Student thesis series INES nr 407

The spatial growth pattern and directional properties of *Dryas octopetala* on Spitsbergen, Svalbard

Sophie Rudbäck

2016
Department of
Physical Geography and Ecosystem Science
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Sophie Rudbäck (2016).

The spatial growth pattern and directional properties of Dryas octopetala on Spitsbergen, Svalbard

Dryas octopetalas växtmönster på Spetsbergen, Svalbard

Master degree thesis, 30 credits in *Geomatics*

Department of Physical Geography and Ecosystem Science, Lund University

Level: Master of Science (MSc)

Course duration: *January* 2016 until *June* 2016

The spatial growth pattern and directional properties of *Dryas octopetala* on Spitsbergen, Svalbard

---

Sophie Rudbäck

Master thesis, 30 credits, in *Geomatics*

Supervisor: Veiko Lehsten

Department of Physical Geography and Ecosystem Science

Supervisor: David Tenenbaum

Department of Physical Geography and Ecosystem Science

Exam committee:

Jonas Åkerman, Department of Physical Geography and Ecosystem Science

Jutta Holst, Department of Physical Geography and Ecosystem Science

Abstract

Exposed, well-drained and nutrient poor areas on Spitsbergen are mainly covered by a plant alliance typical for Svalbard, the *Caricion nardinae*. *Caricion nardinae* is a circum-polar alliance, which is dominated by the creeping, ever-green dwarf-shrub *Dryas octopetala*. On the beach flats of western Spitsbergen, Jonas Åkerman (1983) observed in 1979 the plant *Dryas octopetala* growing in an unusual pattern in the form of half-moons. In the summer of 2015, Veiko Lehsten visited the same area as Åkerman documented in the late 1970s, with the purpose to further investigate this vegetation pattern and the factors causing it. Åkerman suggested in 1983 that the wind was the main contributing factor to the unusual growth of *Dryas octopetala*.

This thesis will attempt to verify this suggestion and also evaluate the likelihood of other factors playing a role in this phenomenon. This will be done by developing a method for assembling images taken by a standard camera, and thereafter describe and investigate the vegetation patterns of *Dryas octopetala* as well as its potential changes over time.

The results show that *Dryas octopetala* was, at the study sites, directed towards north-northeast, with Åkerman's data from 1979 being directed a little bit more towards northeast than the vegetation in 2015. The vegetation in both study areas grew close to each other and had a dispersed distribution. This thesis was not able to prove that the prominent wind direction is causing the unusual growing forms and pattern of *Dryas octopetala* but it is still the most likely cause after reviewing other potential factors. The method for assembling pictures was time consuming and did not give a perfect final image but it resulted in an acceptable approximation of the study area.

Keywords: Physical Geography and Ecosystem analysis, *Dryas octopetala*, vegetation pattern, ArcGIS, Spitsbergen, wind direction.

Svensk sammanfattning

Den lågväxande vintergröna dvärgbusken *Dryas octopetala* är den dominerande arten i växtalliansen *Caricion nardinae*, som på Svalbard finns på utsatta, torra och näringsfattiga områden. *Caricion nardinae* är typisk för Svalbard men existerar på många platser på norra halvklotet som har ett kallt klimat. På strandbankarna i de västra delarna av Spetsbergen observerade Jonas Åkerman år 1979 att växten *Dryas octopetala* växte i ett halvmånsformat mönster, vilket inte är vanligt för denna art. Sommaren 2015 åkte Veiko Lehsten tillbaka till samma område som Åkerman besökte 1979 med syfte att ytterligare undersöka detta ovanliga växtmönster och de faktorer som kan ha skapat det. Åkerman (1983) föreslog att den mest bidragande faktorn till att *Dryas octopetala* växer annorlunda på denna plats är riktningen på vinden.

Genom att först utveckla en metod för hur man bäst sätter ihop bilder tagna med en vanlig kamera och sedan beskriva och undersöka hur *Dryas octopetala* växer i studieområdet samt potentiella förändringar över tid ska denna uppsats försöka bekräfta Åkermans teori att vinden har skapat växtmönstret och även undersöka om andra faktorer också kan ha påverkat växten.

Resultaten visar att *Dryas octopetala* i studieområdet är riktade mot nord-nordöst medan de 1979 var riktade lite mer åt nordöst. Plantorna växte nära varandra och var jämt utspridda i studieområdet. Denna uppsats kunde inte bevisa att det var vinden som orsakade detta ovanliga växtmönster, trots detta så är det den mest troliga förklaringen efter att ha undersökt andra möjliga påverkande faktorer. Metoden som användes för att sätta ihop bilderna var långsam och resultatet blev inte perfekt men slutprodukten gav en acceptabel bild av hur studieområdet ser ut.

Acknowledgements

I would like to express my gratitude to my supervisors Veiko Lehsten and David Tenenbaum. Your advice and support have helped me greatly. I would also like to thank my mother Charlotte Rudbäck and Christian Fridlund for their endless support.

Table of Contents

1. Introduction

Exposed, well-drained and nutrient poor areas on Spitsbergen, the main island of Svalbard, are mainly covered by a plant alliance typical for Svalbard, the *Caricion nardinae* (Elvebakk 1994; Koroleva 2015). *Caricion nardinae* is a circum-polar alliance, which is dominated by the creeping, ever-green dwarf-shrub *Dryas octopetala.* The growth of *Dryas octopetala* is generally described as patches or cushions of 0.5 to 1 meter in diameter (Elkington 1971). However, on the beach flats of western Spitsbergen, Jonas Åkerman (1983) observed in 1979 the plant *Dryas octopetala* growing in an unusual pattern in the form of half-moons. This pattern shows more complexity than the regional vegetation pattern of the area, indicating that there are local factors influencing how the vegetation grows at this site (Åkerman 1983).

In the summer of 2015, Veiko Lehsten visited the same area that Åkerman documented in the late 1970s, with the purpose to further investigate this vegetation pattern. Since high resolution satellite images or areal photography's of Svalbard would be too coarse to capture small scale pattern and not being able to use a drone as originally planned, Lehsten manually took pictures of the vegetation by walking through the area, taking around 420 pictures to cover approximately 20 by 25 meters of the study site. These pictures, as well as Jonas Åkerman's pictures from 1979, will now be assembled and digitalized in order to enable statistical analyzes and comparison with environmental data as well as against each other.

Important environmental factors affecting growth of arctic vegetation are: Wind (Triloff 1944; Wilson 1959), presence of snow, soil moisture, temperature of soil and air as well as the accessibility of nutrients (Wielgolaski 1997). Åkerman (1983) suggested that the wind was the main contributing factor to the unusual growth of *Dryas octopetala*. This thesis will attempt to verify this suggestion and also evaluate the likelihood of other factors playing a role in this phenomenon.

The assembly in a Geographical Information System (GIS) photographs taken manually from a short distance to the ground presents many challenges due to the distortion of pictures by the lens and by unintentional variations in camera angle. Part of this thesis has, therefore, been dedicated to describing the development of the final method for generating an overview map of an area, based on manually taken photographs causing minimal amount of distortion, since this might be of interest for researchers that have collected data in a similar way.

1.1 Aim

This thesis aims to:

- Describe the unusual vegetation patterns of *Dryas octopetala* found on Spitsbergen by analyzing its direction and spatial distribution.
- Investigate Åkerman's (1983) theory that wind direction is the main factor causing the unusual vegetation pattern of *Dryas octopetala* on Spitsbergen by comparing wind direction to the direction of *Dryas octopetala* plants in the area, as well as evaluate the potential influence of other environmental factors affecting *Dryas octopetala*.
- Investigate changes in vegetation patterns of *Dryas octopetala* on the location from 1979 to 2015.

- Develop a method for assembling images taken by a standard camera and from a short distance to the ground.

Two hypotheses about the winds possible effect on the growth of *Dryas octopetala* in the study area were made:

- That the half-moon shape was caused by desiccating winds carrying snow and other particles outside growing-season, or
- That the winds during growing season was affecting the newly developed leaves and branches and therefore forced the plant to grow in a half-moon shape.

1.2 Limitations

Only the vegetation pattern of *Dryas octopetala*, growing in the study location visited by Veiko Lehsten and Jonas Åkerman, will be investigated in this thesis.

Since the work associated with this thesis did not allow a new visit to the study area, the evaluation of environmental factors on the location will be limited to existing data as well as observations made by Jonas Åkerman in 1979 and Veiko Lehsten in 2015.

2. Background

2.1 Study area

Data for this thesis was collected on Svalbard, a group of islands under Norwegian sovereignty. The main island Spitsbergen along with the three islands Edgeøya, Bjørnøya and Nordaustlandet, are the major archipelago of Svalbard (Joly et.al 2015).

The study area, as described by Åkerman (1983), is located in the western part of Spitsbergen in the outskirts of Isfjorden, east of Isfjord Radio Station and Kapp Linné (see Figure 1). The open sea sets the boundary of the study area in the westerly direction and Isfjorden in the northerly direction. East of the study area, the mountain ridges Vardeborgksla and Starostinaksla can be seen. Åkerman (1983) further states that the area mostly consists of broad beach flats with a number of beach ridges that are permanently frozen with an active layer of approximately 2 meters.

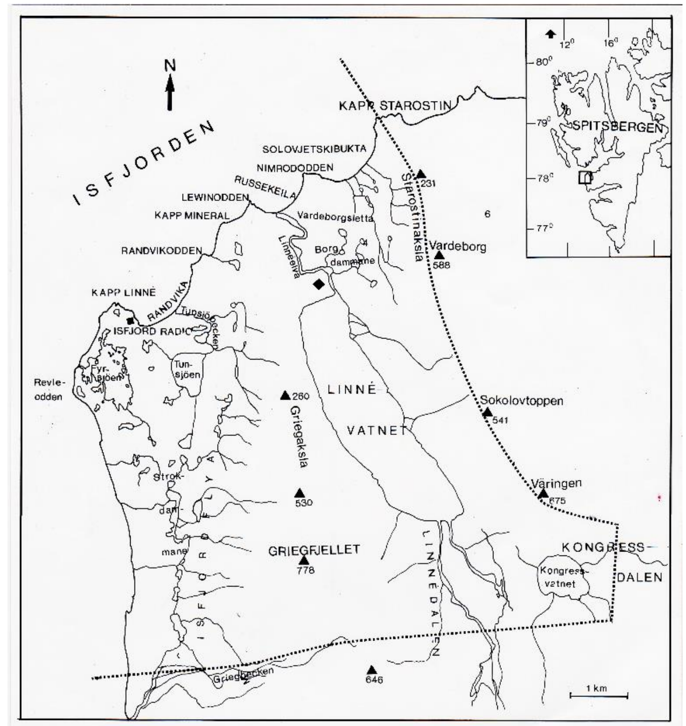

Figure 1. Map showing the location of the study area in western Spitsbergen. Black diamond marks the area of this vegetation study. The map is modified from Åkerman (1983).

The vegetation study (Åkerman 1983) was performed within a 500 x 300 meter deflated area located 20-40 meters above sea level. Flat beach ridges, together with polygon furrows, dominate the morphology of this area (Åkerman 1983). Åkerman (1983) describes two types of polygon patterns visible in the study area, a large-scale pattern and a small-scale pattern. The larger polygon patterns are caused by an ice-wedge system and are between 0.5 to 1.5 meters in width and 0.2 to 0.5 meters in depth, while the smaller polygon patterns are narrower and shallower and consists of fissures in the active layer due to frost (Åkerman 1983). The first 1.5 to 3 meters of the soil in the study area mainly consists of uniform well-washed beach gravel and beneath lies thick glaciomarine silty deposits. Åkerman (1983) states that due to the absence of finer material in the beach gravel, it is dry, well-drained and only holds a small amount of ground ice during winter time. Lehsten chose a study site in this deflated area that was as homogenous as possible to remove the effect of pattern ground from his study location. The study site slopes downwards to the Linné elva and the five study areas were placed on the flat parts of the slope which is shown in Figure 2, where Åkerman's four study areas as well as Lehsten's study area is marked.

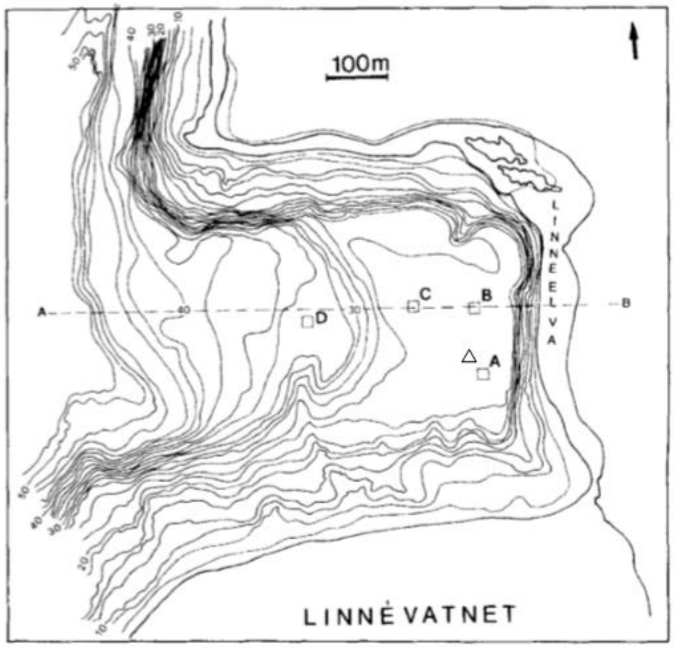

Figure 2. A contour map of the area with the approximate location of the study area in 2015 marked as a triangle and with Åkerman's four study areas marked squares (A-D). Map modified from Åkerman (1983).

