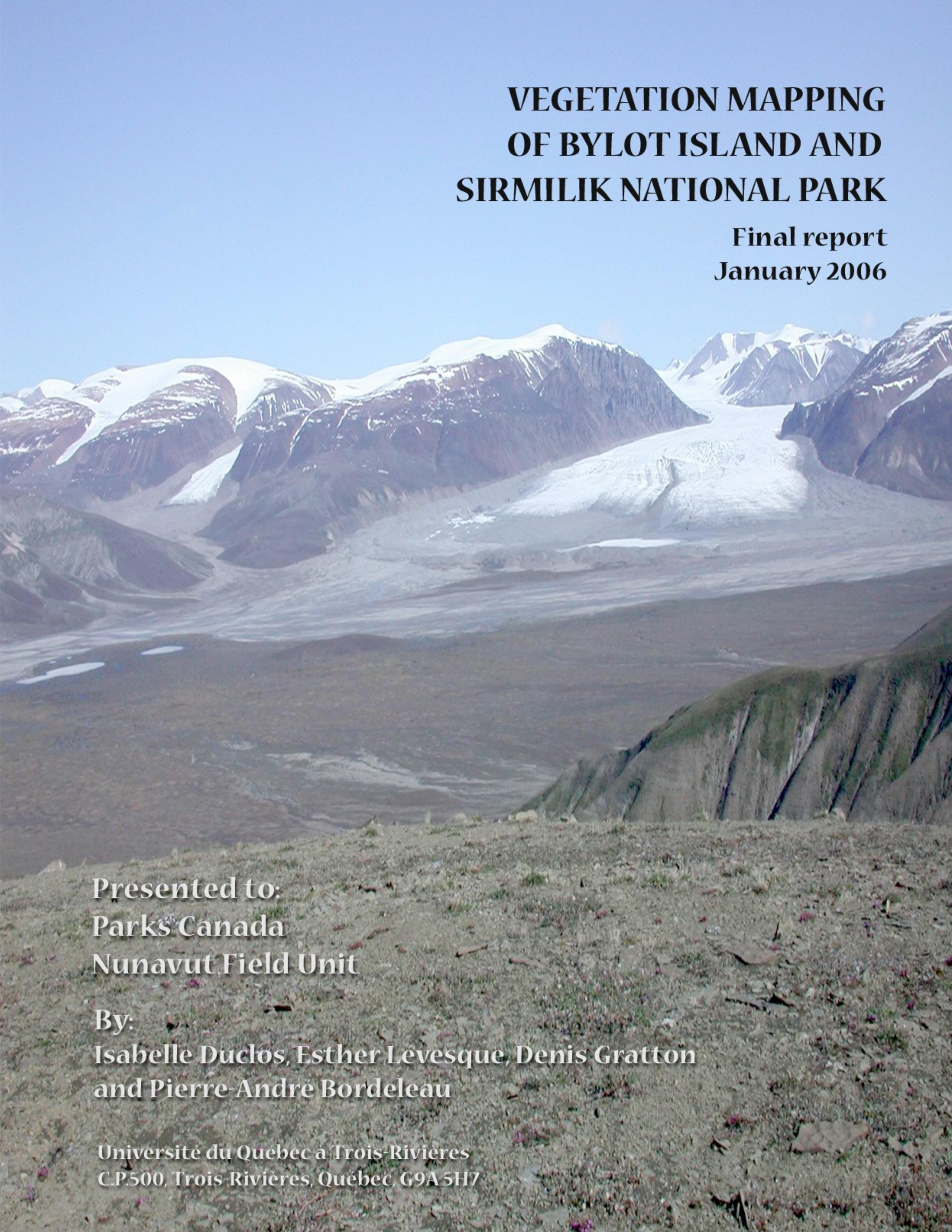

VEGETATION MAPPING OF BYLOT ISLAND AND SIRMILIK NATIONAL PARK

Final report
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SUMMARY

This project was initiated in 2002 in Sirmilik National Park, Nunavut, with the objective of identifying dominant vegetation types and plant communities; and generating a vegetation map, using satellite imagery and the vegetation information collected.

In order to map the vegetation of the whole park, we used images from the satellite Landsat 5 with the Thematic Mapper (TM) taken in July 1998, a Digital Elevation Model (DEM) produced from the 1:250 000 scale topographic maps and a digitized, orthorectified mosaic of 1:60 000 and 1:30 000 scale photographs (National Air Photo Library, mostly from 1982 but also from 1958, 1960, and 1961). The field sampling was guided through a rigourous site pre-selection process done using three parameter images: a normalized difference vegetation index (NDVI), an incidence angle image and a surface texture image. Each potential sampling site was identified in a sequential manner: first by selecting areas where the vegetation index showed a high probability of vegetation cover; then on areas of specific topographic conditions, and finally, sites were identified on surfaces where the texture image showed a relative homogeneity in the spatial patterns (a minimum of 6 contiguous pixels).

Within these homogeneous sites, standard ecological information on the plant communities, their dominant plant cover, species richness and environmental characterisitics was collected within 5m x 5m plots. Field data were collected in the course of two field seasons with 175 plots sampled in 2002 and 274 plots in 2003. In addition, data from 94 plots, gathered with similar methods by Duclos (2002) in summer 2000 and 2001, were merged to the Parks dataset for a total of 141 vascular taxa and 543 sites located on Bylot Island (n=307), Borden Peninsula (n=191) and Oliver Sound (n=45). Of these, 59 plots were marked permanently to allow monitoring of change over time. We recommand monitoring every 5-10 years to evaluate change in biodiversity, abundance and/or disturbance.

Vegetation and environmental parameters were analysed using standard multivariate techniques (classification and ordination) to identify and describe a total of 10 vegetation types ranging from wet meadows to shrub-heath tundra and barrens. For the satellite image classification, only vegetation types with >25% cover and sufficient spatial coverage could be reliably identified thus vegetation types IX (Dwarf-shrub tundra typical to mountain sites) and X (Barrens with sparse plant cover) were excluded. The image was classified using a Neural Net classifier and a subset (n=295) of the appropriate sites (NDVI value, sufficient plant cover etc.). To reduce confusion during this digital classification, the sites from the 8 vegetation types were separated into two groups according to vegetation cover: group 1) greater than 75%; and group 2) between 25% and 75% resulting in 15 classes used for the neural net classication (8 classes for the first group and 7 classes for the second group). A second group of sites (n=174) was used to evaluate the automated classification. The classification produced had an average accuracy of 76% and a Kappa coefficient of 0.619 which is above average indicating that the classification can be used with confidence. Some vegetation types are particularly well recognised by the classification (*e.g.* wetlands) others are less reliably assigned (*e.g.* moist shrub tundra).

Many parts of Sirmilik National Park prouved to be polar oases with lush vegetation not restricted only to valley bottoms but found on rolling hills and even some terraces and mountain

slopes. The plant communities described within the park compare well to others from northern oases. As in other arctic studies, the plant distribution is explained best by topography, moisture availability and soil characteristics. The vegetation map produced is presented in a versatile digital format to allow every user to take advantage of all the information available in each pixel. This map offers great advantages compared to previously available documents, it integrates vegetation and environmental information collected in a standard manner in plots distributed in most regions of the Park and classified using standard tools that will allow to quantify change in time.

As some areas of Bylot Island and Baffin Island have not been sampled yet or have been undersampled (*e.g.* wetlands, elevated plateaux with low vegetation cover, seashore, moraines), new species or plant communities can most likely be discovered. We strongly recommand that some areas be sampled to complete de work (for example, wetlands on Borden Peninsula and eastern valleys on Bylot Island). In the future, such mapping exercise should combine even better expertise of plant ecologists and geographer by having both expertise present during field sampling, this would certainly improve integration as well as data collection and interpretation.

Keywords:

Vegetation mapping, Classification, Ordination, Neural Net classification, Arctic plant community, Satellite images, Sirmilik National Park, Bylot Island, Baffin Island.

EXTENDED ABSTRACT: HOW TO READ AND USE THIS VEGETATION MAP

The vegetation map produced for Sirmilik National Park is a tool designed to help evaluate the distribution of the dominant vegetation types throughout the Park. This information should be useful for Park managers (*e.g.* habitat protection, establishment of least disturbing hicking path), for visitors (*e.g.* choice of sites to visit) as well as for researchers (*e.g.* selection of sampling sites). It is produced in a digital format that should be used, preferentially to the more limited printed format, to produce more specific maps (digital or printed) that correspond better to the needs of the users (specific location, resolution, smoothing of the pixels, etc.).

This map offers great advantages compared to previously available documents:

- The map integrates vegetation and environmental information collected in a standard manner in plots distributed in most regions of the Park.
- The whole Park was classified using standard tools that will allow to quantify change in time.
- Associated with this map are permanent plots marked to improve the monitoring of change.
- The map is available in a versatile digital format.

Prior to using this map it is important to know that it covers a very large area and that the information used in the analyses was the most accurate available at the time but nevertheless, each have their own resolution and limitations. In addition, the map produced could not be ground truthed extensively. It is thus important for all users to understand how the classification and the map were produced and be aware of the following considerations:

1) Ecological considerations:

The field sampling was done to represent, as much as possible, the diverse habitats present in Sirmilik National Park (SNP). Sampling sites were positioned only in large (6 pixels of 30m x 30m) homegenous zones (same NDVI, same texture). Costs, time limitation and weather always constrain such sampling. Some areas of the Park could not be surveyed during this project (especially valleys on the East side of Bylot Island, and northern and western parts of Borden Peninsula) and rare or isolated plant communities may not have been sampled (*e.g.* some types of wetlands on Borden Peninsula or along the Mala River). However, the dominant vegetation types were characterised with as much precision as possible and for this reason, some specific plant communities (*e.g. Dryas integrifolia/Saxifraga oppositifolia* Dwarf-Shrubland) were described within broader vegetation types (*e.g.* Heath tundra).

To describe the diversity of the vegetation and give all users some information on the different plant communities, the vegetation data collected was analysed with standard multivariate statistical approaches. The dominant groupings were identified based on their species composition and analysed in relation to their specific environmental characteristics. Refer to Table 11 and 12 for a list of the dominant vegetation types and their characteristics and to Tables 13 to 22 for community specific species lists. Plant communities represent a continuum of vegetation assemblages according to varying environmental conditions. Groupings are useful but always artificial, there is always some overlap among groupings, some sites being more characteristic and others more marginal. However, all sites from a given vegetation type are assigned to the same category for the mapping exercise which introduces inevitable noise in the analysis.

The plant communities found in SNP grow as a mosaïc in the field (for example, in a polygon field some areas will be characteristic of the wetlands whereas the rims will belong to the mesic plant communities). Since the resolution of the map (pixel size 30m x 30m) represents this mosaïc rather than pure stands of the plant communities, the classes used in the map relate more to the substrate condition (wetness, rockiness, depth of soil, relief…) and the general vegetation structure than to specific taxon or plant communities. The assignment of each pixel to the more general vegetation types should, generally, be more reliable than to specific plant communities.

It is also important to remember that not all plant communities present in the Park were sampled thus can be described in this document. The specific plant communities described here have a general distribution and should help understand the local diversity but new associations (or alliances) could be described within the dominant vegetation types.

2) Geographical considerations:

The vegetation map of Sirmilik National Park was produced using principally a mozaic of 3 Landsat 5 TM (Thematic Mapper) images acquired on July 21 and 26 1998. These images acquire spectral information over 6 optical bands with a spatial resolution of 30m. With this in mind, the first precaution when analysing the vegetation map applies to the aggregation level of the plant community on one hand and the non-vegetated surfaces on the other. A rule of thumb, is that for most vegetated surfaces smaller than 50m, the classification will probably fail to indentify the cover.

