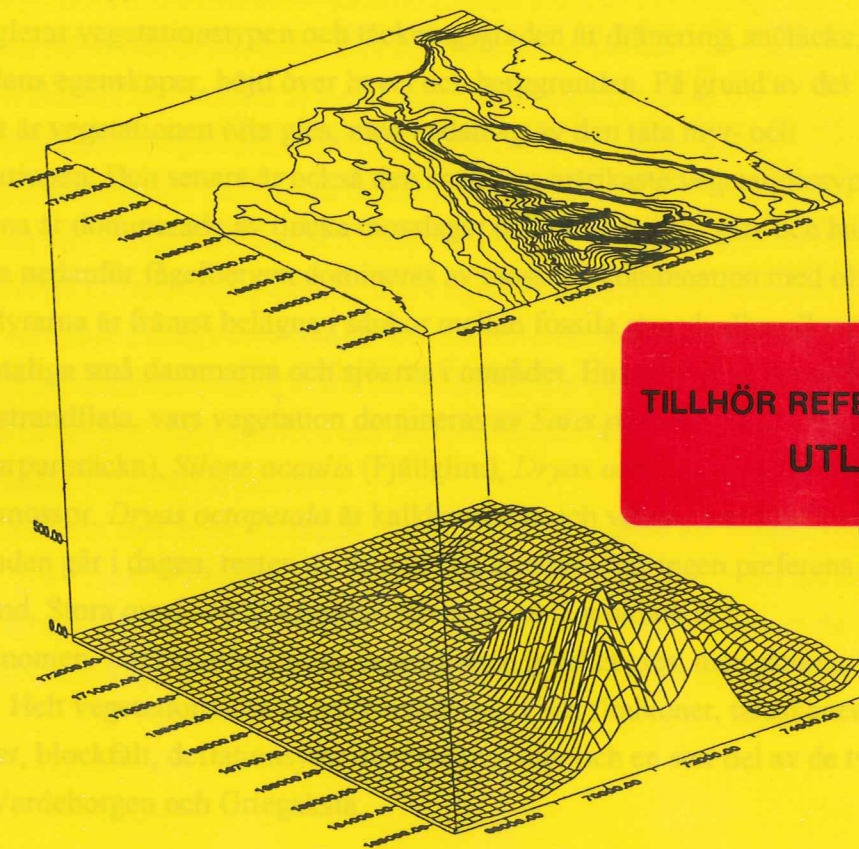


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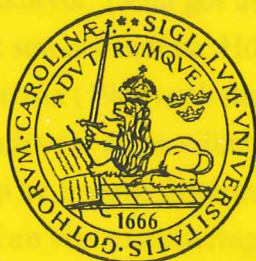
**A vegetation map and a Digital Elevation Model over
the Kapp Linné area, Svalbard**

-with analyses of the vertical and horizontal distribution of the vegetation



TILLHÖR REFERENSBIBLIOTEKET
UTLÅNAS EJ

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Sammanfattning

En vegetationskarta och en digital höjdmmodell har gjorts över ett 54 km² stort område beläget på Svalbards västkust, vid Isfjorden. Vegetationskartan är baserad på flygbilder och en undersökning gjord i fält under juli månad 1994. Systemet som användes vid klassificeringen av de olika vegetationstyperna är utarbetad av Elven et al. (1990) för en liknande studie i Gipsdalen på Svalbard. Vår vegetationskartering resulterade i en karta i skala 1:14 000, med 20 vegetationsklasser och med en total noggrannhet på 61,3%. Kartan digitaliserades och finns nu presenterad i denna uppsats i skala 1:40 000.

Faktorer som reglerar vegetationstypen och täckningsgraden är dränering, snötäcke, exponering, jordens egenskaper, höjd över havet och berggrunden. På grund av det hårda arktiska klimatet är vegetationen ofta gles, med undantag av den täta myr- och fågelbergsvegetationen. Den senare är också den i särklass artrikaste vegetationstypen på Svalbard. Myrarna är dominerade av tjocka mosslager och olika sorters gräs och halvgräs, medan områdena nedanför fågelbergen domineras av mossor i kombination med olika perenna örter. Myrarna är främst belägna i sänkor mellan fossila strandvallar eller runt kanterna på de otaliga små dammarna och sjöarna i området. En stor del av området består av en väl dränerad strandflata, vars vegetation domineras av *Salix polaris* (Polarvide), *Saxifraga oppositifolia* (Purpurbräcka), *Silene acaulis* (Fjällglim), *Dryas octopetala* (Fjällsippa) och olika lavar och mossor. *Dryas octopetala* är kalkberoende och växer i området främst där dolomitberggrunden går i dagen, resten av de nämnda arterna visar ingen preferens för någon särskild berggrund. Stora områden är karakteriserade av polygonmark och frostsorтерingsfenomen. I dessa områden är vegetationen mycket gles, men samma arter som ovan dominerar. Helt vegetationslösa är havsstränderna, vissa flodkoner, taluskoner, vissa gelifluktslober, blockfält, deflationsytor, recenta moräner och en stor del av de två bergsryggarna, Vardeborgen och Griegaksla.

Den digitala höjdmodellen framställdes med hjälp av en metod som utvecklats av Eklundh och Mårtensson (1994). Metoden är en förenkling av datainsamlingen till digitala höjdmodeller. Höjddata digitaliseras in i form av punkter i ett regelbundet nät istället för höjdkurvor. Detta gör att digitaliseringen går betydligt snabbare än annars, men resultatet blir i stort sett det samma. Höjddatan erhöles från tre olika kartor, av vilka två var gjorda av Åkerman (1980) och den tredje erhöles från Norskt Polarinstitut. Sju olika interpoleringar testades för att se vilken som passade området bäst. Fyra av interpoleringarna gjordes med hjälp av Inverse distance interpolering och tre med hjälp av Kriging interpolering, var och en med en viss modifiering av parametrarna men med samma höjddata. Resultatet utvärderades med hjälp av 125 slumpvis utvalda punkter. Den bästa höjdmodellen erhöles med Inverse distance interpolering, där sökfönstret hade en storlek av 6 x 6 pixlar och viktningen hade

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satts till 2, dvs punkter som ligger nära den punkt som ska interpoleras ges större inflytande än de som är belägna längre bort. Den resulterande höjdmodellen hade en upplösning på 50 m i horisontal planet och 2 m i vertikal planet.

Höjdmodellen kombinerades med vegetationskartan och några analyser av vegetationens vertikala och horisontella utbredning gjordes. Varje vegetationsklass analyserades var för sig för att få reda på deras respektive preferenser med avseende på aspekt, lutning och höjd över havet.

Resultatet visade att en av de viktigaste begränsande faktorerna var lutningen. De flesta vegetationsklasserna återfanns i områden med en sluttninggradient på mindre än 5°.

Antagligen beror detta på att jorden på sluttningar med högre gradient än 5° är så instabil att växterna har svårt att finna fäste.

Analyserna av aspekten visade att de flesta vegetationsklasserna föredrog aspekter mellan 225 och 315° (SW-NW). Nästan ingenting växte i aspekter mellan 90 och 225°, med undantag av två klasser: Vegetation vid sent framsmälta snölegor och Våt mosstundra med frosthävning/frostsortering, och dessa två klasser karaktäriseras av ett mycket glest vegetationstäckte.

Det mesta av vegetationen föredrog att växa på lägre höjd än 100 m, men under fågelbergen kunde den växa ända upp till 350 m över havet.

Abstract

A vegetation map and a Digital Elevation Model has been generated over a 54 km² area situated at the western coast of Svalbard, at the Isfjorden fiord. The map is based on aerial photographs and a field survey made during the summer of 1994. The classification system used is described by Elven et alia (1990), for a similar study in Gipsdalen in the inner part of Isfjorden. The classification of the vegetation in our investigation area resulted in a map in scale 1: 14 000, with a reliability of 61,3% and with 20 vegetation classes. The map was digitized and presented in scale 1: 40 000.

The two most widespread classes are type 113* - Exposed gravelly ridges with *Salix polaris*, and type 142 - Early snowbed/snowflush vegetation with *Salix polaris*. In areas with dolomitic bedrock, *Dryas octopetala* is frequent (type 112). Large areas are characterized by patterned ground and other frost sorting phenomena (type 112a*, 113a*, 226). The poorly drained sites have a thick moss layer and an abundance of grasses (type 222), while the areas below the birdcliffs are dominated by mosses and perennial herbs (subgroup 16).

The DEM was generated using a method developed by Eklundh and Mårtensson (1994). The method is based on point sampling in a regular grid. The data was obtained from three maps, two of them made by Åkerman (1980) and the third one from a preliminary print from Norskt Polarinstitut. Seven different interpolations were tested using the Inverse distance and Kriging methods, with a slight modification of the parameters. The best interpolation was achieved using Inverse distance with a search-window of 6 x 6 pixels and a distance weight of 2. The resulting DEMs had a resolution of 50 m in the horizontal plane and 2 m in the vertical plane.

The DEM was combined with the vegetation map and some analyses of the vegetation were made, considering the preferred aspect, slope angle and elevation.

The results showed that most of the plants grew at angles less than 5 degrees and at aspects between 225 - 315 degrees (SW - NW). Hardly any vegetation was growing in the interval between 90 and 225 degrees (E - SW). Most of the vegetation preferred to grow beneath the 100 metres level. However, beneath the birdcliffs, vegetation could survive up to about 350 metres above sea level, 220 metres higher than elsewhere in the area.

Preface

This paper is the project part (NGE 107, 20 credits) of two Masters of Science. The project was carried out at the Department of Physical Geography, University of Lund.

Terése Josefsson has written chapters: 1.2, 2, 3, 4, 5.3, 5.4, 5.5, 6.2, 6.3, 8, 9, 10.2, 11.2, 11.3.
Ingrid Mårtensson has written chapters: 1.1, 2, 5.1, 5.2, 5.6, 6.1, 7, 10.1, 11.1.

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1. Introduction

1.1 An outline of earlier vegetation studies on Svalbard.

The plantlife of Svalbard has for over a century been subject to a number of scientific investigations. In the beginning the aim was mostly to provide a pure description of all the plants found. Lists of species were made for example by Nathorst (1871) and by Resvoll-Holmsen (1920). Scholander (1934) made an attempt to group the different plant species after their growth habitat. Six classes were incorporated in his classification, namely shore vegetation, tundra vegetation, moving soil vegetation, marsh vegetation, aquatic habitats and cliff vegetation. Nowadays the vegetation is grouped into different plant communities and a large number of maps covering different parts of Svalbard have been produced using this context (see eg Brattbakk 1981-1985 and Thannheiser 1992). Four different classification systems have been used in describing the vegetation of Svalbard.

The first one is the phytosociological approach where the vegetation types are defined after some characterizing species (eg Eurola 1971, Thannheiser 1977 & 1992 and Thannheiser & Hofmann 1977). However, this classification shows some disadvantages when applied to arctic vegetation. One problem is the low number of species compared to the number of habitats which makes it hard to find one species that is unique to one particular habitat. Another problem is the decreased competition among the plants at these latitudes. Many species show a much wider ecological distribution and are no longer characteristic of a specified habitat as they might be further south. The instability of the ground also complicates the application of the classification just as the fact that it has not yet been applied to all kinds of vegetation found in the arctic region (Elven et alia 1990).

The second classification system is the series approach, where the vegetation is divided into the heath, meadow and mire series (eg Brattbakk et alia 1976). This approach is mainly used in Scandinavia and thus less suited for the arctic region.

The third classification system is the modified series approach, which for example has been applied in Gipsdalen (Elven et alia 1990), which is an area close to our investigation area. This approach is used in this paper. It is based on the series approach but the big difference is that this new classification is hierarchical and differentiates the flora according to major differences in habitats and floristic composition. This classification has several advantages compared to the series approach. Beside the fact that it is hierarchical and takes into account

both different habitats and floristic composition, it also opens for the possibility of adding new vegetation types without any significant change in the structure (Elven et alia 1990). Finally, there is a classification system developed by Rønning (1970). In this system the 162 vascular species found on Svalbard have been grouped into high-, middle- and low arctic elements, and a widely distributed element. The high arctic group consists of plants that occur only on Svalbard and not on the northwest European mainland. The middle arctic element includes species which are all common on Svalbard but have a more limited distribution in Scandinavia. The last two groups contain plants with a wide distribution both on Svalbard and in Scandinavia.

1.2 Remote sensing and Geographical Information Systems

Remote sensing and Geographical Information System (GIS) are tools which undergo quick technological development, in the area of physical geography. Through these methods mapping and analysis can be done much more quickly, large areas can be analysed with less effort and areas that were quite impossible to deal with, because of their remoteness or inaccessibility, can now be surveyed. Remote sensing and GIS are thus good tools with many advantages, but when using them you will soon learn about their limits. Transmission of printed data (for example maps) to digital pictures can be a quite time consuming and tiring work. There are three methods: scanning, manual digitizing and line following, of which scanning and manual digitizing are the most common. The advantage of scanning is that you can quickly and with high accuracy transmit your data to digital form, but the disadvantage is that you then have to edit the data to obtain the important information, and this can be very time consuming. Manual digitizing on the other hand is a slow way to transmit data, but it has one great advantage: you can choose what information to digitize in advance. This means that you have to spend less time editing the data afterwards. Which method to choose therefore depends on the circumstances and the amount of data. The third method, line following, is a semi-automatic way to digitize contour lines. It needs initial manual setting of the cursor at the beginning of the line that should be digitized and attendance if an ambiguity should arise. This method is however costly and has limited reliability. The results obtained are not more reliable than those obtained from manual digitizing (Tuladhar and Makarovic 1988).

2. The aim of the study

The aim of this paper was to produce a DEM and a vegetation map covering a small coastal area at Isfjorden on western Spitsbergen. This area has for some decades been subject to

studies concerning periglacial processes and geomorphology, made by students and scientists from the Department of Physical Geography in Lund (for example Åkerman 1980). The vegetation map was based on airphotos and classified according to a system described by Elven et alia (1990). By combining the DEM and the vegetation map some analyses of the vegetation types were made.

3. Description of the area

3.1 Brief description of Svalbard

The investigation area is situated on West Spitsbergen, the biggest and most important island in the archipelago of Svalbard. Other main islands are Nordaustlandet, Edgeøya and Barentsøya. The archipelago, whose positions fall roughly between 74° N, 10° E in the southwest corner and 81° N, 25° E in the northeast, are all surrounded by the Arctic ocean.

Svalbard belongs to Norway since 1925 and the largest urban settlement is Longyearbyen where mostly Norwegians live. Nearly half of the population are Russians living in two coalmining villages, Barentsburg and Pyramiden.

Almost all human activity is concentrated to the western parts of Spitsbergen in the area of the Isfjorden fiord, where the climate is warmer than elsewhere on the islands. The most important industry is coalmining which is concentrated to the area round the Isfjorden fiord. (Nationalencyklopedin no.17)

The large-scale features of the geology of Svalbard are comparatively simple. The oldest formations include Precambrian, Cambrian and Ordovician deposits and are found along the west coast of Spitsbergen. These have been folded and metamorphosed during the Caledonian orogeny (Hecla Hoek). Devonian deposits are found between Isfjorden and the north coast of Spitsbergen in a downfaulted area. In these stratas there are excellently preserved fossils of primitive fishes. Rocks of Carboniferous and Permian origin are dominant in the inner parts of Isfjorden, in a stripe east of Hecla Hoek and in the northeastern parts of Spitsbergen. Mesozoic deposits are found on the east coast of Spitsbergen, north of Isfjorden and are completely dominating Edgeøya and Barentsøya. The youngest rocks are of Tertiary age and are found chiefly in the central, southern parts of Spitsbergen. These stratas are of economic importance since they contain coal seams. Beautiful fossils of leaves and twigs can be found in the Tertiary rocks. (Hisdal 1976). The topography carries strong evidence from the last glacial period and a large part of Svalbard is still covered with glaciers. The accompanying land elevation has created vast strandflat areas and a landscape of deep fiord valleys. (Nationalencyklopedin no.17)

To get an overall picture of the vegetation of Svalbard the map prepared by Brattbakk (1986) is very suitable. Four vegetation zones are discerned on this map; *Cassiope tetragona* zone,

Dryas octopetala zone, *Salix polaris* zone and *Papaver dahlianum* zone. The last two zones are mostly found on Nordaustlandet, Barentsøya and Edgeøya, while the other two dominate the western parts of Svalbard.

The investigation area is situated on the western part of Spitsbergen (Fig. 1), facing Isfjorden northwards and the Arctic ocean westwards (limits: 78° 04' N, 13° 38' E (Kapp Linné), 78° 01' N, 13° 38' E, 78° 06' N, 13° 52' E (Kapp Starostin) and 78° 01' N, 14° 03' E (Åkerman 1980)).

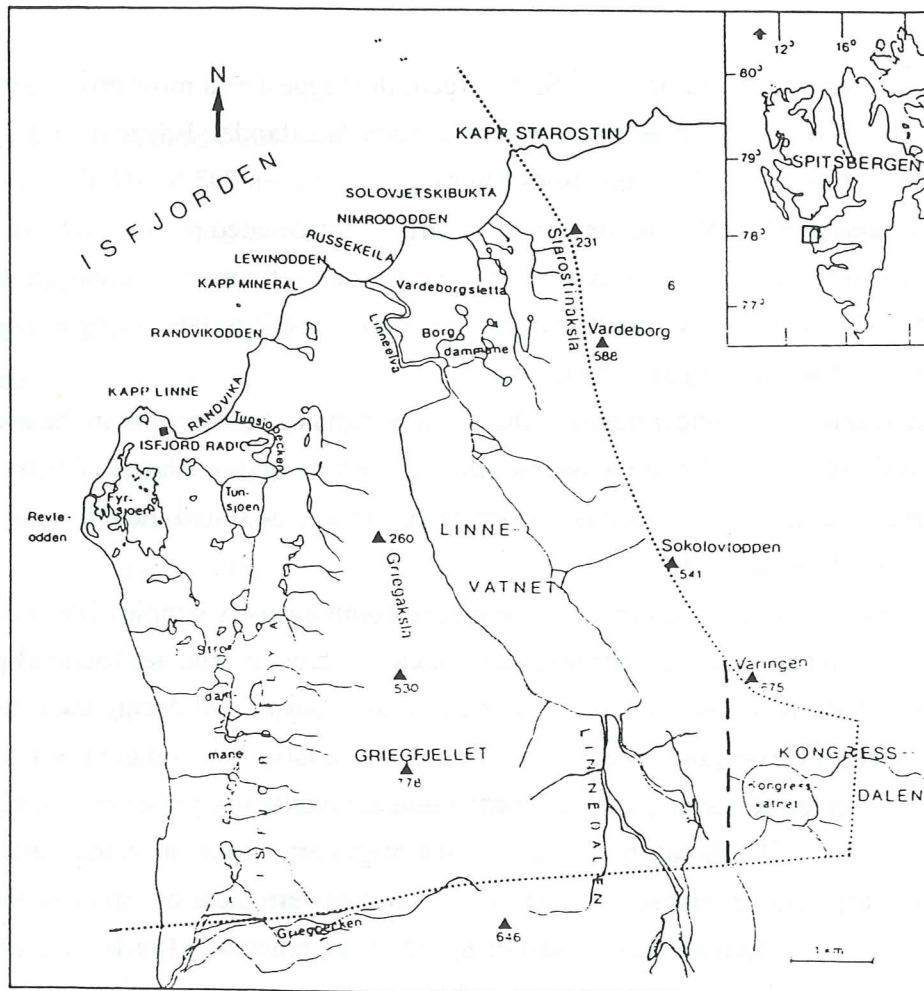


Fig.1 The investigation area. Note that the area around lake Kongressvatnet is not included in our study. From Åkerman 1993.