2.1.1 Vegetation at the study area

The ground at the study site is poor in nutrients (Lehsten, pers.comm.) and the vegetation of the deflation surface mainly consists of isolated plants of *Dryas octopetala*, *Silene acaulis*, *Saxifraga oppositifolia*, *Draba nivalis* and *Stella crassipes* but mosses and lichens can also be found in great numbers (Åkerman 1983). In the polygon furrows, *Salix Polaris* and different mosses are found and *Dryas octopetala* grows as individually, parabolic, possibly wind-eroded plants distributed over the area, covering 19.4 percent of the study site in 1979. *Saxifraga oppositifolia*, generally found evenly distributed all over Spitsbergen is here growing at the marginal of its existence. *Saxifraga oppositifolia* could not exist on its own in this area, but needs the support of *Dryas octopetala* tufts as 92.3 percent of the *Saxifraga oppositifolia* plants grows adjacent to or in the *Dryas octopetala* tufts and 73 percent grows at the lee-side. *The Silene acaulis* also showed signs of wind erosion on the north-east exposed side (Åkerman 1983). In ditches close to the study area that are completely covered by snow, *Dryas octopetala* was found to grow as a homogenous mat (Lehsten, pers.comm.).

2.1.2 Climate

The climate of the study area is, as stated by Åkerman (1980), a true tundra climate (ET) using the Köppen classification system, since the area is experiencing temperatures above 0°C but below 10°C during at least one month per year. Climate data that Åkerman (1980) retrieved from Isfjord Radio Station, located close to the study area, states that the mean annual temperature was -4.8°C between the years 1912 and 1975 and the mean annual precipitation was 400.8 mm between 1934 and 1975. Isfjord Radio Station has 3-4 month per year of continuous sunlight during summer and 3-4 months of continuous darkness in winter (Hanssen-Bauer 1990). Unfortunately, Isfjord Radio Station was decommissioned as a climatic measuring station in 1976 (Hanssen-Bauer 1990; Nordli

2014) and did not re-open again until August 2014, leading to a gap of 28 years in the data set, and data for the present time only covers the last 19 months.

Wind direction at the study area changes over the year, with prevailing winds coming from northeast-southeast all year except during the summer months where wind blowing from south-southwest is more common (Åkerman 1980; Hanssen-Bauer 1990). In winter, the study area is experiencing strong winds (Åkerman 1980; Hanssen-Bauer 1990) with 15-20 days per month of stronger winds than 6 Beaufort and winds at the study site are further strengthened due to its location close to Isfjorden (Hanssen-Bauer 1990). Wind data downloaded from Norwegian Metrological Institute (eKlima 2016) is presented in Figure 3-5. This data corresponds well to Hanssen-Bauer (1990) findings of the change in wind direction during the year with winds dominantly blowing from northeast all year except in the summer months where the wind direction becomes more southerly. The growing season in Spitsbergen is during the summer months (Welker 1997) during which the winds are, as described above, more southerly compared to the rest of the year.

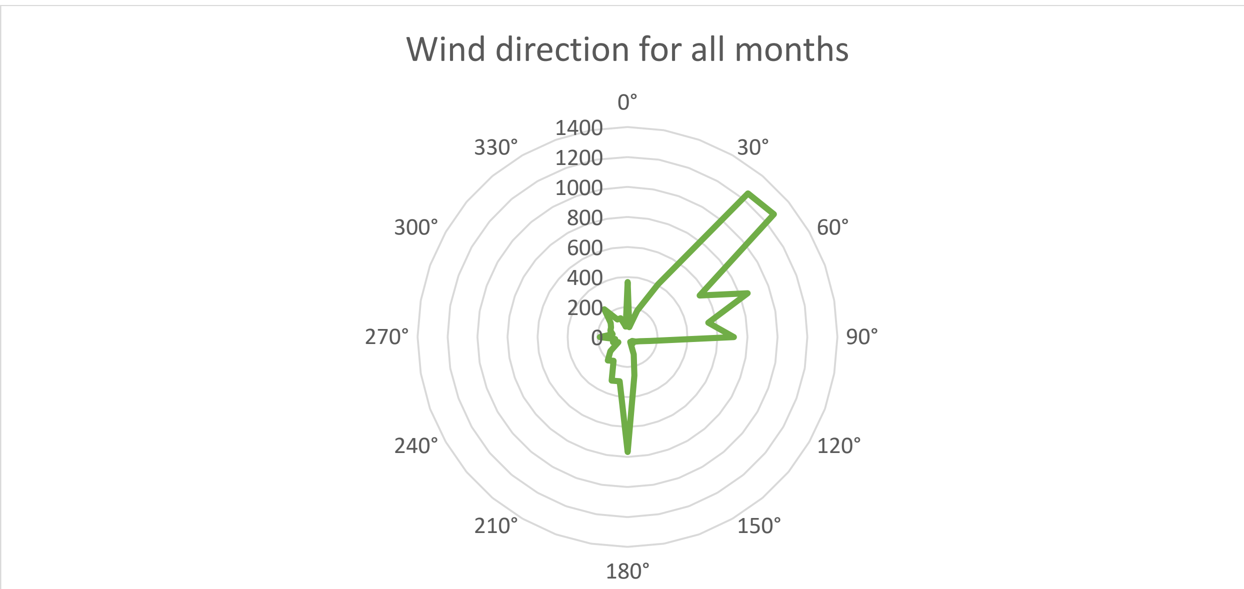

Figure 3. Wind rose of wind direction for all months at Isfjord Radio Station. Based on data from the Norwegian Meteorological Institute measured once a day at noon between the years 1947-1975 and 2014-2016.

Figure 4. Wind rose for wind direction at Isfjord Radio station divided into winter, spring, summer and autumn. Based on data from the Norwegian Meteorological Institute measured once a day at noon between the years 1947-1975 and 2014-2016.

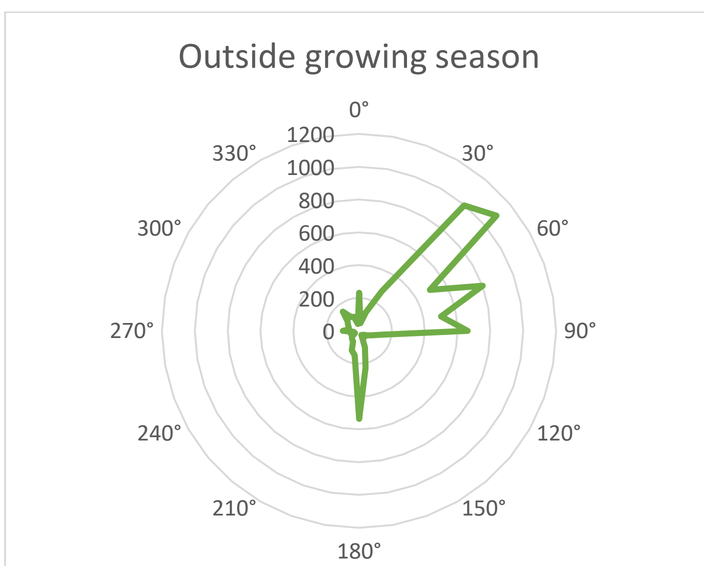

Figure 5. Wind rose of wind direction at Isfjord Radio Station for the months outside growing season (September - May). Based on data from the Norwegian Meteorological Institute measured once a day at noon between the years 1947-1975 and 2014-2016.

Due to Spitsbergen's topography, the local wind direction could differ significantly from location to location (Åkerman 1980; Hanssen-Bauer 1990). Firstly, because the wind is channeled through fjords and valleys, from the inland to the coast and secondly, because cold air from the glaciers at the inland is transported to the warmer sea (Hanssen-Bauer 1990). Due to the heavy wind and dry snow, the snow is continuously moving and the snow depth is highly dependent on the exposure. No current data regarding snow depth is available for Isfjord radio but historical data from 1934-1974 showed a variation of snow-depth in the winter between 0 and 80 centimeters (Hassen Bauer 1990, eKlima 2016) but a snow cover of several meters as well as bare wind swept areas are common in this region (Åkerman 1980). The study area generally has a very thin snow cover, due to that any snow landing in the area will be blown away (Lehsten, pers. comm.), that covers the ground from late September to late May (Åkerman 1980).

2.2 *Dryas octopetala*

The plant of interest in this study is *Dryas octopetala*, also known as Mountain Avens. *Dryas octopetala* is a low evergreen plant that grows in planus cushions and is on Svalbard typically found on morainic ridges or old shore ridges, as well as on screes with thin snow cover and well-drained soil (Rønning 1996). *Dryas octopetala* on Spitsbergen also prefers to grow in areas with an aspect of 225° to 315° (Josefsson and Mårtensson 1995). Besides Svalbard, *Dryas octopetala* can be found all across the northern hemisphere and are in the arctic regions almost circumpolar, with sightings on for example Greenland, Iceland and in Northern Europe (Hultén 1959; Elkington 1971). *Dryas octopetala* prefers to grow on dry calcareous soils (Elkington 1971; Rønning 1996) and, as described by Elkington (1971), the plant is in the arctic and sub-arctic areas growing as a part of communities that have very similar characteristics such as dwarf-shrub heaths and fell fields, the latter being a common community in Spitsbergen. This alliance is named *Caricion nardinae* (Elvebakk 1994; Koroleva 2015).

In these communities, *Dryas octopetala* is a known pioneer species of areas that are open and the soil has a high pH-value, in which the plant grows in patches with a diameter of around 1 meter and in some cases a diameter of several meters (Elkington 1971), or as a continuous vegetation cover at some locations (Welker 1997). Where the plant grows in sheltered and ungrazed areas, it can be up to 5 centimeters high with woody roots growing under and often into rock crevices. The shoots of the plant can grow up to 6 centimeters and it usually flowers in April or May, or in June-July in montane areas, with germination taking place in the spring (Elkington 1971). The flower of this plant, usually 8-merous, is mainly hermaphrodites but some male flowers can develop. The achenes' main way of dispersal is by wind and this is aided by the achenes having long lateral hairs. However, many of the achenes ends up at the base of the plant, which can partly be explained by the achene's way of twisting round each other and therefore being shed together in this way, leading to the wind dispersal being less effective (Elkington 1971). Elkington (1971) describes *Dryas octopetala* as having a low relative growth rate (RGR), the growth normally occurring during late spring and summer and the plant retains its leafs during the winter, either in a living or dead state. The plant normally does not produce flowers until it is 3 years old and mature plants sets seeds each year (Elkington 1971). Elkington (1971) states that there has not been any reported drought damage to *Dryas octopetala* and that this plant is totally resistant to frosting. However, Nilsen and

Elvebakk (2014) describes the *Dryas octopetala* growing in exposed, silt dominated soils to be damaged by many severe freeze-thaw cycles.

2.3 Vegetation patterns in arctic environments

In tundra communities, a mosaic pattern of vegetation usually develops and it is according to Chernov and Matveyeva (1997) mainly due to three factors:

- The formation of patterned ground, caused by permafrost and cryogenic processes active in the ground as well as thawing in the summer months (Washburn 1956).
- Due to environmental factors such as soil nitrogen deficiency, higher temperatures (Bliss 1960) and reduced wind-speed (Wilson 1959) closer to the ground, the vegetation is small and roughly of the same size. This means that many different species have to split the same ecological niches. Since the vegetation does not grow tall due to the unfavorable climate in the Arctic, it leaves a tight space for the plants to grow on.
- The vegetation has, due to the harsh climate, developed growing strategies such as growing in dense cushions and slow growth. Growing in dense mats results in phytogenic patterns while slow growth coupled with the small sized vegetation leads to plants that are incapable of smoothing out the irregularities of the ground. The cushion growth form is common amongst many chamaephytes (bearing hibernating buds or persisting shoots near the ground) where they benefit from the reduced wind-speed and higher temperature due to the warming of the soil (Bliss 1962).

Chernov and Matveyeva (1997) have divided the different types of tundra-vegetation horizontal structures into five groups; homogeneous, sporadically spotted, nodal, regular cyclic and irregular mosaics. The homogenous type is not a typical tundra community as it mainly develops in environments that are more uniform, such as wet areas where the ground is not patterned by cryogenic actions or in areas where patterned ground exist but is not well pronounced (Chernov and Matveyeva 1997).

The sporadically spotted type of vegetation structures usually occur in the early stages of succession on both dry fell-fields and snow beds. The main reason for this type of mosaic pattern is biotic since it is caused by individual plants capability to grow as dense cushions or for several individuals to form compact groups on the boarder to its ecological habitat (Chernov and Matveyeva 1997). These types of communities found in the polar desert, are perdurable pioneers in succession, as their development is restricted due to abiotic factors such as postponed growth or physical destruction. This leads to plants that often grow in cushions of only a few centimeters in diameter and thus, no soil develops beneath them (Chernov and Matveyeva 1997). Chernov and Matveyeva (1997) described a sporadically spotted fell-field in Maria Pronchishcheva Bay, Taymyr where *Dryas punctata* (a *Dryas* species very similar to *Dryas octopetala*) grew in an elongated and crescent shape as “permanent pioneers” which are hindered in their development.