The second precaution relates to the different date of acquisition. Each image have their own atmospheric transparency which influences directly on the variability of the spectral response (in other words, intraclass variance) of similar plant communities. This required that we put an emphasis on the spectral band ratios which enhances the vegetation community. The band ratio used was the Normalised Difference Vegetation Index (NDVI). This ratio will enhance the image enabling us to identify the vegetation surfaces and this on a variety of relief. While the threshold used to segment the vegetation from the non-vegetation was inclusive using all *in situ* sampling sites, very small or patchy vegetation cover (<25% cover) will, in most cases, be missed.

The third precaution relating to the image classification, relates to the geometric or geographic accuracy of the document. The number of accurate position control points (Ground Control Points or GCP) in this environment is very limited. The general geographic accuracy for the map over different parts of the Park will be roughly ± 25m. And this is an estimate on the number of control points used compared to the 1:250 000 scale topographic map which has its own spatial "fuzziness". A user of the map with specific GPS position will have to be extra carefull in relating sampling points inside an area smaller than $2500m^2$.

The last precaution to be applied when reading the vegetation map applies to the classification algorithm used. A neural network classifier is a per-pixel classifier which has a tendency to produce a classification having strong spatial variability in the class assignments. In other words it will produce a very patchy map distinctive from the usual polygon-type map. To produce such polygon-map, some kind of filtering is applied to regroup the unusual pixel with the more abundant ones. This was not applied to the original vegetation map because it would mask information that could be valuable to some user. With this in mind, however, if it is desirable for some specific usage, such a smoothing procedure could be applied to all or a portion of the map.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 INTRODUCTION

1.1 Background

The project was initiated on the request of Parks Canada following some initial vegetation analyses performed in the vicinity of the Goose Camp on Bylot Island (Duclos 2002). The previous map produced of the vegetation for the region was completed in the 1980's based on aerial photograph interpretation and some limited ground survey (Zoltaï *et al.*1983). Recently, a circumpolar vegetation map was produced as a result of more than 10 years of work of the Circumpolar Arctic Vegetation Mapping Project (CAVM Team, 2003). Based on the analysis of NOAA's satellite images (spatial resolution of 1 km), this map allows to compare broadly SNP vegetation with vegetation around the pole. However, this classification is coarse at a scale of 1:7500000, grouping Bylot Island, for example, in the broad following classes:

G : GRAMINOID TUNDRAS
G1 : Rush/grass, forb, cryptogam tundra
G2 : Graminoid, prostrate dwarf shrub, forb tundra

W: WETLANDS
W1 : Sedge/grass, moss wetland

B: BARRENS
B3: Non carbonate mountain complex
B3b : subzone b
B3n : nunatak areas

Sirmilik National Park was established in 1999 and represents the Northern Eastern Arctic Lowlands Natural Region of Canada's national parks system. The Park extends from 71º45'N to 73°46'N and from 76°11'W to 84°38'W, covering 22 200 km^2 approximately, which makes it the third largest National Park after Wood Buffalo and Quttinirpaaq National Parks. Sirmilik National Park comprises three parcels of land (Figure 1). Bylot Island forms the important core of the Park while part of Borden Peninsula and the land areas around Oliver Sound Fiord are the second and third parcels located on the north of Baffin Island. As Parks Canada is responsible for the protection and management of the park ecosystems, it is essential to inventory, describe and evaluate the main ecosystem components of the park. This project contributes to a first step in this work.

Through a review of previous studies, a preliminary species list has been produced (Appendix 1), but few detailed vegetation studies focusing on plant communities have been done inside the Park. In its expedition of 1954, in the valley at the mouth of the Aktineq Glacier, Drury (1962) described eight general vegetation associations using standard phytosociological approaches (Table 1). These associations are characteristic of exposed sites, uplands, damp slopes, late melting snow areas, sunny south facing slopes, marshes, drifting sands and raised gravel bars, and sea beaches. Drury also provided a species list comprising 15 taxa of lichens, 14 of mosses, and 101 species of vascular plants. The ecology of some species is discussed in his report as well as the general environmental factors controlling the distribution of the vegetation. Drury also studied the effects of vegetation on soil formation.

Table 1. Characteristics of the eight vegetation associations described by Drury (1962).

Vegetation associations	**Variants**	**Dominant species**
1. Exposed sites – Barren		Mosses, lichens, *Luzula confusa, Salix arctica, Papaver radicatum, Saxifraga oppositifolia*
2. Uplands	a- Exposed – Barren	Lichens, mosses and some graminoids, forbs and shrubs
	b- Sheltered – Dry mat plants	Lichens, mosses, *Poa glauca, L. confusa, S. arctica, Dryas integrifolia, Cassiope tetragona* and some forbs
3. Damp slopes – Wet, mossy		Mosses, *Carex aqualitis, L. confusa, S. arctica* and some forbs
4. Late melting snow areas		Mosses, *Salix herbacea* and some graminoids and forbs
5. Sunny south slopes – Dry mat plants	a- Fine-grained slump	Lichens, *P. glauca, Trisetum spicatum, Hierochloë alpina, Kobresia myosuroides, L. confusa, S. arctica, S. reticulata, D. integrifolia* and some forbs
	b- Sandy alluvial fan	*P. glauca, H. alpina, S. arctica, S. reticulata, Oxytropis maydelliana, Arnica alpina, Taraxacum lacerum* and many other forbs
	c- Stable raised beaches or ridges	*Poa arctica, P. glauca, T. spicatum, H. alpina, L. confusa* and some forbs
6. Marshes – Wet, mossy	a- Raised ridges and margins	Mosses, *C. aquatilis, S. arctica* and some grasses and forbs
	b- Wet centres	Mosses, *Arctagrostis latifolia, Hierochloë pauciflora, Eriophorum angustifolium, E. scheuchzeri, Carex aquatilis* and some lichens and forbs
7. Drifting sands and raised gravel bars		Clumps of *S. arctica* and many forbs
8. Sea beaches		*Phippsia algida, Puccinellia langeana, Deschampsia pumila, Elymus arenarius* and many forbs

In 1982, Zoltai, McCormick and Scotter (1983) had been asked to summarise the natural resources of the potential new National Park. As part of their objectives, they mapped and described five broad vegetation types at a scale of 1:250 000. Their classification was based on the physiognomy of the floral assemblages rather than on floristics, and some broad types contain subtypes of vegetation (Table 2). Willow-grass tundra, Heath-herb tundra, *Dryas* barrens, *Saxifraga-Papaver* barrens, Shrub-sedge tundra, Sedge-moss wet meadow, *Eriophorum*-grass wet meadow and Lichen barren were identified by these authors. They recorded 22 new vascular plant species in the course of their inventory, which led to a total of 130 species for the Park. Their contribution on bryophyte and lichen knowledge in the Canadian Arctic Archipelago was significant by identifying 105 species of bryophytes and 178 of lichens. Although the resulting work was general and supported by only a brief period of field work, they managed to provide an excellent basic for further work.

Table 2. Characteristics of the five vegetation types described by Zoltai *et al*. (1983).

Vegetation types	Vegetation subtypes	Dominant or characteristic species	Specific characteristics
1. Low shrub-herb tundra	a- Willow-grass tundra	*Alopecurus alpinus, Poa glauca, Arctagrostis latifolia, Festuca brachyphylla, Salix arctica* Rich assortment of forbs	- On well drained lowlands - Nearly complete vegetation cover - Dominated by grassy plants
	b- Heath-herb tundra*	*Vaccinium uliginosum, Ledum decumbens, S. arctica.* Idem for forbs	
2. Dwarf shrub barrens	a- *Dryas* barrens	*Dryas integrifolia, S. arctica, A. alpinus, F. brachyphylla, Kobresia myosuroides, Luzula confusa*	- Widespread - Characteristic of the polar semi-desert
	b- *Saxifraga-Papaver* barrens	*Saxifraga oppositifolia, Papaver radicatum,* graminoids and forbs	
3. Shrub-sedge tundra		*S. arctica, Carex misandra, C. atrofusca, C. aquatilis var. stans, Oxytropis maydelliana* and other forbs	- *Cassiope tetragona* grows in areas of snow accumulation
4. Wetland meadow	a- Sedge-moss wet meadow	*Carex aquatilis var. stans, Luzula nivalis, Pedicularis sudetica, Saxifraga hirculus, Ranunculus nivalis*	- High soil moisture - Mosses are usually constant
	b- *Eriophorum*-grass wet meadow	*Eriophorum scheuchzeri, E. vaginatum ssp. spissum, E. callitrix, A. alpinus*	
5. Lichen barren		Hardy crustose lichens growing on rocks, *L. confusa* or *S. oppositifolia*	- Low vascular plants cover - At high elevations in polar deserts

* Subtype only found on Baffin Island.

After the Goose Camp had been established in 1989 by Dr. Austin Reed (Canadian Wildlife Services) and Dr. Gilles Gauthier (Université Laval), habitat studies related to geese took place on the south plain of Bylot Island, especially in the Goose Camp valley which is intensively used by goose families. In a 14 km^2 study area, Hughes (1992) described three habitat types - Pond/Lake, Wet meadows and Uplands- used by Greater Snow Goose (*Chen caerulescens atlantica*) families during the brood rearing period (Table 3). His study essentially focused on wetlands and was based on habitat physiographic features rather than on floristics. After this inventory, Hughes added 6 new vascular plant species to the Park species list.

Table 3. Habitat types described by Hughes (1992) in the Goose Camp valley. Only most dominant species are shown (mean abundant score >2).

Habitats	**Subhabitats**	**Dominant species**
1. Pond/lake	- Large polygon ponds	*Dupontia fisheri, Salix arctica*
	- Small polygon ponds	*D. fisheri, S. arctica, Carex aquatilis var. stans*
	- Broad lakeshores	*S. arctica, D. fisheri, Arctagrostis latifolia*
	- Wet moss flats	*D. fisheri, Eriophorum angustifolium, C. aquatilis var. stans*
2. Wet meadows	- Wet moss meadows	*D. fisheri, C. aquatilis var. stans, E. scheuchzeri*
	- Irregular ponds	*S. arctica, A. latifolia, Luzula confusa*
3.Uplands	- Isolated wet patches	*S. arctica, A. latifolia, Equisetum arvense*
	- Sparsely vegetated mud*	*S. arctica, Poa arctica*
	- Deep canal polygons*	*S. arctica, L. confusa, C. aquatilis var. stans*
	- Dry moss meadows*	*S. arctica, A. latifolia, C. aquatilis var. stans, Stellaria longipes*
	- Dry valley bottom	*S. arctica, Dryas integrifolia, S. reticulata, A. latifolia*
	- Dry hills	*S. arctica, A. latifolia, Cassiope tetragona, L. nivalis*

*Dryer habitats intersecting Pond/lake or Wet meadow habitats.

In order to estimate the carrying capacity of the wetlands on the south plain of Bylot Island, Massé (1998), based on Hughes' work, characterised and mapped five types of wetlands by studying nine sites with high wetland concentrations. Streams and wet polygons were the two most important habitats in terms of food supply available for geese. As for previous work, the description of the wetland habitats was based on morphometric features rather than floristic (Table 4). Massé *et al*. (2001) estimated that the area covered by wetlands represents about 11% of the south plain of Bylot Island.