3.2 An outline of the vegetation

According to a map prepared by Brattbakk (1986) where the vegetation regions of Svalbard are shown, the western part of the study area lies in the *Dryas octopetala* zone, while the area

east of Lake Linnévatnet belongs to the *Cassiope tetragona* zone (fig.2). These two zones are part of the mid arctic region. The Griegaksla mountain ridge contains two zones which belong to the high arctic region; *Salix polaris* zone and *Papaver dahlianum* zone. This seems to agree fairly well with our investigation, with the exception that almost no stands of *Cassiope tetragona* were found. In addition, *Salix polaris* seemed to be a ubiquitous species and the most frequent plant found in the *Dryas octopetala* zone as well as in the *Cassiope tetragona* zone.

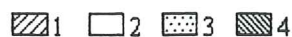
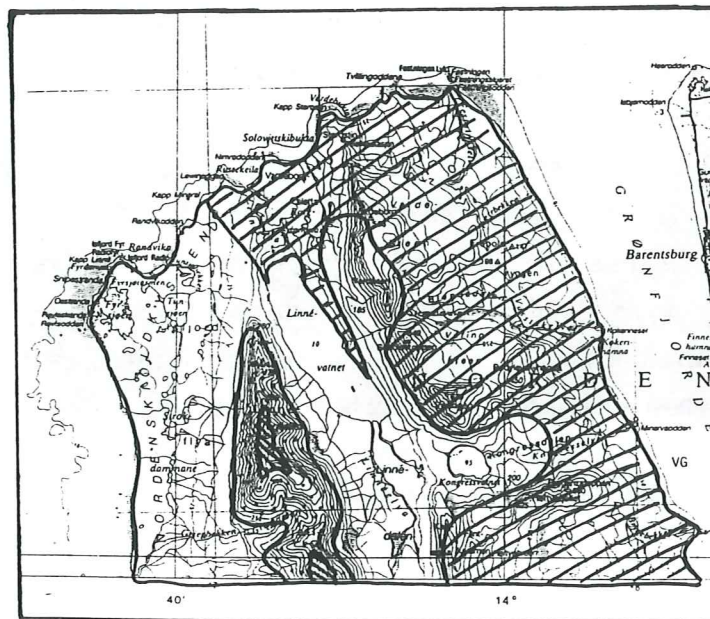


Fig.2 Map showing the different vegetation regions according to Brattbakk. 1. *Cassiope tetragona* zone, 2. *Dryas octopetala* zone, 3. *Salix polaris* zone, 4. *Papaver dahlianum* zone.

3.3 The topography/geomorphology

The topography of the area is quite simple. The main features are a vast flat area (in west and north-east) with numerous small lakes and ponds scattered over it, and two mountain ridges which abruptly rise from the plain and surround the eastern part of the area with Lake Linnévatnet (fig.3 and 4). On a closer look one notices that the terrain on the plain has plenty of small-scale topographic variations due to a number of ridges, caused by a succession of raised beaches and the bedrock. The lowest of the beach ridges is about 6 metres and the highest about 60 metres above today's main sea level (Åkerman 1980). Between the beach ridges several ponds and bogs have formed. There is also a fault line heading north across the

plain. It is not impressive, but in some places it reaches some 6 metres (Åkerman 1980). Along the western side of this faultline water has collected and formed a number of lakes. The coastline to the west is gentle, in contrast to the one facing the Isfjorden fiord, which in some areas rises abruptly some ten metres or more.

The eastern part of the area is a glacial valley, dominated by Lake Linnévatnet (the second largest lake of Svalbard) which covers almost the entire valley floor. It is 4.5 km long and 1.3 km wide (Åkerman 1980). The margins of the lake are in most places steep, especially on the western shore where the talus cones of the Griegaksla mountain reach the margin of the lake. The southern end is more gentle, as it is built up of deltaic deposits and modified morain deposits, which have been eroded by melt-water and icings.

The two mountains, Griegaksla and Vardeborgen are quite different in appearance, due to differences in geology. Griegaksla is steep and has a sharp profile with arêtes and horns. The highest peak of Griegaksla is 778,0 m (Norsk polarinstitutt). Vardeborgen (which is barely included in our work) has a much smoother appearance. Its western slope is very steep, whereas the eastern slope is quite gentle. Vardeborgen never reaches the heights of Griegaksla. Its highest peak is 587,7 m (Norsk Polarinstitutt).



Fig.3 Vardeborgsletta seen from the birdcliffs on the Starostin/Vardeborgsaksla mountain ridges. On the left, Griegaksla and Linnévatnet. (Photo: T. Josefsson)



Fig.4 The Griegaksla mountain ridge and the coastal plain facing the Arctic ocean. (Photo: T.Josefsson)

3.4 Geology

The investigation area lies within two different rock formations: one older, metamorphosed, the Hecla Hoek, and one younger consisting of unaltered sedimentary rocks (fig. 5). The Hecla Hoek formation, which build up the whole western plain and Griegaksla, consists of sedimentary rocks (conglomerate, schists, quartzites, dolomites, limestones and tillites) of Precambrian-Ordovician origin. These have been folded and metamorphosed during the Caledonian orogeny and have given rise to the rugged mountain chains of the west coast. The eastern part of the investigation area, including Vardeborgen, is made of sedimentary rocks of Carboniferous origin. This strata are very rich in marine fossils. Around Lake Linnévatnet sandstone is dominating, followed by limestone and marlstone on Vardeborgssletta and Vardeborgen. (Norskt Polarinstitut 1994).

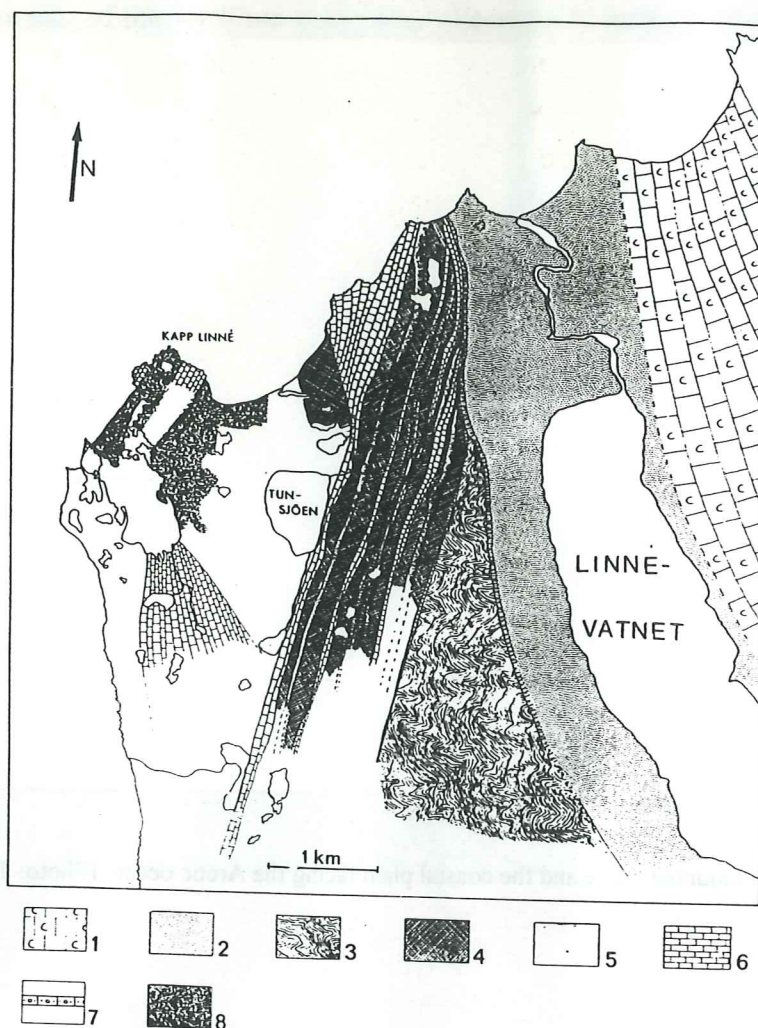


Fig.5 Geological map of the north-western parts of the area. 1. Cyathophyllum limestone (middle Carboniferous), 2. Sandstones (Culm), 3. Phyllites (Hecla Hoek), 4. Schists (Hecla Hoek), 5. Quartzites (Hecla Hoek), 6. Dolomitic limestone (Hecla Hoek), 7. Conglomerate (Hecla Hoek) and 8. Tillites (Hecla Hoek). (Åkerman 1980)

3.5 Hydrology

As already mentioned, the area is dotted with shallow lakes, extending to a few metres depth (except Lake Linnévatnet). There are also quite a number of small streams which originate from the perennial to semi-perennial snowpatches on the slopes of Griegaksla and Vardeborgen. The streams and lakes on the western plain seem uncomplicated, that is, they simply convey the water from the hillside to the sea. On Vardeborgsletta the hydrology is not that simple, some lakes actually lack outlet and some streams disappear into sink-holes (Åkerman 1980). The complicated hydrology found here is caused by karst phenomena, developed in the limestone which underlies the morain (Salvigsen & Elgersma 1985).

There is one fairly large stream worth mentioning, Linnéelva. It originates from the southern end of the valley, where it begins as melt-water from the small valley glacier, Linnébreen. On its way to Linnévatnet it gets supply from melting icings and some small lakes. The icings in turn get their water from springs which are subterranean outlets from the lake Kongressvatnet (another example of karst morphology). The Linnéelva stream continues at the northern end of Lake Linnévatnet, where it has cut through the sediments to form a canyon, which has its outlet in Isfiorden.

3.6 The climate

Svalbard has a polar tundra climate according to the Köppen system. The warmest month has an average temperature above 0 °C but below + 10 °C. The inflow of solar energy depends on the length of the day (Tab.2). The perpetual polar day is characteristic of areas at altitudes beyond the arctic circle, but because the sun is never very high above the horizon, the inflow of solar radiation restricts the growing season. Much of the sunlight is also reflected by ice and snow. The Arctic is one of the cloudiest regions of the world (Martyn 1992), thereby reducing the amount of direct sunlight reaching the ground.

The area lies within the continuous permafrost zone and the depth of the active layer varies from a few decimeters to almost two meters. Table 1 shows the mean and maximum extension of the active layer for sites with different soil characteristics.

Tab.1 The mean and the maximum depth of the active layer at different sites, for the period 1972 - 1994. After Åkerman 1995 in prep.

Site characteristics	Elevation	Active layer mean	Active layer max
Raised beach ridges	8 m	1,93 m	2,26 m
Active beach	4 m	1,20 m	1,61 m
Mosstundra	9 m	0,38 m	0,55 m
Ice and soil wedges	8 m	1,08 m	1,27 m
Sorted net surface	6 m	0,91 m	1,11 m
Sorted nets (small scale)	11 m	1,04 m	1,27 m
6° slope with small sorted steps	12 m	1,02 m	1,17 m
Raised beach ridges with soil wedges	19 m	0,88 m	1,12 m
High deflation surfaces	59 m	1,07 m	1,21 m
Deflation surfaces with Dryas	23 m	1,15 m	1,37 m

The annual air temperature is -4.9°C (1912-1994) with July being the warmest month and March the coldest (Fig. 7).

The study area is maritimately influenced which is reflected in the fact that Kapp Linné has higher mean annual air temperature than the more centrally located Longyearbyn, which has a annual mean of -5.8°C for the period 1957-1976 (Det norske meteorologiske institutt, 1982). The Gulfstream creates a warmer climate than would normally be found on these high latitudes. Figure 6 shows the annual air temperature at Kapp Linné for the last 48 years. Also to be taken into account is the well-developed and highly differentiated atmospheric circulation (Martyn 1992). During wintermonths the Arctic areas are dominated by two high pressure centras, the Asian high and the Canadian high with a col crossing the Arctic ocean linking them together. Cyklogenesis occur southeast of Greenland, The Icelandic low with a col heading northeast up to Novaja Zemlja, and at the Aleutian islands between Alaska and northeast Siberia (Aleutian low).

During the summer the intense heating of Asia and North America (especially above Baffin Island) causes low pressure centres to form above them. It should be noted that the cyklon activity is much less strong and less frequent than in the winter. The Icelandic low is weakened and the Aleutian low is broken up. Anticyklones develop above Greenland, north of Alaska and above the sea between Svalbard and Novaja Zemlja

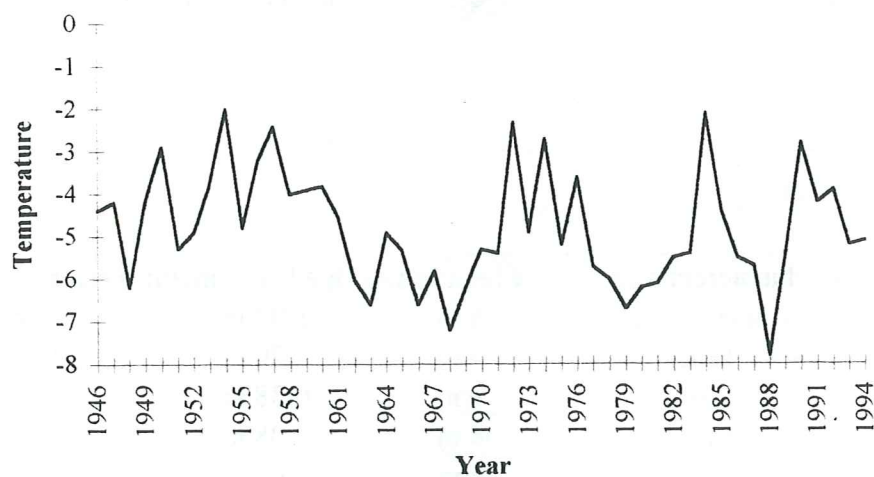


Fig.6 Annual air temperature ($^{\circ}\text{C}$) at Kapp Linné, 1946 - 1994. The last 19 years measurements are made at an inofficial record station maintained by the department of Physical Geography in Lund. Data after Åkerman (1980).

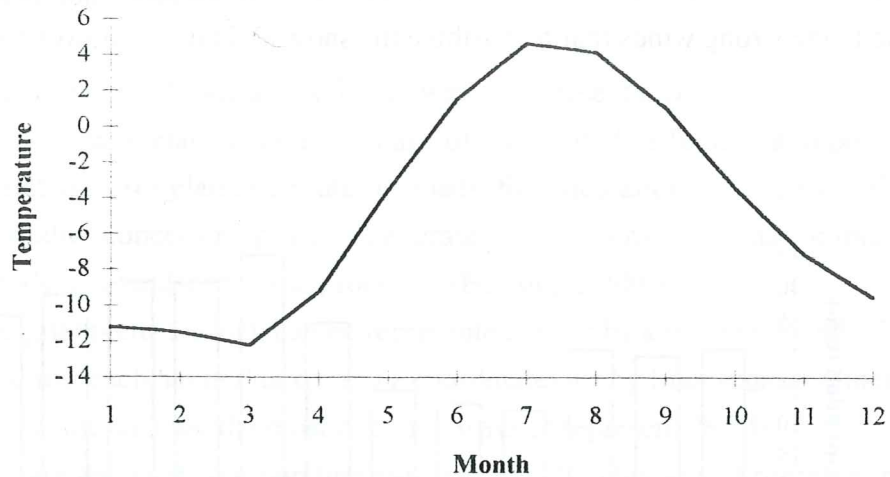


Fig.7 Mean monthly air temperature (°C) at Kapp Linné of the period of 1912 - 1991. Åkerman (1993).

The annual precipitation on Svalbard varies between 300-600 mm (Fig.8) with a mean of 400 mm for Kapp Linné for the period 1934-1975 (more recent measurements have not been recorded due to the fact that the meteorological station at Kapp Linné no longer exists. Today the measurements are made at the airport close to Longyearbyn). These are relatively high figures compared to most polar stations which receive less than 200 mm annually (Ahrens 1991).

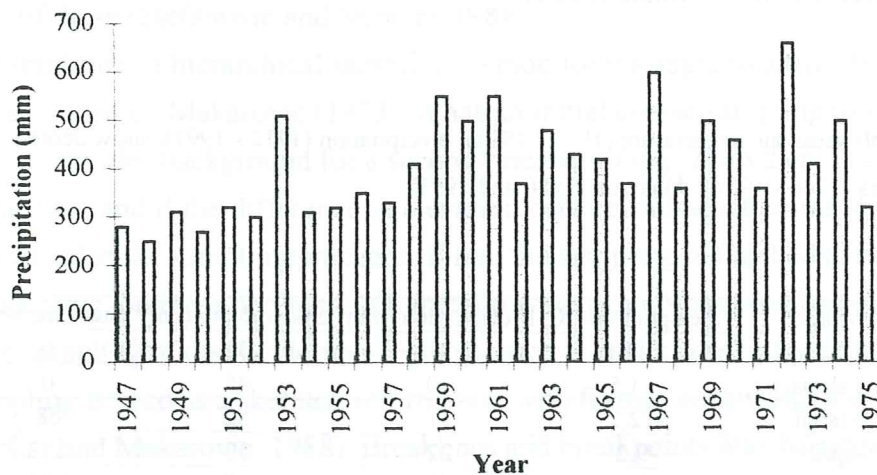


Fig.8 Annual precipitation at Kapp Linné, 1947 - 1975. Åkerman (1980).

Because of the low evaporation rates, moisture is sufficient. Relative humidity is often above 90 % (Martyn 1992). The wettest period is July to December, while the driest is the spring months from April to June (Fig.9). A large part of the precipitation falls as snow. The area is

normally snowcovered from late September to late May (Tab.2). The snow cover can be very uneven due to the strong winds that redistribute the snow and favour snowdrifts in sheltered positions.

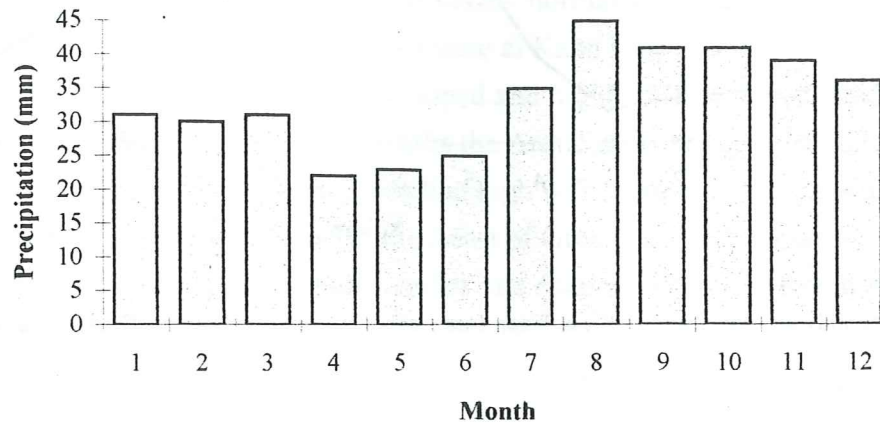


Fig.9 Mean monthly precipitation (mm) at Kapp Linné of the period 1912 - 1991. Åkerman (1993).

The wind climate is simple; the winter is dominated by northeasterly winds, while the summer experiences both southwestern and northeastern winds. Katabatic wind systems can however alter the wind climate locally.

Tab.2 Monthly mean air temperature (1912 - 1991), precipitation (1912 - 1991), snow depth (1946 - 1965) and sunshine hours (1946 - 1974). Åkerman (1980 and 1993).

Month	Temperature °C	Precipitation (mm)	Snow depth (cm)	Sunshine hours
January	- 11,2	31	32	0
February	-11,5	30	45	0
March	-12,2	31	52	68
April	-9,2	22	53	212
May	-3,5	23	37	230
June	1,6	25	13	161
July	4,7	35	0	151
August	4,2	45	0	142
September	1,1	41	0	63
October	-3,4	41	5	10
November	-7,1	39	12	0
December	-9,5	36	23	0

4. Digital Elevation Models

DEMs, Digital Elevation Models, is a digital way to represent a continuous variation of relief over space. DEMs have many uses: for storage of elevation data for digital topographic maps in national databases; for planning routes of roads; for calculations of slope length, slopes and aspect etc in studies concerning physical geography; or for obtaining data for image simulation models of landscapes and processes (Burrough 1986).

A DEM is a digital picture which can be represented either by a mathematically defined surface, by points, each having its x,y and z coordinates, or by lines (contour lines, profiles). In GIS points or line data are the most common ways to represent DEMs.