The nodal type of vegetation structure is created when plants, such as *Dryas octopetala*, locally alters the growing environments by acting as a node by creating suitable conditions for other organism, which would otherwise not be able to occur at that site, to grow around the node (Chernov and Matveyeva 1997). The fourth structure, regular cyclic, is common in the tundra as well as in the polar deserts, where cryogenic processes have caused the ground to be patterned and hence, have a constant repetition of a specific set of nanorelief components (Chernov and Matveyeva 1997).

The irregular mosaic type of vegetation structure is caused by both abiotic and phytogenic factors. Cryogenic processes cause the main heterogeneity in the horizontal structure by creating irregular patterns of nanoreliefs of 10 to 20 centimeters. However, phytogenic factors cause the vegetation of this structure type to typically have a continuous cover consisting of aggregations of the same or different species (Chernov and Matveyeva 1997). The authors Chernov and Matveyeva (1997) states that it is rare that a tundra community only is composed of one horizontal structure but instead it is usually a mix between several structures, where one is more dominant.

2.3.1 Environmental factors affecting vegetation growth

Besides patterned ground causing vegetation patterns, as described in the previous section, the formation of vegetation patterns in the Arctic is influenced by factors such as wind (Triloff 1944; Wilson 1959), presence of snow, soil moisture, temperature of soil and air as well as the accessibility of nutrients (Wielgolaski 1997). In plant communities dominated by *Dryas* species, vegetation pattern is mostly caused by the microclimate of the locations, instead of the regional climate (Koroleva 2015).

Wind

Although the wind speed is of roughly the same magnitude in the arctic as it is in temperate areas, the lack of trees and other objects in the arctic regions is causing the wind speed close to the ground to be higher (Wilson 1959), especially during winter when strong winds and storms are common (Åkerman 1980). Vegetation in the Arctic is therefore often significantly affected by wind, that both alter the growth of the vegetation and its appearance (Wilson 1959) as well as clearing the area from litter, which will hinder humus to develop (Triloff 1944; Sonesson and Callaghan 1991). Wilson (1959) states that it is uncommon for wind itself to cause damage on artic vegetation. However, when the wind is carrying sand particles or snow crystals, it can affect the vegetation through abrasion (Wilson 1959; Sonesson and Callaghan 1991). Wind deflation and erosion could also be initiated by factors disturbing the vegetation cover, such as desiccation cracking, thermokarst or frost cracking, resulting in vegetation scars vulnerable to wind erosion (Åkerman 1980). On the western part of Spitsbergen, Åkerman (1980) found vegetation with deflation scars in the same direction as the winter wind from north-northeast, but also evidence of wind erosion on the south-west side of the plants caused by storm occurring during summer when the vegetation is drier. Åkerman (1980) further states that it is the snow and ice particles carried by wind that are responsible for the majority of wind erosion on Spitsbergen, while the erosion of mineral particles is small in comparison. McGraw (1985) studied the influence of different environmental factors on the growth of *Dryas octopetala* in Alaska (65°26’N, 145°30’W) on tundra fell-fields by manipulating several factors in the field and came to the conclusion that *Dryas octopetala* was not sensitive to changes in wind regarding shoot growth.

Wilson (1959) studied how wind affected the vegetation on the plateaus of Cairngorm in the Scottish Highlands. The study area consisted of evenly distributed tussocks of *Juncus trifidus* approximately 1 meter apart and with fine gravel between the vegetation. Wilson (1959) found that vegetation exposed to wind blowing mostly in the same direction was formed into a more asymmetrical shape, with the leafage being longer at the side of the tussock that was more protected from the wind. In Wilson's study (1959), the wind speed on the lee side of the vegetation was one-fifth as strong as it was at the more wind exposed higher part of the plant. Wind was also responsible for soil erosion in this study area, causing the formation of soil banks. At the lee side of these banks, a wide range of vegetation species was found and Wilson (1959) concludes that the reason for this most probably is the reduced wind speed at the lee side of the bank and that the establishment of vegetation itself further provides shelter for other plants to grow there. The evaporation rates around the vegetation seems closely related to wind speed as it was found to be highest at the top of the tussock where the wind speed was highest, and lowest at the lee side of the tussock where the wind speed also was found to be low (Wilson 1959). Furthermore, the growth rate of vegetation exposed to wind was found by Wilson (1959) to be 30 to 40 percent lower than for vegetation growing in sheltered areas.

Triloff (1944) studied vegetation patterns in Spitsbergen and found many locations where wind was the main factor causing vegetation pattern and that areas with no wind usually had a continuous vegetation cover. Abrasion or desiccation caused by wind could explain some of the dead vegetation found at the wind exposed side of cushion vegetation in Spitsbergen, which is more pronounced in areas of sparse vegetation. Triloff (1944) also found that it is not only individual plants growing pattern affected by the prominent wind direction, but entire plant populations sometimes showed an orientation towards the wind in the form of long parallel lines similar to the patterns of sand dunes.

Temperature and light

Triloff (1944) states that it is difficult to distinguish the positive effects from high temperature from those emanating from light exposure, since differences in temperature of areas with low vegetation are generated by sun exposure. The combined favorable effect of west/south light exposure in Spitsbergen results in increased number of species, plant-size and number of flowers.

Local differences in light conditions are common in Spitsbergen, due to low clouds and mist, which occur regularly at specific locations and shadowing from high mountain ridges. The combination of the two could lead to certain locations having permanent shadow (Triloff 1944; Hanssen-Bauer 1990). Shadow/light was shown to be the single most important factor affecting the growth of *Dryas octopetala* in controlled experiments while changes in length of growing season has little effect on the plants vegetation pattern (McGraw 1985).

Snow

Snow cover protects vegetation against the damaging effects of abrasion and desiccation caused by high wind speeds, as well as helps mitigating temperature extremes (Triloff 1944; Åkerman 1980; Sonesson and Callaghan 1991). Desiccation is most prominent in places where the snow cover is thin and shoots reaching above the snow cover are heated. The resulting evaporation cannot be compensated for by the frozen plant under the snow, causing the plant to dry out (Triloff 1944; Sonesson and Callaghan 1991). Vegetation in these exposed areas is mostly evergreen shrubs with the capacity to endure the effects of abrasion and desiccation (Callaghan 1987). When the snow cover is thick, the resulting pressure caused by the snow is damaging to the plants. A thick snow cover also thaw slowly which lead to a shorter growing season for the vegetation. However, the slow thaw of the snow does provide a source of humidity during the entire summer period (Triloff 1944; Åkerman 1980; Sonesson and Callaghan 1991). According to Rønning (1965), *Dryas octopetala* is not found in areas with thick snow cover. This is not due to any damaging effect caused by the snow on *Dryas octopetala* but rather the inability to compete with other plants such as *Cassiope tetragona* when growth conditions are less harsh (Rønning 1965).

Humidity

The drainage conditions of arctic areas are unique with respect to the permafrost layer, which is found everywhere at varying depths (Rønning 1965). The permafrost layer prohibits drainage of water from the part of the soil which is thawed during the summer period. Arctic areas with poor drainage give rise to large area of tundra populated by grass, moss and sedge. Areas with high drainage produces a podsol-like earth where the soil mainly consists of minerals. The *Caricion nardinae* is confined to these high-drainage areas (Rønning 1965). Since the root-system of arctic plants are shallow, the local variations of water supply is very important (Triloff 1944) but *Dryas octopetala* was found by McGraw (1985) to be insensitive to changes in water supply.

Chemical composition and nutrients

Vegetation growth in the arctic is affected by a limited nutrient supply, especially nitrogen and phosphorus, and the plants therefore recycle many of the nutrients they need (Jonasson 1983). Fertilization in Spitsbergen is mainly achieved via bird colonies (Triloff 1944). Fertilization has a positive effect on the arctic flora because the growth of plants in general is enhanced and the growth of each plant is changed. However, selection of species is also performed based on the ability to use the nitrogen richness of the soil. (Triloff 1944). In controlled experiments performed by McGraw (1985) where nutrient was added to the vegetation, the biological mass of *Dryas octopetala* declined, probably due to enhanced competition to other types of vegetation.

The chemical composition of the earth does, on different levels, play a large role in the arctic vegetation system. Areas consisting of limestone often have a poorer flora than other habitats. This could depend on not only the chemical composition and pH of the earth but also the pattern of disintegration of the limestone leading to only small amounts of fine material which could be penetrated by the roots of the plants (Rønning 1965).

3. Method

3.1 Data

The raw data for this thesis was provided by the researcher Veiko Lehsten from the Department of Physical Geography and Ecosystem Science at Lund University as a series of manually taken pictures in CR2 format covering 25x20 meter of the area. Lehsten deliberately chose a typical fell-field area without any patterned ground in order to remove the effect of this from the study. The GPS coordinates of the study area can be seen in Figure 6 below.

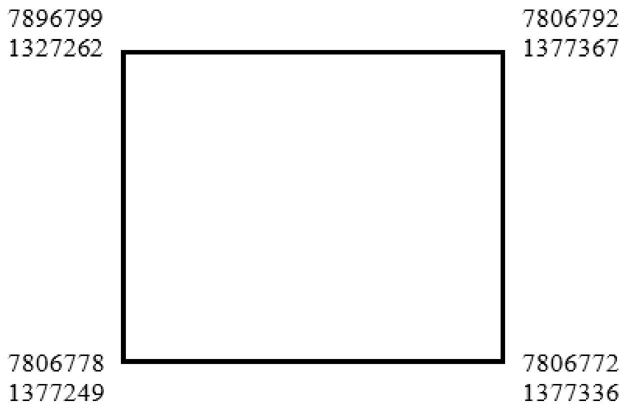

Figure 6. Coordinates for the study area in longitude and latitude.

The quadrant was marked out by measuring tape along the x-axis and a folding rule along the y-axis, that both had to be moved for each column of images. Lehsten documented the study area by taking pictures of the vegetation pattern, using a digital camera with a fish-eye lens held straight out facing down from the body, at approximately 1.5 meters' height. Starting from the northeastern corner of the quadrant, Lehsten moved along the x-axis, taking approximately 30 pictures per row and 14 pictures per column. An example of a picture can be seen in Figure 7 below. Elevation data was collected of the area by measuring the elevation, using a leveling tool, every two meters along the borders of the study area as well as diagonally across the study site. This data was used to create a DEM of the area in ArcGIS by creating points with their respective elevation and then interpolate between these points.

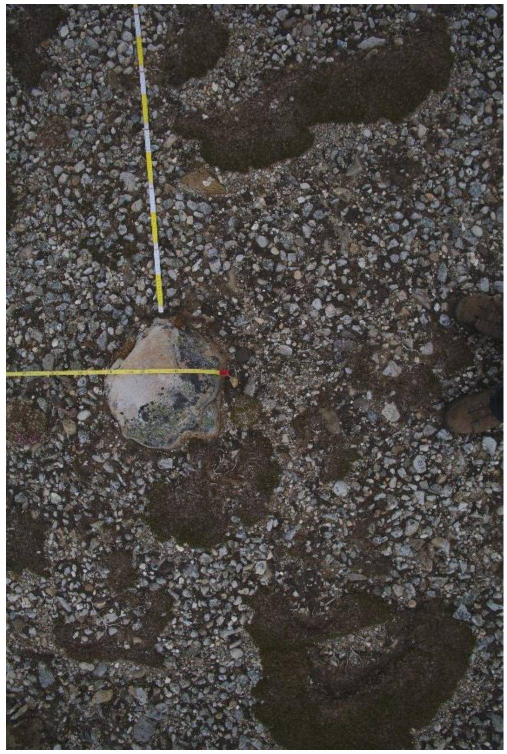

Figure 7. An example of a picture taken by Veiko Lehsten. It is located at south-east corner of the quadrant.

The same vegetation pattern was originally documented by Jonas Åkerman in 1979. Åkerman photographed four test surfaces (see Figure 8) of the area from six meters above ground, each area 7 x 4 meters in size.

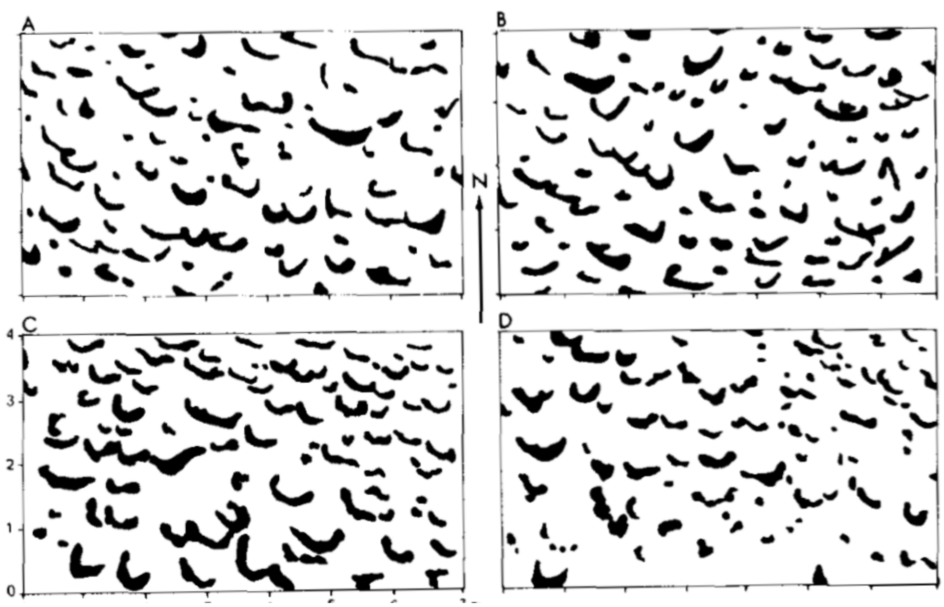

Figure 8. The four areas studied on Spitsbergen by Åkerman in 1979 (Åkerman 1983).