Recently, Duclos (2002) characterised and mapped the mesic and dry plant communities in a 70 km^2 study area around the Goose Camp. This study was the first based on floristics and using multivariate analyses. Classification analysis of 88 taxa and 94 plots led to six mesic, two mesic-xeric and two xeric plant communities (Table 5). Total vegetation cover was generally high (>95%), except in xeric plant communities. Diversity of plant communities was linked to the heterogeneous topography and reflected a moisture and disturbance gradient. Environmental factors influencing plant distribution were also identified and discussed. According to a direct gradient analysis, slope angle, altitude, exposition, cover of litter and bare ground, and surficial deposits influenced most the distribution and cover of vegetation. Six vascular plant species were newly identified in the course of this study. Finally, sampling associated with the current report added two species, bringing the total for the Park to 153 vascular plant species. (Appendix 1).

Continuing ecological studies at the Bylot Island goose camp focus on trophic dynamics (soil-plants-herbivores-predators) in relation to global changes and include long-term monitoring (Gagnon *et al*. 2004). Other studies address the geomorphology (Allard 1996; Fortier 2005) and paleoecology of the sites (*e.g.* Ellis and Rochefort 2004, Fortier and Allard 2004). In 2004 and 2005 a detailed botanical study was initiated that is revising the vascular plant species list based on recent taxonomical changes using vaucher specimen and an extensive new plant collection (Tremblay and Lévesque in prep.) the most recent evaluation proposes 155 vascular species, 73 genera and 27 families for SNP.

Table 4. Morphometric description of wetland habitats on the south plain of Bylot Island, modified from Massé (1998) and Massé *et al*. (2001).

Habitat type	**Proportion of the habitat covered with forage for geese**	**Description**
1. Wet polygon	60%	Low-centre polygon surrounded by dry elevated rims.
2. Polygon channels	5% reduced to a narrow strip (<35 cm) along the channels	Narrow, steep channels with standing water, located mostly between high-centre polygons.
3. Lake polygon	7% consists of a narrow strip (<40cm) along the shore of the lake polygon.	Low-centre polygon permanently covered by standing water up to 3m deep.
4. Stream	93%	On sloppy terrain, strip of vegetation about 2m wide on both sides of seasonal or permanent stream. On flat terrain, this habitat is characterised by anastomozed channels (meltwater channels) flooding the area and forming wet meadows.
5. Lake	1%	Vegetation strips about 2m wide located around lakes. This habitat differs from the *lake polygon* habitat because lakes are much larger and do not result from the coalescence of polygons.

Table 5. Ten plant communities described by Duclos (2002) in the area of the Goose Camp.

General vegetation types	**Plant communities**	**Habitats**
	Mesic conditions	
1. Heath tundra	1.1 *Cassiope* heath tundra	Gentle slopes where snow accumulate
2. Mesic meadows	2.1 *Arctagrostis* meadow	Flat terraces
	2.2 *Salix-Arctagrostis* meadow	Flat terraces, gentle slopes, valley bottom
3. Dwarf-shrub tundra	3.1 *Salix*-graminoid-forb tundra	Medium slopes facing south or west
	3.2 *Salix*-graminoid tundra	Valley bottom
	3.3 *Salix*-cryptogam tundra	West facing slopes exposed to wind
	Mesic-Xeric conditions	
4. Dwarf-shrub-legume tundra	4.1 *Salix*-legume-graminoid tundra	South facing slopes in mountains
	4.2 *Salix*-moss-legume tundra	South, west and east facing slopes in hills or mountains
5. Barrens	Xeric conditions	
	5.1 Forb-*Salix* barrens	Scree slopes
	5.2 Graminoid barrens	Beaches

1.2 Objectives

The aim of this project is to produce a vegetation map of Sirmilik National Park using satellite imagery. Many studies in the Canadian Arctic have successfully mapped the vegetation using classification of satellite images and ground-thruthing (*e.g.* Ferguson 1991, Pearce 1991, Jaco *et al*. 1998, Laidler 2002). More precisely, the objectives of this project are:

- To map the vegetation of the entire park using Thematic Mapper Landsat imagery, ground truthing and digital image analysis;
- To evaluate approaches to use remotely sensed information in the mid-Arctic for developing vegetation maps;
- To develop a more complete vascular plant, bryophyte and lichen species list for the park area;
- To contribute to a better understanding of vegetation types and plant communities in the mid-Arctic;
- To evaluate potential long term vegetation monitoring protocols.

2 METHODS

Principally two images from the satellite Landsat 5 TM, taken on July 21st and 26th 1998, were used in this project. The images were georeferenced using an orthorectification procedure and put together in a mosaic to produce a single composite image, orthorectified and resampled to 30m. A third image corresponding to a small upper portion of Bylot Island was also used to complete the analysis of the Park.

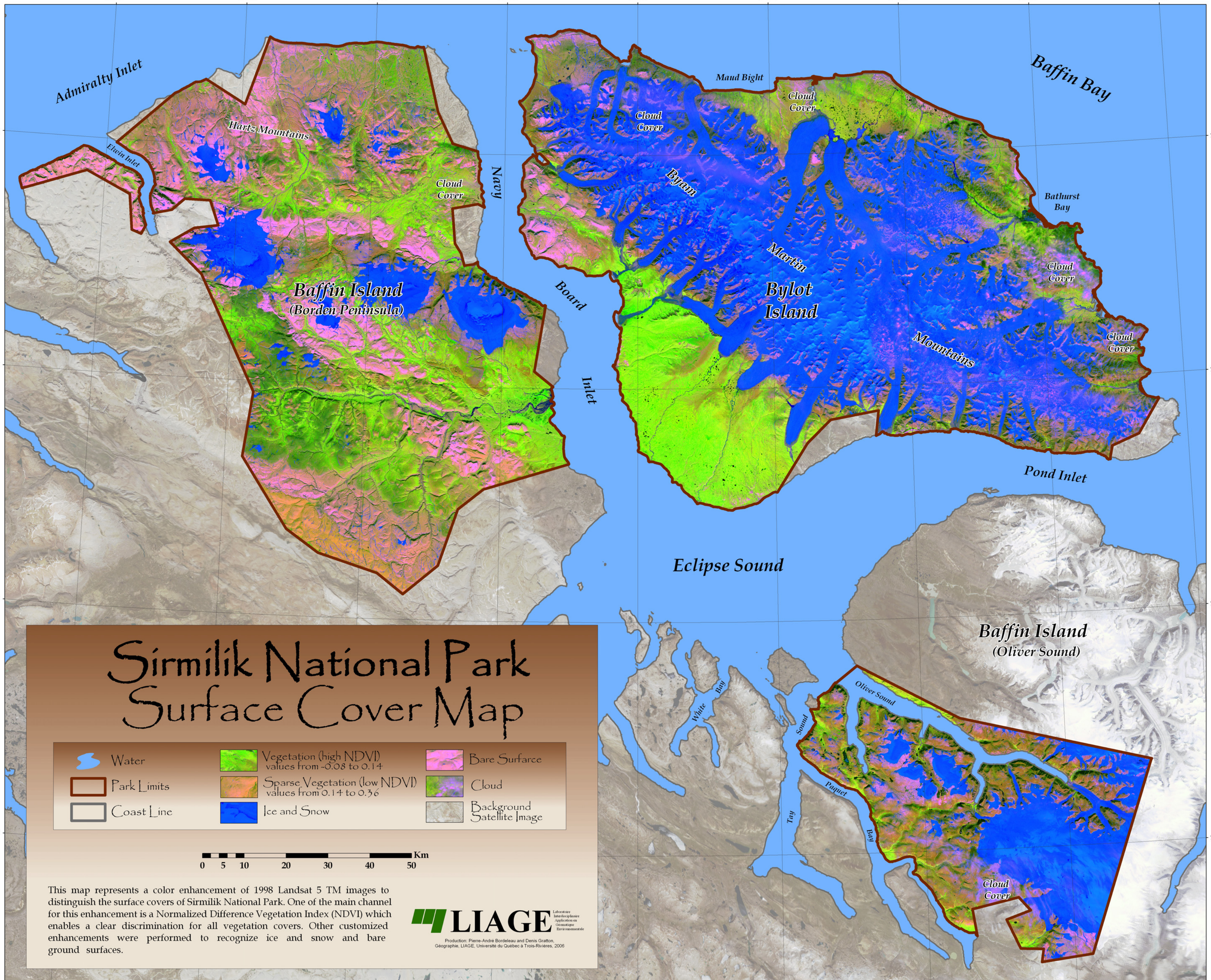
2.1 Selection of sampling sites

In order to link the vegetation classes with information from the spectral domain on the TM images, in other words, to attempt on classifying vegetation information which has a chance of being present on the images, it is important to guide the *in situ* sampling strategy with information intrinsincaly linked with the spectral images.

In order to identify sampling sites which must account for the Thematic Mapper (TM) image characteristics, a selection strategy for the potential sampling plots was established prior to the field campaign. The image characteristics to consider relate principally to: 1) the TM bands spectral response to the vegetation cover reflection; 2) the topographically induced incoming solar radiation; and 3) the vegetation and background cover spatial distributions. Each characteristics were modeled using specific image analysis strategies.

First, a Normalized Difference Vegetation Index (NDVI) image was produced in order to enhance the spectral patterns permitting to delineate areas which have a spectral response corresponding to the spectral signature for vegetation (Figure 1).

Figure 1. The Normalized Difference Vegetation Index (NDVI) image of Sirmilik National Park, Nunavut, based on three orthorectified Landsat 5 TM images from July 1998. Low NDVI values correspond to values between -0.08 to 0.14 and High NDVI values correspond to values between 0.14 to 0.36.



Sirmilik National Park Surface Cover Map

This map represents a color enhancement of 1998 Landsat 5 TM images to distinguish the surface covers of Sirmilik National Park. One of the main channel for this enhancement is a Normalized Difference Vegetation Index (NDVI) which enables a clear discrimination for all vegetation covers. Other customized enhancements were performed to recognize ice and snow and bare ground surfaces.

This NDVI is obtained by dividing the near-infrared (TM4) and red bands (TM3) difference over the sum of both bands:

1 NDVI = (TM4-TM3) / (TM4+TM3)

The TM3 and TM4 images were not corrected for atmospheric effects prior to calculating the NDVI because no specific atmospheric parameters were available. In the absence of any atmospheric corrections, the resulting NDVI values do not match the normal range of NDVI values which one would expect when all corrections are applied. On a corrected NDVI image, the 0 value separates surfaces which have vegetation (from 0 to 1) from surfaces without any vegetation (from –1 to 0). The NDVI values obtained from images on which we did not apply any corrections will have a tendency to underestimate the NDVI values for vegetation covers. Nonetheless, this will have no consequence on the sampling site selection. In fact, this underestimation ensures that the site selection will apply solely to a vegetated cover.