Contour lines, are the most common line model of DEMs. This way of representing height values is, however not so suitable when you want to compute slopes aspects etc, so they are often converted into point models.

Point models are most often used as Altitude matrices, where point data are distributed as rectangles in a regular grid, each representing a height value. In raster based GIS the rectangles are called cells. The size of the cells is equal to the resolution of the image. This means that an object has to have at least the size of a cell to be shown.

There are basically three sources of data to DEMs: field surveys, photos or other images and existing maps. Since field surveys are comparatively expensive they are not so often used. The most popular sampling patterns are contours, profiles, grids, breaklines and points, and combinations of these (Stefanovic and Sijmons 1984).

Progressive sampling is a hierarchical sampling method for photogrammetric DEM generation, developed by Makarovic (1973). It has an initial coarse sampling followed by data analysis, which provides background for a second finer sampling. Then there is another analysis of the data, and if the difference in elevation between adjacent points still exceeds a certain threshold value the sampling proceeds, if not, the sampling is finished (Tempfli 1986). Composite sampling, on the other hand, is a method which combines progressive sampling with selective sampling of distinct terrain features, such as breaklines or breakpoints. The selective sampling is used as a skeleton information with fillings consisting of contour data or points (Tuladhar and Makarovic, 1988). Breaklines and breakpoints may be ridges, drainage lines or just abrupt changes in slope. Composite sampling may provide for substantial reduction of the sampling effort and increase comprehensiveness of the acquired data. Small but significant terrain features, which might otherwise be lost, are covered and redundancy of data can be avoided (Makarovic, 1977).

The accuracy of a DEM is strongly dependent on the data source. If the source is a topographic map, the map scale, the quality of the original survey and the cartographic presentation are of great importance (Stefanovic and Sijmons, 1984).

5. Interpolation methods

Interpolation is a way to estimate values between known points. The method can therefore be used if you want to fill gaps in measurements or to obtain a continuous surface from scattered points. The theory behind interpolation is that points close together are more likely to have similar values than points lying further apart.

The problem of interpolation is to find the best model for the data sample that one wishes to interpolate, because different methods can give very different results although derived from the same set of data. The following outline of interpolation methods is taken from Burrough (1986), Surfer for windows: users guide (1994) and Davis (1973).

5.1 Trend Surface Analysis

This method gives as a result a continuous spatial change that can be described by a smooth, mathematically defined surface.

Trend surface is a global technique, which means that local variations can not be shown. The idea behind the method is to fit the data points to a polynomial line or surface, either linear, quadric or cubic. By increasing the number of terms it is possible to fit any complicated curve exactly. It is, however, a smoothing method that should not be used if one wishes to emphasize the complexity of a curve or a surface. The advantage of trend surface is that it is a technique which is easy to understand and that it can be used to reveal trends in the data before using any other local interpolation method.

5.2 Thiessen Polygons

The theory behind this method is that the best information about an unvisited point can be derived from the data point nearest to it. This point will therefore be situated in the middle of each Thiessen polygon. The method is completely dependent on the spatial distribution of data points. If the points are regularly spaced all polygons will be equal, regular squares, and if irregular, an irregular lattice of polygons is the result. This method is often used when dealing with qualitative data. It has several drawbacks, first of all it is completely dependent of distribution of the sample points. Secondly, the value in each cell is estimated by only one sample. Thirdly, no consideration is given to the idea that points close together are more likely to be similar than points far apart.

5.3 Moving Averages

Moving average is a method that calculates an average value from local neighbour points. Which points to be included in the calculation is regulated by the size of the search-window. A narrow window emphasizes small-scale variations and a broad window gives the interpolation a smoothing effect.

Inverse distance weighted moving average is a specific type of this method, which gives more weight to points closer to the grid node: less distance = more influence. Weighting is assigned to data points through the use of a weighting power. As the power increases, the grid node value approaches the value of the nearest data point. For small powers the weights are more evenly distributed among the neighbouring data points.

Inverse distance can either be an exact or a smoothing interpolator. When it is used as an exact interpolator all observations that coincide with a grid node are given the weight of 1, all other observations surrounding it are given a weight of 0. This means that the grid node is given the value of the coincident observation. When used as a smoothing interpolator a smoothing parameter makes sure that no point observation is given an overwhelming weight. This smoothing parameter also prevents the generation of Bull's-eyes. This term used to describe a typical feature of Inverse distance, namely its tendency to generate images where the point data clearly can be seen as circular dots. Another disadvantage is that maxima and minima in the interpolated image can only occur at data points. The method is also time-consuming. The advantage with Inverse distance is that local anomalies can be accommodated.

5.4 Kriging Interpolation

Kriging is a geostatistical gridding method, which relies on a regionalized variable theory. A regionalized variable is a variable that varies from one place to another with apparent continuity. This theory assumes that the spatial variation of any variable can be expressed as the sum of three major components: 1) a structural component associated with a constant mean value or trend, 2) a random spatially correlated component and 3) a random noise or residual error term (Burrough 1986). This means that Kriging not only estimates the values of a spatially distributed variable, but also estimates the probable error associated with the estimates.

Kriging, like Inverse distance, gives more weight to points near the grid node than points further away. Kriging can also determine the distance where points no longer have any influence on the grid node, and this is called the Range (fig. 10).

Several factors are incorporated in kriging interpolation: the Variogram model, the Drift type and the Nugget effect. The variogram is used to determine the optimal size of the search window, the Range, but also how the weights should be applied (it can be derived from the slope of the curve: linear, quadric or cubic or any other). The shape of the search window can also be determined. Figure 10 is an example of a variogram. The x-axis represents the distance between the points in the sample and the y-axis represents the semi-variance, which is defined as:

$$\gamma(h) = (1/2m) \sum_{i=1}^m [z(x_i) - z(x_i + h)]^2$$

where $\gamma(h)$ is the semi-variance in the sample, h is the distance between pairs of points, z is the value of a single point (x_i) and m is the number of pairs of points. As the distance between points increases so will the expected difference in point values and thereby the semi-variance. The nugget is determined by the point where the graph crosses the y-axis and is a measure of the potential error in the interpolation. The sill is the distance beyond which values of the semi-variance are considered to be independent of one another. Drift type is used when you want to interpolate data which are unevenly dispersed or when you want to extrapolate beyond the limits of the data. By using this parameter Kriging becomes more of a smoothing interpolator.

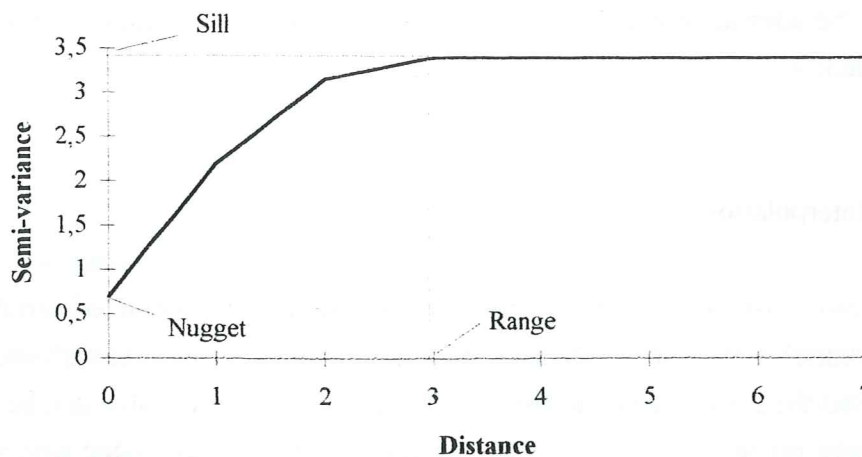


Fig.10 Example of a variogram showing the different terms associated with it. The x-axis represents the distance between the points in the sample and the y-axis represents the semi-variance. The nugget shows the potential error of the sample and the sill is the distance beyond which points are considered to be independent of each other. The range shows the optimal size of the search-window.

One problem with Kriging is that it can only use a single variogram for each interpolation. If the area is very heterogenous one single variogram may not be able to represent the spatial co-

variation in all parts of the area, and the interpolation may yield a poor result. One solution to this problem could be to generate different variograms for different areas. Other problems with Kriging is that the theory behind the method is difficult to understand and the computing takes long time and requires a lot of disk space. Apart from these drawbacks Kriging is the ideal interpolator which can even give an estimate of the possible error associated with each interpolation.

6. Materials and Methods

6.1 The vegetation

The study area consists of a flat area surrounding a steep mountain ridge, Griegaksla. Since no vascular plants or mosses were found on the Griegaksla mountain ridge above 100 m.a.s.l., this specific area was excluded. The area is the same as the one described in Åkerman (1980). Place names refer to the map Isfjorden, sheet B9, 1: 100 000, Norwegian Polar Research Institute, Oslo 1989.

The vegetation mapping is based on aerial photographs (Norwegian Polar Research Institute, filmtyp IR, 18-19/8-1990, scale 1: 15 000, S90 no 5935-5942, 5897-5902 and 6279-6287) and a field survey carried out between the 1-19 of July in the summer of 1994. The interpretation was made in conventional stereoscopes on transparent plastic sheets and was then transferred to an orthogonal projection in a zoom transfer scope (Bausch and Lomb) with the topographic map from Åkerman (1980) as a support, providing the coastline and lake contours. Only a blind interpretation was made, i.e. areas of the same colour, texture and topographic level were grouped together into different classes, but no attempt was made at this stage to relate these different classes to the vegetation types described by Elven et al (1990).

This classification is built on differences in altitude/latitude, vegetation density, drainage and/or substrate types, habitat types (defined by snowcover and soilwater) and floristically characterized vegetation types (Elven et al 1990). Table 3 shows the classification system. During the field survey we correlated the different classes of the blind map with the vegetation types in the field. A reinterpretation of the airphotos was necessary, where the multitude of small areas were reduced and where the different areas of the blind map were connected with the vegetation classes. The floras used in classifying the different plants were Svalbards flora (Rønning 1979) and Nordisk fjällflora (Nilsson 1986). Appendix 1 shows a list of the most important species that we found in the area. The last days of the field survey were devoted to evaluating the map. A grid of 1 x 1 km was overlaid on the map. 15 gridcells

were randomly chosen and all vegetation in these quadrants was checked. In these 15 gridcells all the vegetation classes were checked (511 discrete areas were checked).

Before the different groups and types are presented, a few words need to be said about the classification system. Since the classification system was developed for an innerfiord area, it was not fully applicable to our investigation area. Therefore we had to add five new classes.

A large part of the area studied consists of a dry closed heath vegetation dominated by *Salix polaris*. Other related species are *Saxifraga oppositifolia*, *Silene acaulis*, *Polygonum viviparum* and *Ranunculus nivalis*. Different kinds of lichens are also present. This type is described for example by Sjörs (Nordisk växtgeografi 1967, s 194) and by Rønning (Svalbards flora 1979, see polarviermark) and is assigned 113*.

Areas with ice-wedges or frost fissure polygons have been put into specific types. There are two kinds; polygons with *Dryas octopetala* and polygons with the same flora as the *Salix polaris* heath. The reason for this separation between type 112 (exposed gravelly ridges with *Dryas*) and polygons with *Dryas octopetala* (112a*) respectively between *Salix polaris* heath (113*) and polygons with *Salix polaris* heath vegetation (113a*) was to stress the different growth habitat of the heaths and the polygons. The plants are confined to the polygon furrows while the heaths show a more even plantcover. A new subgroup has also been added to group 5 (gravelly river fans). This new subgroup has been assigned 53* and includes fans with absolutely no vegetation. Finally, some areas were found at the outlet of the river Linnéelva which consisted of wellrounded stones (10 cm in diameter) covered with a thick mossmat. Since no class in the classification seemed appropriate for this stony shore (only shores with a finegrained or gravelly substrate were mentioned), a new subgroup, 73*, was added. These five new types have all been assigned to the appropriate groups and subgroups. The number combinations given to the new types are chosen so that they can be seen as a continuation of the system described by Elven et al (1990). The new types added have an asterisk after their number combination, indicating that these types are not present in the classification system of Elven et al (1990).

Tab.3 The classification system by Elven et alia (1990) with modifications marked with *.

A Lowland areas with more or less closed vegetation cover

Group 1 Well-drained sites

Subgroup 11	Exposed gravelly ridges with discontinuous vegetation cover
Type 112	Open <i>Dryas</i> type
Type 112a*	Polygons with <i>Dryas</i>

- Type 113* Open *Salix* type
- Type 113a* Polygons with *Salix*
- Subgroup 12 Dry closed heath vegetation
- Type 121a Closed *Dryas*- *Carex rupestris* type
- Subgroup 13 Warm, favourable slopes with closed, thermophilic vegetation
- Subgroup 14 Early snowbed and snowflush vegetation
- Type 142 *Salix polaris* type
- Subgroup 15 Late snowbeds
- Type 152 *Cerastium regelii* type
- Subgroup 16 Bird-cliffs

Group 2 Poorly drained sites

- Subgroup 21 Moss tundra
- Type 212 *Homalothecium* - *Salix* - *Dupontia* type
- Subgroup 22 Wet moss tundra
- Type 222 *Homalothecium nitens* - *Carex subspathacea* type
- Type 226 Frost upheaval
- Subgroup 23 Swamp tundra
- Subgroup 24 Swamp

B Lowland areas with open vegetation cover

Group 3 Very exposed, stable or eroded ridges

- Subgroup 31 Ridges with gravelly substrate
- Type 312 *Draba* - *Saxifraga* - *Cerastium arcticum* type
- Subgroup 32 Ridges with a silty substrate

Group 4 Sedimentaion flats with silty substrate

- Subgroup 41 Flats with more or less continuous vegetation
- Type 411 Dry *Polygonum viviparum* type
- Subgroup 42 Flats with discontinuous vegetation

Group 5 Gravelly river fans

- Subgroup 51 Fans with vegetation cover
- Subgroup 52 Fans with scattered plants
- Subgroup 53* Fans with no vegetation

Group 6 Recent moraines

Group 7 Seashores

- Subgroup 71 Salt/ brackish marshes on fine-grained substrates
- Subgroup 72 Gravel shores
- Subgroup 73* Stone shores **C and D Upland areas** (not treated in our paper)

6.2 Interpolation of the DEM

The DEM created was based on three topographic maps. Two of the maps were manually drawn, 1:10 000, with an equidistance of 2 m, made in an aviograph by Jonas Åkerman (1980). The third, covering Griegaksla mountain, was a preliminary print in scale 1:50 000 with an equidistance of 50 m, received from Norskt polarinstitut.

We used a method by Eklundh and Mårtensson (1995) to create the DEM. This method is easy to use and makes manual digitizing of relief much faster than any other common method, and it will still have almost as high accuracy. Instead of digitizing contour lines points are being digitized in the intersections of an equally spaced grid or as close as possible to the intersections (it has to be on a contour line - otherwise you cannot know the height of the point). When areas containing elements of varying complexity are being digitized, one can easily adjust the density of the points, just add some extra when the terrain is complex and omit some when it is simple. It is also possible to supplement the grid with points near breaklines in the terrain, to get an even better result (but this complement was not used in our case). The minimum size of the squares (the smallest distance between two digitized points on the map) is calculated by the formula:

$$D = CI \times \cot \alpha$$

where CI is the equidistance between the contour lines on the map and α is the average slope angle of the terrain. We decided to use a grid with a distance of 150 m between the intersections on the two maps in scale 1:10 000, and 100 m on the small one (1:50 000). This difference in size was due to the fact that the density of the contour lines was quite different on the two map types, the small one (1:50 000) covering a steep mountain ridge and the other almost level ground. The grids were drawn on transparent paper and were used as overlays on the maps when these were digitized. This made it easy for us to mark each point with a number. This number was later used to identify the point in the database, where we could connect it to its height value.

Before we started digitizing we had to calculate the coordinates of the boundary of the area, because the only coordinate we had was that of the lighthouse of Kapp Linné. All the others were either outside the area of interest, could not be found on the maps or gave insufficient accuracy (as in the case of the highest peak of Griegaksla). It took about five working days to digitize the maps. During this time approximately 3 500 points were digitized, covering an area of 54 km². Apart from this we also digitized all the other features of the maps, such as lakes, streams, bogs, icings, snowpatches, houses and the coastline. When this was done the three parts of the map were appended to each other.

The resulting map was interpolated, using different methods to see what results we could obtain. We started by testing Trend surface and Thiessen polygons, to see what these two rather simple methods could produce. But the results were so poor, based on a visual examination, that these methods were no longer pursued. Instead we decided to concentrate on Inverse distance weighted moving average and Kriging interpolation. Four different interpolations were made using Inverse distance weighted moving average, each having a modification: different size of the window (6, 8 and 12 pixels), or different distance weighting (1, equal weighting, or 2, inverse of the distance squared). The four interpolations were: 6,1; 6,2; 8,1; 12,1 (the first figure being the size of the window and the last being the distance weighting). The reason for not testing the combinations 8,2 and 12,2 was that both 6,1 and 6,2 gave a better result than 8,1 and 12,1, both visually and statistically (tab.6 and appendix 2). We also made several interpolations with Kriging, and of these we kept three. Two of them were made through interpolation of the whole area based on linear variograms (fig.11), and one of them also had linear drift to see if there could be a trend in the data (the area showed a tendency to slope upwards towards east). The third was made by dividing the area into two parts, one covering Griegaksla mountain (fig.13) and one the plain surrounding it (fig.12), and then interpolating each with Kriging interpolation based on variograms made specially for each of these areas. This meant that the plain was interpolated with linear Kriging, and the mountain with exponential. The two interpolations were then appended to each other and evaluated the same way as the others. The variograms are shown in figure 11 to 13.

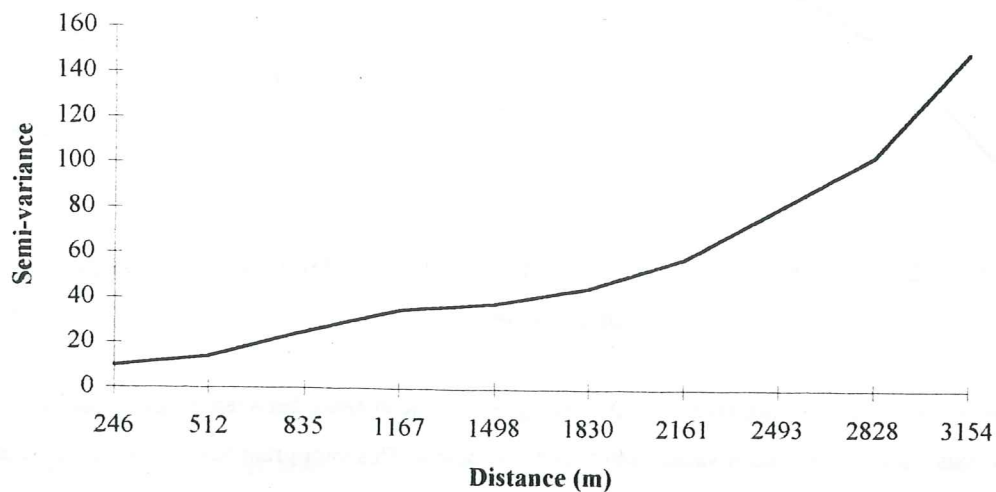


Fig.11 Variogram of the whole area. The X-axis represents the distance between the points in the sample and the Y-axis represents the semi-variance between two points. As seen in the variogram, no sill can be specified.