3.2 Data processing

To be able to work with the pictures in ArcGIS, the images were transformed from the original format CR2 to JPEG and the contrast and brightness of the images were altered so that the vegetation would be clearly distinguishable. Before starting the georeferencing process, some assumptions had to be made:

- The distance from the measuring tape to the left and right border of the image of the bottom image are the same for all images in the entire column.
- The axes visible in the images in the form of the measuring tape are always assumed to be straight and perpendicular to each other.
- The distance between each image in a row is considered to be the same.

3.2.1 Creating the mosaic – Development of assembly method

Three methods were tested in this thesis. Method 3 was chosen to create the whole mosaic but all methods are described below to enable a comparison.

Method 1 – Only georeferencing

All images were imported to ArcGIS 10.2 and the bottom right image was georeferenced using the Georeferencing tool. The affine transformation was used to transpose the original image to its true coordinates and therefore a minimum of three control points, evenly distributed in the image, were created based on the measuring tape. The image to the left of the georeferenced image was then georeferenced by finding objects visible in both images and creating links between them. As for the first image, the affine transformation was used to transform the image and hence, at least three links needed to be established. This procedure was then repeated for all the images in the first row.

Method 2 - Warp with calculated height values

In this method, images were imported into ArcGIS and the first image in each column was georeferenced using the Georeferencing tool in the same way as in method 1, while the remaining images in each column were georeferenced using the Warp tool. This was done using four points of coordinate pairs, one in each corner of the image that will be warped. The bottom two points are created by locating two features in each corner of the image that is also visible in the image in the correct coordinate system below and recording their coordinate values. Due to the distortion in the images as well as the nature of the warping tool in ArcGIS, the bottom points was decided, based on visual interpretation, to in this case lie around 20 percent of the image height from the bottom and 7.5 percent of the image width from its border to avoid the most extreme distortions caused by the fish-eye lens. The y-values for the top two points were calculated based on the distance in pixels from the bottom two points and the x-values were set to have the same x-coordinate as the left and right edge of the bottom image in each column.

The distance from the bottom points to the top of each image was measured in pixels in ArcGIS and multiplied with a scaling factor to obtain the true height. To get the scaling factor, the distance in pixels of 30 centimeters on the measuring tape in the original image was measured and then divided by 30 to get the distance in pixels per centimeter. This distance was then added to the bottom points' y-value to obtain the total height of the column so far. The procedure was then repeated of all images in each column. In cases where the height at the top of the image was visible on the measuring tape, it was used instead of calculating the y-value.

Method 3 – warp with fixed height values

The images were imported into ArcGIS and the first column, consisting of 14 images, was georeferenced according to the measuring tape in each image. Each column was then constructed by warping the images to their correct location in the quadrant using the Warp tool in ArcGIS. The procedure for finding the true coordinate values for the bottom two points in each image was the same as in method 2, but for the top two points y-values, a mean height of the images was used.

The top two points' coordinates were set to have the same x-coordinate as the left and right edge of the bottom image in each column. The value of the y-coordinate was either read from the measuring tape or, if the tape was unreadable, was calculated by adding a mean height to the previous images' y-value. Some adjustment of the value read from the measuring tape was made due to the fact that the tape did not always cross the x-axis at zero. The latest readable value at the top of an image was subtracted from the next visible value of the measuring tape further up in the column. This was then divided with the number of images between the two y-values and the quotient was added to the latest y-value until it reaches the value of the next readable y-value. Lastly, after all images have been warped, they were mosaicked using the Mosaic to new raster tool in ArcGIS to create the whole image.

3.2.2 Digitizing

Before beginning with the digitizing process, some rules where established, such as how the plant should be digitized and the smallest acceptable size of the plant that should be digitized. It was decided that only the plant leaves should be digitized and that the roots should be ignored. The smallest acceptable plant size was decided to be 10 x 10 centimeters.

The digitizing was done in ArcGIS using the Editing tool. For each *Dryas octopetala* plant, a polygon was created by manually drawing the contours of the plant with the mouse. A total of 1269 polygons were digitized and used for further analysis. This procedure was repeated for the polygons in Åkerman's images from 1979.

3.3 Direction of vegetation

The direction of a plant in this thesis defined as the way the open part of the crescent is oriented. To obtain this, a line was digitized between the two ends of the crescent shape and the tool Linear Directional Mean was used to find the direction in degrees of all lines separately. All values were then imported to Excel and reduced by 90 degrees to get the perpendicular angle to the direction of the line. In the case that the original angle was smaller than 90 degrees, the new angle was calculated as $NewAngle = 360 - (90 - OldAngle)$.

To be able to perform linear analysis of the data, they were transformed to northness and eastness gradients. Northness is achieved by calculating the cosine of the direction in degrees and describes how each polygon is angled from south to north, where a value of -1 = south and 1 = north. To get the eastness gradient, the sine of all directions was calculated, showing how the polygons are oriented from west to east, where a value of -1 = west and 1 = east. In both northness and eastness, a value of 0 indicates that the polygon is not oriented in any of the directions described by northness or eastness respectively.

A randomization test was used to check if the observed direction of the plants could have occurred randomly, with no specific process causing the plants to be directed in a certain way. This statistical test was chosen due to the fact that the data was not normally distributed and a parametric test, such as a t-test, could not be applied. Using Excel, random directions in sine and cosine values drawn from a uniform distribution where assigned to each polygon 1000 times, making it 1001 directions for all 1269 polygons in the study area. The means of all randomized samples were then compared to the mean of the directions for northness and eastness of the plants in the quadrant and all values with a value above of equal to this mean were counted. To get the p-value for northness and eastness, the number of values above or equal was divided by the number of samples i.e. 1001.

3.3.1 Direction of vegetation compared to wind direction

To investigate if wind direction is causing the half-moon shaped *Dryas octopetala*, and if wind direction from different seasons was affecting the plants' shape more than others, a randomization test of means was performed on the data. Using the statistics program Minitab Express, wind direction divided into winter, spring, summer/growing season, autumn and outside growing season was tested against the direction of *Dryas octopetala* in the study area from 1979 and 2015. Each test was resampled 1000 times and the difference in means of the two groups were compared each time. Each difference in means was plotted on a graph and a p-value for the likelihood that the two samples where from the same population were given.

Means of wind direction for all seasons were calculated, as described in Rogerson (2010), by taking the means of sine ($\bar{S}$) and cosine ($\bar{C}$) and then calculate R as $R = \sqrt{\bar{S}^2 + \bar{C}^2}$. The mean angle for wind direction were then calculated as $\alpha = \arcsin\left(\frac{\bar{S}}{R}\right)$.

3.4 Vegetation structure

3.4.1 Spatial distribution of vegetation

The distribution of *Dryas octopetala* was investigated using the tool Average Nearest Neighbor in ArcGIS which checked if the distribution was clustered, random or dispersed. To further analyze the growing pattern in the study area, the tool Create Near Table in ArcGIS was used to find, for each polygon, the shortest distance to another polygon. This data was imported into Excel and plotted as a histogram.

4. Result

4.1 Method development

The result of only using georeferencing to assemble the images can be seen in Figure 9. To the left the first 10 images of a row is shown while only image 1 and 10 is shown to the right. This demonstrates the amount of shrinking that occurs using this method and as the 1^{st} image is 401.8 dm^2 while the 10^{th} image is 63.84 dm^2, which is a decrease in area of 84.1 percent.

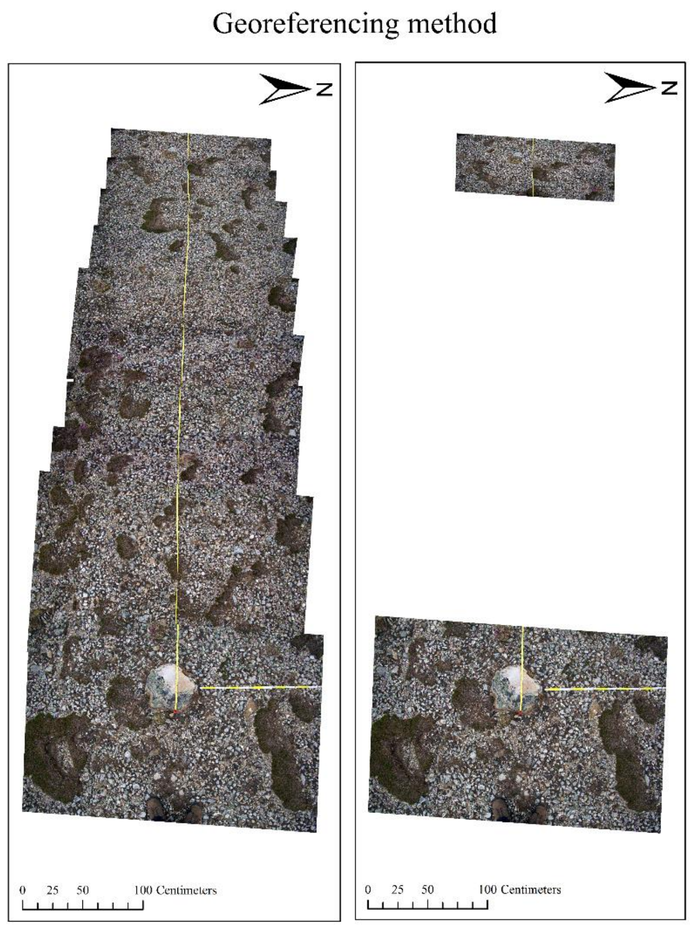

Figure 9. An example of the distortion using method 1 – only georeferecing. A column of 10 images (left) and only image 1 and 10 (right).

Instead of georeferencing, the second method aims to solve the shrinking problem, by warping the image to force each image to have the same size and calculates the correct height of the image if the measuring tape was not visible. The result of this method can be seen in Figure 10. The height of the images had to be calculated using a scaling factor due to that the measuring tape was flipped in five images, causing the image where the tape was visible to be 50 percent higher than the bottom image.

Warp with calculated heights

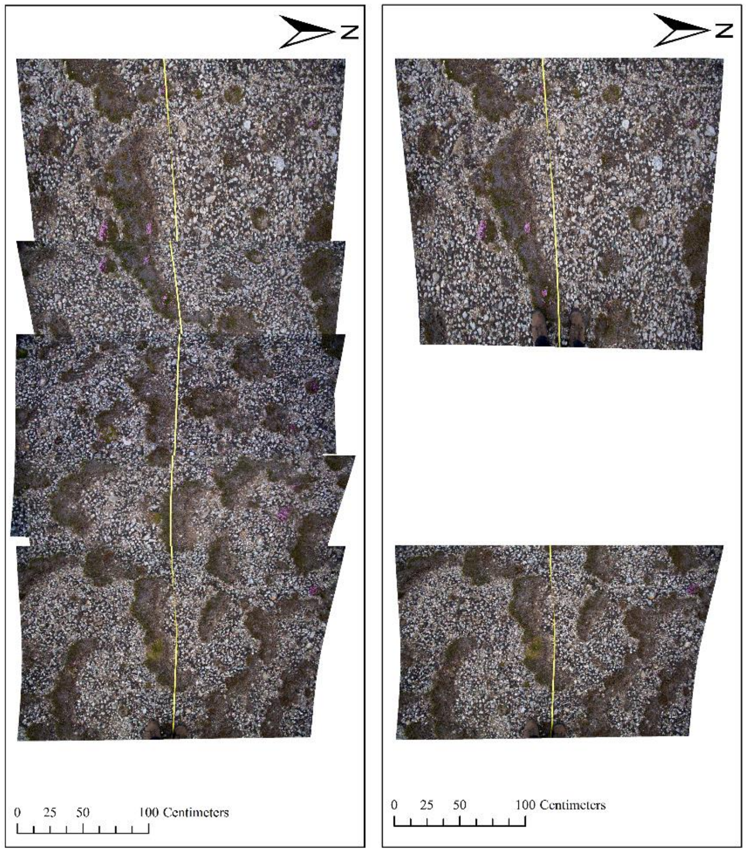

Figure 10. An example of the distortion using method 2. Five images in a column (left)t and image 1 and 5 (right).

All warped images were mosaicked to one image, by using the chosen method (method 3) explained in paragraph 3.2.1, and can be seen in Figure 12. The images have been forced to have the same extent, as shown in Figure 11, to avoid the shrinking or expansion seen with the other two tested methods. Table 1 summarizes the advantages and disadvantages of each method. Method number one is almost twice as fast as the other two but it also had the most noticeable distortion.

Warp with fixed image heights

Figure 11. An example of the distortion using method 3. A column of 10 images (left) and image 1 and 10 (right).