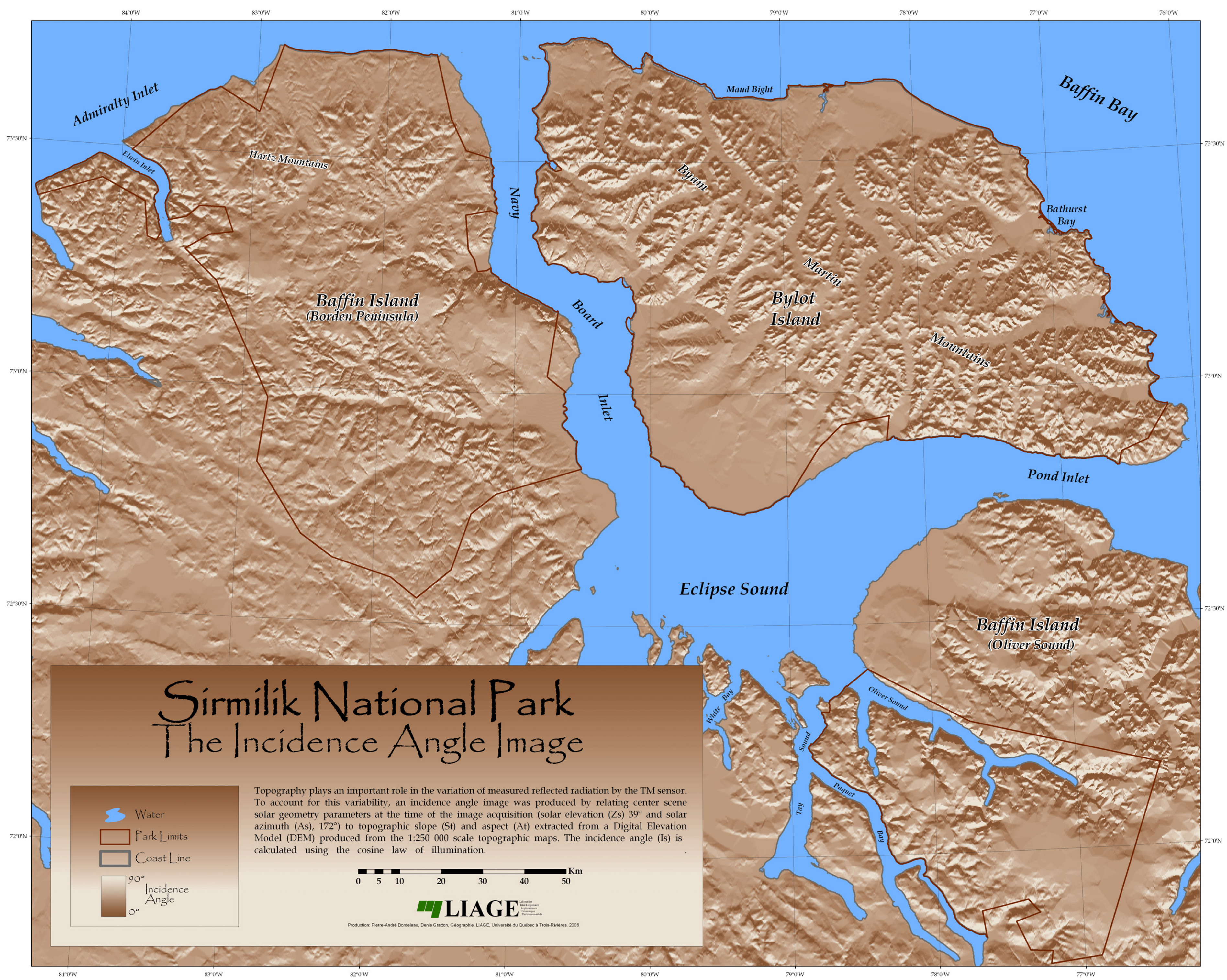
Secondly, topography plays an important role in the variation of measured reflected radiation by the TM sensor. To account for this variability when selecting potential sampling sites, an incidence angle image was produced by relating center scene solar geometry parameters at the time of the image acquisition (solar elevation (Z_s) 39° and solar azimuth (A_s), 172°) to topographic slope (S_t) and aspect (A_t) extracted from a Digital Elevation Model (DEM) produced from the 1:250 000 scale topographic maps. The incidence angle (I_s) is calculated using the cosine law of illumination:

2 $I_s = \text{acos}\ (\cos(S_t)\cos(Z_s) + \sin(S_t)\sin(Z_s)\cos(A_s - A_t))$

Prior to the site selection and to allow the identification of sufficiently large areas with similar topographic conditions, the incidence angle image was reclassified into 6 classes of incidence angles (Figure 2):

<25º
>=25º to <35º
>=35º to <45º (considered to be the flat surfaces)
>=45º to <55º
>=55º to <65º
>=65º
9
Thirdly, a large variability in the spectral response comes from the structural composition of the vegetation cover (primarily density and height) mixed with the soil and rock background. In order to account for the spatial patterns, a texture analysis was performed on digitized and orthorectified aerial photographs. The orthotransformation and mosaic of 1:60 000 and 1:30 000 scale photographs (National Air Photo Library, 1982, 1958, 1960, and 1961) resulted in the production of a 5m spatial resolution panchromatic image of the Park (Figure 3).

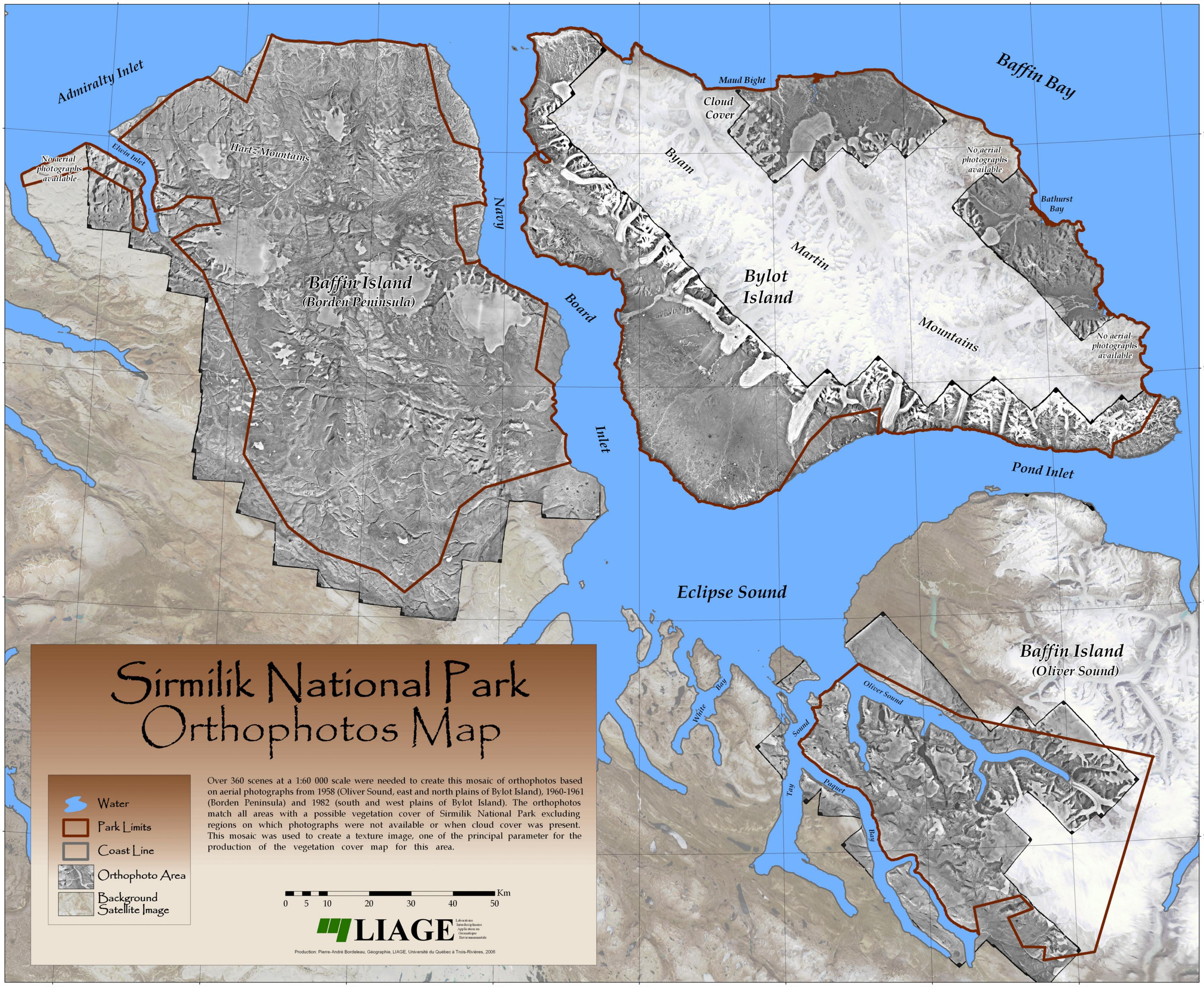
Figure 2. The incidence angle image of Sirmilik National Park, Nunavut, produced from a 1:250 000 scale DEM using the cosine law of illumination.



Sirmilik National Park
The Incidence Angle Image

Topography plays an important role in the variation of measured reflected radiation by the TM sensor. To account for this variability, an incidence angle image was produced by relating center scene solar geometry parameters at the time of the image acquisition (solar elevation (Zs) 39° and solar azimuth (As), 172°) to topographic slope (St) and aspect (At) extracted from a Digital Elevation Model (DEM) produced from the 1:250 000 scale topographic maps. The incidence angle (Is) is calculated using the cosine law of illumination.

Figure 3. The orthophotomap of Sirmilik National Park, Nunavut, based on digitized, orthorectified aerial photographs taken at 1:60 000 in 1982 for the southern part of Bylot Island and aerial photographs taken at 1:30 000 in 1958, 1960 and 1961 for the rest of SNP.