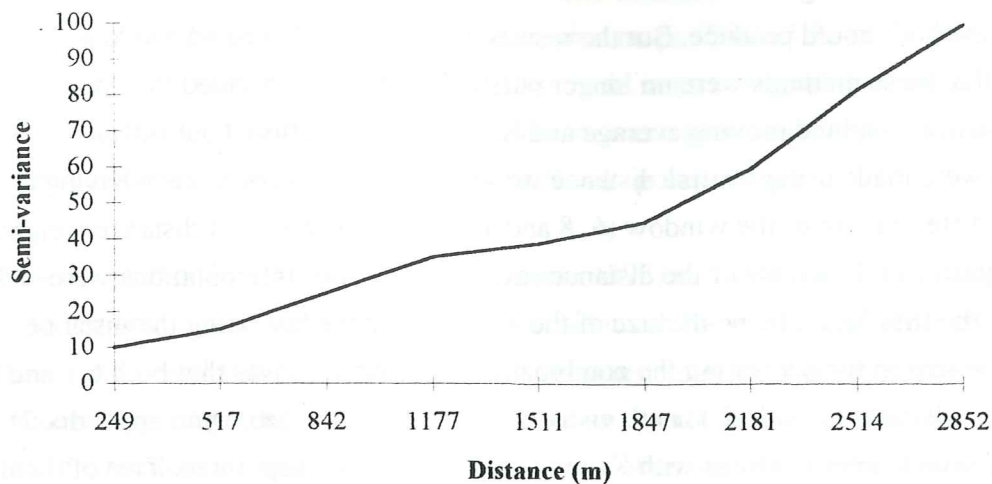


Fig.12 Variogram of the plain. The X-axis shows the distance between the points in the sample and the Y-axis shows the semi-variance between two points. No sill can be found.

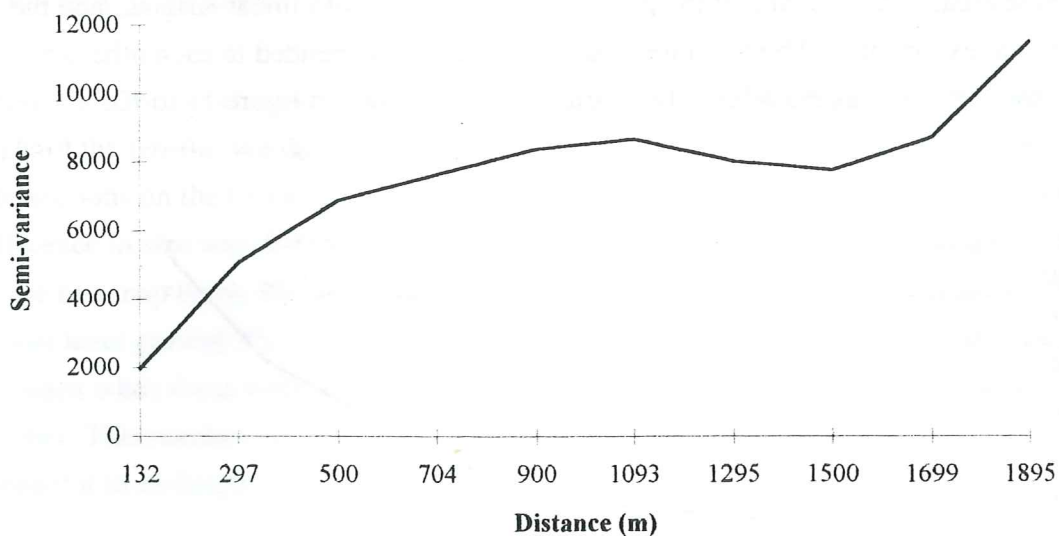


Fig.13 Variogram of the Griegaksla mountain. The X-axis represents the distance between the points in the sample and the Y-axis represents the semi-variance between two points. This variogram has a sill at approximately 700 m.

For the evaluation we randomly sampled 125 points on the maps. These points were digitized and compared with the corresponding points on the interpolated images. The differences between the interpolated images and the truth were calculated and shown statistically.

The result was seven Digital Elevation Models (DEMs) made as altitude matrixes, with a resolution of 50 m in the horizontal plane and 2 m in the vertical plane.

The analyses of the vegetation were made by putting the digital vegetation map as an overlay on the DEM and examining where the different vegetation types grew: at which aspects, heights and on which slopes. But because the vegetation map did not fit exactly with the DEM it had to be adjusted to match, by using rubber sheeting. The vegetation map was compared with the base map of the DEM and number of points on the vegetation map were linked by vectors to the correct positions on the base map. The rubber sheeting algorithms then stretch and compress the vegetation map until the linking vectors have shrunk to zero length. A visual examination of the result showed a good agreement between the vegetation map and the DEM, and can not have had a large influence on the vegetation analyses.

6.3 The software

We used both raster and vector based programs to obtain the DEM and to evaluate it. The raw data was transmitted to digital form in *ARC/INFO* (a vector based program), we also made all nessecary corrections here. Height values were added to the points by using *Lotus Approach*, a database management software.

Interpolations, both Distance weighted moving average and Kriging, were made in *Surfer*, but the variograms were obtained in *Geocus*.

The vegetation map was digitized in *ARC/INFO* and edited in *Arcview* and *Corel Draw*.

Analyses were made in *Idrisi* (a raster based program) and evaluations in *Excel*.

Pictures and illustrations of the DEM was made in *Surfer* and *Corel Draw*.

7. The vegetation map

7.1 Distribution of the different classes in the study area.

The final result of the investigation was a map in scale 1: 14 000, showing all the vegetation classes. This map was later digitized and used in the vegetation analyses. The digitized map is presented in scale 1: 40 000 in appendix 3.

The vegetation types are divided into two main groups; lowland areas with more or less closed vegetation cover (A) and lowland areas with open vegetation cover (B). The former group is further divided according to hydrology (well-drained (group 1) resp. poorly drained sites (group 2)).

7.1.1 Lowland areas with more or less closed vegetation cover (A)

7.1.1.1 Well-drained sites (group 1)

The well-drained sites are divided into six subgroups according to the duration of snowcover (ie length of the growing season). Woody plants, lichens, tussock forming grasses and sedges are common in these sites. Mosses play a minor role.

The first subgroup (11) includes exposed gravelly ridges with a discontinuous vegetation cover. The crests of the ridges are omitted (included under the second main group) and it is the zone just beneath the crests which is of interest. This zone has patches covered with lowgrowing lichens, mosses and forbs alternating with open patches. *Salix polaris* (fig.18) is common. The vegetation type found in the area is the open *Dryas* type (112), which may consist of the calciphilic *Dryas octopetala* (fig.18) alone or together with the other plants just mentioned. This type is found on the small rock outcrops in the southwestern part of the area and is also following a SW-NE going band of limestone starting from the rock outcrops just mentioned and heading towards the Lewinodden (fig.15). A few areas in the Linnédalen valley are also assigned to this type.



Fig.14 Type 112a*- polygons with *Dryas* (in the background) and 113* - gravelly ridges with *Salix* (foreground). The picture is taken on the east side of Linnéelva. (Photo: T.Josefsson)



Fig.15 Type 112 (gravelly ridges with *Dryas*). (Photo: T.Josefsson)

Type 112a* has the same vegetation as 112 with the difference that it grows on different kinds of patterned ground, mostly icewedge and frost fissure polygons. The vegetation is in these cases confined to the wedges. 112a*(fig.14) is found in the same areas as 112.

The open *Salix polaris* type (113*) is the largest class found in this area (fig.14). It is widely distributed in the lower parts, especially near the western and northern seashores, where it grows on the raised beach ridges. Beside the willow, *Salix polaris*, species like *Saxifraga caespitosa* (fig.19), *Saxifraga oppositifolia* (fig.20), *Saxifraga flagellaris*, *Silene acaulis* (fig.21) and *Draba corymbosa* are found together with mosses and lichens. Graminids play a minor role.

Type 113a* includes vegetation growing on patterned ground (icewedge and frost fissure polygons). The species are the same as in type 113*, ie *Dryas octopetala* is missing. The vegetation is confined to the wedges. This type is found in the northern parts of the map, especially around Lake Linnévatnet and the river Linnéelva.

The second subgroup (12) includes dry closed heath vegetation growing in the upper parts of the ridges and hills beneath the preceding zone. It is also found on well-drained plains and raised beach ridges. The vegetation in this group is often poor in species and the dominants are prostrate shrubs. The type growing in the study area is the closed *Dryas-Carex rupestris* type (121a), where the graminid is the dominating species and *Dryas octopetala* the less prominent. There are only two areas assigned to this class in the whole investigation area. They are situated on the eastern side of the river Linnéelva in sheltered parts of the raised beach ridges.

Subgroup three (warm favourable slopes with closed thermophilic vegetation; 13) is not found in the area.

The fourth subgroup (14) embraces early snowbed and snowflush vegetation. The type found is the *Salix polaris* type (142), which is widely distributed on the slopes of the Griegaksla and Starostin and Vardeborgaksla mountain ridges. This snowflush vegetation is irrigated by the late snowbeds of the upper parts of the ridges. *Salix polaris* is the most prominent species, but *Saxifraga oppositifolia* is also common. It should be stressed though, that this type showed a very scattered plant cover.

Late snowbeds make up the fifth subgroup (15) and this group includes all areas with a snowcover lasting into July. The type found is *Cerastium regelii* (152) (fig. 16) and this class is confined to the eastern side of Lake Fyrsjöen, the ravine of the river Linnéelva and the thermokarst features of the Vardeborgsletta plain. The ground just free from its snowcover is often covered with *Cerastium regelii*. *Draba alpina* and *Saxifraga spp* are also common.

The last subgroup is the birdcliffs (16), which have the richest vegetation in the whole area (fig. 17). The birdcliffs are found on the eastfacing slopes of Griegaksla and on the westfacing slopes of Starostin and Vardeborgaksla. The luxuriant bird-manured vegetation consists of *Oxyria digyna*, *Cochlearia groenlandica*, *Saxifraga spp*, *Draba spp* and *Salix polaris*. A thick mossmat is also present.



Fig.16 Type 152 - Late snowbeds with its dominating species *Cerastium regelii* (between the stones). (Photo: T.Josefsson)



Fig.17 Subgroup 16 - Birdcliff vegetation, Vardeborgen. (Photo: T.Josefsson)



Fig.18 *Dryas octopetala* and *Salix polaris*. (Photo: I.Mårtensson)



Fig.19 *Saxifraga caespitosa*. (Photo: I.Mårtensson)



Fig.20 *Saxifraga oppositifolia*. (Photo: I.Mårtensson)



Fig.21 *Silene acaulis*. (Photo: I.Mårtensson)

7.1.1.2 Poorly drained sites (group 2)

The poorly drained sites (group 2) are divided into three subgroups according to the depth of the active layer, the depth of the ground water level during the growing season and the drainage conditions. The ground water level is often situated at the soil surface. The growth season can be a bit delayed if one compares with the well-drained sites, but on the other hand, autumn is also delayed, making up for the late spring. Mat-forming grasses, sedges, rushes and forbs are common, while woody plants are of minor importance.

Mosstundra is the first subgroup (21) and it includes the least moist marches. The type found is the *Homalothecium nitens*-*Salix polaris*-*Dupontia pelligera* type (212), where the moss is the dominating species (fig.22). This type is often found as margins around rather wet marshes.

The second subgroup (22) includes wet mosstundra, which is found all over the area except for the southeastern part. It occurs on even ground around lakes and in depressions between raised beach ridges. It has a high and stagnant water table. The type recognized is *Homalothecium nitens*-*Carex subspathacea* (222). *Dupontia pelligera* and *Eriophorum scheuchzeri* are also common (fig.23).



Fig.22 Type 212 - Mosstundra, Lake Fyrsjøen. (Photo: I.Mårtensson)



Fig.23 Type 222 - Wet mosstundra. (Photo: T.Josefsson)



Fig.24 Type 226 - Wet mosstundra with frost upheaval, Tunsjøen. (Photo: I.Mårtensson)

The third largest class in this area is type 226; frost upheaval (pattered ground features) (fig.24). Especially great parts on the western side of the Griegaksla mountain ridge are occupied by this type, which is dominated by *Salix polaris* and *Saxifraga oppositifolia*. It is also found as margins around type 222.

The last two subgroups (swamp tundra; 23 and swamp; 24) are not found in the area.

7.1.2 Lowland areas with open vegetation cover (B)

The other main group (B); lowland areas with open vegetation cover, is separated into five groups according to differences in exposure (abrasion by snow and dust), drought, wind erosion, salinity and instability of the substrate.

The first group (3) includes very exposed, stable or eroded ridges. A further division is made between ridges with a gravelly substrate and ridges with a silty substrate (subgroup 31 resp. 32). The crests of these ridges are often free of snow in the winter, thus permitting abrasion by both snow and dust. Only ridges with a gravelly substrate are found in the area (type 312). These are mostly raised beach ridges, which often have a scattered plant cover on their crests due to the harsh climate. The plants found on the top of these ridges are different *Draba* and *Saxifraga* species. *Salix polaris* is also present just as *Cerastium arcticum*.

The second group (4) includes sedimentation plains with a silty substrate, which are subject to flooding at different time intervals. Decreased flooding leads to minor sedimentation and the vegetation has a chance to develop, while increased flooding leads to a destruction of the plants. This group is divided into two subgroups according to the vegetation density. The only subgroup found is plains with more or less continuous vegetation (41). The type represented is 411; dry *Polygonum viviparum* and this class is the second smallest in the whole area, only discovered on a big fan in the southwestern parts. *Salix polaris* and *Saxifraga oppositifolia* are also present.

Gravelly river fans make up the third group (5) where the division into subgroups is based on differences in the developmental stages. The fans range from the ones with only sterile gravel and no plant cover to those with a closed vegetation cover and a stabilized substrate. Fans with vegetation cover (subgroup 51) are found on the southwestern side of Lake Linnévatnet. *Saxifraga oppositifolia*, *Salix polaris* and *draba spp* are the most common species.

Fans with only a scattered plant cover (subgroup 52) should be seen as an initial stage to the fans in subgroup 51. The species are the same as in the former subgroup, but the plants are more scattered.

The last subgroup (53*) includes fans which are completely barren. These three classes all alternate on the fans due to the shifting courses of the brooks.

The fans are mostly situated in the upper parts of the Linnédalen valley. It should be noted that gravelly river beds are counted among this group.

The fourth group is recent moraines (6). The oldest moraines may have a vegetation similar to that of the vegetated river fans, while the youngest are completely sterile. Since only young moraines are found in the area, this group is regarded as nonvegetated and thus made white on the map.

The fifth and last group includes the seashores (7). It is further divided into two subgroups according to the size of the beach material and the amount of vegetation.

Both the western and northern shores consist of gravel and coarse sand where absolutely no vegetation can be seen (subgroup 72).

A different and very rare class is found in the area around the outlet of the river Linnéelva. It consists of wellrounded stones with a diameter of about 10 cm covered with a thick mossmat (73*).

Areas regarded as nonvegetated are talus slopes, some gelifluction lobes, some of the rock outcrops, block streams/fields, deflation surfaces, icings, recent moraines and certain raised beach ridges. All these areas are made white on the map, just as the human influenced zone around Kapp Linné. Some areas, especially around the Lake Fyrsjöen were flooded during the field survey and thus not further investigated. These areas are also white on the map.

7.2 Evaluation

The total accuracy of the map is 61.3%. Table 4 shows the distribution of the evaluation sample in the form of a matrix. Table 5 presents both the reliability of the interpretation for every class and a measure showing the under respectively over representation of a specific class on the map in percentage compared with its areal extension according to field data (the areal difference). The values of the reliability in table 5 are calculated from the figures in table 4.

The accuracy of our map can be compared with the one achieved by Klintonberg (1995). He obtained an accuracy of 83%. However, his investigation was made in the northern part of Swedish Lapland, where the vegetation has a different composition. The vegetation in this area includes bushes like willow and birch forests, classes which probably are more easily recognized in the aerial photos (Klintonberg achieved an accuracy of 100% in these two classes). The area also has a greater amount of groundcover, facilitating the interpretation. Another difference is that Klintonberg used a different classification system, defined by Nordiska Ministerrådet.

The class best interpreted is seashores (72) which shows an accuracy of 100%. Also polygons with *Dryas octopetala* (112a*) and birdcliffs (16) have high accuracy, in the former case probably due to the fact that this type of patterned ground is easily seen in air photos. Polygons with *Dryas octopetala* (112a*) could be separated from those without, with a knowledge of the geological relations in the area; *Dryas octopetala* is a calciphilic species growing on the limestone outcrops in the area. The open *Dryas* type (112) was in the same way separated from the *Salix polaris* type (113*), both classes not separable in the air photos. The accuracy of these two classes was not so good however, especially 113* which was interpreted for example as snowflush vegetation (142) and frost upheaval (226). Birdcliffs (16) were also easily discerned in the air photos because of their bright colours and specific topographical position.

The frost upheaval type (226) was also fairly well interpreted in the air photos. It is probably the symmetric pattern of this class that helped in distinguishing it from the other classes. Some areas of this class were however assigned to the open *Salix polaris* type (113*). Snowflush vegetation (142) was mostly mixed up with the birdcliffs (16) and the open *Salix polaris* type (113*). The accuracy was 59.9%. This misinterpretation of type 142 to birdcliff vegetation is confined to the slopes of Starostin and Vardeborgaksla, where it was hard to see in the air photos where the vegetation influenced by the bird manure ended.

Of the different types of gravelly river fans, subgroup 51 (fans with vegetation cover) was best interpreted and second best subgroup 53* (fans with no vegetation). Subgroup 52 (fans with scattered vegetation cover) had just like type 411 (sedimentation flats), type 212 (mosstundra), type 121a (*Dryas-Carex rupestris*) and the stoneshore with the moss an accuracy of 0%. These classes are in fact (with the exception of mosstundra) too small to be evaluated since too few evaluation points were found in these classes (this is due to the fact that we used a random sample method and unfortunately none of these small areas got sufficient representation), and they are therefore not further discussed.

Mosstundra (212) on the other hand was mixed up with the bogs (222), the frost upheaval type (226) and the late snowbeds (152). Similar topographical position, colour and brightness in the air photos with the other classes just mentioned made it very hard to discern.

Half of the areas with type 222 were correctly interpreted. The rest was mainly assigned to the snowflush vegetation (142). This error can be traced to the areas beneath the birdcliffs on the westfacing side of Starostin and Vardeborgaksla, where it was very difficult to draw the border between the bogs and snowflush vegetation, since the later type in this area showed an unusually rich flora, due to the bird manure.

More than one third of the areas with late snowbeds (152) were interpreted as birdcliffs. The accuracy was 29.6%, almost the same as type 312 (very exposed eroded gravelly ridges) showed. In the latter case we have to blame the poor representation of this class for making evaluation uncertain.

An explanation of the poor figures of the late snowbeds is that the aerial photographs were taken in August, when probably a large part of the snowbeds were melted and these areas were interpreted as birdcliffs. The field survey was made in July, when most of the snowbeds were still existing. If the field survey had been made in August, the accuracy would probably have been higher.

No evaluation was made of the nonvegetated areas.

Tab.4 Matrix showing the evaluation of the vegetation map. Columns represent the control points (the truth) and rows the corresponding points on the vegetation map.

Class	112	112a*	113*	113a*	121a	142	15	16	212	222	226	312	411	51	52	53*	72	73*	Sum
112	56		2			4				1									63
112a*	2	11	2	1		1	1									1			19
113*	9	1	44	1	1	21	2	1		1	7					1			89
113a*	3		4	4	1					1									13
121a																			0
142	4	1	6			88	2	6		11		1		3	4	1			127
152			1			2	8		1			1							13
16					1	16	10	40		2									69
212						2													2
222			5		1	2	1	1	4	18						1			33
226	1		6			4			1	1	17				1	3			34
312			3							1		1							5
411																			0
51							1							9	1	1			12
52																1			1
53*	1					7	2			1				1		13			25
72												1				1	4		6
73*																			0
Sum	76	13	73	6	4	147	27	48	6	37	24	4	0	13	6	23	4	0	511

Tab.5 The reliability, the area and the areal difference of every class. The total reliability was 61.3%. The values of the reliability are obtained from the matrix in table 4.

Class	Reliability (%)	Area (ha)	Areal difference (%)
112	73,7	176,5	-17,1
112a*	84,6	125,1	46,2
113*	60,3	1029,4	21,9
113a*	66,7	205,9	116,6
121a	0,0	25,6	
142	59,9	626,3	-13,6
152	29,6	84,8	-51,9
16	83,3	91,1	43,8
212	0,0	164,6	-66,7
222	48,6	237,2	-10,8
226	70,8	595,1	41,7
312	25,0	92,0	25,0
411		4,4	
51	69,2	24,0	-7,7
52	0,0	39,8	-83,3
53*	56,5	218,6	8,7
72	100,0	124,8	50,0
73*		4,3	

7.3 Discussion

The results of the evaluation clearly show that the classes with only a modest areal extension can not be properly evaluated. This is due to the fact that we used a random sample method and unfortunately none of these small areas got sufficient representation.