Table 1. A comparison between the three methods used to georeference the images. The severity of distortion is based on a visual interpretation of the distortion found during the method development process.

	Method 1 - Georeferencing	**Method 2 – Warp with calculated heights**	**Method 3 – Warp with fixed image height**
Average time/Image	6 minutes	11 minutes	10 minutes
Number of GCP’s	> 6	4	4
Distortion of image	Shrinking	Elongation and stretching between top corners	Stretching between top corners
Severity of distortion	+ + +	+ +	+
GIS tool used	Georeferencing	Warp	Warp

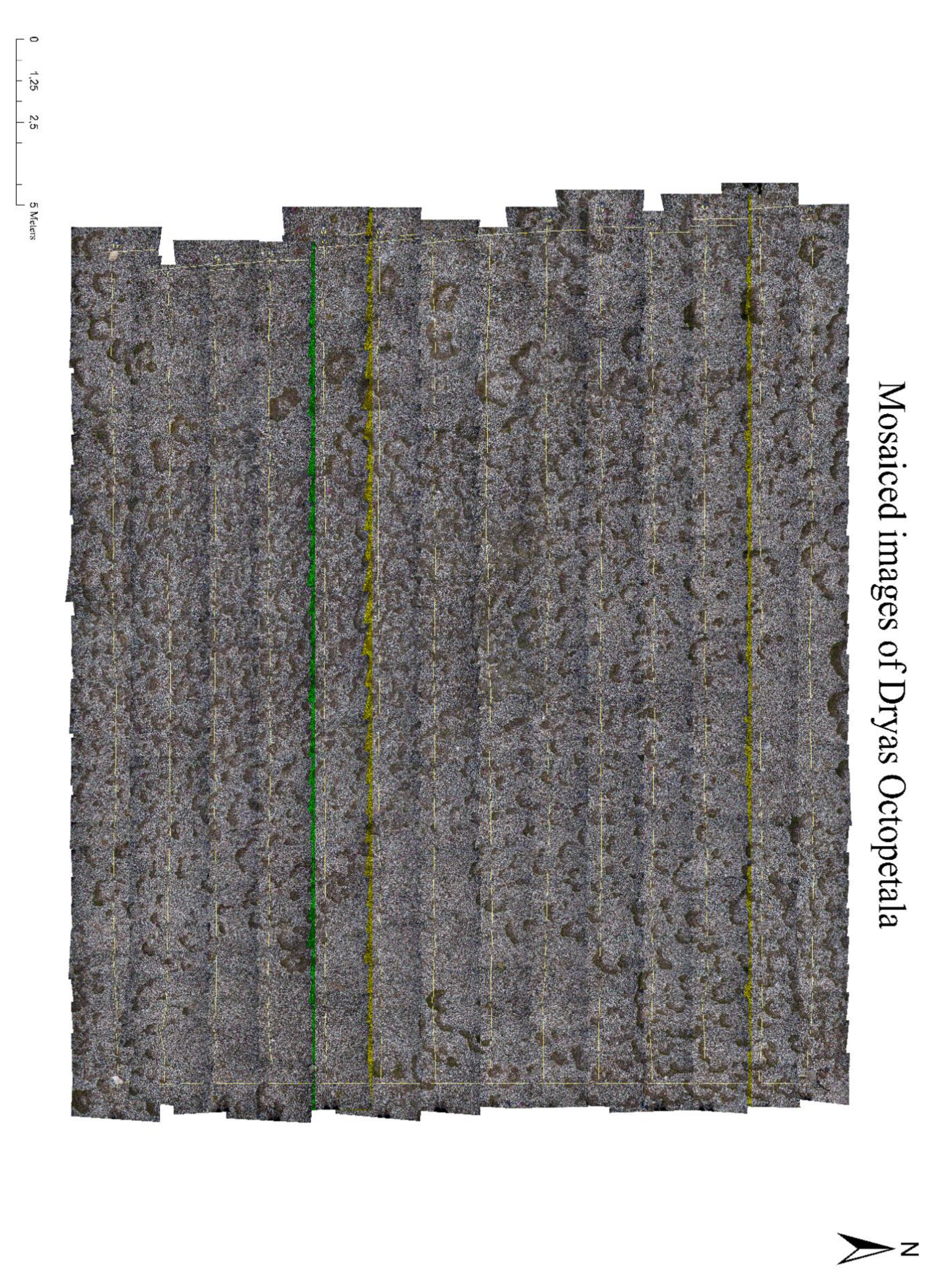

Figure 12. Mosaic of 420 images taken of Dryas octopetala in the study area (2015).

4.2 Direction of vegetation

Directions of *Dryas octopetala* from 1979 and 2015 can be seen in Figure 13 and 14 respectively. The majority of the vegetation from 1979 had a direction of between 0° and 40°, while it in 2015 had a direction of between 330° to 45°.

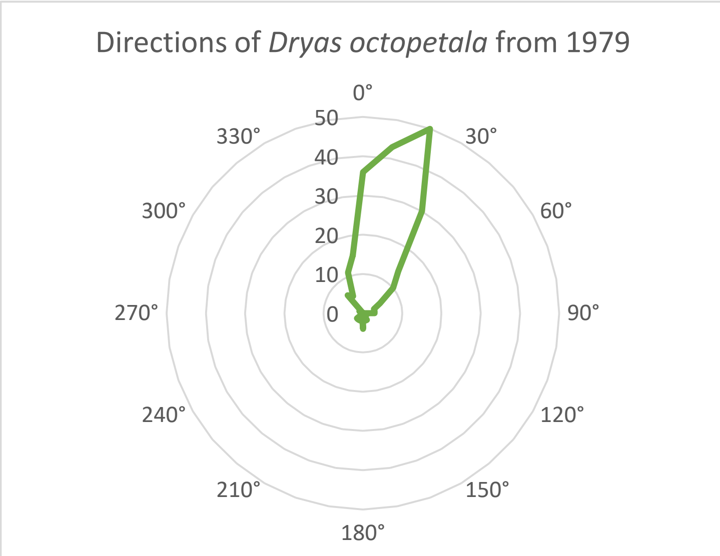

Figure 13. Vegetation direction rose of Dryas octopetala 1979.

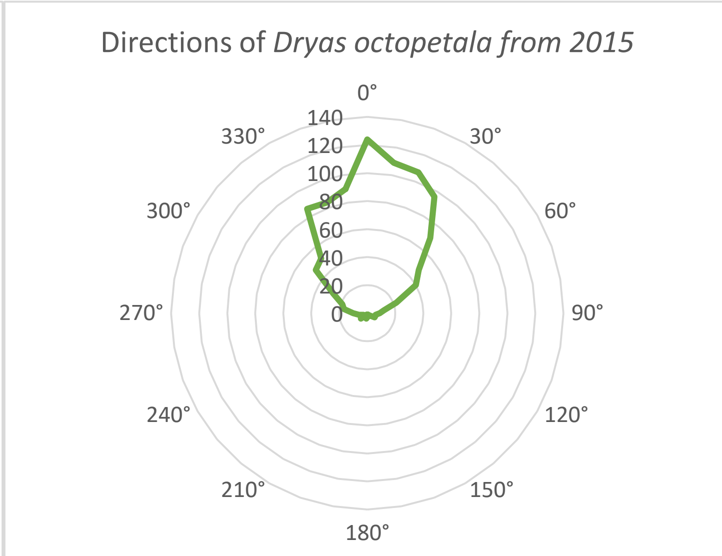

Figure 14. Vegetation direction rose of Dryas octopetala 2015.

The result of the sine transformation of each polygon direction can be seen in Figure 15. There is no clear difference in the number of polygons facing either west or east but the number of polygons with values around 0 is slightly larger than other classes of values, representing a direction that is neither west nor east. This is clearly shown in Figure 16, a histogram with the directions transformed using cosine, where the majority of polygons are facing north and therefore have a value that is close to 1. The class 0.91 to 1 contains 46.6 percent of all polygon directions and the two largest classes (0.81 to 0.9 and 0.91 and 1) together contains 63.4 percent of all polygon directions.

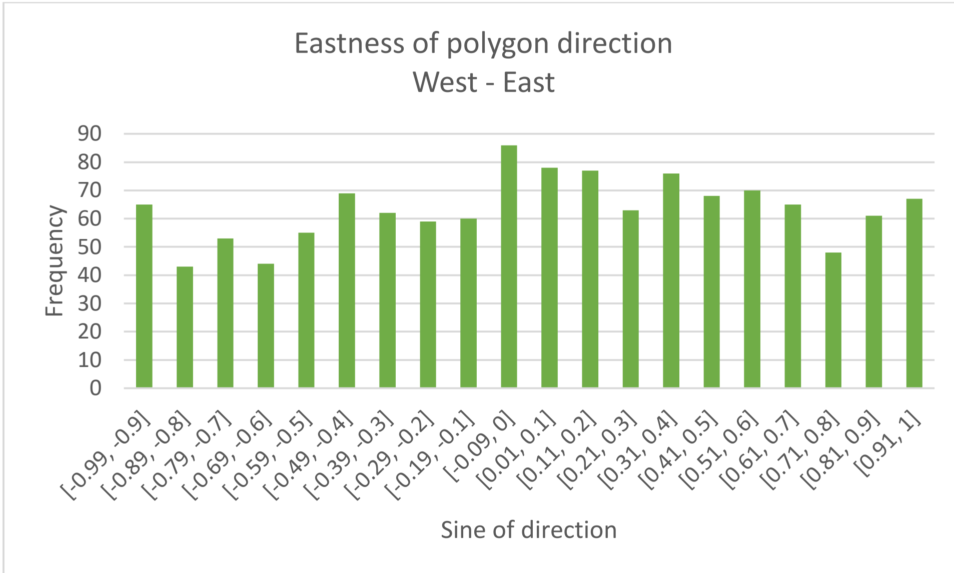

Figure 15. Histogram of polygon directions transformed into a west to east gradient (eastness).

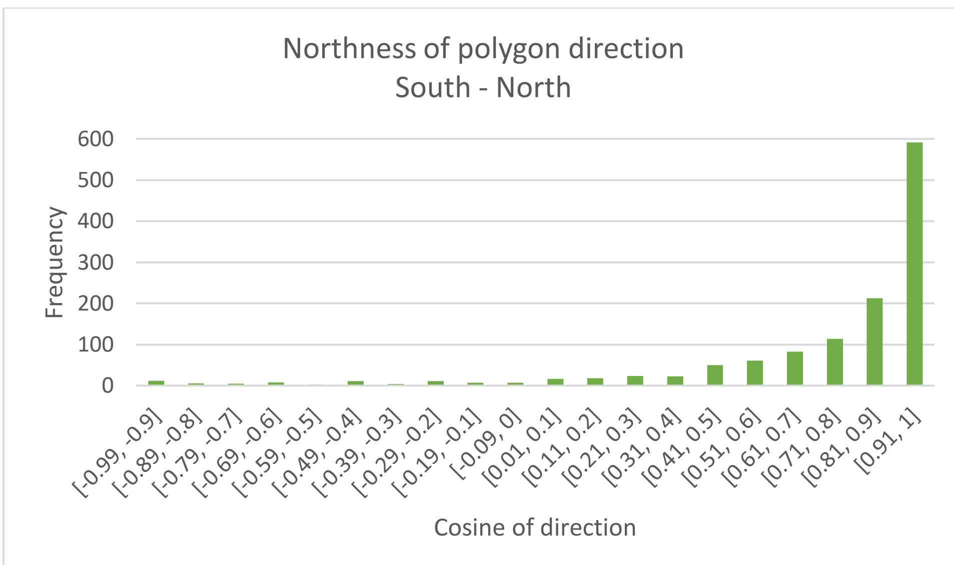

Figure 16. Histogram of polygon directions transformed into a south to north gradient (northness).

As shown in Table 2, both northness and eastness for the vegetation direction 2015 is significantly different from a random distribution of directions. Northness and eastness for the direction in 1979 are also significantly different from a random distribution with p-values of 0.001 respectively.

Table 2. Randomizations of northness and eastness from 2015 and 1979 with their respective means and p-value.

	Direction of vegetation 2015		**Direction of vegetation 1979**	
	Northness	Eastness	Northness	Eastness
Mean (COS – SIN)	0.735	0.034	0.737	0.231
Number of randomizations	1000	1000	1000	1000
Means above of equal to mean	1	18	1	1
P-value	0.001	0.018	0.001	0.001

Mean direction for the vegetation in year 2015 was 2.64° while it in year 1979 was 17.4°, a difference of 14.7°. When performing a randomization test for vegetation directions for 1979 against 2015 after transforming the directions using sine (eastness) and cosine (northness) it became evident that, while eastness only got a p-vale of <0.002, northness showed a great similarity with a p-value of 0.959. The differences in means from the randomization test is shown in Figure 17 for eastness and Figure 18 for northness.