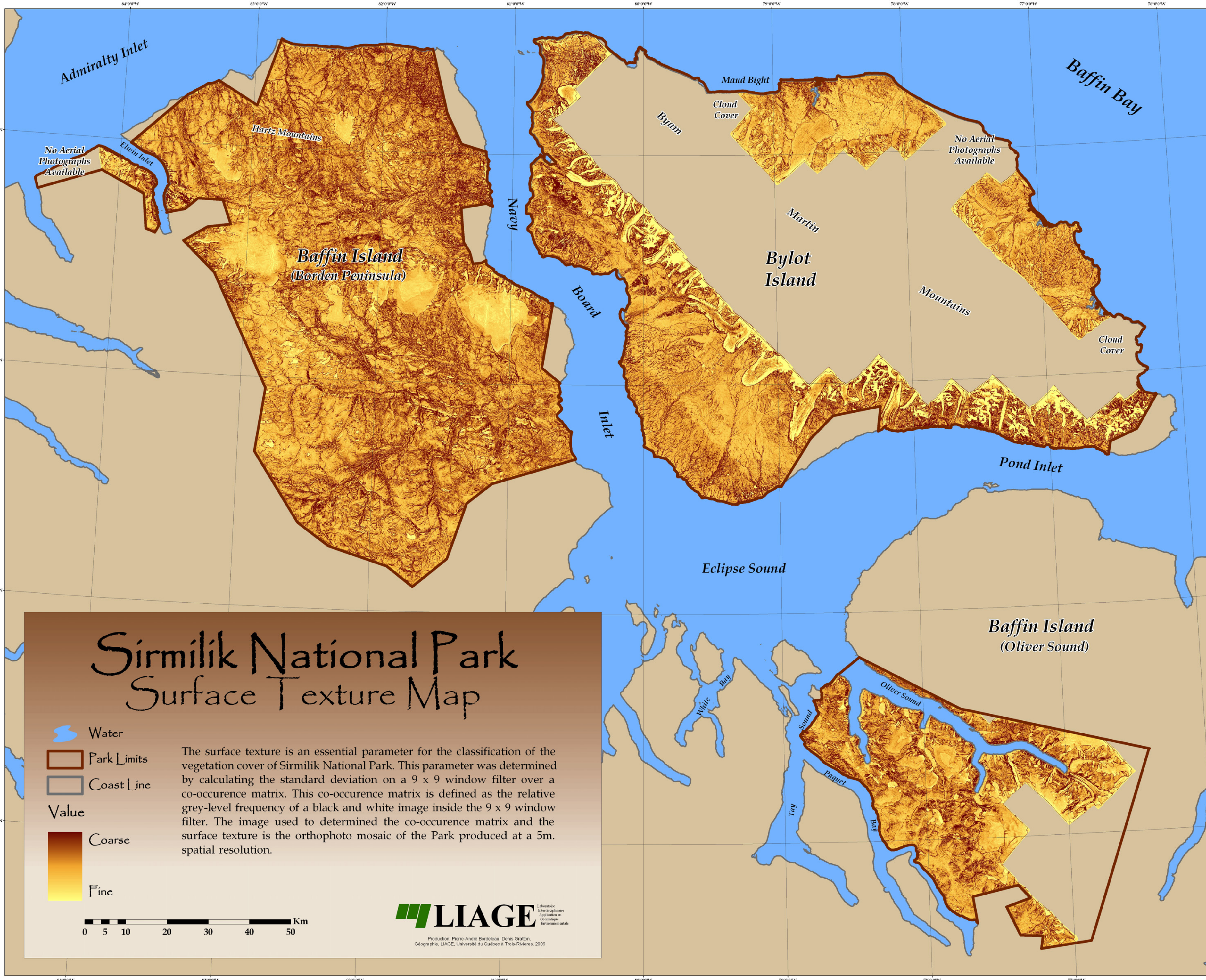


Sirmilik National Park Orthophotos Map

Over 360 scenes at a 1:60 000 scale were needed to create this mosaic of orthophotos based on aerial photographs from 1958 (Oliver Sound, east and north plains of Bylot Island), 1960-1961 (Borden Peninsula) and 1982 (south and west plains of Bylot Island). The orthophotos match all areas with a possible vegetation cover of Sirmilik National Park excluding regions on which photographs were not available or when cloud cover was present. This mosaic was used to create a texture image, one of the principal parameter for the production of the vegetation cover map for this area.

Production: Pierre-André Bordeleau, Géographie, LIAGE, Université du Québec à Trois-Rivières, 2006

Figure 4. The texture image of Sirmilik National Park, Nunavut produced from the orthophoto map of the Park and using the standard deviation of grey level co-occurrence over a 9 x 9 pixels window size.


Sirmilik National Park
Surface Texture Map
Water
Park Limits
Coast Line
Value
Coarse
Fine
The surface texture is an essential parameter for the classification of the vegetation cover of Sirmilik National Park. This parameter was determined by calculating the standard deviation on a 9 x 9 window filter over a co-occurence matrix. This co-occurence matrix is defined as the relative grey-level frequency of a black and white image inside the 9 x 9 window filter. The image used to determined the co-occurence matrix and the surface texture is the orthophoto mosaic of the Park produced at a 5m. spatial resolution.
0 5 10 20 30 40 50 Km
LIAGE
Production: Pierre-André Bordeleau, Denis Gratton, Géographie, LIAGE, Université du Québec à Trois-Rivieres, 2006
Admiralty Inlet
Hartz Mountains
Elwin Inlet
No Aerial Photographs Available
Baffin Island
(Borden Peninsula)
Navy
Board
Inlet
Maud Bight
Cloud Cover
Byam
Martin
Bylot Island
Mountains
Baffin Bay
Pond Inlet
Eclipse Sound
Baffin Island
(Oliver Sound)
Oliver Sound
White Bay
Sound
Paquet
Bay
Tay
84°0'0"W
83°0'0"W
82°0'0"W
81°0'0"W
80°0'0"W
79°0'0"W
78°0'0"W
77°0'0"W
76°0'0"W
73°30'0"N
73°0'0"N
72°30'0"N
72°0'0"N

The texture analysis was done by first creating a co-occurrence matrix (the grey level occurrence inside a specific area) of the grey-level values of the panchromatic image (Marceau *et al*, 1994). One of the principal aspect of the texture analysis in a co-occurrence matrix is the size of the "window" inside which the spatial relationship among the pixel spectral response is established. A rule of the thumb is to relate the texture analysis with the spatial resolution of the principal spectral image, which, in this case, is the 30m TM images. The standard deviation for the grey level value spatial occurrence was used to estimate spatial texture. Furthermore, in order to account for the errors in the geometric matching between all spatial information as well as the average size of the *in situ* vegetation sampling sites, a window size of 9 pixels x 9 pixels over the 5m spatial resolution orthorectified panchromatic image was chosen. This lead to an analysis of the texture patterns inside an area of 45m by 45m (Figure 4).

The pre-site selection was done using the three parameter images: a normalized difference vegetation index (NDVI, Figure 1), an incidence angle image (Figure 2) and a surface texture image (Figure 4). Each potential sampling site was identified in a sequential manner: first by selecting areas where the vegetation index showed a high probability of vegetation cover; then on areas of specific topographic conditions, corresponding to the 6 classes for incidence angles; and finally, sites were identified on surfaces where the texture image showed a relative homogeneity in the spatial patterns (a minimum of 6 contiguous pixels).

2.2 Vegetation sampling

In the field, each sampling site was located using a GPS. Error was generally less than 10 meters and should ensure that the data collected was within the identified site. A site (50m x 50m plot) was sampled if the topography and vegetation (cover and species composition) were homogeneous. At each site, general landscape characteristics were noted and plant cover (%) was evaluated using the abundance classes presented in Table 6. The information collected using standard data sheets (Appendix 2) was:

Date of sampling
Reference number of the sample site
Name of data collectors
Location using a GPS (latitude and longitude in degrees-minutes using NAD 83)
Elevation (m; measured with the GPS, error usually less than 10m)
Slope angle (degree; measured with a clinometer)
Slope aspect (degree; measured with a compass or assessed from a topographic map)
Landform (terrace, plateau, valley bottom…)
Topography (flat, mid-slope, upper-slope,…)
Microtopography or microrelief (hummocky, mud-boils, stripes…)
Stoniness (stone >15 cm: 1-low to 6-high) and rockiness (bedrock cover: 1-low to 6-high; based on the Canadian system of soils classification, 1978)
Cover of the dominant type of rocks (%): gravel (<8 cm), stone (8-25 cm) and rock (>25 cm; sized based on the Canadian system of soils classification, 1978)
Cover of the dominant plant type (%): shrubs, grasses, forbs, mosses, lichens
Cover of the dominant ground cover (%): rock, sand, gravel, water, moss, vegetation
Moisture index: 1-wet; 2-wet to mesic; 3- mesic; 4-mesic to dry; 5-dry
Presence of herbivore or carnivore faeces
Presence of grazing marks (leaves, inflorescences, grubbing/shoot pulling)

Pictures of the site, plot and surrounding landscape.

At the centre of each sampling site, vegetation was sampled within a 5m x 5m plot and the cover of the following vegetation features were recorded using the abundance classes presented in Table 6:
Every vascular plant species present in the plot
Moss stratum
Lichen stratum
Biological crust (a mixture of cyanobacteria, algae, fungi, lichens and sometimes mosses covering the soil surface)

and of the following ground features:
Litter
Bare ground
Rocks (gravel (< 8 cm), stone (8-25 cm), rock (>25 cm))
Water (standing or running water).

The overall cover of each vegetation stratum was also recorded:
Shrub stratum
Graminoid stratum
Forb stratum
Herb stratum (Graminoids + Forbs)
Moss stratum (moss and lichen)
Cryptogam stratum (moss, lichen and biological crust).

In addition, vascular plant species that had not been recorded within the 5m x 5m plot but were present within a radius of 20m were noted and their cover evaluated using the abundance classes in Table 6. There was no systematic collection of vauchers done during the field sampling due to lack of time. However, when necessary, identification was confirmed using collections available at UQTR herbarium. Nomenclature of vascular plants follows Porsild (1957) and Porsild and Cody (1980).

Table 6. Cover abundance classes used in the field (modified from Braun-Blanquet 1932). The mid-class value was be used in analyses.

Classes	**Range of cover percentage (%)**	**Mid-class value (%)**
T	Very few individuals	0.05
f	Few individuals	0.2
1	Less than 1%	0.5
2	1-5%	3
3	5-10%	7.5
4	10-25%	17.5
5	25-50%	37.5
6	50-75%	62.5
7	Over 75%	87.5

2.3 Permanent plots

In order to monitor any change in vegetation composition or abundance, we marked some plots permanently in the field. A total of 59 plots (32 in 2002 and 27 in 2003) sampled for their vegetation characterisation (5m x 5m) were converted into permanent plots in Sirmilik National Park. Part of these plots were selected based on their level of surface stability (*e.g.* exposed sites like plateau). The remaining plots were distributed across the Park in order to represent a variety of texture. Two six inches nails were hammered in two opposite corners of the plot and each nail was marked with a metal tag identifying the plot number.

We propose that these permanent plots should be resampled every 5 to 10 years. We recommend that a complete list of species should be done inside the 5m x 5m plot and outside within a radius of 20m following a similar procedure as what was followed for this project. The cover of all vegetation parameters and ground features should be evaluated as described above. This monitoring would allow to trace changes in the vegetation (relative abundance of species), plant species diversity (addition or dissappearance of some species) and surface characteristic stability (*e.g.* erosion, water saturation, frost action).

2.4 Vegetation classification and distribution

Prior to the analysis of the vegetation, data set gathered with similar methods by Duclos (2002, n=94) in summer 2000 and 2001 were merged to the data set collected by Parks Canada in summer 2002 (n=175) and 2003 (n=274). In total, 141 taxa (mean cover) and 543 sites located on Bylot Island (n=307), Borden Peninsula (n=191) and Oliver Sound (n=45) were sampled and analysed. After preliminary classification analyses, wetland samples (n=30, summer 2002) were clearly isolated at the first division and since they shared few species with the rest of the sampled communities they were removed from the data set for further analyses. Beach samples (n=6, Duclos 2002) were also removed from the analysis because their low vegetation cover and high sand cover resulted in a NDVI value equalling 0. The following analyses were thus performed on the remaining 507 plots.

In order to determine the structure of the vegetation in Sirmilik NP, we classified the data using a two-way indicator species analysis (Twinspan, default settings; Hill 1979, PC-ORD v4). Species with a low occurrence and having an overdue influence on the classification were removed from the data set. A Detrended Correspondence Analysis (DCA, Hill 1979, Canoco v4) was then performed to visualize the distribution of the sites along ordination axes and verify that the vegetation types were well defined (no considerable overlap).

To explore the multivariate relationships among stands on the basis of the composition and abundance of vascular species and cover of mosses, lichens and biological crust, the 507 plots were subjected to an ordination by DCA (Hill 1979, Canoco v4).

Even though wetlands and beaches were not included in the previous overall classification analysis, they were each subdivided into plant communities based on a one-level Twinspan analysis (Duclos *et al*. 2003). For wetlands, plots sampled on polygon rims were removed before performing the one-level Twinspan analysis because of their different species composition (mesic habitat).