Dryas- Carex rupestris (121a), sedimentation flats (411), stone shore (73*) and subgroup 52 (fans with scattered vegetation cover) all belong to this category. What is striking is that mosstundra (212) also had a poor reliability, a class which has an area of 165 ha. The difficulty in drawing the line in the airphotos between this class and the bogs (222) probably counts for the bad figures.

The most frequent misinterpretations were the mixing of snowflush vegetation (142) with birdcliffs (16) and *Salix polaris* (113*) and the mixing of bogs (222) with snowflush vegetation. This type of mistake was almost only made at the slopes of Starostin and Vardeborgaksla where the dividing-line between these classes in the airphotos was very indefinite, but also in the field we met some difficulties in the delineating of classes since the snowflush vegetation just as the bogs obviously were influenced of the manure from the birdcliffs.

Otherwise, it was the bogs and the birdcliffs which were most easily discernable in the airphotos (except from the areas at Starostin and Vardeborgaksla) together with the different classes of patterned ground (226, 112a* and 113a*) and the seashore (72).

A knowledge of the geology in the area is however essential in separating 112a* from 113a* resp. 112* from 113*.

Gravelly river fans (except 52) were also fairly well interpreted due to their distinct morphological form.

The mixing of late snowbeds (152) with birdcliffs can, as we mentioned in the evaluation, be due to the fact that the time of the field survey did not coincide with the time of the photographing. Shadow effects in the airphotos from the mountains also complicated the interpretation.

Thus, in improving the accuracy of the map, a better agreement between the field survey and the time of photographing would be desirable. The fact that we were two persons in making the interpretation perhaps led to minor differences in the delineation of areas etc, since it is very unlikely that two persons have exactly the same perception of colour, brightness etc. A stereoscope with a better magnification could perhaps improve the interpretation but such an instrument was not at our disposal during the field survey.

It could also be discussed if a different classification system would be more appropriate in this area. Brattbakk for example, who has made several maps on Svalbard using the series approach (heath, meadow and mire), has in his classification included the idea of showing the amount of groundcover in each class using a scale of three steps from open to closed cover. This approach might have been useful in our case too, since for example type 112 and 113* sometimes showed a very different rate of vegetation cover which readily could be separated into different coverage classes.

The classification system used had before only been applied in innerfjord valleys which are not so maritimately influenced as Kapp Linné. It was thus a test to see if this approach also worked in a more near coastal environment. The outcome of that test is that the approach suited our investigation area fairly well. However types that demand warm and sheltered environments were not present at Kapp Linné, just as certain subgroups among the poorly drained sites. Ridges and beaches with a silty substrate were also absent.

8. The DEM - results and discussion

The seven interpolations were evaluated to show the differences between them. We used four different statistical parameters in our evaluation: Mean error (which shows the average

difference in meters between a point on the map and a point in the interpolated image), Standard deviation, Maximum error, showing the amount and sign (overestimation or underestimation) of the greatest difference and RMSE (Root Mean Square Error = $\sqrt{(d_1^2 + d_2^2 + \dots + d_n^2) / n}$), where d is the difference in every point and n is the number of points). The result is presented in table 6.

These parameters showed that the best interpolation was an Inverse distance made with a window radius of 6 pixels and a distance weight of 2. Although this interpolation had a bigger mean error than some of the others, it has to be considered the best model since all the other parameters were better. Figure 25 shows the resulting DEM of the best interpolation. The results were a bit surprising, because we had expected the interpolations made with Kriging to be better than those made with inverse distance. But only Linear Kriging came close to the result of the best interpolation with Inverse distance. We had also expected a better result if the size of the search-window was increased, but this was clearly not the case. Maybe because the optimum size of a search-window, in this particular area, happened to be 6 pixels, or maybe because a distance weight of 2 was more appropriate than 1. The variograms (fig. 11-13) made of the area did not help much in obtaining a value of the search-window, since all but the one over the Griegaksla mountain showed no sign of a sill. The variogram over Griegaksla had a sill at approximately 500 m, which means that the optimal size of the search-window for this area is 10 pixels (500 m divided by 50 m (the resolution of the image)).

The interpolation which combined linear and exponential Kriging was not so good. It had the second largest mean difference of about -2 m, only linear Kriging with trend was worse. The large errors in the image were, as in all the other interpolations, found in the area around Griegaksla, and surprisingly enough not in the junction between the interpolated images. Maybe the poor result was due to the fact that we could not use the variogram that was obtained from our data, we could only look at it and decide what form it had: linear, quadric, exponential etc, and then use Linear, Quadric or Exponential Kriging. This was of course a disappointment to us and a weakness of this, in other ways, excellent program.

The Kriging interpolation made with a linear drift, Trend Kriging, was an definitely a failure compared with the others. The explanation to this might be the Griegaksla mountain, which of course did not suit the trend of an inclined plane sloping upwards towards east, but rather resembled a hump in an almost flat area. The evaluation showed a mean error of - 8 m, compared to - 0.52 m for the best interpolation, a maximum error of - 316! and finally an RMSE which was more than 6 times larger than the best. These figures clearly show that we were mistaken about the trend.

Images showing the position of the biggest errors of each interpolation (errors bigger than ± 10 m) showed that these were mainly located in the area on and around the mountain of Griegaksla (Appendix 2). In this area both exaggerations and underestimations were made. This did not come as a surprise to us, since this is the only place in the area in which there is an abrupt change in elevation over a relatively short distance. Yet, another explanation could be the irregular shape of the mountain.

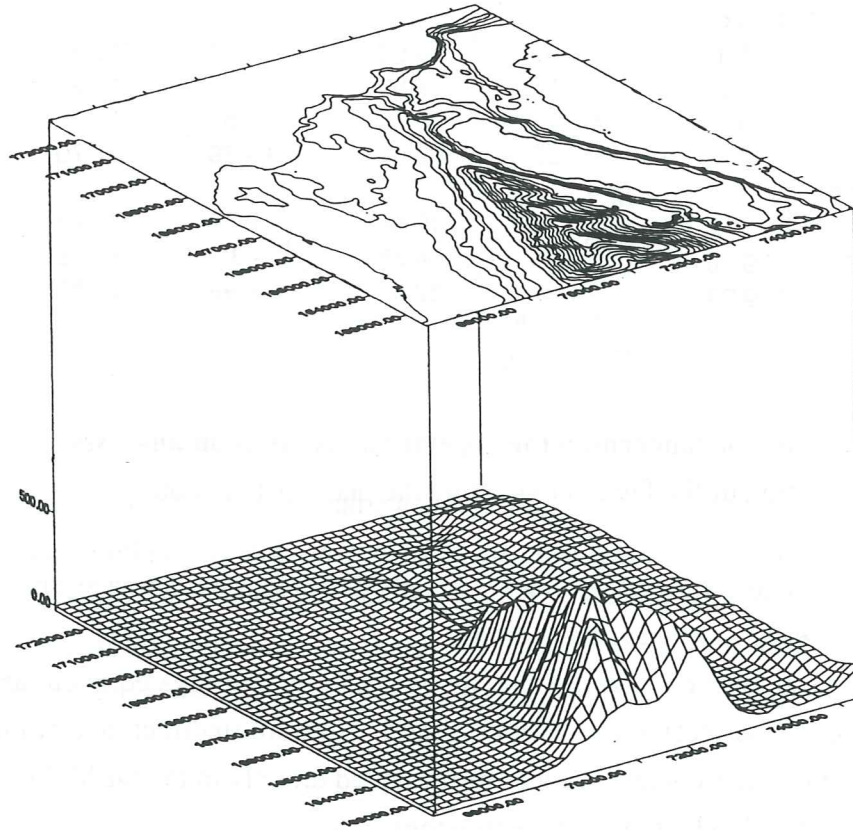


Fig.25 The resulting DEM from the Inverse distance interpolation 6,2.

There were some other places where big errors occurred in each of the interpolations, and these were located on the south-eastern side of Lake Linnevatnet, on the slopes of the Vardeborgen Mountain. These errors could be caused by insufficiency of data in this area, since they were located on the edge of our research-area.

One of the interpolations, Inverse distance: 12, 1, has errors which are more or less scattered over the area. This interpolation did not fit the area, maybe because it had a too big search-window.

One obvious example of the difference between the interpolations is shown in the varying shape of Lake Linnévatnet, which can hardly be recognised on the Inverse distance 12,1; 8,1

and Combi Kriging but is much better shown on the Inverse distance 6,2 and 6,1 and on Linear Kriging and Trend Kriging.

Tab.6 Statistics of the different interpolations.

INTERPOLATION	MEAN ERROR	STD.DEV	MAX. ERROR	RMSE
Inverse Distance:				
6,1	- 0,33	20,00	+ 100	19,93
6,2	+ 0,52	17,96	- 78	17,90
8,1	+ 0,25	20,36	- 87	20,28
12,1	+ 0,25	22,79	+ - 89	22,70
Kriging:				
Linear Kriging	+ 0,88	19,49	+ 79	19,43
Trend Kriging	- 7,96	64,86	- 316	65,09
Combi. Kriging	- 1,97	22,60	+ 99	22,59

9. Results and discussion concerning the vegetation distribution analyses

9.1 A short presentation of the factors regulating the plant distribution

The distribution of plants in these latitudes is mainly dependent on drainage, snowcover, exposure, soil properties, altitude and bedrock.

Of these six factors at least four can be directly or indirectly investigated in our analyses, namely the drainage (indirect), snowcover (indirect), exposure (indirect) and altitude (direct). The drainage (or the water content) cannot be measured directly in the DEM, but the water content can be expected to be higher in depressions.

The snow cover is thicker in depressions and on the leeward side of obstacles, from the direction of the prevailing winter winds.

Exposure, like snow cover, is dependent on the prevailing winter winds. Slopes facing these winds are more likely to have a scattered vegetation cover, since the wind blows away the snowcover, and exposes the ground to snow blasting and freeze-drying. A windward developed snow-drift can protect some parts of a windward facing slope, but not to the same extent as on the leeward side.

Finally, the altitude can of course be measured directly in the DEM.

9.2 The Aspect

To begin with, an examination of the distribution of the aspect in the area was made, to see if the aspects had a normal distribution. The result showed that more than 50% of the aspects

could be found in the SW to NW directions. The less frequent directions were NW to N and E to SW (tab. 7). This uneven distribution of the aspects should be kept in mind when reading the result of the analyses of the preferred aspects of each class.

Tab.7 The distribution of the aspects in the area; the Griegaksla mountain ridge is not included.

Aspect	Area	Percent
1-45°	481 ha	11.7%
45-90°	574 ha	13.9%
90-135°	160 ha	3.9%
135-180°	237 ha	5.8%
180-225°	272 ha	6.6%
225-270°	1086 ha	26.4%
270-315°	1072 ha	26.1%
315-360°	233 ha	5.7%

The analysis of the aspect showed that hardly anything grew at aspects between 90 and 225 degrees (east to south-west), but these are also the least represented slopes in this area. There are only two classes which contradict this picture: 226, wet mosstundra with frost upheaval, and 152, late snowbed vegetation, but these two classes are characterized by having a scattered vegetation cover, wherever they are found. Table 8 shows the aspects of the different classes.

The most preferred aspects were 225 to 315 degrees (south-west to north-west), but 0 to 90 degrees (north to east) were also well represented. The abundance of vegetation at 225 to 315 degrees can be explained by looking at the direction of the prevailing winter winds, which come from the north-east. These winds will make the snow accumulate on the south-west side of obstacles, where it can protect the vegetation from the low temperatures, but also minimize the effects from snow-blasting and freeze-drying. But how is it possible for the vegetation to grow at places facing these winds, at northeasterly aspects? It is hard to say from our small investigation. Maybe the vegetation growing at these sites has developed mechanisms which make it possible for it to withstand the harsh winds, maybe it is growing at more or less protected sites in the terrain, as for example the Linnéelva canyon or even smaller depressions (Åkerman 1983) or maybe it is protected by windward snow accumulation. The resolution of the DEM is 50 m in horizontal plane and 2 m in vertical plane, and this means that small but important shelters are not included in the analysis. Vegetation which can withstand the low temperatures and the winds could have the advantage of an extended vegetation period. With no snow covering it, the vegetation can start growing as soon as spring comes.

Apart from the snow distribution, the effect of shading is probably very important in this area. In this latitude (75° north) the sun never reaches more than 35,5 degrees above the horizon (Ahrens 1991, p. 91), which means that a bigger amount of the area will be completely in the shade than if the area had been situated more to the south. If a place is shaded most of the day, it could mean that nothing can grow there because there is a permanent snow-cover or permafrost. The effects from shading could account for the concentration of vegetation at 225 to 315 degrees. These aspects get a lot of sun from the late morning to the evening due to the fact that there are no mountains preventing the radiation from reaching the ground. The area is also sloping gently upwards towards the east, thus providing the vegetation with a better angle towards the sun.

Tab.8 This table shows where 75 % of the vegetation in each class are found, at which aspect, slope angle and elevation.

	CLASS	ASPECT (0 = level ground, 1 - 360 degrees)	SLOPE ANGLE (degrees)	ELEVATION (m)
~ 75 %	112	225 - 315	0 - 5	10 - 50
"	112a*	1 - 90, 225 - 315	0 - 5	10 - 40
"	113*	0, 1 - 45, 225 - 315	0 - 5	1 - 10, 20 - 40
"	113a*	1 - 90, 225 - 315	1 - 5	1 - 10, 20 - 50
"	121a	270 - 360	1 - 5	10 - 20
"	142	45 - 90, 225 - 315	1 - 10	10 - 40, 50 - 80
"	152	1 - 90, 180 - 315	1 - 5	1 - 20, 30 - 40
"	16	45 - 90, 225 - 315	1 - 10, 30 - 40	50 - 90
"	212	0, 1 - 45, 225 - 315	1 - 5	1 - 20
"	222	0, 1 - 45, 225 - 315	0	1 - 20
"	226	0, 180 - 315	0	1 - 20
"	312	1 - 90, 225 - 315	0 - 5	1 - 20, 40 - 50
"	411	1 - 45, 270 - 315	1 - 5	1 - 10
"	51	1 - 90, 225 - 270	1 - 5	10 - 30
"	52	1 - 90, 225 - 315	0 - 5	1 - 20
"	73*	270 - 315	1 - 5	1 - 10

Circular diagrams have been made to show where a majority (75 %) of the vegetation in each class prefers to grow. In these the shaded area represents vegetation.

Class 112 - Exposed gravelly ridges with *Dryas*. This class is, as can be seen in figure 26, mainly growing at 225 to 315 degrees, on the lee-side of rock outcrops with a north-south orientation.

This means that it is probably protected by a thick snow-cover during the winter, but the orientation also means that it gets a relatively early start in the spring.

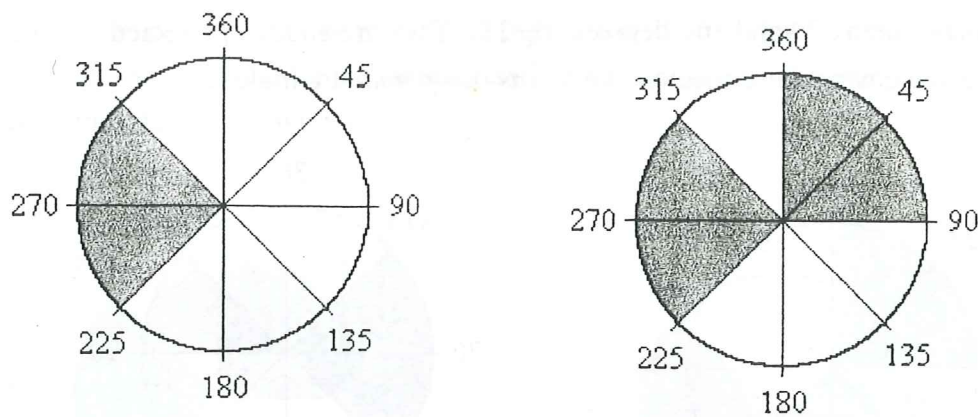


Fig.26 Diagram showing the preferred aspects of class 112 (exposed gravelly ridges with *Dryas*) and 112a* (polygons with *Dryas*) respectively.

Class 112a* on the other hand, does not have the same demands as 112, although it consists of the same species (fig.26). This class has a preference of aspects stretching from 0 to 90 degrees and 225 to 315 degrees and is growing in depressions made by ice-wedges. These depressions have a better micro climate than the surrounding ground, due to a protective snow cover, which is enough to increase the vegetation cover (Åkerman 1983).

Classes 113*(gravelly ridges with *Salix*) and 113a*(polygons with *Salix*) almost have the same demands considering the aspect (fig.27), though 113a* seems to be slightly more tolerant, probably because it grows in depressions made of ice-wedges as 112a*. In fact 112a* and 113a* have identical preferences of aspect.

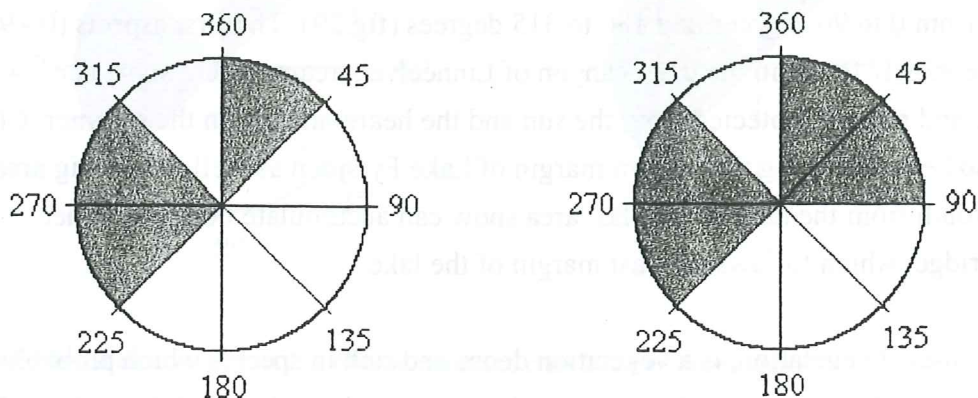


Fig.27 Preferred aspects of class 113*(Exposed gravelly ridges with *Salix*) and 113a*(polygons with *Salix*) respectively.

Class 121a (dry closed heath vegetation) was only found in two places which happened to have aspects between 270 and 360 degrees (fig.28). They are enough protected to have a dense vegetation cover where species like *Dryas octopetala* are included.

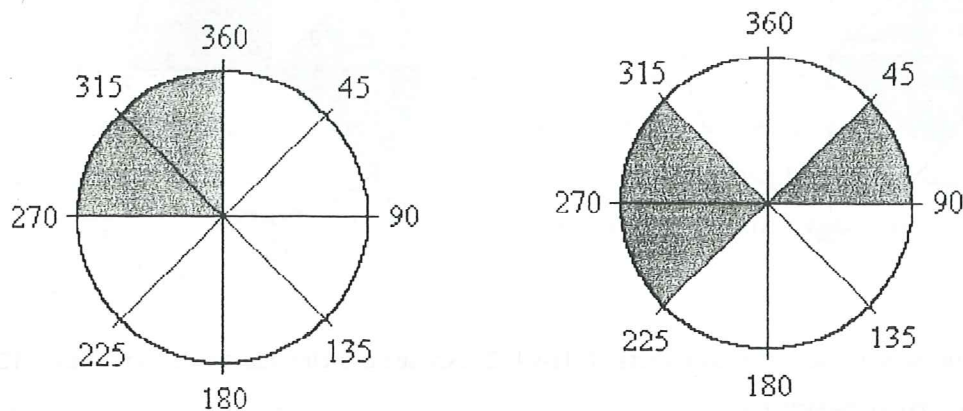


Fig.28 Preferred aspects of class 121a (Closed *Dryas-Carex rupestris*) and 142 (Early snowbed and snowflush vegetation) respectively.