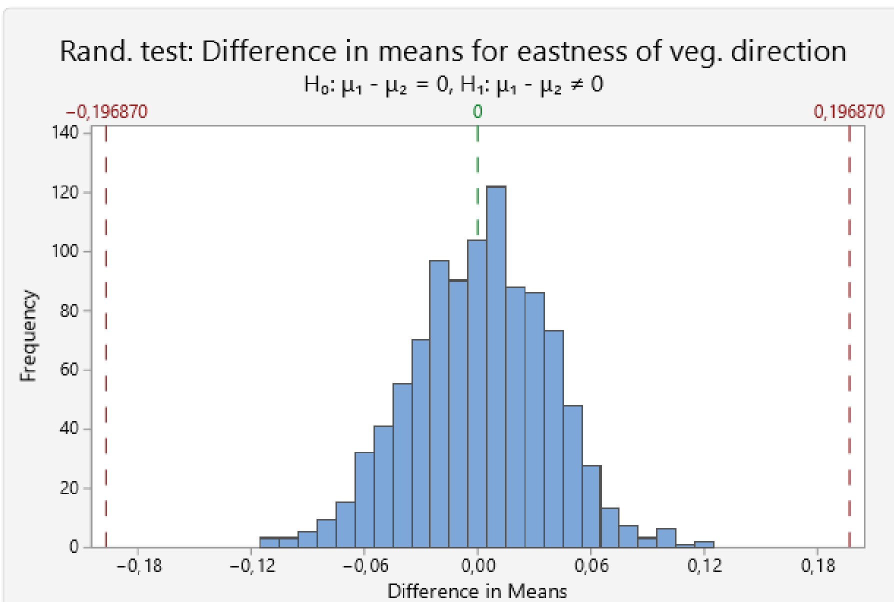

Figure 17. Randomization test for difference in means for eastness of vegetation direction from 1979 compared to 2015, using the program MiniTab Express.

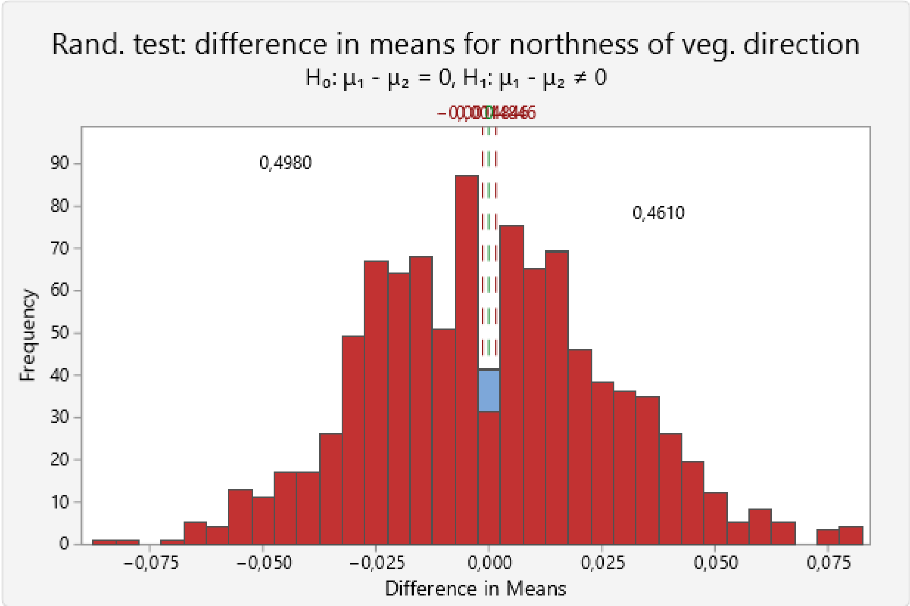

Figure 18. Randomization test for difference in means for northness of vegetation direction from 1979 compared to 2015, using the program MiniTab Express.

4.2.1 Direction of vegetation compared to wind direction

Wind data for the period 1947-1975 and for the period starting in 2014 to present showed strong similarities when testing them against each other using a randomization test, having a p-value for northness of 0.883 and a p-value for eastness of 0.420. They will therefore be treated as one time series in this thesis.

Means of wind direction for each season is shown in Table 3. Wind direction for winter and outside growing season have a fairly similar direction, only differing 4.1°, while wind direction in summer has the highest value of 89.4. The mean wind direction for all months was 63.6° while it for 2015, the only whole year since Isfjord Radio Station was recommissioned, was 62°. The result of the randomization test comparing the direction of *Dryas octopetala* for 1979 and 2015 to wind direction can be seen in Table 4. All of the data tested here showed a significant difference from each other with a p-value lower than 0.002 except when comparing wind directions for all months to the direction of *Dryas octopetala* 1979 which had a p-value of 0.011. Although it is higher than the other p-values, the null hypothesis that there is no difference between the two sample, is still rejected.

Table 3. Mean wind direction for the four categories all months, summer, winter and outside growing season.

	Wind direction All months	Wind direction Summer	Wind direction Winter	Wind direction Outside growing season
Mean direction (°)	63.6	89.4	51.0	54.1

Table 4. P-value for the likelihood of each category of wind direction to come from the same population as the direction of Dryas octopetala from 1979 and 2015.

	Wind direction All months	Wind direction Summer	Wind direction Winter	Wind direction Outside growing season
Direction of vegetation 2015	<0.002	<0.002	<0.002	<0.002
Direction of vegetation 1979	0.011	<0.002	<0.002	<0.002

4.3 Vegetation structure

In Figure 19, *Dryas octopetala* is shown over a DEM. The elevation ranges from 125 to 185 centimeters, with the highest values at the north and west edges of the study area and the lowest in the southeast corner. Vegetation is present at all altitudes and the area is fairly flat.

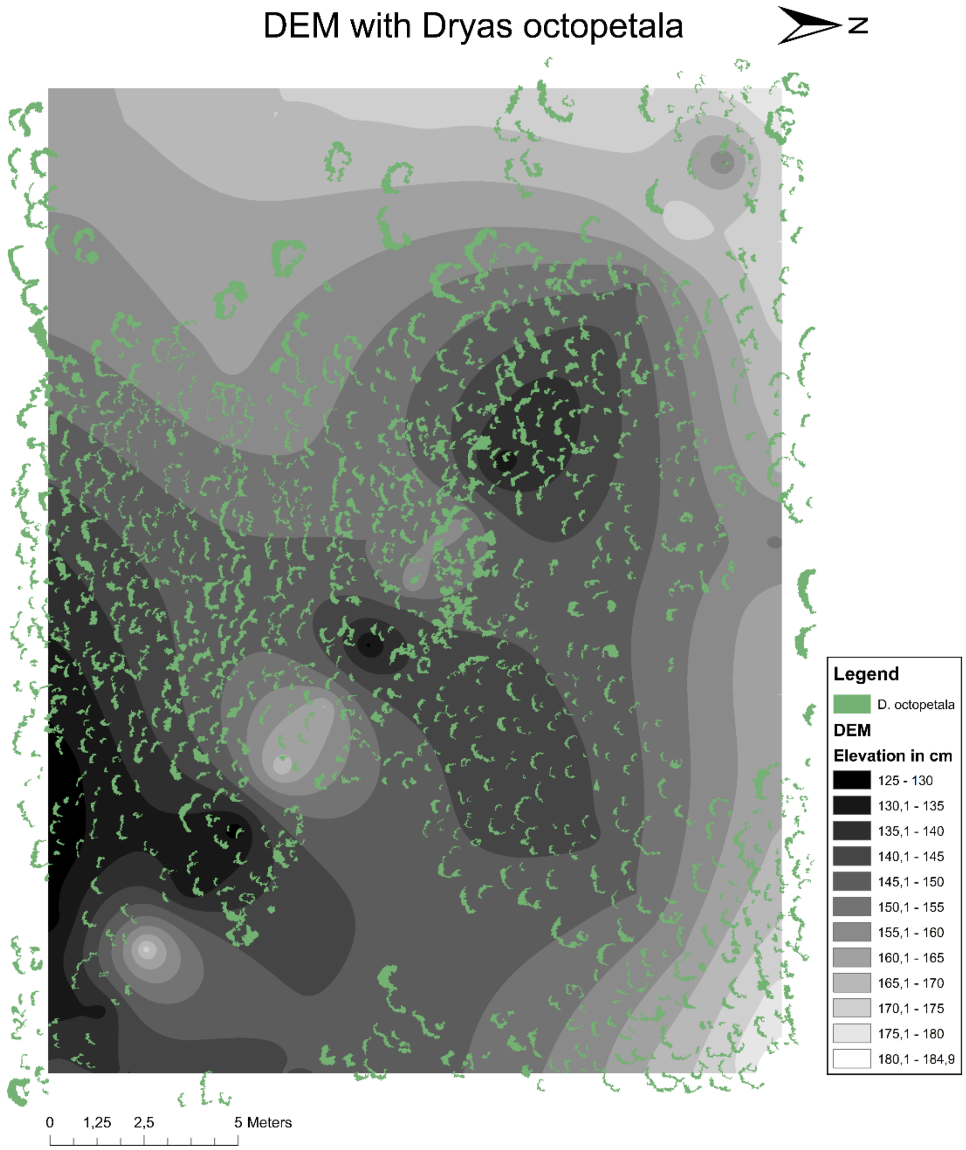

Figure 19. Dryas octopetala over a DEM of the study area 2015. Elevation data for the area was collected by Lehsten in 2015.

The majority of *Dryas octopetala* plants in the study area are growing close to other plants, as shown in Figure 20. Over 66.6 percent of all plants grow closer than 10 centimeters from another plant and only 3 percent grew further apart than 30 centimeters. The same growing pattern was found with the *Dryas octopetala* plants documented in 1979 with the majority of the plants growing close to other plants (see Figure 21).

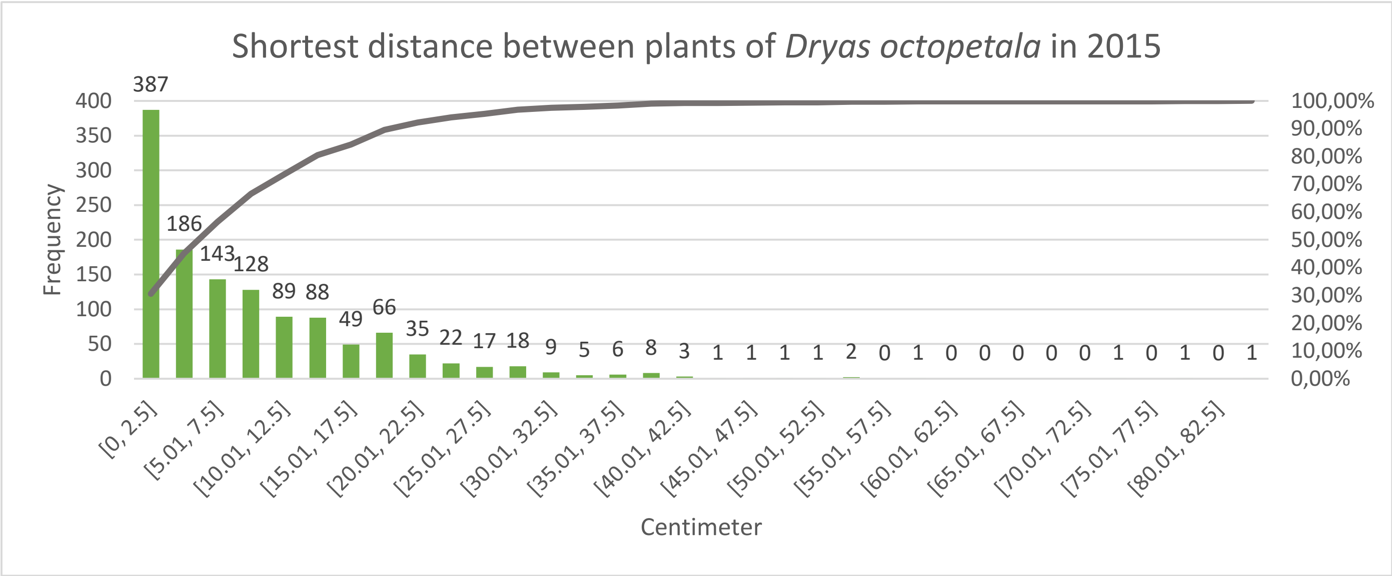

Figure 20. Shortest distance between Dryas octopetala plants in the study area (2015).

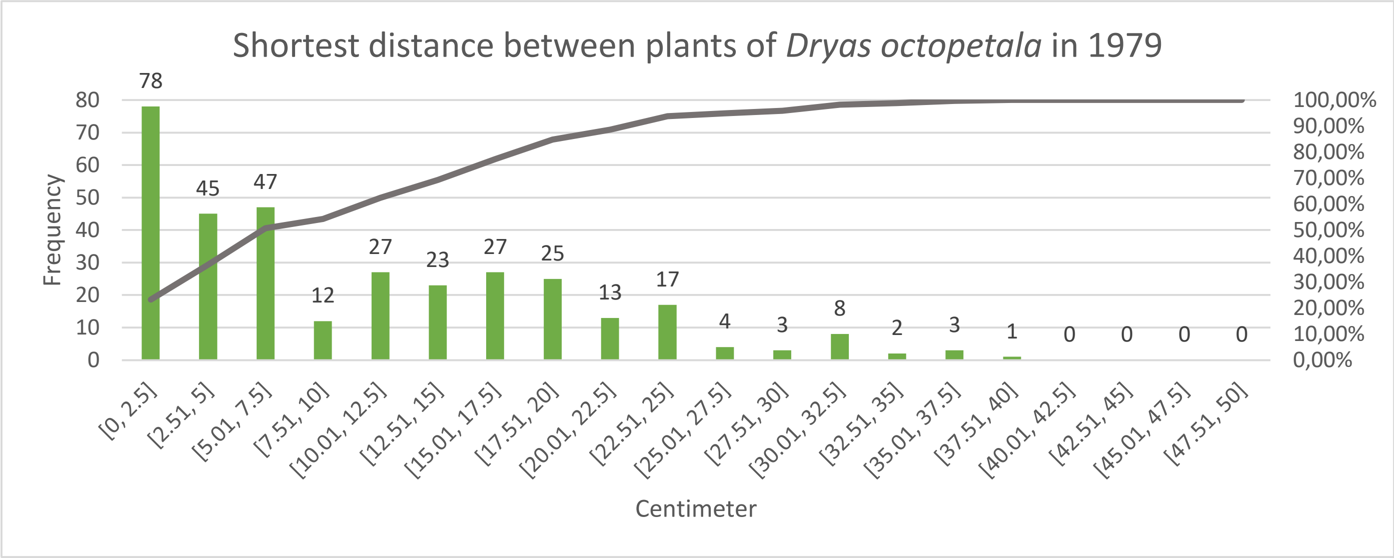

Figure 21. Shortest distance between Dryas octopetala plants in the study area (1979) derived from pictures in Åkerman (1983).