Environmental parameters influencing the distribution of the vegetation were identified using a canonical correspondence analysis for all 141 taxa and 543 sites (CCA; ter Braak 1995, Canoco v4, settings: Hill's scaling, log transformation). A second analysis was performed without the wetland and beach samples (see above). Because two other types (Shrub-Forb Tundra (mountains) and Shrub Heath Tundra (*Vaccium-Cassiope*)) were isolated in the first CCA, these two types were also removed from the second analysis. A total of eight environmental parameters were used in the analyses: altitude, slope angle, exposition, and cover of litter, bare ground, gravel, stone and rock. Surficial deposits and bedrock could not be included in this analysis compared to the 2002 analysis because Klassen's map (1993) used to determine these parameters does not cover the Borden Peninsula and Oliver Sound portions of the Park. A summary of the surficial deposits and bedrock present on Bylot Island is given in Table 7.
Considering the large number of environmental parameters, a manual forward selection was used to retain parameters that influenced most the plant distribution (1000 Monte Carlo permutations, α level of 0.1). Because slope exposition was directly linked to slope value, two variables were generated, EW and NS, in order to interpret exposition ecologically (Duclos 2002):

$$EW = \sin(\text{exposition}) * \sin(\text{slope})$$

$$NS = \cos(\text{exposition}) * \sin(\text{slope}).$$

EW represents east-west exposition while NS is the north-south exposition. Plots on flat terrain or on gentle slope have no particular exposition (small value of EW and NS) while plots on steep slopes have gradually higher values (for a maximum of 1) of EW (positive values for East, negative for West) or NS (positive values for North, negative for South).
Prior to analysis, some variables were log-transformed except for EW and NS (no transformation) to minimise the effect of outliers on results.

2.5 Vegetation type and community names

Vegetation types (or alliances) were first named according to their dominant plant life form (highest mean percent cover) and physiognomic characteristics (*e.g.* meadow, heath, tundra or barren). They were also named based on standard references developed by the International Classification of Ecological Communities in conjunction with the Natural Heritage Network, NatureServe and The Nature Conservancy (Grossman *et al*. 1998). **Plant communities** (or associations) were named as defined in the International Classification of Ecological Communities (Grossman *et al*. 1998). Plant species that are dominant (cover the greatest area) and diagnostic (found consistently in some vegetation types but not others) are the foundation of alliance and association names. Since no standard names have yet been defined for the Arctic region, alliance and association names presented here are tentative.

Table 7. Description of the microtopography and the surficial deposits and bedrock present on Bylot Island.

MICROTOPOGRAPHY	Description
Flat	- no pattern
Hummocky	- hummocks of various sizes
Mud-boil	- round surfaces of bare ground ~30-50cm, most were active
Polygon	- most sampled polygons were low-centre and surrounded by mesic or dry elevated rims
Stripe	- alternative stripes of vegetation and bare ground or gravel
Lobe	- small-sized gelifluction lobe (vegetated)
Undulating	- heterogeneous pattern including mound, fissures and flat surface
Sorted circle	- circular form where small stones dominate the central area and larger stones form the border (diameter: 50-100 cm)[1]
SURFICIAL DEPOSITS[1]	**Description**
Eolian	- well sorted, coarse to fine sand, deposited by wind and interbedded with organic material and thin sheets of outwash, characterised by polygonal patterned ground
Marine -sediments and landforms related to marine inundation during two or more periods of higher relative sea level, sparsely vegetated.	- Littoral (nearshore): coarse sand, gravel and boulders, 1 to 5m thick, forming flights of beaches, bars and spits - Deltaic: mud, sand, gravel, and boulders deposited in the sea near stream mouths and forming deltas and delta fans
Glacial -sediments transported by either foreign (regional ice sheets) or native ice and deposited directly from ice, by meltout during ablation, and from ice marginal meltwater streams	- Foreign drift: muddy sand to sandy diamicton characterised by abundant foreign debris and including fragments of marine shells - Native drift: sandy diamicton characterised by angular crystalline boulders - Ice marginal drift: poorly sorted gravel to boulder gravel, deposited or reworked by ice or meltwater, or both, along an ice margin, characterised by short morainic ridges and by meltwater channels
Glaciofluvial -sediments and landforms either deposited or modified by meltwater in contact with or in front of glacier ice	- Stratified and nonstratified drift: well to poorly sorted sand and gravel, forming low pads and terraces on lowlands, preferentially along valley margins, commonly thin and discontinuous - Ice contact stratified drift: well to poorly sorted sand and gravel, 5 to 60m thick, deposited either within or against glacier ice
BEDROCK[2]	**Description**
Sedimentary rock	- poorly consolidated to unconsolidated: sandstone, mudstone, and coal of Cretaceous and Tertiary age forming rolling lowlands on southern Bylot Island

[1] From Washburn 1980.
[2] From Klassen 1993.

2.6 Satellite image classification

From a total of 410 sites identified in the field, 21 sites where removed from the analysis as described below. Of these 21 sites, 10 sites were identified because of very low NDVI values, lesser than –0,08 (Figure 5), which probably relate to the variation in the water surface content between time of the TM image acquisition in July 1998 and the in situ sampling campaign in 2003. In fact, most of these sites were in close proximity to standing water covers. The sites (and their NDVI value) are: SP11-3 (-0,189), SP15-10 (-0,143), SP15-11 (-0,226), SP15-6 (-0,140), BSE-462 (-0,350), SSE-410 (-0,209), BE-950 (-0,105), OS-396 (-0,093), OS-231 (-0,156), BSN-262 (-0,125).

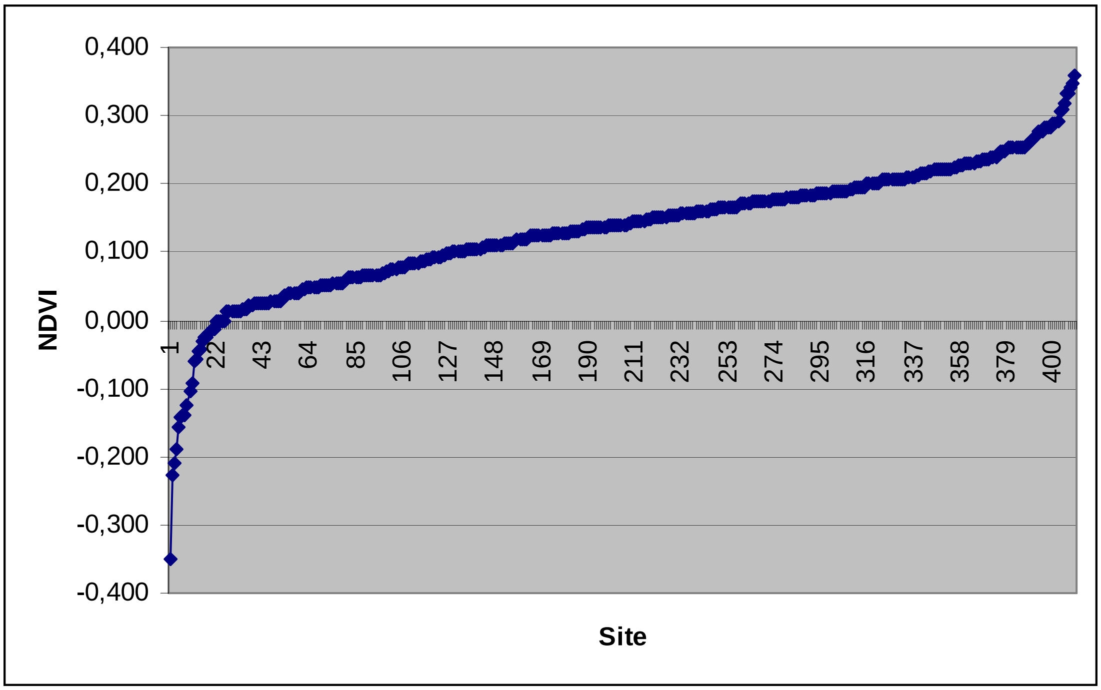


Figure 5. The NDVI values for the 410 in situ vegetation sampling sites.

Secondly, all resulting sites were regrouped using the information on the percent of vegetation cover identified in the field (Table 8). Three groups of vegetation cover were formed: lesser than or equal to 25%, between 25% and 75 %, 75% and above. From this information, 9 sites (BSE-715, NP3-1, NP3-2, OS-006, BE-997, OS-230, BSN-261, BE-625, OS-375) were removed because of a vegetation cover less than 25% (class 4 and lower, Table 6). Also, 2 sites were removed (OS-301 and OS-047) because they were the only two samples for the vegetation class Shrub Heath-Tundra (*Vaccinium uliginosum)* in the percent vegetation cover class between 25% and 75%. The resulting 388 sites were used for the classification.

To reduce confusion during the digital classification because of the varying vegetation cover density, the 388 sites were separated into two groups according to vegetation cover: group 1) greater than 75%; and group 2) between 25% and 75% resulting in 15 classes used for the classication (8 classes for the first group and 7 classes for the second group). In order, to verify the accuracy of the classification, 93 test sites (1-93; Table 8) were selected using a stratified random sampling approach of the 8 vegetation types while the remaining 295 sites (Table 9) were used to train the automated classification approach.

The 93 test sites are grouped with an additional 81 vegetation sampling sites (94-174; Table 8) to test the image classification. These 81 sites were selected from 117 sampling sites visited mostly on the south plain of Bylot Island in 2000 and 2001 (Duclos, 2002). From these 117 sites, the first 27 sites were excluded because of their low vegetation cover in the mountain and shore environments and 9 sites were excluded because of their very low NDVI value: BN-BARE2 (-0,184), BORDEN02 (-0,126), CH01 (-0,190), CH02 (-0,154), CH03 (-0,177), CH04 (-0,197), PT-06 (-0,086), PT-08 (-0,153), BN-BARE1 (-0,179).

The resulting 174 sites used to evaluate the automated classification are distributed as follows: 9 sites for Neural Network (NN) class number 4 and for vegetation class, graminoid wet meadow (Type I), 11 sites for NN class number 2 and for vegetation class, graminoid moist meadow (Type II), 64 sites for NN class number 5 and for vegetation class, moist meadow (Type III), 24 sites for NN class number 6 and for vegetation class, moist shrub-tundra (Type IV), 31 sites for NN class number 1 and for vegetation class, grass mesic meadow (type V), 6 sites for NN class number 7 and for vegetation class, Type VI (*Dryas integrifolia* Dwarf-Shrub land Alliance), 19 sites for NN class number 8 and for vegetation class, type VII (*Cassiope tetragona* Dwarf-Shrub land Alliance) and 10 sites for NN class number 3 and for vegetation class, type VIII (*Vaccinium uliginosum* Dwarf-Shrub land Alliance) (Table 10).

Table 8. Plot number, vegetation class and vegetation cover of the 174 sites used to test the classification. #1-93 are test sites randomly selected from the 388 valid sites and #94-174 are additional sites sampled by Duclos 2002.