Class 142 (early snowbed/flush vegetation) are dependent on the accumulation of snow and are found beneath perennial to semiperennial snowbeds. Logically enough, it is found at 225 to 315 degrees, aspects opposite to the prevailing winter winds, but also at 45 to 90 degrees, facing the wind (fig.28).

This last aspect could be explained by the fact that a lot of snow can accumulate on the eastern side of Griegaksla and thus nourish this kind of vegetation

Class 152 is the vegetation of late snowbeds. As seen this class can be found at a wide range of aspects, from 0 to 90 degrees and 180 to 315 degrees (fig.29). The first aspects (0 - 90 degrees) are mostly found in the deep canyon of Linnéelva stream, where snow can accumulate and remain protected from the sun and the heat until late in the summer. Class 152 can also be found along the eastern margin of Lake Fyrsjöen as well as in a big area stretching south from the lake. In this last area snow can accumulate behind a rather prominent ridge, which follows the east margin of the lake.

Class 16, bird-cliff vegetation, is a vegetation dense and rich in species which probably needs protection during the winter. It is however, as the name implies, above all dependent of bird manure and therefore is only found on steep slopes beneath cliffs inhabited by large populations of arctic birds. Bird cliffs are only found at two sites in our area: at Mt Vardeborgen, at aspects stretching from 225 to 315 degrees, and on the south-eastern side of

Mt Griegaksla, at aspects of 45 to 90 degrees (fig.29). The most luxurious vegetation is found at Mt Vardeborgen, mainly due to a bigger population of birds, but also because of the better climate: more sunlight during the summer and better protection from the prevailing north-easterly winds during the winter.

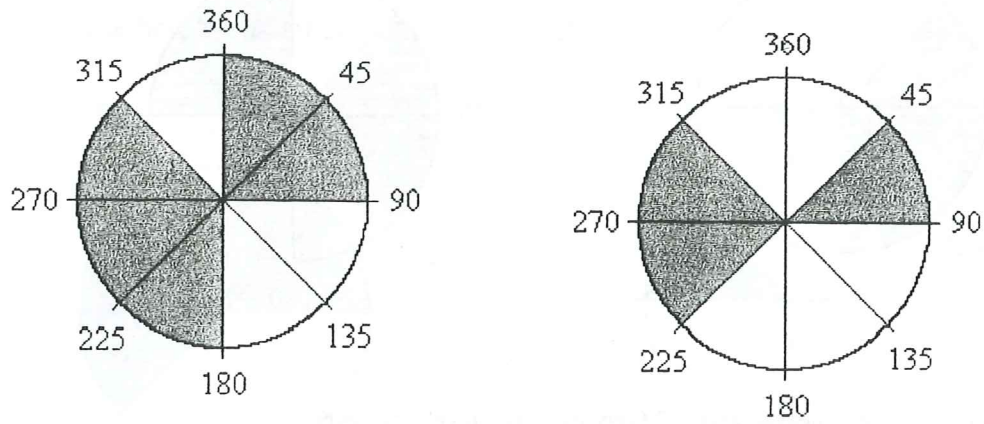


Fig.29 Class 152 (late snowbeds) and 16 (bird-cliffs).

Classes 212 (mosstundra) and 222 (wet mosstundra) prefer exactly the same aspects: 0 to 45 degrees and 225 to 315 degrees (fig.30). They are also often found on level ground, which is quite natural because they are both dependent on high soil moisture. These two classes are found where it is sufficiently wet for them to exist, rather than at any specific aspect.

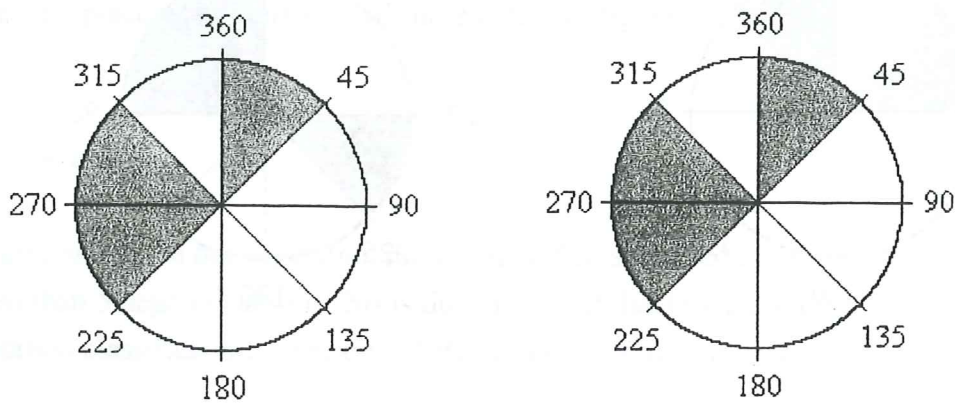


Fig.30 Preferred aspects of class 212 (mosstundra) and class 222 (wet mosstundra).

Class 226 (wet mosstundra with frost upheaval) is also extremely dependent on a constant supply of water. It is often found on level ground but also at aspects stretching from 180 to

315 degrees (fig.31), that is on the leeward side of the prevailing winter winds. The class has not much of a vegetation cover because of the constant motion in the soil

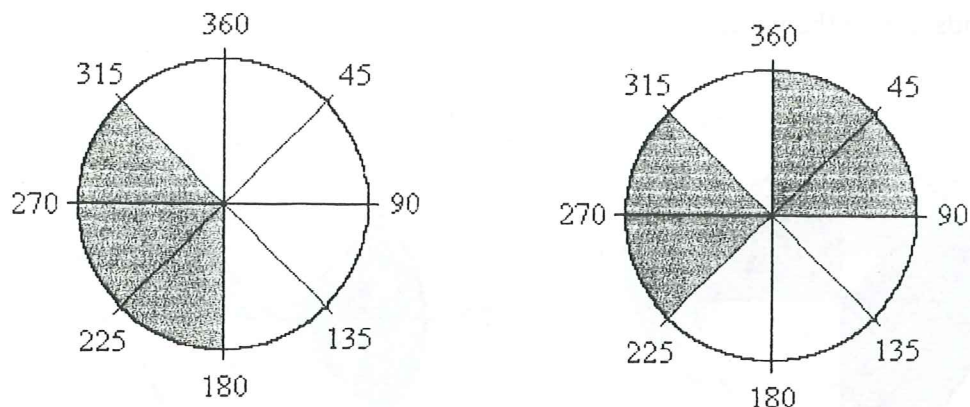


Fig.31 Classes 226 (frost upheaval) and 312 (very exposed gravelly ridges)

Class 312 (very exposed gravelly ridges): all that can be said about this class is that the vegetation is very scattered, with some crests being completely bare. The analysis of the aspect is not so interesting, because the ridges found in this area are orientated in roughly the same direction, that is south-north (fig.31).

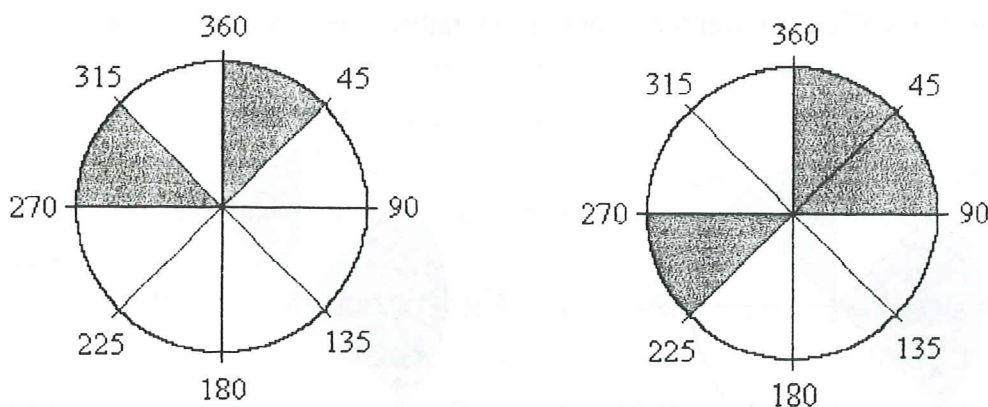


Fig. 32 Preferred aspects of class 411 (silty sedimentation flats) and 51 (fans with vegetation cover) respectively.

Class 411 (silty sedimentation flats) is only found in a small area in the southwest and it happens to be sloping in a west-northeast direction. This class is of course deeply dependent on the composition of the substrate. It is therefore hard to say what kind of aspect it prefers,

However, there is no vegetation in a sector between 315 and 360 degrees, which is in between the seemingly preferred aspects (fig.32).

Classes 51 and 52 (fans with vegetation and fans with scattered plants respectively) are dependent on a presence of a stream and not so much on the aspect itself. But a better aspect will of course help the plant community to develop, and stabilize the fans (fig.32 and 33).

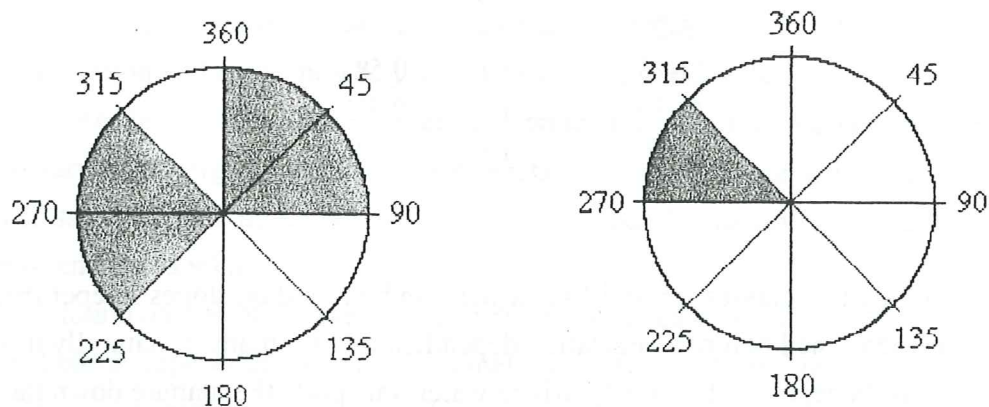


Fig.33 Aspects of class 52 (fans with scattered plants) and 73*(stone shores).

Class 73* (stone shores) is only found in two small areas along the northern coast. These are fairly well-protected from strong winds. It is likely though, that the class is above all dependent on the substrate, which is well-rounded stones, rather than the aspect, because this is the only place where this kind of shore is found (fig.33).

9.3 Slope angle

The area shown on our vegetation map is quite flat, about 85% of the slopes have a gradient of less than 5 degrees (tab.9). This is due to the fact that Griegaksla is not included in our vegetation classification, since only different kinds of lichens grew there.

As shown in table 8 and figure 34 the slope angles are mostly moderate, from 0 to 5 degrees. This is probably due to the fact that steeper slopes are instable and have a poorly developed soil layer.

Tab.9 The distribution of the slope angles in the area, except the Griegaksla mountain ridge (which was not included on our vegetation map).

Slope angle	Area	Percent
0-1°	1896 ha	39.4%
1-5°	2162 ha	44.9%
5-10°	508 ha	10.5%
10-15°	133 ha	2.8%
15-20°	47 ha	1.0%
20-25°	24 ha	0.5%
25-30°	23 ha	0.5%
30-40°	25 ha	0.5%

There are in fact only two classes, 16 and 142, which can be found on slopes steeper than 5 degrees. 16 is as mentioned before a vegetation dependent on bird manure, naturally it is therefore found just beneath the bird cliffs, where water transports the manure down the hillside. The manure makes the vegetation dense and lush so that it can keep the substrate from being washed away from these steep slopes. According to the analysis class 16 can be found on slope angles up to 40 degrees. Class 142 is dependent on a constant flow of water from melting snow beds, because of this it is found on the slopes of Vardeborgen and Griegaksla. It can manage to survive at slope angles of up to 10 degrees. The smallest slope angles were found in class 222 and 226. These classes are dependent on high water content and this is why they are found at a slope angle of 0 degrees, where water can accumulate.

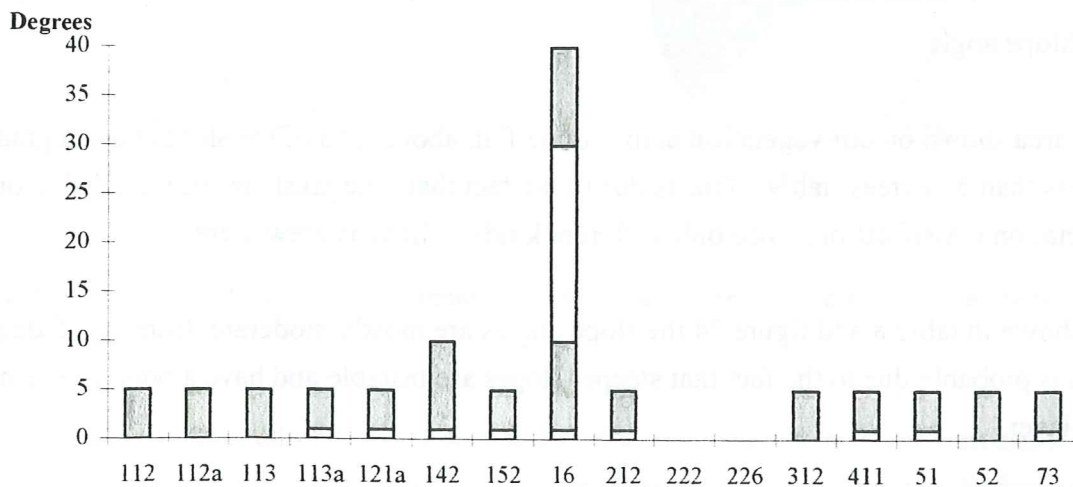


Fig.34 Diagram showing the slope angles where 75 % of each class prefers to grow (in grey).

9.4 The elevation

Most of the vegetation is found at heights less than 50 m above sea level, maybe because there is not enough soil above this limit (tab.8 and fig.35). Lack of soil means lack of moisture and problems finding a stable place to grow in. In this area the plain could be said to stretch to about 50 m above the sea level and above this the mountains of Griegaksla and Vardeborgen take over, abruptly increasing the slope angle.

There are, however, two classes which mainly grow above this limit and that is 16 and 142 (birdcliff vegetation and early snowbed/flush vegetation respectively).

Class 16 is a very lush, bird manured vegetation, which through its dense vegetation cover can manage to survive at heights far above other vegetation classes. In our analysis areas covered with this class were found up to 340 m above sea level, but the majority of the areas were found between 50 and 90 m.

Class 142 is found on heights between 10 and 80 m above sea level. This class is, as mentioned before, dependent on water from melting snow. It is therefore most often found beneath perennial to semi-perennial snowbeds on the slopes of Mt Vardeborgen and Griegaksla, at heights above 50 m, but apparently also at lower slopes, especially around Lake Linnévatnet.

Many classes are logically situated in the lower lying areas, for example 222, 226 and 212, the wet classes, which are found at heights between 1 to 20 m above sea level. These classes are dependant on a constantly high water table and are therefore situated in depressions where water is pushed to the surface. Another thing to notice is that the vegetation classes that prefer well-drained sites are normally found at higher elevations than the previously mentioned classes, for the same reason - water. They do not want to be drowned! These classes, 112, 112a*, 113*, 113a* and 312 are mostly found on the ridges constituted of raised beaches, whereas 222, 226 and 212 are found between these ridges.

Class 411(silty sedimentation flats) is found at low heights, 1 - 10 m above sea level. This was expected, since silt will only accumulate at low gradients. These gradients are only found on the plain, and most of all in the flat area in the west and this is also where this class is found.

Class 152 (late snowbeds) is a class which can be found at many elevations, 1 to 20 m and 30 to 40 m.

The class is, as the name implies, first of all dependent on snow cover. But why could it not extend to above the 50 metres level? Perhaps because of lack of soil. This vegetation class has

an opened vegetation cover and would almost certainly be washed away from the steep slopes above the 50 metres level.

Class 51 and 52 (fans with with vegetation cover and fans with scattered plants respectively) have slightly different preferences of elevation. Class 51 is found at higher elevations than 52. One explanation could be that 51 has a denser vegetation cover merely because it is situated higher above the active stream channels than 52. Because of this, it would be better protected from erosion.

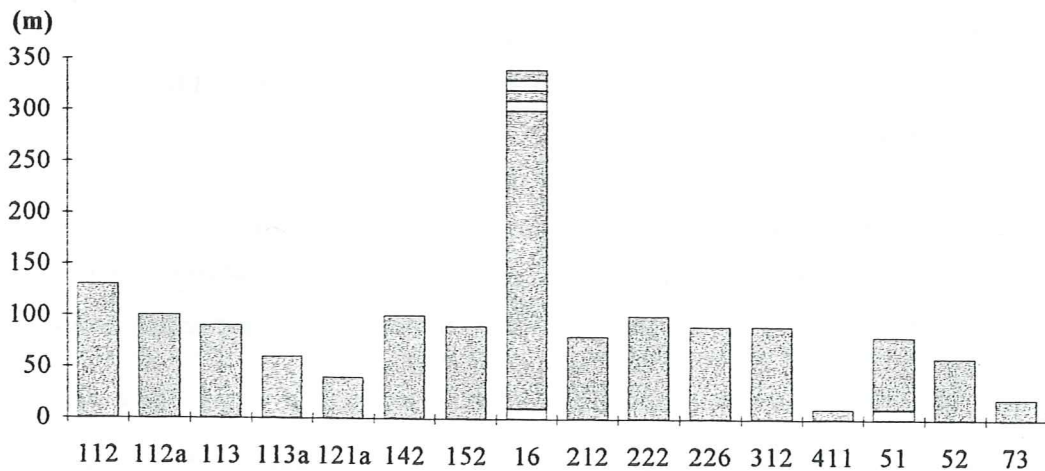


Fig.35 The diagram shows the vertical distribution of each class (in 100%).

In our analysis of the vegetation we have only considered three parameters, but there are of course many more, which are equally or more important to the distribution of the vegetation. Three apparently important factors which determine where a special kind of vegetation can grow are substrate, moisture and bedrock. These three factors were incorporated in the classification system we used when we created our vegetation map, and could therefore, in a way, be said to be incorporated in this analysis.

10. Applications

10.1 Applications of the vegetation map

Today the environmental pressure of the mountains in central and northern Europe is increasing. Mining, road constructions, new settlements, water regulation, scooter tracks and tourism all play a part in the wear of the mountains. Many of these activities cause irreparable damages. Since the arctic region is a very vulnerable and easily disturbed environment,

changes are quickly detected and for example tracks from a vehicle can be seen for years in a permafrost environment.

In this context a vegetation map could be very useful. Areas that are particularly sensitive could be spotted on the map and suitable protective steps could be taken. Both botanical and zoological values (the habitats of the animals are indirectly seen on the map) could be preserved. Apart from these direct physical traces that man left behind, other kinds of human activities also cause indirect disturbance on the Arctic environment. What we have in view are the increasing levels of carbon dioxide that are likely to effect the climate. Climatologists have shown that air temperatures would increase because of the greenhouse effect. Since permafrost is a thermal condition, rapid anthropogenic climatic changes can quickly affect the distribution of permafrost and periglacial processes (Åkerman 1991). All these changes can be detected in a vegetation map, due to the fact that periglacial and geomorphologic changes are reflected in the vegetation. The map also shows which areas that are passable (useful to know during construction works) and suited for tourism. The snowdepth and the pasture for the reindeers could also be estimated. (Ihse et alia 1977)

The distribution of different vegetation types can be used to indicate a range of soil properties eg. water content, acidity, nutrient content, stability. Also the distribution and the depth of the permafrost can indirectly be seen. Several reports discuss large differences in ground temperatures under different types of vegetation. The most common relation is that there appeared to be a general decrease in temperature with increased moss cover and peat thickness, and temperature amplitudes also decreased in the same order (Åkerman 1991). Snowcover, on the other hand, has an insulating effect.

