansen, B.B., Grøtan, V., Aanes, R., Sæther, B.-E., Stien, A., Fuglei, E., Ims, R.A., Yoccoz, N.G., Pedersen, Å.Ø., 2013. Climate events synchronize the dynamics of a resident vertebrate community in the high Arctic. Science 339, 313–315.
Hill, G.B., Henry, G.H.R., 2011. Responses of high Arctic wet sedge tundra to climate warming since 1980. Global Change Biol. 17, 276–287.
Hodkinson, I.D., Coulson, S.J., Webb, N.R., 2003. Community assembly along proglacial chronosequences in the high Arctic: vegetation and soil development in north-west Svalbard. J. Ecol. 91, 651–663.
Hope, A.S., Kimball, J.S., Stow, D.A., 1993. The relationship between tussock tundra spectral reflectance properties, and biomass and vegetation composition. Int. J. Remote Sens. 14, 1861–1874.
Jackson, R.D., Pinter Jr., P.J., 1986. Spectral response of architecturally different wheat canopies. Remote Sens. Environ. 20, 43–56.
Johansen, B., Tømmervik, H., Karlsen, S.R., 2009. Vegetasjonskart over Svalbard basert på satellittdata, Dokumentasjon av metoder og vegetasjonsbeskrivelser. NINA Rapport 456. 54 s.
Johansen, B.E., Tømmervik, H., Karlsen, S.R., 2012. Vegetation mapping of Svalbard utilizing Landsat TM/ETM+ data. Polar Rec. 48, 47–63.
Jordan, C.F., 1969. Derivation of leaf area index from quality of light on the forest floor. Ecology 50, 663–666.
Justice, C.O., Townshend, J.R.G., Holben, B.N., Tucker, C.J., 1985. Analysis of the phenology of global vegetation using meteorological satellite data. Int. J. Remote Sens. 6, 1271–1318.
Keeling, C.D., Chin, J.S.F., Whorf, T.P., 1996. Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. Nature 382, 196–149.
Liu, H.Q., Huete, A., 1995. A feedback based modification of the NDVI to minimize canopy background and atmospheric noise. IEEE Trans. Geosci. Remote Sens. 33 (March), 457–465.
McNaughton, S.J., Sala, O.E., Oesterheld, M., 1989. Ecosystem-level pattern of primary productivity and herbivory in terrestrial habitats. Nature 341, 142–144.
Mitchell, C., Colhoun, K., Fox, A.D., Griffin, L., Hall, C., Hearn, R., Holt, C., Walsh, A., 2010. Trends in goose numbers wintering in Britain & Ireland, 1995 to 2008. Ornis Svecica 20, 128–143.
Myneni, R.B., Hall, F.G., Sellers, P.J., Marshak, A.L., 1995. The interpretation of spectral vegetation indices. IEEE Trans. Geosci. Remote Sens. 33, 481–486.
Nilsen, L., Brossard, T., Joly, D., 1999. Mapping plant communities in a local Arctic landscape applying a scanned infrared aerial photograph in a geographical information system. Int. J. Remote Sens. 20, 463–480.
Prince, S.D., 1991. Satellite remote sensing for primary production: comparison of results for Sahelian grassland 1981–1988. Int. J. Remote Sens. 12, 1301–1312.
Raynolds., M.K., Walker, D.A., Maier, H.A., 2006. NDVI patterns and phytomass distribution in the circumpolar Arctic. Remote Sens. Environ. 102, 271–281.
Reimers, E., 1977. Population dynamics in two subpopulations of reindeer on Svalbard. Arct. Alpine Res. 9, 369–381.
Riedel, S.M., Epstein, H.E., Walker, D.A., Richardson, D.L., Calef, M.P., Edwards, E., et al., 2005. Spatial and temporal heterogeneity of vegetation properties among four tundra plant communities at Ivotuk, Alaska, U.S.A. Arct. Antarctic Alpine Res. 37, 25–33.
Rønning, O.I., 1965. Studies in Dryadion of Svalbard, Norsk Polarinstitutt Skrifter Nr 134. 52 pp.
Rønning, O.I., 1996. The Flora of Svalbard, Translation, third ed. Norwegian Polar Institute, Oslo, Norway.
Sellers, P.J., 1985. Canopy reflectance, photosynthesis, and transpiration. Int. J. Remote Sens. 6 (8), 1335-1372.
Serreze, M.C., Barry, R.G., 2011. Processes and impacts of Arctic amplification: a research synthesis. Glob. Planet. Change 77, 85–96.
Slayback, D., Pinzon, J., Los, S., Tucker, C.J., 2003. Northern Hemisphere photosynthetic trends 1982–1999. Global Change Biol. 9, 1–15.
Speed, J.D.M., Woodin, S.J., Tømmervik, H., Tamsdorf, M.P., Van der Wal, R., 2009. Predicting habitat utilisation and extent of ecosystem disturbance by an increasing herbivore population. Ecosystems 12, 349–359.
Spjelkavik, S., 1995. A satellite-based map compared to a traditional vegetation map of Arctic vegetation in the Ny-Ålesund area, Svalbard. Polar Rec. 31, 257–269.
Stien, A., Loe, L.E., Mysterud, A., Severinsen, T., Kohler, J., Langvatn, R., 2010. Icing events trigger range displacement in a high-Arctic ungulate. Ecology 91, 915–920.
Tyler, N.J.C., Øritsland, N.A., 1989. Why don't Svalbard reindeer migrate? Holarctic Ecol. 12, 369–376.
Tucker, C.J., Sellers, P.J., 1986. Satellite remote sensing of primary production. Int J. Remote Sens. 7, 1395–1416.
Walker, D.A., Epstein, H.E., Jia, G.J., Balser, A., Copass, C., Edwards, E.J., Gould, W.A., Hollingsworth, J., Knudson, J., Maier, H.A., Moody, A., Raynolds, M.K., 2003. Phytomass, LAI, and NDVI in northern Alaska: relationship to summer warmth, soil pH, plant functional types, and extrapolation to the circumpolar Arctic. J. Geophys. Res. 108, 8169.
Wiegand, T., Snyman, H.A., Kellner, K., Puluero, J.M., 2004. Do grassland have a memory: modeling phytomass production of semiarid South African grassland. Ecosystems 7, 243–258.
Wielgolaski, F.E., Nordli, Ø., Karlsen, S.R., O'Neill, B., 2011. Plant phenological variation in Norway during the 1928–1977 period related to temperature. Int. J. Biometereology 55, 819–830.
Xu, L., Myneni, R.B., Chapin III, F.S., et al., 2013. Temperature and vegetation seasonality diminishment over northern lands. Nat Climate Change 3, 581–586, http://dx.doi.org/10.1038/NCLIMATE1836.
Zonneveld, I.S., Lebouille, M., de Nies, N., van Dijk, A., Heinemeijer, H., Oosterveld, P., 2004. Landscape ecology ('land unit') map of Edgeøya, Spitsbergen with emphasis on vegetation. In: Boschman, N., Hacquebord, L. (Eds.), Permanence in diversity. Netherlands Ecological Research on Edgeøya, Spitsbergen. Circumpolar Studies, vol. 1. Arctic Centre, University of Groningen, pp. 103–156.

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