	Plot	Vegetation			Plot	Vegetation			Plot	Vegetation	
#	number	Class	Cover	#	number	Class	Cover	#	number	Class	Cover
1	BE-1179	1	>75%	61	SP18-2	5	>75%	120	P041	5	>75%
2	BE-1180	1	>75%	62	SP12-1	5	>75%	121	P042	5	>75%
3	BSN-240	1	>75%	63	BS-163	5	>75%	122	P046	5	>75%
4	BE-923	1	>75%	64	SP2-8	6	>75%	123	P047	5	>75%
5	BSE-892	1	>75%	65	SP2-91	6	>75%	124	P048	5	>75%
6	PLAT-12	1	>75%	66	PLAT-06	8	>75%	125	P049	5	>75%
7	SP13-5	1	>75%	67	PLAT-02	8	>75%	126	P050	5	>75%
8	BE-414	1	>75%	68	PLAT-04	8	>75%	127	P054	5	>75%
9	SP5-4	1	>75%	69	BS-151	8	>75%	128	P111	5	>75%
10	PLAT-11	1	>75%	70	BS-158	8	>75%	129	P113	5	>75%
11	PLAT-17	1	>75%	71	BS-142	8	>75%	130	P114	5	>75%
12	BE-1384	1	>75%	72	SP11-9	8	>75%	131	P115	5	>75%
13	BE-1442	1	>75%	73	BS-144	8	>75%	132	P116	5	>75%
14	BS-123	1	>75%	74	BSN-228	8	>75%	133	P117	5	>75%
15	BE-1203	1	>75%	75	BE-1169	9	>25% - <75%	134	P121	5	>75%
16	BN-1445	1	>75%	76	SP10-7	9	>25% - <75%	135	P122	5	>75%
17	BSE-402	2	>75%	77	NP4-2	9	>25% - <75%	136	P128	5	>75%
18	S-832	2	>75%	78	SP10-12	9	>25% - <75%	137	P129	5	>75%

19	BN-1506	2	>75%
20	BN-1369	2	>75%
21	BSE-526	2	>75%
22	BN-1376	2	>75%
23	BSE-478	2	>75%
24	BYN-1136	2	>75%
25	BSE-857	2	>75%
26	SS-1427	2	>75%
27	OS-029	3	>75%
28	OS-225	3	>75%
29	OS-267	3	>75%
30	BS-148	3	>75%
31	BS-156	3	>75%
32	OS-408	3	>75%
33	SP15-9	4	>75%
34	SP7-7	4	>75%
35	SP9-1	4	>75%
36	SP9-6	4	>75%
37	SP1-1	4	>75%
38	SP3-6	4	>75%
39	SP9-8	4	>75%
40	SP6-3	4	>75%
41	SP9-10	5	>75%
42	SP17-1	5	>75%
43	SP12-10	5	>75%
44	SP12-9	5	>75%
45	SP12-11	5	>75%
46	BE-1164	5	>75%
47	SP13-11	5	>75%
48	SP12-2	5	>75%
49	NP8-2	5	>75%
50	BSN-314	5	>75%
51	SP7-11	5	>75%
52	SP17-3	5	>75%
53	SP18-3	5	>75%
54	SP4-3	5	>75%
55	SP7-10	5	>75%
56	SP4-4	5	>75%
57	SP5-10	5	>75%
58	BSN-355	5	>75%
59	BN-1494	5	>75%
60	BSN-328	5	>75%
79	SP6-4	9	>25% - <75%
80	BE-926	9	>25% - <75%
81	BE-1375	9	>25% - <75%
82	SP10-3	9	>25% - <75%
83	OS-399	11	>25% - <75%
84	OS-008	11	>25% - <75%
85	SP7-9	12	>25% - <75%
86	SP13-8	13	>25% - <75%
87	NP8-1	13	>25% - <75%
88	SP6-8	13	>25% - <75%
89	SP8-5	14	>25% - <75%
90	S-847	15	>25% - <75%
91	SP8-3	15	>25% - <75%
92	SP17-4	15	>25% - <75%
93	BE-1374	15	>25% - <75%
94	P024	1	>75%
95	P052	1	>75%
96	P125	1	>75%
97	PB-01	1	>75%
98	PB-02	1	>75%
99	PB-03	1	>75%
100	PT-04	1	>75%
101	BORDEN01	2	>75%
102	P011	3	>75%
103	PB-06	3	>75%
104	P006	5	>75%
105	P007	5	>75%
106	P017	5	>75%
107	P020	5	>75%
108	P021	5	>75%
109	P022	5	>75%
110	P023	5	>75%
111	P025	5	>75%
112	P026	5	>75%
113	P027	5	>75%
114	P031	5	>75%
115	P032	5	>75%
116	P037	5	>75%
117	P038	5	>75%
118	P039	5	>75%
119	P040	5	>75%
138	PB-04	5	>75%
139	PT-01	5	>75%
140	PT-07	5	>75%
141	PT-09	5	>75%
142	BN-BARE3	6	>75%
143	P009	6	>75%
144	P012	6	>75%
145	P013	6	>75%
146	P015	6	>75%
147	P016	6	>75%
148	P035	6	>75%
149	P036	6	>75%
150	P045	6	>75%
151	P051	6	>75%
152	P053	6	>75%
153	P063	6	>75%
154	P107	6	>75%
155	P108	6	>75%
156	P110	6	>75%
157	P119	6	>75%
158	P123	6	>75%
159	P124	6	>75%
160	P126	6	>75%
161	P127	6	>75%
162	P130	6	>75%
163	P120	7	>75%
164	PB-05	7	>75%
165	P008	8	>75%
166	P014	8	>75%
167	P018	8	>75%
168	P028	8	>75%
169	P043	8	>75%
170	P055	8	>75%
171	P102	8	>75%
172	P106	8	>75%
173	P109	8	>75%
174	P112	8	>75%

Table 9. Plot number, vegetation class and vegetation cover of the 295 sites used to train the vegetation classification.

	Plot	Vegetation	
#	number	Class	Cover
1	BN-1367	1	<75%
2	BE-1012	1	<75%
3	S-920	1	<75%
4	BE-1005	1	<75%
5	BE-1016	1	<75%
6	BN-1224	1	<75%
7	BYN-1120	1	<75%
8	BE-1006	1	<75%
9	BSE-900	1	<75%
10	BN-1394	1	<75%
11	BE-1200	1	<75%
12	PLAT-14	1	<75%
13	BE-1177	1	<75%
14	BSN-267	1	<75%
15	BSN-266	1	<75%
16	BSN-263	1	<75%
17	BE-1166	1	<75%
18	S-844	1	<75%
19	BN-1223	1	<75%
20	PLAT-13	1	<75%
21	BS-1021	1	<75%
22	BYN-1123	1	<75%
23	BE-1383	1	<75%
24	BYN-1122	1	<75%
25	PLAT-19	1	<75%
26	BE-1004	1	<75%
27	BN-1466	1	<75%
28	BSE-915	1	<75%
100	BE-1015	5	<75%
101	SP9-11	5	<75%
102	PLAT-09	5	<75%
103	SP13-9	5	<75%
104	PLAT-03	5	<75%
105	BSN-236	5	<75%
106	SP2-3	5	<75%
107	BS-1348	5	<75%
108	BS-1349	5	<75%
109	PLAT-08	5	<75%
110	SP12-8	5	<75%
111	SP7-12	5	<75%
112	SP7-13	5	<75%
113	SP1-6	5	<75%
114	BSN-354	5	<75%
115	SP17-2	5	<75%
116	SP18-5	5	<75%
117	SP18-6	5	<75%
118	BSN-250	5	<75%
119	SP17-7	5	<75%
120	BS-129	5	<75%
121	SP4-2	5	<75%
122	SP12-7	5	<75%
123	SP13-4	5	<75%
124	SP13-1	5	<75%
125	SP18-4	5	<75%
126	BSN-313	5	<75%
127	SP5-5	5	<75%
199	BS-181	8	<75%
200	SP6-6	8	<75%
201	BS-146	8	<75%
202	OS-303	8	<75%
203	BS-180	8	<75%
204	BS-145	8	<75%
205	PLAT-20	8	<75%
206	BS-128	8	<75%
207	BS-147	8	<75%
208	BS-165	8	<75%
209	BS-126	8	<75%
210	BSN-260	8	<75%
211	BE-896	9	>25% - <75%
212	BSE-694	9	>25% - <75%
213	BE-623	9	>25% - <75%
214	BE-1171	9	>25% - <75%
215	SP10-10	9	>25% - <75%
216	BYN-1140	9	>25% - <75%
217	SP10-9	9	>25% - <75%
218	SP10-6	9	>25% - <75%
219	SP10-8	9	>25% - <75%
220	SP10-11	9	>25% - <75%
221	SP10-5	9	>25% - <75%
222	NP4-1	9	>25% - <75%
223	BN-1447	9	>25% - <75%
224	SP6-2	9	>25% - <75%
225	S-916	9	>25% - <75%
226	NP2-1	9	>25% - <75%

29	BYN-1141	1	<75%
30	PLAT-15	1	<75%
31	BN-1365	1	<75%
32	BE-1228	1	<75%
33	BS-162	1	<75%
34	BN-1446	1	<75%
35	BSN-264	1	<75%
36	BS-125	1	<75%
37	BSE-398	2	<75%
38	BSE-405	2	<75%
39	BSE-401	2	<75%
40	BSE-531	2	<75%
41	BSE-456	2	<75%
42	BSE-540	2	<75%
43	S-831	2	<75%
44	S-846	2	<75%
45	S-845	2	<75%
46	NP9	2	<75%
47	BSE-704	2	<75%
48	BN-1504	2	<75%
49	BN-1500	2	<75%
50	BSE-735	2	<75%
51	SE-1299	2	<75%
52	BSE-721	2	<75%
53	BSE-739	2	<75%
54	BSE-726	2	<75%
55	BN-1374	2	<75%
56	SS-1426	2	<75%
57	BN-1382	2	<75%
58	SE-1194	2	<75%
59	BN-1496	2	<75%
60	NP1-2	2	<75%
128	SP5-8	5	<75%
129	SP5-9	5	<75%
130	SP6-11	5	<75%
131	SP6-9	5	<75%
132	SP7-3	5	<75%
133	SP7-6	5	<75%
134	BSN-317	5	<75%
135	SP8-7	5	<75%
136	BSN-353	5	<75%
137	SP7-2	5	<75%
138	SP7-4	5	<75%
139	SP13-3	5	<75%
140	SP5-6	5	<75%
141	SP3-1	5	<75%
142	SP4-1	5	<75%
143	BSN-316	5	<75%
144	BSN-326	5	<75%
145	SP12-5	5	<75%
146	SP12-4	5	<75%
147	SP4-6	5	<75%
148	BSN-246	5	<75%
149	SP12-3	5	<75%
150	SP13-7	5	<75%
151	BSN-356	5	<75%
152	BS-124	5	<75%
153	BS-164	5	<75%
154	BSN-265	5	<75%
155	SP8-6	6	<75%
156	SP2-9	6	<75%
157	SP3-2	6	<75%
158	SP8-9	6	<75%
159	SP2-14	6	<75%
227	BO-713	9	>25% - <75%
228	SP10-4	9	>25% - <75%
229	BN-1527	9	>25% - <75%
230	BE-1369	9	>25% - <75%
231	BE-927	9	>25% - <75%
232	BE-1380	9	>25% - <75%
233	SP10-2	9	>25% - <75%
234	SP10-1	9	>25% - <75%
235	BE-635	9	>25% - <75%
236	BE-636	9	>25% - <75%
237	BSE-729	10	>25% - <75%
238	BN-1222	10	>25% - <75%
239	BE-650	10	>25% - <75%
240	BE-649	10	>25% - <75%
241	BE-624	10	>25% - <75%
242	SNE-800	10	>25% - <75%
243	SNE-801	10	>25% - <75%
244	SNE-716	10	>25% - <75%
245	OS-283	11	>25% - <75%
246	SP11-7	11	>25% - <75%
247	OS-288	11	>25% - <75%
248	OS-273	11	>25% - <75%
249	SP11-8	11	>25% - <75%
250	OS-009	11	>25% - <75%
251	OS-304	11	>25% - <75%
252	OS-416	11	>25% - <75%
253	OS-364	11	>25% - <75%
254	OS-370	11	>25% - <75%
255	OS-410	11	>25% - <75%
256	OS-295	11	>25% - <75%
257	OS-415	11	>25% - <75%
258	SP6-1	12	>25% - <75%