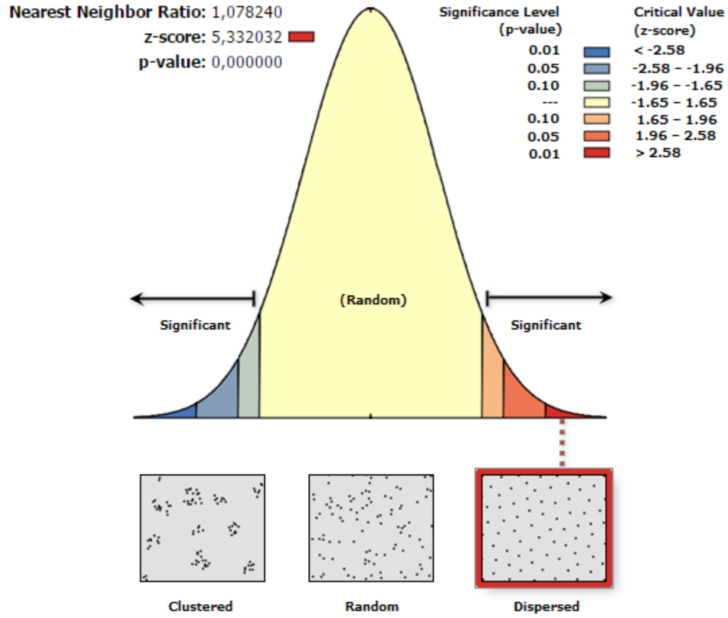

Figure 22. P-values and z-scores showing that the Dryas octopetala plants are dispersed over the study area (2015).

As can be seen in Figure 22, the spatial pattern of *Dryas octopetala* from 2015 is dispersed, with a less than 1 percent likelihood to have happened randomly. *Dryas octopetala* from 1979 showed the same dispersed pattern and low p-value.

5. Discussion

The atypical half-moon shaped growth at the study site has a significant direction facing north with a mean direction of 2.6°. It was shown by the randomization test of directions that each plants' direction did not occur simply by chance and hence, there must be one or several factors causing the vegetation to be directed dominantly towards north.

5.1 Wind direction compared to the direction of *Dryas octopetala*

The wind-direction at the nearest meteorological station, Isfjord Radio Station, was compared to the direction of the *Dryas octopetala* plants. After performing a randomization test of the individual wind directions for the whole year compared to the direction of the *Dryas octopetala* plants, it was shown that the populations were significantly different from each other. Since the wind directions at Spitsbergen are different during growing season (summer) and outside growing season (autumn, winter, spring) two hypotheses were made:

- That the half-moon shape was caused by desiccating winds carrying snow and other particles outside growing-season, or
- That the winds during growing season was affecting the newly developed leaves and branches and therefore forced the plant to grow in a half-moon shape.

The mean wind direction during growing season was 89.4° and outside growing season 54.1°, while the mean direction of *Dryas octopetala*, defined in this thesis as the direction the open part of the crescent is oriented, was 2.6°. When performing a randomization test, there was a significant difference between these populations compared to the direction of *Dryas octopetala*. Since this occurred when dividing the wind direction into seasons as well as when testing wind direction for all months, this study cannot conclude that the wind is causing the effects on the growth of *Dryas octopetala* at the study sites from 1979 and 2015.

It is, however, possible that it is wind that causes the unusual shape of *Dryas octopetala* just as it has been described in literature as a main cause of such vegetation patterns (Triloff 1944; Wilson 1959; Åkerman 1980) although McGraw (1985) found that *Dryas octopetala* is not sensitive to wind. In McGraws' study only the growth of the shoots is measured and other effects on wind, such as abrasion and desiccation, was not studied. The wind directions have been measured at Isfjord Radio which is situated approximately 5 kilometers from the study site. The mountain to the east of the study area might force the wind to blow from the north, instead of from the north-east as indicated by the wind data, and thus affecting how *Dryas octopetala* grows in the study area. The tunneling effect described by Hanssen-Bauer (1990), could also make the wind locally stronger at the study site, resulting in an extra strong effect on the vegetation. This was indicated by Åkerman (1983) when he noticed that the more sensitive species *Saxifraga oppositifolia* only grew in connection with *Dryas octopetala* and in 73 percent of the cases on the lee-side. Since there is no wind data available from the study site this cannot be confirmed and further investigations have to be made with wind measurements on the study site in order to establish the exact cause of the half-moon growth of *Dryas octopetala*. Wind strength has not been analyzed in this thesis but is an aspect of wind that affects vegetation, as stated by Åkerman (1980). If winds coming from north are stronger compared to the other directions, then its effect on vegetation pattern might be larger than the prominent wind direction from north-northeast. Åkerman (1980) and Hanssen-Bauer (1990) stated that the study area is experiencing especially strong winds in winter, which also is the time of year the wind direction is the most northerly. Winter winds carrying snow and ice particles was found by Åkerman (1980) to affect vegetation the most, further indicating that wind strength coupled with wind direction, could be an important factor.

More measurements on site is needed to finally establish how wind is affecting *Dryas octopetala* in the study area. Wind direction and strength, measured at the study site, would substantially improve the analyses by eliminating the effect of local topography on the wind in the area and potential changes in wind direction and strength from what is measured at Isfjord Radio Station. It would also be useful to model the wind flow around the plants to see how this could affect the growth by moving snow or seeds and, as done by Wilson (1959), measure the actual wind speeds close around the plants.

5.2 Other factors affecting plant growth

Regular cyclic growth structures are common in the arctic and polar desert, where heavy frost action has caused the ground to form patterns to which the vegetation has adapted. However, in order to remove this aspect of patterned ground, Lehsten deliberately chose a study area which did not contain any traces of pattern ground caused by frost heaving. The study site is a typical fell-field, dry and well-drained and only holds a small amount of ground ice during winter time. From looking at the image of the study area, no obvious differences in the grounds water content can be seen which indicates that water content is not a contributing factor to the vegetation pattern at this site. The vegetation growing in this area have a couple of similarities with the sporadically spotted vegetation structure described by Chernov and Matveyeva (1997), such as the presence of cushion type vegetation and the physical destruction of plants in the area. Crescent shaped *Dryas* vegetation, belonging to the sporadically spotted structure type, was found by Chernov and Matveyeva (1997) in Russia and was described as hindered in their development, which further suggests that the *Dryas octopetala* vegetation in the study area on Spitsbergen belong to this vegetation type. Another type of vegetation structure that can be seen in the study area is the nodal structure, were plants create suitable conditions for other species to grow around it. This vegetation structure in the study area was described by Åkerman (1983), were he found several other vegetation species growing in and around *Dryas octopetala.*

Light and soil temperature are factors known to have large impact on the arctic vegetation. Although the study area is experiencing continuous sunlight during summer, the sun reaches its highest point in the south and will affect the vegetation more. This is consistent with the growth of the half-moon shaped *Dryas octopetala* in the study area, with the green, vegetative, outer radius facing straight south. However, the direction of light is identical for the entire polar area and if this was the only factor, all *Dryas octopetala* should have a similar shape all over the northern hemisphere. Shadowing was also found in literature as a factor influencing vegetation pattern but the mountains around the study site are not shadowing the area (Lehsten, per.comm.) and shadows caused by clouds would affect the entire area and hence, would not be a factor here.

According to personal communication from Lehsten, the study sites are typical fell-field with a very thin snow-cover and snow on the ground will be blown away. This is consistent with Rønning (1965) findings that *Dryas octopetala* has difficulties competing with other species when the snow-cover is thick. However, a homogenous cover of *Dryas octopetala* was found under layers of snow adjacent to the study area. This suggests that snow is not a factor causing the half-moon shape at these locations, but rather the absence of snow. Another factor that could cause vegetation patterns is nutrients, which are crucial for the growth of plants in the Artic and can cause atypical formation of plants around carcasses and under bird cliffs. However, according to personal communication from Lehsten, no such nutrient contributions sources exist in the study area.

To determine the exact effect each factor has on the growing patterns of *Dryas octopetala*, more measurements on site is required. With soil samples taken in and around the plant it would be possible to investigate the soils effect by looking at nutrient composition and soil temperature. If the soil is homogenous over the area, it is possible of eliminate soil as a factor. It would also be interesting to examine the age of the plants to try and understand how the crescent shape was developed. Both the age of vegetation in each plant itself as well as age between different plants in the area would be of interest. If wind is causing the half-moon shape, it would be logical if the young *Dryas octopetala* plants are more round while the older plants, which would have been exposed to winds for a longer period of time, would have been forced to grow in the half-moon shape. Although the area has little snow, it would also be useful to monitor the snow cover of the area, since snow has been described in literature to affect the growing pattern of *Dryas octopetala* by protecting vegetation from damaging winds (Triloff 1944; Sonesson and Callaghan 1991) but also increase the competition to *Dryas octopetala* from other plants due to the more favorable conditions a snow cover creates (Rønning 1965).

5.3 Distribution and direction of vegetation

The growth of *Dryas octopetala* in 2015 is mainly similar to the growth in 1979, with an almost identical dispersion pattern and distance to the closest plant. The overall shapes are similar but there is a shift in mean direction of growth, from 17.4° to 2.64° and this results in that the data are found to be identical in randomization test for northness, but from different populations when analyzing eastness. No northerly shift in wind direction between data from 1974-1975 and 2015 could be found when analyzing yearly mean wind direction. This could indicate wind is not causing the half-moon shaped pattern, but since only one full year from the recent data set was available, it cannot be determined.

The *Dryas octopetala* grows dispersed with a short distance from each other, 66.5 percent growing less than 10 centimeters from another plant. A possible explanation for this could be the stress of wind on the plants, as growing closely to other plants would provide shelter from damaging winds. The sporadically spotted vegetation pattern described by Chernov and Matveyeva (1997) is caused by the vegetation growing close together under stress at the border of its habitat, which looks similar to the vegetation pattern in the study area on Spitsbergen. No clustering could be found but since all plants grow close to each other in the study area, there could be clusters over a bigger area where the vegetation in the study area might be part of a cluster. The DEM of the study area was examined but no connection could be seen between the elevation and the direction and distribution of *Dryas octopetala*. The elevation is highest at the northeast corner of the area, while it is lowest at the southwest corner of the study area, but the difference in elevation between the northeast and southwest is only 60 centimeters which over 25 meters is a very small height difference and hence, the area could be seen as a flat surface. To further investigate the vegetation distribution in this area, one would have to closely analyze the aspects that differs between the locations at which *Dryas octopetala* grows and the places without vegetation by making measurements of, for example, soil and snow as discussed in section 5.2. Small scale height differences are especially important due to that micro topography could provide shelter from the harsh climate, as Koroleva (2015) stated that microclimate is important for vegetation patterns in *Dryas* communities. To analyze the small difference in topography, a detailed DEM needs to be created.

5.4 Method for assembling images

A method for assembling manually taken photographs from low height using the software ArcGIS was developed during this thesis. Due to the distortion of the individual pictures, it was not possible to assemble them by only georeferencing, since this resulted in a shrinkage of the picture size by 84 percent after 10 pictures and the shrinkage continued with each images added to a row. Warping of each picture had to be performed in order to maintain the width and height of the picture by forcing the two upper corners to be higher and further apart than they would with only georeferencing. Since the measuring tape was not readable in many images, two options were available, to use a scaling factor or to use a fixed height of each picture. Trial and error showed that using fixed height worked better since the scaling factor produced very elongated pictures when the measuring tape was not readable for a couple of images, indicating that there are other distortions that is not compensated for by the scaling factor. The method of using fixed image heights does however, assume that all images were taken at exactly the same height so that all images were the same size in real life. Since no tripod or similar camera support where used, the images are likely to have been taken at slightly different heights as well as angles, but this had to be disregarded in this thesis. To minimize the effects of distortion caused by the use of a fish-eye lens, the points chosen for warping the image were not placed on edges of the picture as it is the most distorted. However, the points should not be placed too far into the center of the image as it would result in that the warping will be based only on a small section of the image. The chosen method (method 3) proved to the best method in this study as it distorted the images less than the others and it made sure that each images had the same approximate size.

