The relationship between phytomass, NDVI and vegetation communities on Svalbard

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A B S T R A C T

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 phytomass were used to estimate the total plant phytomass for the entire Nordenskjold peninsula. The overall phytomass for the entire Nordenskjold peninsula (3972 km$^2$) is estimated to 604.4 ton $\times$ 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.

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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
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/m².

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 (alitudinal 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, Edgeoya and Barentsaya 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 km². 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 inhabitants 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...
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
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:

\[
NDVI = \frac{(NIR - RED)}{(NIR + RED)}
\]

In this equation NIR represents the Near Infrared band 4 (0.76–0.90 \(\mu\)m) of Landsat 5 and 7 and RED the corresponding band 3 (0.63–0.69 \(\mu\)m). 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 Svalbard 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 Adventalen/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 \( \times \) 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.
Table 1
Areal statistics for the study areas of Adventdalen/Bjørndalen and Kapp Linné.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Vegetation units</th>
<th>Adventdalen/Bjørndalen</th>
<th>Kapp Linné</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>km²</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>Sea, ocean</td>
<td>75.5</td>
<td>10.6</td>
</tr>
<tr>
<td>2</td>
<td>Inland water</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>Rivers</td>
<td>10.9</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>Glaciers</td>
<td>123.5</td>
<td>17.4</td>
</tr>
<tr>
<td>5</td>
<td>Wet flats, non/sparsely veg.</td>
<td>105.6</td>
<td>14.8</td>
</tr>
<tr>
<td>6</td>
<td>Dry barrens, slopes, ridges</td>
<td>57.7</td>
<td>8.1</td>
</tr>
<tr>
<td>7</td>
<td>Shadows and shade effects</td>
<td>120.5</td>
<td>16.9</td>
</tr>
<tr>
<td>8</td>
<td>Pioneer vegetation</td>
<td>34.1</td>
<td>4.8</td>
</tr>
<tr>
<td>9</td>
<td>Snowbed and snowflush areas</td>
<td>8.9</td>
<td>1.3</td>
</tr>
<tr>
<td>10</td>
<td>Swamp and wet moss tundra</td>
<td>4.0</td>
<td>0.6</td>
</tr>
<tr>
<td>11</td>
<td>Mires and marsh tundra</td>
<td>7.8</td>
<td>1.1</td>
</tr>
<tr>
<td>12</td>
<td>Moist tussock tundra</td>
<td>19.1</td>
<td>2.7</td>
</tr>
<tr>
<td>13</td>
<td>Exposed Dryas tundra</td>
<td>15.6</td>
<td>2.2</td>
</tr>
<tr>
<td>14</td>
<td>Established Dryas tundra</td>
<td>35.7</td>
<td>5.0</td>
</tr>
<tr>
<td>15</td>
<td>Arctic meadows</td>
<td>21.3</td>
<td>3.0</td>
</tr>
<tr>
<td>16</td>
<td>Exposed graminoid tundra</td>
<td>19.1</td>
<td>2.7</td>
</tr>
<tr>
<td>17</td>
<td>Gravel barren communities</td>
<td>23.7</td>
<td>3.3</td>
</tr>
<tr>
<td>18</td>
<td>Gravel snowbed communities</td>
<td>27.4</td>
<td>3.8</td>
</tr>
</tbody>
</table>

(a) The sparsely vegetated areas on dry substrate are in both sub-
areas displayed in the classes 6, and 17. Due to the sparse
vegetation cover it is difficult to define the areas based on botan-
cal 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 Advent-
dalen mainly associated to the established Dryas vegetation. The
Dryas communities on Svalbard has been surveyed by Running
(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 asso-
ciations Cassiope tetragonae-Dryadetum octopetalae Running
(1965) and Dryadetum minoris Hadac 1946 are found on areas
with some snow protection during winter. The overall dis-
tribution 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 tetra-
go. 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 com-
unity 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 occur-
rence of Dryas octopetala is rare, while Cassiope tetragonae is
fully absent (Renning, 1996). Here community types of Luzula-
Saxifraga oppositifolia, partly with lichens, constitute large areas
on the dry and gravel coastal plains. In areas with more heavy
snow protection the lichen Cetraria delisei is common. The
ubiquitous Salix polaris is also a common species of this com-
munity type. Among other species associated to this community
are Bistorta vivipara, Cerastium arcticum, Saxifraga caespitosa,
Pedicularis hirsuta and Silene uralensis. This important vege-
tation community lacks a validly published phytosociological
name, but probably belong to the alliance Luzulion nivalis Nord-
hagen 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 com-
munity types 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 sup-
ply. 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 digyna,
Ranunculus pygmeus and Saxifraga cernua. To some extent
gross-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 sum-
mer is the Deschampsia alpina communities. It is regarded that
these communities are not climatomatically 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 eas-
ily recognize this community. At Kapp Linné the unit is most
commonly developed in the lower parts of hill-slopes. The com-
munity 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 species are Salix polaris, Dryas octopetala, 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 island. 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 scheurzei, Alopecurus alpinus, Dupontia fisheri, 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/dwt (dwt) for gravel barren communities to 551 g/m2 (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 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 + $\beta$. For the dataset given in Fig. 5 the values for $\alpha = 1.06$ and $\beta = 0.04$. When the values for $\alpha$ and $\beta$ 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 Nordskiöld 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 Northordenskiöld is separated into lowland and upland regions. The 200 m contour line is used in this distruction. Areal statistics and computed biomass for Nordskiöld 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
Table 2
Biomass data, NDVI and adjusted biomass values. Aggregated data from the study areas of Adventdalen/Bjørndalen and Kapp Linné.