10.2 Applications of the DEM

Some usefull applications of DEMs have all ready been mentioned in the introduction to this paper, but how can this particular DEM be of use?

This DEM can of couses, like all other DEMs, be used as a storage of elevation data of this area, but perhaps more important is its use in scientific investigations, as calculation of slope lenghts, aspects and slope angles. It could also be used in simulations of landscapes processes, or simply as a three-dimensional display of the land forms in the area. In the field of geomorphology the DEM can be used in combination with geomorphological maps for investigations concerning land forms, for example where different landforms can be found, at what height etc. Statistical analyses and comparison of different kinds of terrain can be made with relatively little effort. The DEM could also be used to detect slopes with concave or convex profiles, which is important in erosion hazard mapping. (Burrough 1986)

11. Summary

11.1 The vegetation map

This paper presents a study of the areal and vertical distribution of the vegetation of the northwestmost part of Nordenskiöld Land on West Spitsbergen.

The main purpose was to produce a vegetation map over the area. The map is based on aerial photographs and a field survey carried out in the summer of 1994. The classification system used is described by Elven et alia (1990) and is based on differences in habitats and floristic composition.

The factors regulating the vegetation type and cover are drainage, snow cover, exposure, soil properties, altitude and bedrock.

Due to the in many cases harsh and severe effects of the above mentioned factors only a discontinuous vegetation cover has been able to develop with the exception of the rich and close vegetation of the bogs and the birdcliffs. The poorly drained sites have a thick moss layer and an abundance of grasses, while the areas below the birdcliffs are dominated by mosses and different kinds of perennial herbs. The bogs are mostly situated in depressions between the raised beach ridges or bordering the many small lakes and ponds. A large part of the remaining area consists of fairly well-drained and flat sites dominated by *Salix polaris*, *Saxifraga oppositifolia*, *Draba alpina*, *Silene acaulis*, *Dryas octopetala* and different kinds of lichens and mosses. *Dryas octopetala* is growing on the limestone outcrops while the rest of the herbs show no preference for any particular bedrock outcrop. Large areas are also characterized by polygonal patterns and other patterned ground features. Here the vegetation shows a scattered cover but the species are the same. No vegetation is found on the seashores, some of the riverfans, talus slopes, some gelifluction lobes, block streams/fields, deflation surfaces, recent moraines and the two mountain ridges Griegaksla and Vardeborg/Starostinaksla.

11.2 The DEM

This paper treats methods and problems concerning the creation of a Digital Elevation Model (DEM) covering an area of 54 km², along the western coast of Svalbard (Kapp Linné). The data were obtained from three maps, two of them made by Åkerman (1980) and the third a preliminary print from Norsk polarinstitutt. The maps were digitized using a method developed by Eklundh and Mårtensson (1994). The method, which makes it much easier to create a satisfying DEM, is based on the fact that point data is much faster to digitize than line data (which is the normal way to represent height values on a map). Eklundh and Mårtensson use a regularly distributed grid of sample points, supplemented with points near

breaklines in the terrain. They show that this gives just as good results as contour lines when interpolated, it takes less computer-space, and it is time-saving. In areas of varying complexity, the grid can easily be adjusted by increasing the number of points.

Some of the interpolations were made using inverse distance weighted moving average, with a slight modification of the parameters at each interpolation, and some by using Kriging interpolation. The results were evaluated by comparing it to a sample of 125 randomly chosen points. The best interpolation was made when using the method of inverse distance with a search-window of 6 x 6 pixels and a distance weighting of 2. Most of the errors in the interpolated image were found in the area of Griegaksla mountain, which is quite logic because this is where the greatest changes in altitude are found.

11.3 The analysis of the vegetation

The DEM was used in combination with the digital version of the vegetation map, covering the area, to make some analyses vertical and horizontal distribution of the vegetation. Parameters that were analysed for each vegetation class were aspect, slope angle and elevation.

The results showed that one of the most important limits was the slope angle. Most of the plants grew at angles less than 5 degrees. Probably because of the poorly developed soil layer and the instable conditions at greater slope angles.

The analyses of the aspect showed that hardly anything was growing in the interval between 90 and 225 degrees (E - SW), with the exception of two classes: 152 (late snowbed vegetation) and 226 (wet mosstundra with frost upheaval), and these two classes had a very scattered vegetation cover. The most preferred aspects were 225 to 315 degrees (SW - NW). When we examined the elevation, we found that the vegetation could grow at quite high elevations, considering the rather harsh climate. Beneath the birdcliffs, vegetation could survive up to about 350 metres above sea level, 220 metres higher than elsewhere in the area. Most vegetation however, preferred to grow below 100 metres level.

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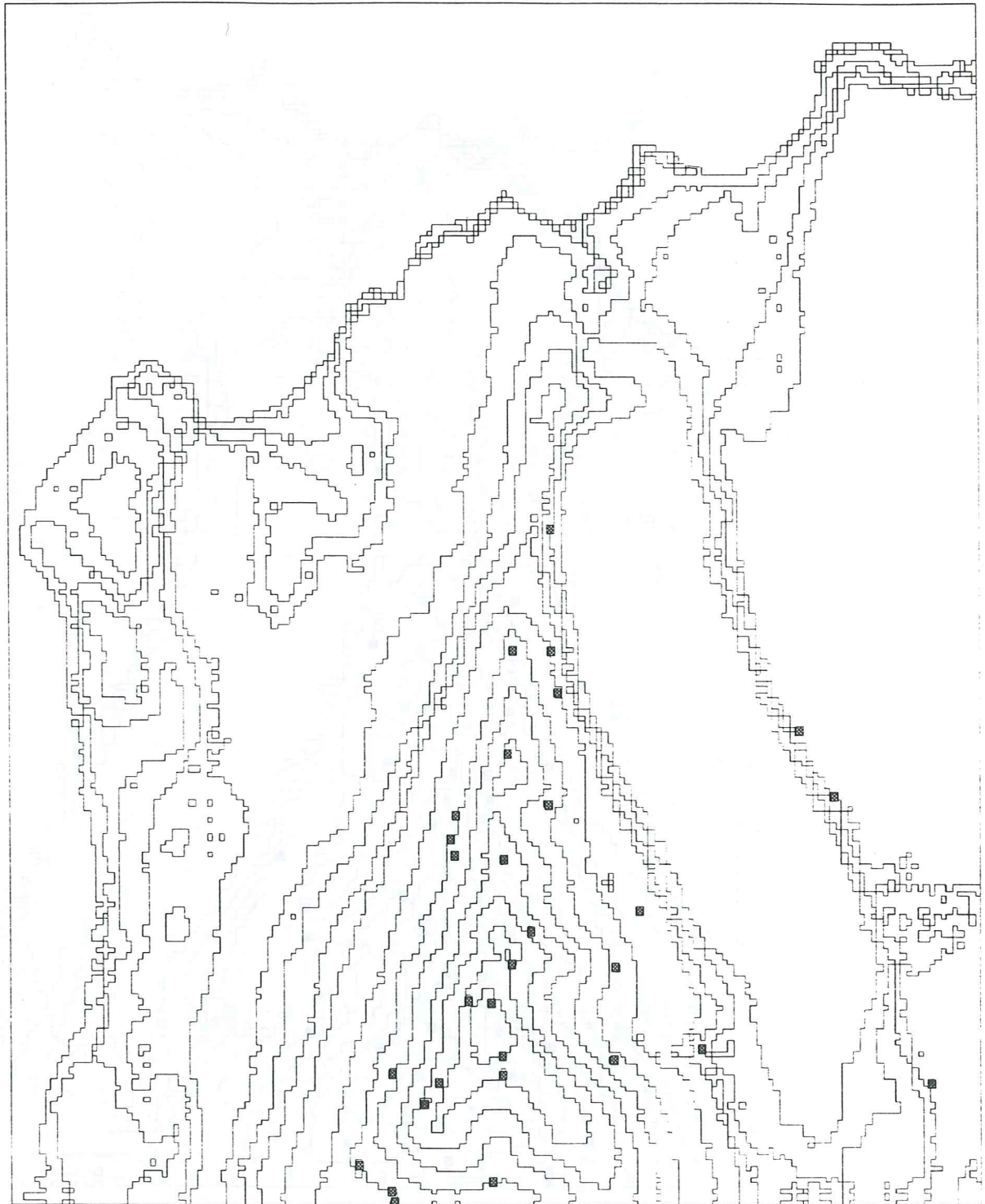
Appendix 1

List of the most important species observed by this investigation in the area around Kapp Linné, botanical and Swedish names.

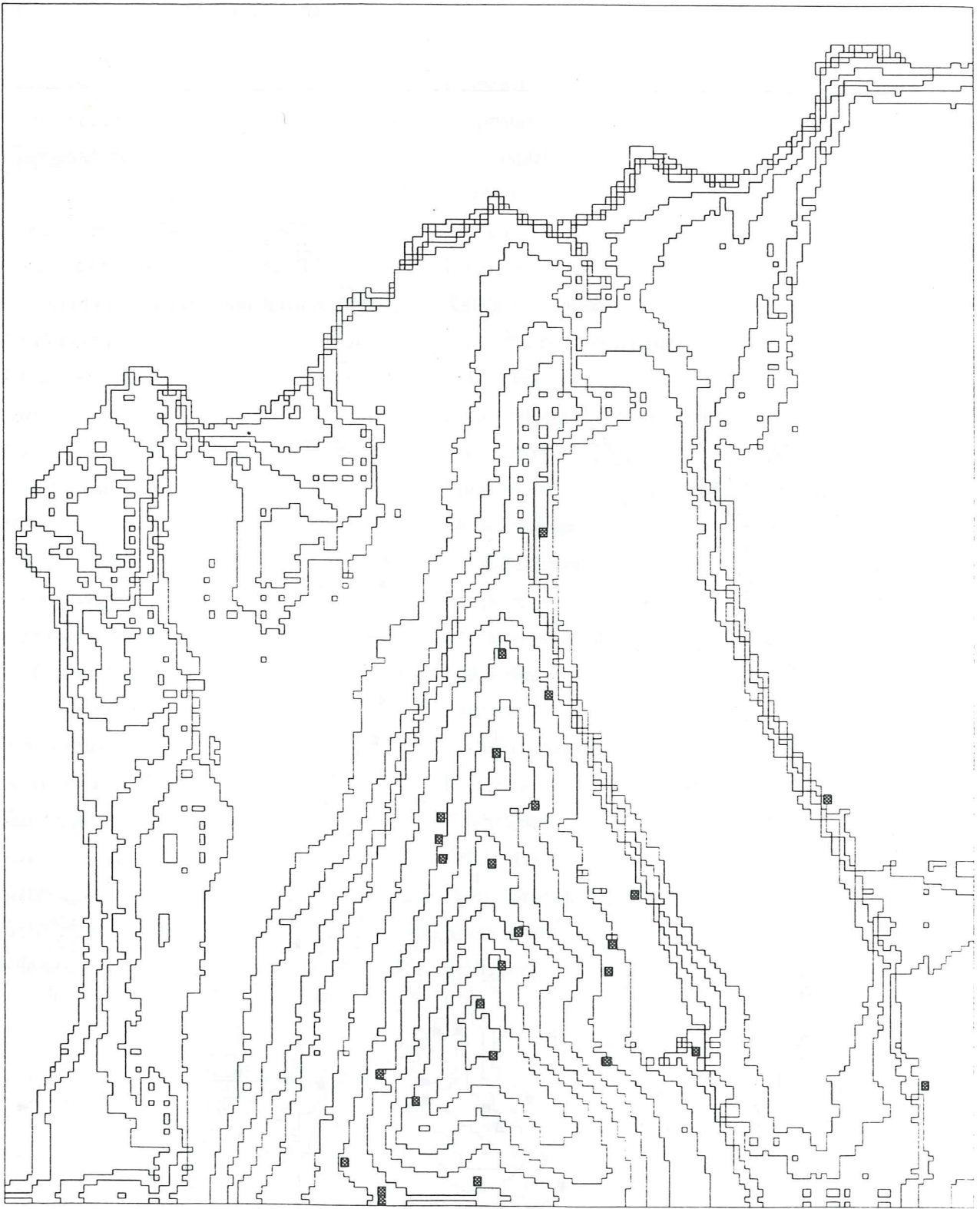
<i>Carex maritima</i>	Bågstarr
<i>Carex rupestris</i>	Klippstarr
<i>Carex subspathacea</i>	Ishavsstarr
<i>Cassiope tetragona</i>	Kantljung
<i>Cerastium arcticum</i>	Snöarv
<i>Cerastium regelii</i>	Polararv
<i>Cochlearia officinalis</i> var. <i>groenlandica</i>	Källskörbjuggsört
<i>Draba corymbosa</i>	Puterublom (Norwegian)
<i>Dryas octopetala</i>	Fjällsippa
<i>Dupontia pelligera</i>	Småtundragras (Norwegian)
<i>Equisetum arvense</i>	Åkerfräken
<i>Eriophorum scheuchzeri</i>	Polarull
<i>Homalothecium nitens</i>	Gyllenmossa
<i>Lycopodium selago</i>	Groddlumner
<i>Oxyria digyna</i>	Fjällsyra
<i>Papaver dahlianum</i>	Spetsbergsvallmo
<i>Pedicularis hirsuta</i>	Fjällspira
<i>Polygonum viviparum</i>	Ormrot
<i>Ranunculus nivalis</i>	Fjällsmörblomma
<i>Salix polaris</i>	Polarvide
<i>Saxifraga ceaspitosa</i>	Tuvbräcka
<i>Saxifraga flagellaris</i>	Trådbräcka
<i>Saxifraga oppositifolia</i>	Purpurbräcka
<i>Saxifraga rivularis</i>	Snöbräcka
<i>Silene acaulis</i>	Fjällglim

Appendix 2

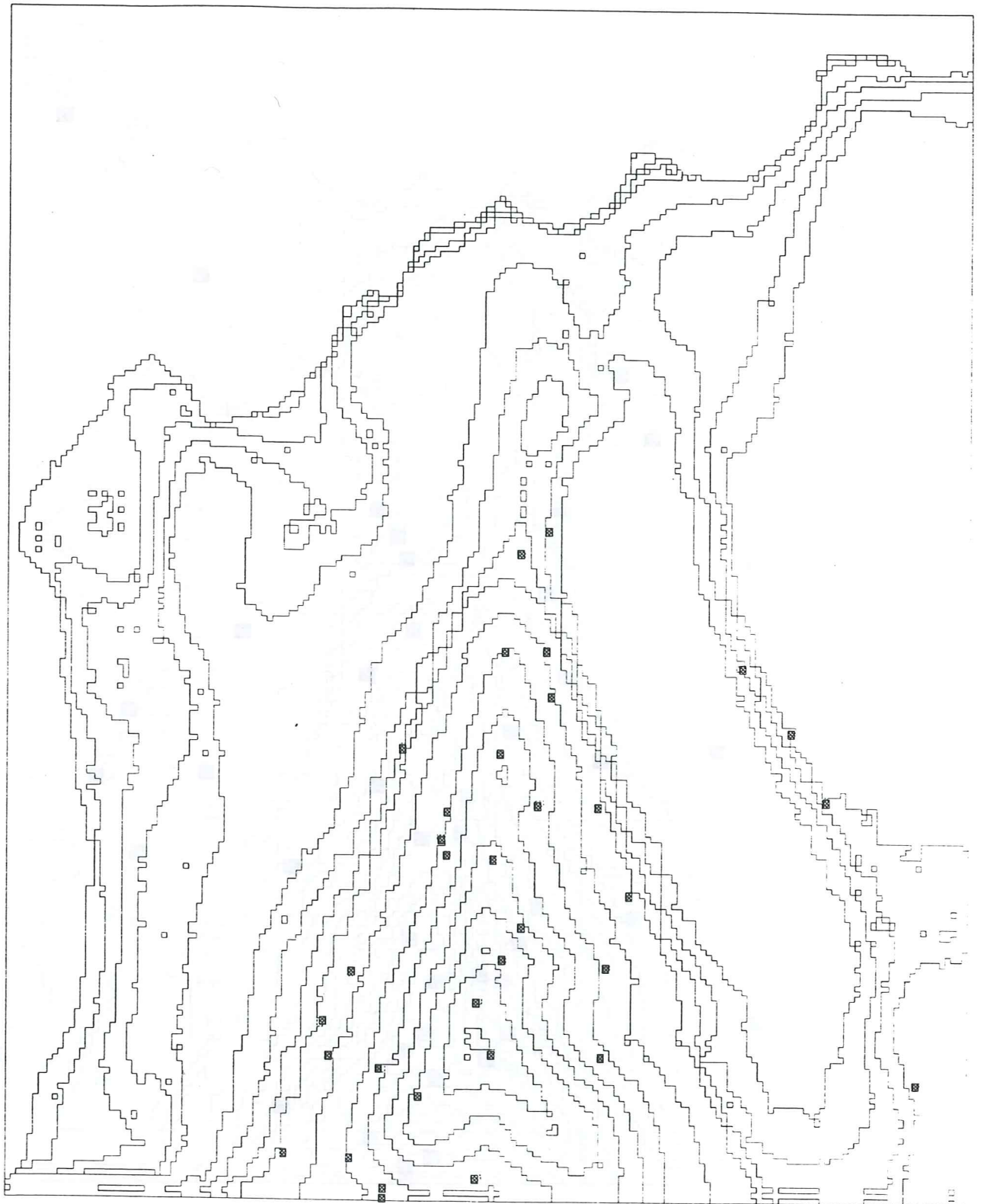
Maps showing errors $> +10$ m and < -10 m in the different Digital Elevation Models.



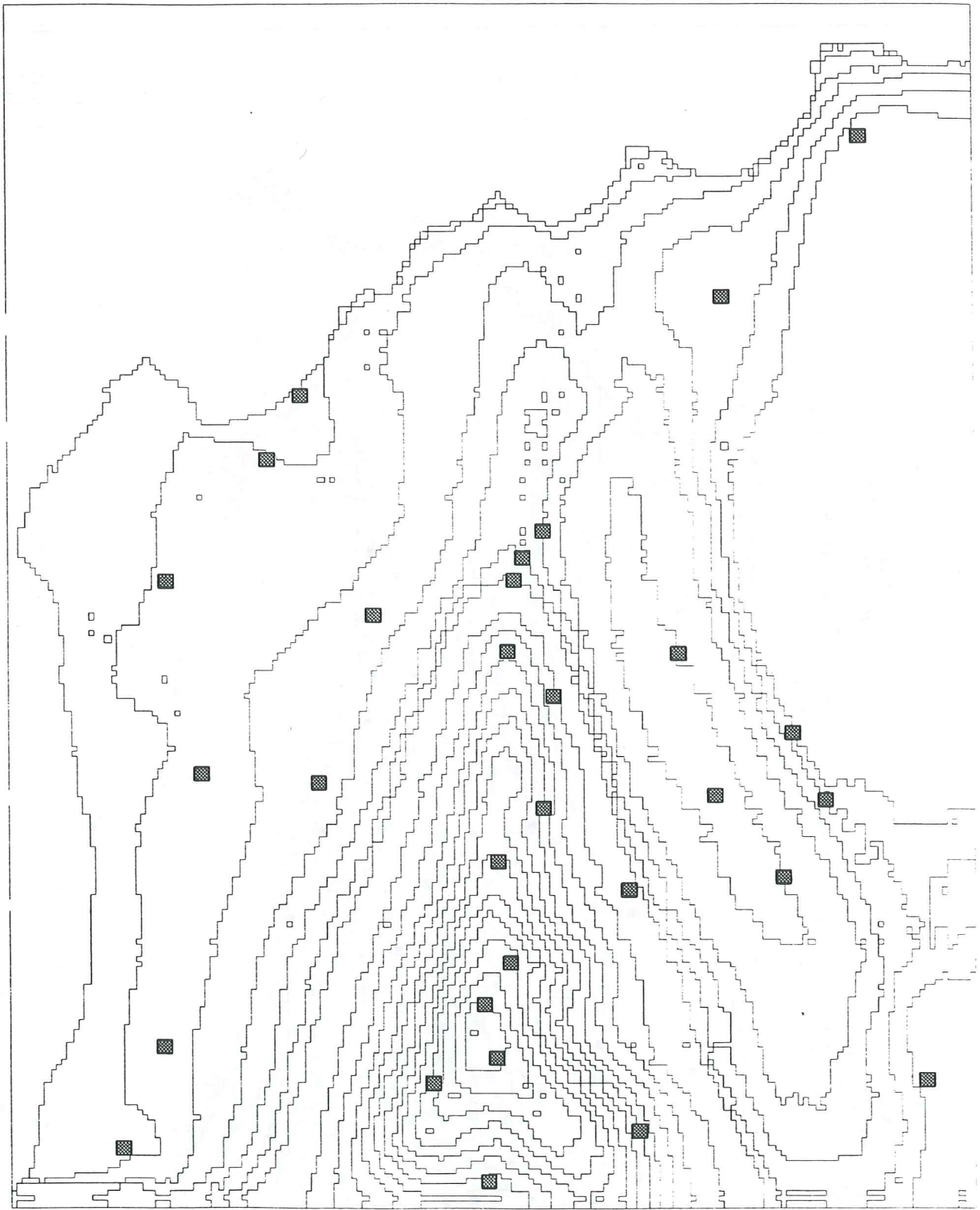
Distance weighted moving average (6,1).