Assembly of photographs taken manually from a low height is very time consuming. No more than 6 pictures per hour could be warped even after the method was developed as far as possible and the computer only taking about 1 minute to warp the image. The mosaicking is highly dependent on the accuracy of the photographs taken. Small changes in angle towards the grounds results in different distortions of the pictures. Furthermore, if the angle between the horizontal and vertical axis is not exactly 90° the assembly of columns is not precise.

The process of piecing the images together would have, as mentioned above, benefitted from a device that made sure that the camera always was facing straight down towards the ground. Perhaps some sort of pendulum attached to the camera, if the winds are not too strong. Further improvement would be that the pictures were taken higher up, for example by a drone as initially planned by Lehsten, so that the distortion of the pictures would be less noticeable as well as to use some type of large grid instead of measuring tape to make sure that it did not move or flip due to wind as well and that the images are perpendicularly placed to each other.

5.5 Sources of error

With regards to the raw data for this thesis there are several sources of error. Camera angle, the short distance from the camera to the ground as well as the lens used presented some problems as described in section 5.4. The angle between the x-axis and the y-axis as well as the axes not being completely straight and problems with finding north using a hand held compass also give rise to errors in this thesis. Furthermore, one source of error is the accuracy of orientation of the images in the study area. The measuring tape facing north was positioned with the help of a hand-held compass and could result in possible error of several degrees. The comparison of compass directions between measurements performed by different persons at different times and with different equipment is also a potential major source of error, as well as the declination and magnetic properties in the ground affecting the compass direction. In 1979, the declination was 2.48° W while it in 2015 was 6.84° E (NOAA 2017) and has not been accounted for due to that other potential uncertainties regarding direction, such as method of determining the direction of the vegetation and not completely straight axes in the images, was of comparable size as the declination and therefore lies within the margin of error regarding direction for this thesis. Due to the problem with declination and other problems concerning direction, the results of this study should interpreted with caution, especially the difference between the direction of vegetation from 1979 and 2015.

Another source of error is that Isfjord Radio Station was not measuring wind direction between 1976 and 2013, and wind direction in that period of time between Åkerman's and Lehsten's images could not be analyzed. The distance between Isfjord Radio Station and the study area also presented some problems in this thesis since the wind direction is not likely to be the same at the two locations.

Determining the direction of a *Dryas octopetala* plant also caused some difficulties. When digitizing it was sometimes hard to determine if it was one big plant or a few small ones. Furthermore, it was sometimes difficult to find the direction of a plant when it did not have a half-moon shape and was not stretched in some direction. The method of manually drawing a line between the ends of the half-moon shape is also a potential source of error since it was in some cases hard to determine the exact location of the two ends. Some plants also had several concavities and a decision had to be made about which one was the most prominent one to use as the plants' direction.

6. Conclusion

Dryas octopetala was, at the study sites, directed towards north-northeast, with the vegetation in 1979 being directed a little bit more towards northeast than the vegetation in 2015. The vegetation in both study areas grew close to each other and had a dispersed distribution. In the study areas, 66.5 percent of the vegetation grew less than 10 centimeters from another plant. Although this thesis was not able to prove that the prominent wind direction is causing the unusual growing forms and pattern of *Dryas octopetala*, it is still the most likely cause after reviewing other potential causes such as light and snow cover.

More research and measurements is needed to determine the exact cause of the unusual growth of *Dryas octopetala* in the study area. Wind data needs to be collected at the location of the study to conclude if wind is the main factors causing this shape and wind speed should also be taken into account. The main focus of this thesis is on the direction *Dryas octopetala* in relation to wind direction but it would also be of interest to further analyze other factors such as for example snow cover, light and soil moisture which would acquire more measurements to be made on site. This would be of help when analyzing the cause of the plants dispersed pattern.

The method for assembling pictures was time consuming and did not give a perfect result, as the images did not fit together seamlessly or was perfectly orientated in the final larger image. However, it resulted in an acceptable approximation of the study area, given the distortion in each image as well as problems with the measuring tape.

References

Bliss, L.C. 1962. Adaptations of Arctic and Alpine Plants to Environmental Conditions. *Arctic* 2: 117-144.

Callaghan, T.V. 1987. Plant population processes in arctic and boreal regions. *Ecological Bulletins* 38: 58-68.

Chernov, Y.I and N.V. Matveyeva. 1997. Arctic ecosystems in Russia. In *Ecosystems of the World 3: Polar and Alpine Tundra*, Wielgolaski, F.E, 146 pp. Amsterdam: Elsevier Science.

Elkington, T.T. 1971. *Dryas octopetala* L. *Journal of Ecology* 59: 887-905.

Elvebakk, A. 1994. A survey of plant associations and alliances from Svalbard. *Journal of Vegetation Science* 5: 791-802.

Hanssen-Bauer, I., M. Kristensen Solås and E.L. Steffensen. 1990. Klima – The Climate of Spitsbergen. Det Norske Meteorologiske Institutt, Report 39/90, Oslo, Norway, 40 pp.

Hultén, E., 1959. Studies in the Genus Dryas. *Svensk Botanisk Tidskrift* 53: 507-542.

Joly, D., G. Arnesen., E. Malnes and L. Nilsen. 2015. Building an indicator to characterize the thermal conditions for plant growth on an Arctic Archipelago, Svalbard. *Ecological Indicators* 66: 623-631.

Jonasson, S., 1983. Nutrient content and dynamics in north Swedish shrub tundra areas. *Holarctic Ecography* 6: 295-304.

Josefsson, T and Mårtensson I. 1995. A vegetation map and a Digital Elevation Model over the Kapp Linné area, Svalbard. Master thesis. Lunds Universitets Naturgeografiska Institution. Seminarieuppsats no. 34: 1-68.

Koroleva, N. 2015. Survey of Dryas octopetala – dominated plant communities in the European and North-West-Siberian Arctic. *Botanica Pacifica* 4: 17-36.

McGraw, J. 1985. Experimental Ecology of Dryas octopetala Ecotypes. III. Environmental Factors and Plant Growth. *Arctic and Alphine Research* 17: 229-239.

Nilsen, L and Elvebakk, A. 2014. Vegetation of exposed calcareous ridges in central Spitsbergen, Svalbard, Norway. *Phytocoenologia* 44: 19-29.

NOAA National Centers for Environmental Information. 2017. Magnetic Field Calculator. Retrieved 3 January, 2017, from https://www.ngdc.noaa.gov/geomag-web/#declination

Nordli, Ø., R. Przybylak., A. Ogilvie and K. Isaksen. 2014. Long-term temperature trends and variability on Spitsbergen: the extended Svalbard Airport temperature series, 1989-2012. *Polar Research* 33.

Norwegian Meteorolical Institute. 2016. eKlima. Retrieved 2 July, 2016, from http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL

Rogerson, P.A. 2010. *Statistical methods for geography*. London: SAGE Publication Ltb.

Rønning, O. 1996. *The Flora of Svalbard*. Norwegian Polar Institute.

Sonesson, M and Callaghan. T. 1991. Strategies of Survival in Plants of the Fennoscandian Tundra. *Arctic* 44: 95-105.

Triloff, E.G. 1944. Verbreitung und Ökologie der Gefäßpflanzen im Gebiete des Hornsundes; ein Beitrag zur Vegetationskunde Spitzbergens. *Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzen geographie* 73:259-360 (In German)

Washburn, A.L. 1956. Classification of Patterned Ground and Review of Suggested Origins. *Bulletin of the Geological Society of America* 67: 823-866.

Welker, J.M., U. Molau., A.N. Parsons., C.H. Robinson and P.A Wookey. 1997. Responses of Dryas *octopetala* to ITEX environmental manipulations: a synthesis with circumpolar comparisons. *Global Change Biology* 3: 61-73.

Wielgolaski, F.E. 1997. *Ecosystems of the World 3: Polar and Alpine Tundra*. Amsterdam: Elsevier Science

Wilson, J. 1959. Notes on wind and its effects in arctic-alpine vegetation. *Journal of Ecology* 47: 415-427.

Åkerman, J.1980. Studies on Periglacial Geomorphology in West Spitsbergen. PhD Thesis. Lunds Universitets Geografiska Inst. Ser. Avh. LXXXIX, 297 pp. ISBN 91-7222-334-0

Åkerman, J. 1983. Notes concerning the vegetation on deflation surfaces, Kapp Linné, Spitsbergen. *Polar Research* 1: 161-169.

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (https://lup.lub.lu.se/student-papers/search/) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (https://lup.lub.lu.se/student-papers/search/) and through the Geo-library (www.geobib.lu.se)

372 Andreas Dahlbom (2016) The impact of permafrost degradation on methane fluxes - a field study in Abisko

373 Hanna Modin (2016) Higher temperatures increase nutrient availability in the High Arctic, causing elevated competitive pressure and a decline in *Papaver radicatum*

374 Elsa Lindevall (2016) Assessment of the relationship between the Photochemical Reflectance Index and Light Use Efficiency: A study of its seasonal and diurnal variation in a sub-arctic birch forest, Abisko, Sweden

375 Henrik Hagelin and Matthieu Cluzel (2016) Applying FARSITE and Prometheus on the Västmanland Fire, Sweden (2014): Fire Growth Simulation as a Measure Against Forest Fire Spread – A Model Suitability Study –

376 Pontus Cederholm (2016) Californian Drought: The Processes and Factors Controlling the 2011-2016 Drought and Winter Precipitation in California

377 Johannes Loer (2016) Modelling nitrogen balance in two Southern Swedish spruce plantations

378 Hanna Angel (2016) Water and carbon footprints of mining and producing Cu, Mg and Zn: A comparative study of primary and secondary sources

379 Gusten Brodin (2016) Organic farming's role in adaptation to and mitigation of climate change - an overview of ecological resilience and a model case study

380 Verånika Trollblad (2016) Odling av *Cucumis Sativus* L. med aska från träd som näringstillägg i ett urinbaserat hydroponiskt system

381 Susanne De Bourg (2016) Tillväxteffekter för andra generationens granskog efter tidigare genomförd kalkning

382 Katarina Crafoord (2016) Placering av energiskog i Sverige - en GIS analys

383 Simon Nåfält (2016) Assessing avalanche risk by terrain analysis An experimental GIS-approach to The Avalanche Terrain Exposure Scale (ATES)

384 Vide Hellgren (2016) Asteroid Mining - A Review of Methods and Aspects

385 Tina Truedsson (2016) Hur påverkar snömängd och vindförhållande vattentrycksmätningar vintertid i en sjö på västra Grönland?

386 Chloe Näslund (2016) Prompt Pediatric Care Pediatric patients' estimated travel times to surgically-equipped hospitals in Sweden's Scania County
387 Yufei Wei (2016) Developing a web-based system to visualize vegetation trends by a nonlinear regression algorithm
388 Greta Wistrand (2016) Investigating the potential of object-based image analysis to identify tree avenues in high resolution aerial imagery and lidar data
389 Jessica Ahlgren (2016) Development of a Web Mapping Application for grazing resource information in Kordofan, Sudan, by downloading MODIS data automatically via Python
390 Hanna Axén (2016) Methane flux measurements with low-cost solid state sensors in Kobbefjord, West Greenland
391 Ludvig Forslund (2016) Development of methods for flood analysis and response in a Web-GIS for disaster management
392 Shuzhi Dong (2016) Comparisons between different multi-criteria decision analysis techniques for disease susceptibility mapping
393 Thirze Hermans (2016) Modelling grain surplus/deficit in Cameroon for 2030
394 Stefanos Georganos (2016) Exploring the spatial relationship between NDVI and rainfall in the semi-arid Sahel using geographically weighted regression
395 Julia Kelly (2016) Physiological responses to drought in healthy and stressed trees: a comparison of four species in Oregon, USA
396 Antonín Kusbach (2016) Analysis of Arctic peak-season carbon flux estimations based on four MODIS vegetation products
397 Luana Andreea Simion (2016) Conservation assessments of Văcărești urban wetland in Bucharest (Romania): Land cover and climate changes from 2000 to 2015
398 Elsa Nordén (2016) Comparison between three landscape analysis tools to aid conservation efforts
399 Tudor Buhalău (2016) Detecting clear-cut deforestation using Landsat data: A time series analysis of remote sensing data in Covasna County, Romania between 2005 and 2015
400 Sofia Sjögren (2016) Effective methods for prediction and visualization of contaminated soil volumes in 3D with GIS
401 Jayan Wijesingha (2016) Geometric quality assessment of multi-rotor unmanned aerial vehicle-borne remote sensing products for precision agriculture
402 Jenny Ahlstrand (2016) Effects of altered precipitation regimes on bryophyte carbon dynamics in a Peruvian tropical montane cloud forest
403 Peter Markus (2016) Design and development of a prototype mobile geographical information system for real-time collection and storage of traffic accident data
404 Christos Bountzouklis (2016) Monitoring of Santorini (Greece) volcano during post-unrest period (2014-2016) with interferometric time series of Sentinel-1A

405 Gea Hallen (2016) Porous asphalt as a method for reducing urban storm water runoff in Lund, Sweden

406 Marcus Rudolf (2016) Spatiotemporal reconstructions of black carbon, organic matter and heavy metals in coastal records of south-west Sweden

407 Sophie Rudbäck (2016) The spatial growth pattern and directional properties of *Dryas octopetala* on Spitsbergen, Svalbard