<table>
<thead>
<tr>
<th>Vegetation map units</th>
<th>Number of sites recorded (n)</th>
<th>Biomass – site recordings kg/m²</th>
<th>NDVI-values – site average Index values</th>
<th>NDVI values – map unit averages Index values</th>
<th>Adjusted biomass values kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7</td>
<td>0.146</td>
<td>0.10</td>
<td>0.06</td>
<td>0.105</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0.160</td>
<td>0.23</td>
<td>0.10</td>
<td>0.143</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0.016</td>
<td>0.00</td>
<td>0.03</td>
<td>0.068</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>0.205</td>
<td>0.21</td>
<td>0.21</td>
<td>0.257</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>0.338</td>
<td>0.30</td>
<td>0.28</td>
<td>0.332</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>0.473</td>
<td>0.42</td>
<td>0.41</td>
<td>0.477</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>0.551</td>
<td>0.44</td>
<td>0.44</td>
<td>0.506</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>0.486</td>
<td>0.36</td>
<td>0.35</td>
<td>0.412</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>0.286</td>
<td>0.21</td>
<td>0.19</td>
<td>0.240</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
<td>0.402</td>
<td>0.21</td>
<td>0.22</td>
<td>0.276</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
<td>0.505</td>
<td>0.36</td>
<td>0.36</td>
<td>0.423</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>0.190</td>
<td>0.41</td>
<td>0.38</td>
<td>0.447</td>
</tr>
<tr>
<td>17</td>
<td>7</td>
<td>0.055</td>
<td>0.07</td>
<td>0.08</td>
<td>0.124</td>
</tr>
<tr>
<td>18</td>
<td>7</td>
<td>0.137</td>
<td>0.19</td>
<td>0.08</td>
<td>0.126</td>
</tr>
</tbody>
</table>

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 Adventalen, 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 Nordskjoeld 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.
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.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Vegetation unit</th>
<th>Nordenskjöld land – lowland</th>
<th>Nordenskjöld land upland</th>
<th>Nordenskjöld land total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area km²</td>
<td>Biomass ton × 10³</td>
<td>Area km²</td>
</tr>
<tr>
<td>1</td>
<td>Sea, ocean</td>
<td>12.2</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>Inland water</td>
<td>23.2</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Rivers</td>
<td>36.2</td>
<td>0.0</td>
<td>31.8</td>
</tr>
<tr>
<td>4</td>
<td>Glaciers</td>
<td>33.5</td>
<td>0.0</td>
<td>759.3</td>
</tr>
<tr>
<td>5</td>
<td>Wet flats, non/sparsely veg.</td>
<td>271.8</td>
<td>28.5</td>
<td>365.7</td>
</tr>
<tr>
<td>6</td>
<td>Dry barrens, slopes, ridges</td>
<td>37.7</td>
<td>5.4</td>
<td>233.1</td>
</tr>
<tr>
<td>7</td>
<td>Shadows and shade effects</td>
<td>173.0</td>
<td>11.8</td>
<td>466.6</td>
</tr>
<tr>
<td>8</td>
<td>Pioneer vegetation</td>
<td>168.3</td>
<td>43.3</td>
<td>62.8</td>
</tr>
<tr>
<td>9</td>
<td>Snowbed/snowflush areas</td>
<td>54.4</td>
<td>18.1</td>
<td>13.3</td>
</tr>
<tr>
<td>10</td>
<td>Swamp and wet moss tundra</td>
<td>31.4</td>
<td>15.0</td>
<td>0.6</td>
</tr>
<tr>
<td>11</td>
<td>Mires and marsh tundra</td>
<td>65.4</td>
<td>33.1</td>
<td>4.0</td>
</tr>
<tr>
<td>12</td>
<td>Moist tussock tundra</td>
<td>125.1</td>
<td>51.5</td>
<td>16.7</td>
</tr>
<tr>
<td>13</td>
<td>Exposed Dryas tundra</td>
<td>53.3</td>
<td>12.8</td>
<td>46.0</td>
</tr>
<tr>
<td>14</td>
<td>Established Dryas tundra</td>
<td>179.9</td>
<td>49.6</td>
<td>79.4</td>
</tr>
<tr>
<td>15</td>
<td>Arctic meadows</td>
<td>159.6</td>
<td>67.5</td>
<td>29.9</td>
</tr>
<tr>
<td>16</td>
<td>Exposed graminoid tundra</td>
<td>70.8</td>
<td>31.6</td>
<td>35.9</td>
</tr>
<tr>
<td>17</td>
<td>Gravel barren communities</td>
<td>57.8</td>
<td>7.2</td>
<td>97.4</td>
</tr>
<tr>
<td>18</td>
<td>Gravel snowbed communities</td>
<td>32.8</td>
<td>4.1</td>
<td>142.0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1586.5</td>
<td>379.5</td>
<td>2386.0</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.239</td>
<td>0.094</td>
<td></td>
</tr>
</tbody>
</table>
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; Cammone 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; Spjellkavik, 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 (Spjellkavik, 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 Ørlistad (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 Ørlistad, 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, Bratbakke (1986a) and Spjellkavik (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 3g 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 trophic 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.

Acknowledgements

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