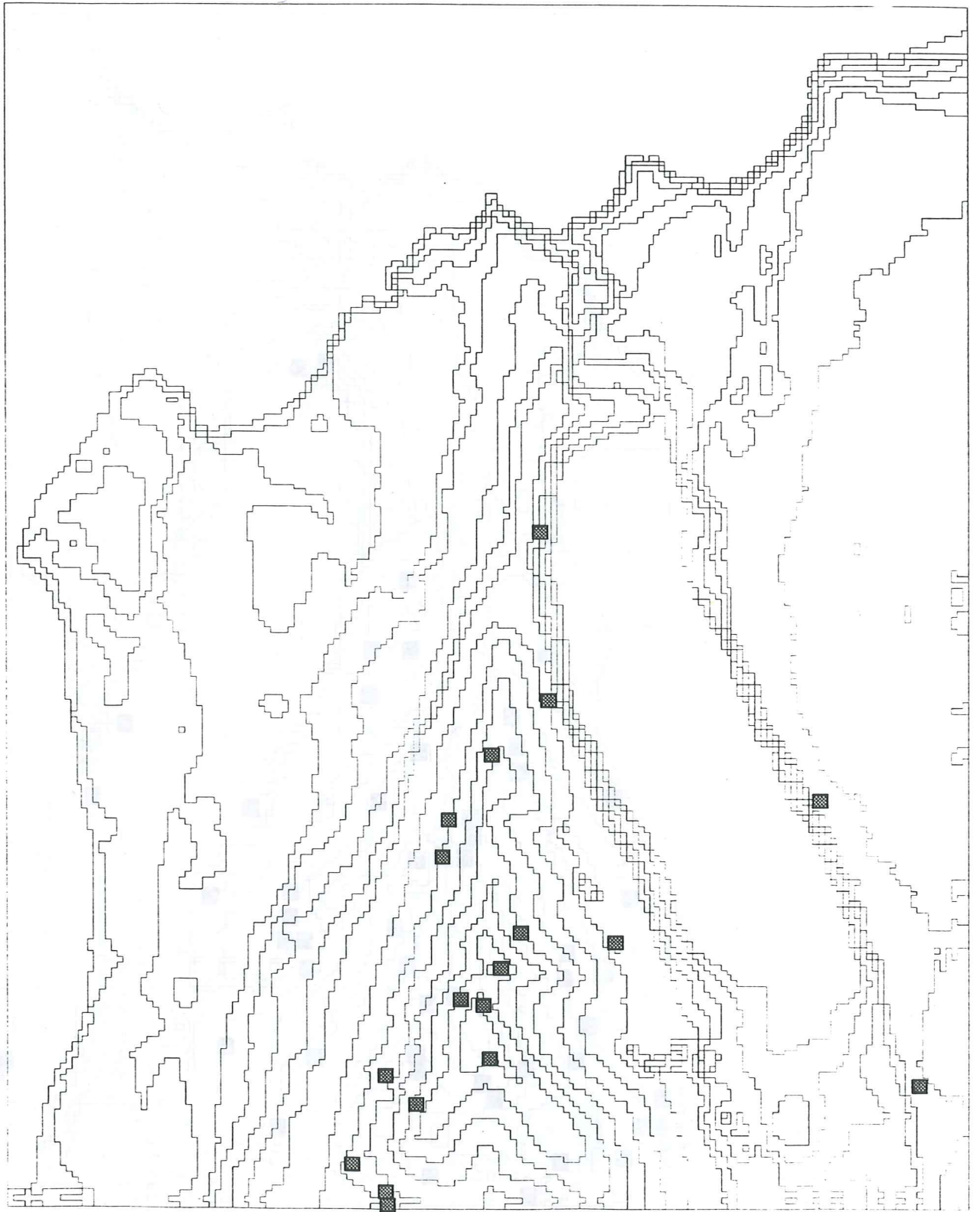
Distance weighted moving average (6,2).



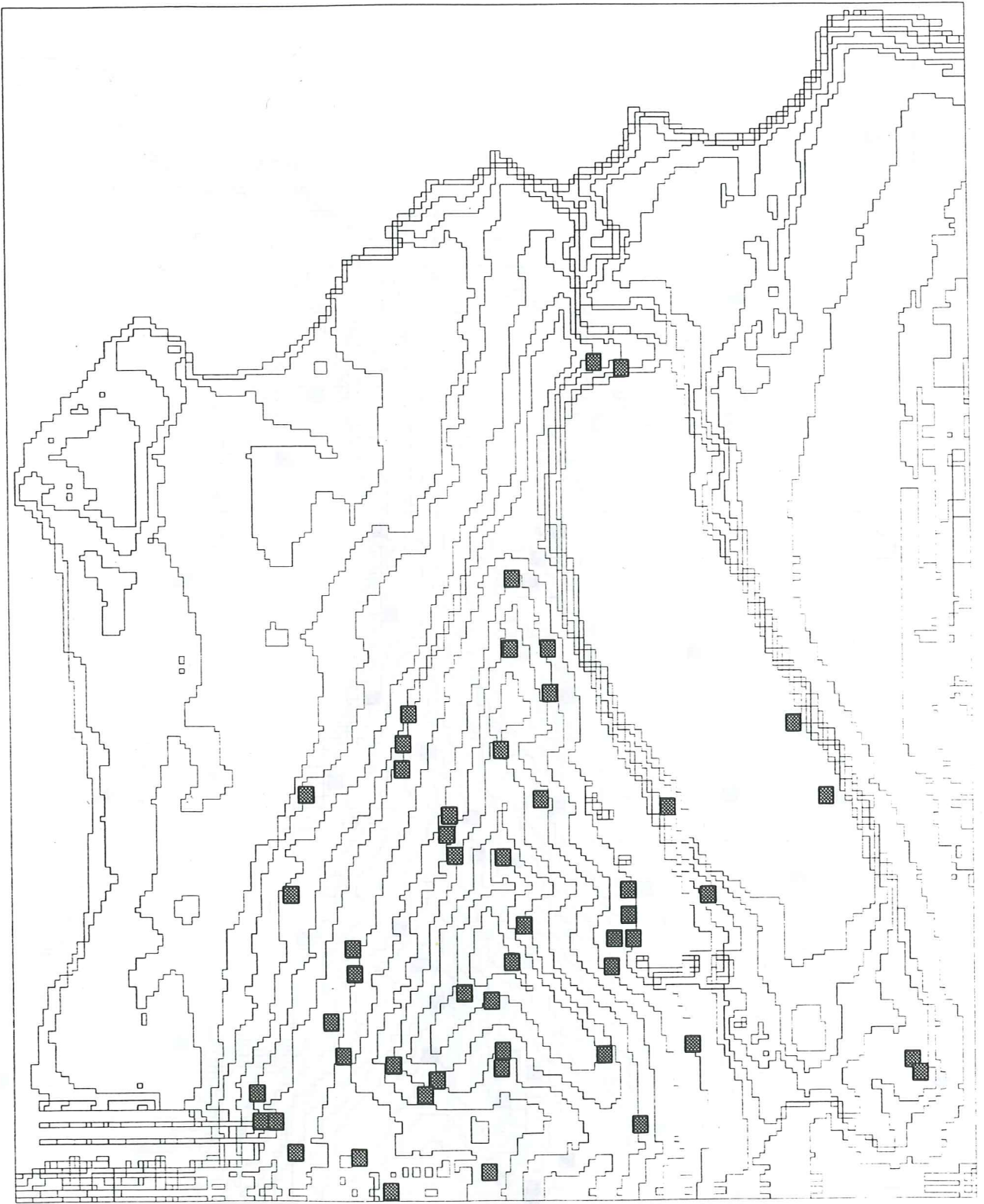
Distance weighted moving average (8,1).



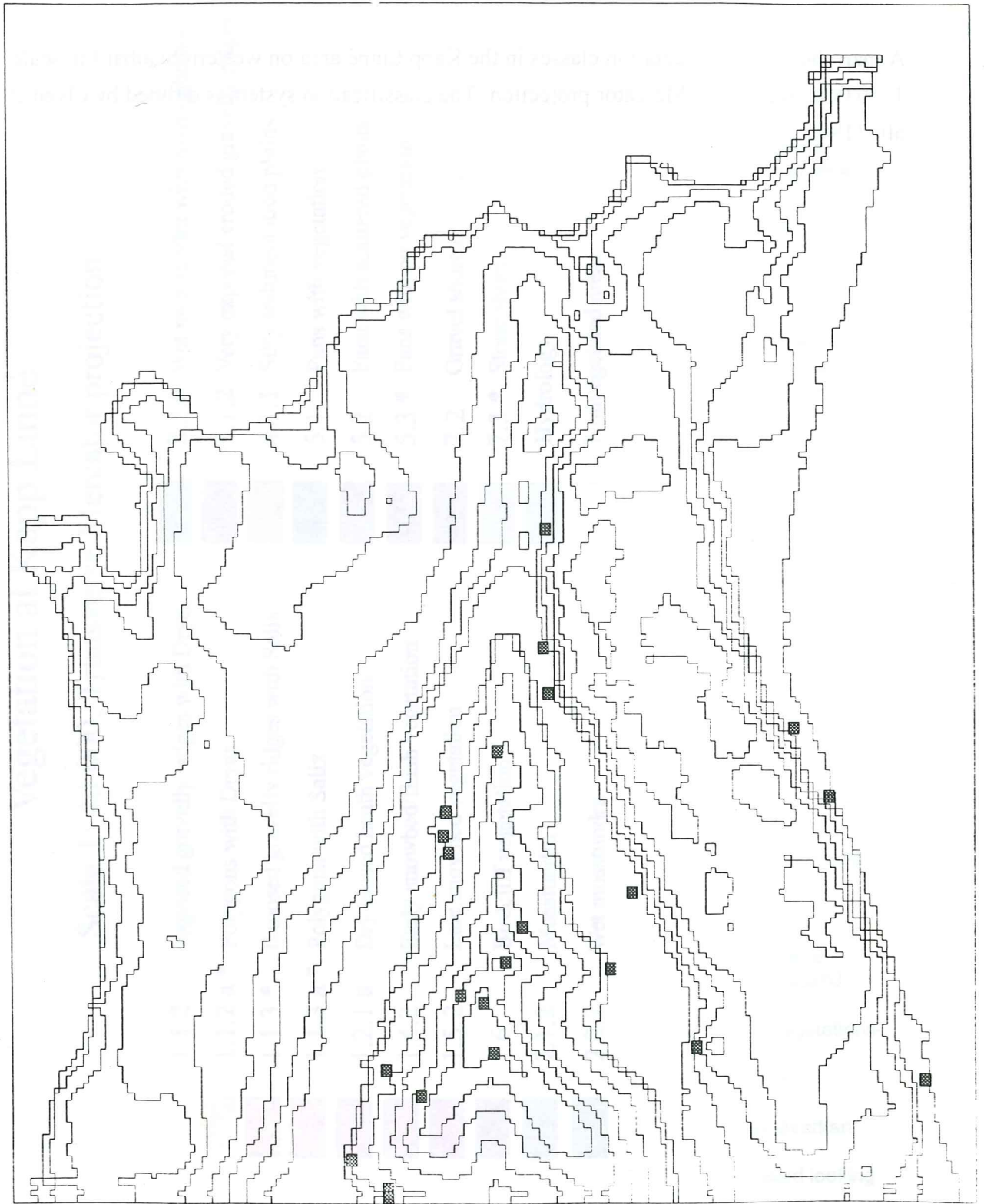
Distance weighted moving average (12,1).



Linear Kriging.



Linear Kriging with trend.



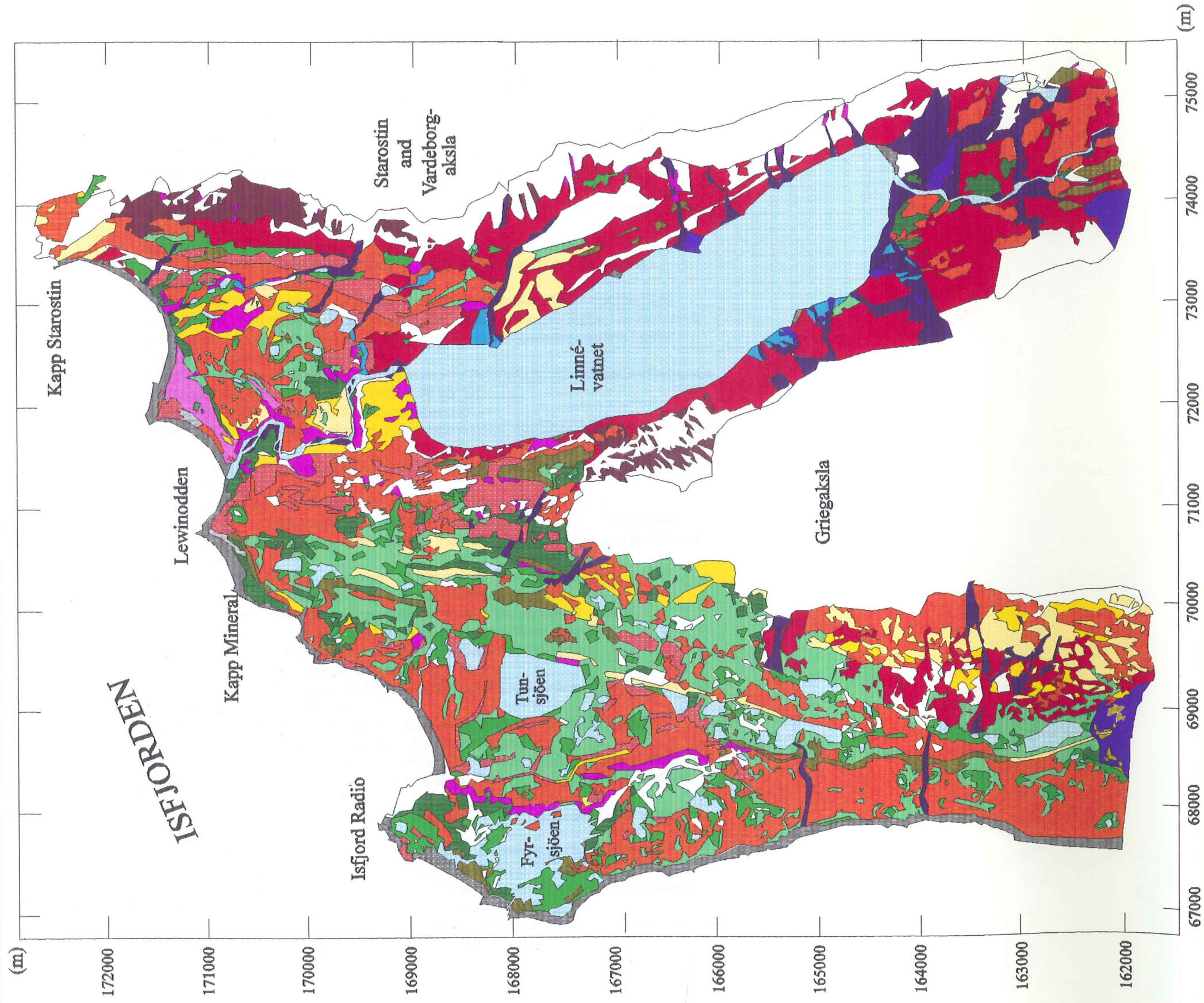
Combination of linear Kriging (the plain) and exponential Kriging (Griegaksla).

Appendix 3

The vegetation map

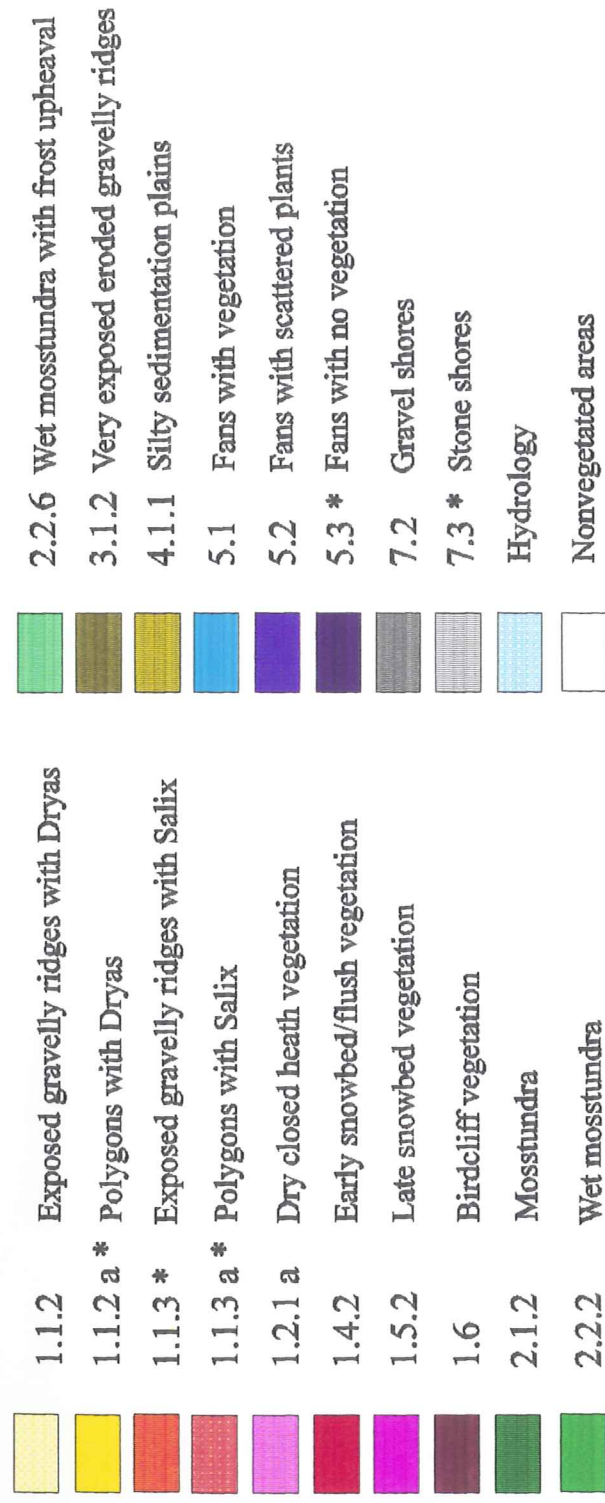
A map showing the vegetation classes in the Kapp Linné area on western Svalbard in scale 1: 40 000, Transverse Mercator projection. The classification system is defined by Elven et alia (1990).





Vegetation at Kapp Linné

Scale 1: 40 000, Transverse Mercator projection



Lunds Universitets Naturgeografiska institution. Seminarieuppsatser. Uppsatserna finns tillgängliga på Naturgeografiska institutionens bibliotek, Sölvegatan 13, 223 62 LUND.

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 13, S-223 62 Lund, Sweden.

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