61	BN-1495	2	<75%
62	SP13-2	2	<75%
63	BSE-580	2	<75%
64	BSE-690	2	<75%
65	BS-143	2	<75%
66	BN-1370	2	<75%
67	OS-030	3	<75%
68	OS-022	3	<75%
69	SP11-1	3	<75%
70	OS-036	3	<75%
71	OS-329	3	<75%
72	OS-407	3	<75%
73	OS-004	3	<75%
74	OS-028	3	<75%
75	OS-328	3	<75%
76	OS-269	3	<75%
77	BS-154	3	<75%
78	OS-266	3	<75%
79	BS-155	3	<75%
80	BS-130	3	<75%
81	OS-402	3	<75%
82	OS-271	3	<75%
83	OS-409	3	<75%
84	OS-414	3	<75%
85	OS-413	3	<75%
86	OS-405	3	<75%
87	SP11-4	4	<75%
88	SP1-3	4	<75%
89	SP15-7	4	<75%
90	SP15-8	4	<75%
91	SP5-2	4	<75%
92	SP5-3	4	<75%
160	SP8-10	6	<75%
161	SP18-1	6	<75%
162	PLAT-22	6	<75%
163	BSN-235	6	<75%
164	BSN-232	6	<75%
165	BSN-233	6	<75%
166	BYN-1142	6	<75%
167	BSE-692	7	<75%
168	SE-1196	7	<75%
169	BSE-464	7	<75%
170	SE-1300	7	<75%
171	BSE-468	7	<75%
172	BSE-481	7	<75%
173	SP5-7	7	<75%
174	BSE-856	7	<75%
175	SSE-593	7	<75%
176	SP4-5	7	<75%
177	SP4-7	7	<75%
178	SP4-8	7	<75%
179	BS-127	7	<75%
180	SP11-6	7	<75%
181	BS-131	7	<75%
182	BS-152	7	<75%
183	SP11-10	8	<75%
184	SP1-5	8	<75%
185	PLAT-05	8	<75%
186	PLAT-07	8	<75%
187	PLAT-10	8	<75%
188	SP2-4	8	<75%
189	OS-025	8	<75%
190	PLAT-01	8	<75%
191	SP2-10	8	<75%
259	SP15-4	12	>25% - <75%
260	SP15-5	12	>25% - <75%
261	SP7-8	12	>25% - <75%
262	SP9-2	12	>25% - <75%
263	SP9-3	12	>25% - <75%
264	SP9-4	12	>25% - <75%
265	SP9-5	12	>25% - <75%
266	SP11-5	12	>25% - <75%
267	SP13-10	13	>25% - <75%
268	SP8-4	13	>25% - <75%
269	SP13-12	13	>25% - <75%
270	OS-035	13	>25% - <75%
271	SP7-5	13	>25% - <75%
272	SP8-1	13	>25% - <75%
273	NP2-2	13	>25% - <75%
274	SP7-1	13	>25% - <75%
275	SP6-10	13	>25% - <75%
276	SP2-11	14	>25% - <75%
277	SP13-6	14	>25% - <75%
278	SP18-7	14	>25% - <75%
279	BE-970	15	>25% - <75%
280	SP8-2	15	>25% - <75%
281	BSE-502	15	>25% - <75%
282	BSE-479	15	>25% - <75%
283	SP6-7	15	>25% - <75%
284	SP18-8	15	>25% - <75%
285	SP17-5	15	>25% - <75%
286	NP1-1	15	>25% - <75%
287	SP17-6	15	>25% - <75%
288	BE-945	15	>25% - <75%
289	SNE-714	15	>25% - <75%
290	SP6-5	15	>25% - <75%

93	SP9-12	4	<75%	192	SP2-12	8	<75%	291	BE-647	15	>25% - <75%
94	SP1-2	4	<75%	193	SP11-2	8	<75%	292	BE-1372	15	>25% - <75%
95	SP2-6	5	<75%	194	BN-1385	8	<75%	293	BE-1144	15	>25% - <75%
96	SP9-7	5	<75%	195	OS-005	8	<75%	294	BE-1370	15	>25% - <75%
97	SP9-9	5	<75%	196	BS-157	8	<75%	295	BE-634	15	>25% - <75%
98	SP12-6	5	<75%	197	SP8-8	8	<75%				
99	SP12-12	5	<75%	198	BS-179	8	<75%				

2.7 The automated classification: The Neural Network (NN)

The neural net (NN) classifier is well adapted to the classification of the vegetation cover of SNP. The NN requires inputs that do not obey a specific statistical law, in particular any normal distribution (Paola and Schowengerdt, 1995). In fact, the parameters of a NN progressively adapt to the pattern of the class signature while we "feed it" known examples from the training sites of any specific class. Any neurone in a net, operates similarly to simple calculator which performs two operations. First, it operates a weighted sum of all input signal and, secondly, it modifies the output signal by applying a specific function. In short, the general function of a neurone is to associate a specific input to an output defined in advance by adjusting its inner parameters, which corresponds to the weigths of the summation.

There are 8 image channels used as inputs to the neural networks. In order to reduce the computing time, they have all been rescaled from a 32 bits real number values to an 8 bits integer number values (0 to 255).

Firstly, the six Landsat 5 TM bands, 1 through 5 and 7 were corrected for topographic effects using the equation:

3 $DN_C = DN * (\cos(Z_S) / \cos(I_S))$

where:

DN_C is the corrected image digital values for each TM band images

DN is the raw image digital values for each TM band images

Z_S is the solar Zenith angle at the center of the scenes (51 degrees)

I_S is the incidence angle calculated using equation 2

The topographic correction was performed on the TM images prior to running the NN because the incoming solar radiation is so intermixed with the TM spectral response for vegetation that any other use of the solar incidence angle information underestimates its contribution. For example, a test on the NN classification using the original TM image with the incidence angle image seperately did not yield very good classification results (<50% average accuracy).

Secondly, an NDVI image where 0 corresponds to surfaces which have no vegetation cover and 255 corresponds to surfaces which have a "complete" vegetation cover was used as the seventh channel. The 0 value threshold was established using the NDVI values corresponding to all *in situ* sampling sites. As stated earlier, from the 410 sampling sites, 10 sites had NDVI values registered on the TM 1998 images which were low. These low values are probably related to differences in surface water cover. Using the NDVI image which was used to establish the sampling plots (between –1.0 to 1.0) a threshold of –0.08 and above was used to characterise the vegetation surface. In summary, the value 0 and the value 255 in the 8bit correspond to the –0.08 and the 1.0 in the original sampling plot NDVI image.

Finally, the last and eighth channel, is the texture image also converted on a 8 bit scale. The rescaling threshold was 0 to 7.5 on the standard deviation texture image. This is the minimum and maximum texture values for the vegetation covers established using the NDVI image described previously. The very high texture values above 6.0 correspond to ravine type surfaces which incorporate vegetation covers.

The neural netwok (NN) requires to be trained prior to the classification. The NN is trained using 295 vegetation sites. The NN is in fact constructed with the 8 input layers (the eight channel) which are interrelated to 15 NN classes (Table 10) using a 16 neurones hidden layer.

Table 10. The vegetation class number used for the classification procedure. Vegetation type numbers and names refer to Table 11.

Vegetation Type Number	**Vegetation Type Name**	**Vegetation cover**	**Neural Net classification numbers**
I	Graminoid wet meadow	greater than 75%	**4**
	Dupontia fisheri / Moss	between 25% and 75%	**12**
II	Graminoid moist meadow	greater than 75%	**2**
	Eriophorum triste / Carex spp.	between 25% and 75%	**10**
III	Moist meadow	greater than 75%	**5**
	Arctagrostis latifolia	between 25% and 75%	**13**
IV	Moist shrub-tundra	greater than 75%	**6**
	Salix spp.	between 25% and 75%	**14**
V	Grass mesic meadow	greater than 75%	**1**
	Luzula nivalis	between 25% and 75%	**9**
VI	Shrub heath-tundra	greater than 75%	**7**
	Dryas integrifolia	between 25% and 75%	**15**
VII	Shrub heath-tundra	greater than 75%	**8**
	Cassiope tetragona		
VIII	Shrub heath-tundra	greater than 75%	**3**
	Vaccinium uliginosum	between 25% and 75%	**11**

Using each training site, the 8 input layers are related to the 16 neurones in the hidden layer by a weigth. In a sense, 128 weigths are established for each training site. Secondly, a function (in fact, this function in a neural network is called an "activation function" because it relates a known output to a particular input) is used to relate the weighted sum to a particular output. In the case of an image classification, this ouput is the thematic class shown in Table 10. The strength of the NN is the learning processs. To "learn" or to train itself, the NN will perform, interatively, a backward estimation of the weights going from the desired output thematic classes to the neurones in the hidden layer in order to minimise the total error which will characterise the final activation function (Paola and Schowengerdt, 1995). An arbitrary threshold is set in order to stop this “optimisation” process to permit the establishment of the final function. In the case, of the vegetation classification the threshold was set at 0.01.

The final step in the automated classification using a NN is to establish a link between the values of each pixel in the input channels to a specific vegetation class. This is done using the final activation function and the corresponding weights established previously during the “learning” process. The result of this weighted function for each pixel in the 8 input layers will be a specific vegetation class. Successively, each pixel is assigned to a specific class (Appendix 3).

3 RESULTS

3.1 Field sampling of the second season

In 2003, sampling of Sirmilik National Park took place between July 17 and August 21. Despite the rainy, foggy and windy weather, we surveyed a total of 274 plots: 38 on Bylot Island, 191 on Borden Peninsula and 45 on Oliver Sound. We were unable to sample the eastern valley of Bylot Island because of bad weather conditions. So this part of the Park has never been sampled for this project. The location of the sampling sites are shown in Figure 6. Site characteristics, GPS coordinates and vegetation data are displayed in Appendices 4 and 5. Weather conditions in the area of Goose Camp (Bylot Island; data from Gilles Gauthier) and Pond Inlet are shown in Appendix 6.

Figure 6. Location of the sites sampled in Sirmilik National Park and used in the satellite image classification. Training sites and testing sites are distinguished to illustrate their spatial distribution.

Sirmilik National Park
Vegetation Training Sites
Training Sites
Testing Sites
Water
Park Limits
Coast Line
Background Satelitte Image
This map shows the position of the vegetation training sites measured during the 2002 and 2003 field campaigns. Only sites which are in green were used in the mapping procedure. Please refer to the report for information on the testing sites.
0 5 10 20 30 40 50 Km
LIAGE
Production: Pierre-André Bordeleau, Denis Gratton, Géographie, LIAGE, Université du Québec à Trois-Rivières, 2006
Baffin Bay
Bathurst Bay
Maud Bight
Byam
Martin
Mountains
Bylot Island
Pond Inlet
Navy
Board
Inlet
Baffin Island
(Borden Peninsula)
Eclipse Sound
Baffin Island
(Oliver Sound)
Oliver Sound
White Bay
Sound
Tay
Paquet
Bay
84°0'W
83°0'W
82°0'W
81°0'W
80°0'W
79°0'W
78°0'W
77°0'W
76°0'W
73°30'N
73°0'N
72°30'N
72°0'N
80°6'0"W
80°0'0"W
79°54'0"W
73°12'0"N
73°9'0"N
73°6'0"N
73°3'0"N

3.2 Classification and description of the vegetation

Vascular species

In total, six vascular species were added to the Park's species list during the 2002 and 2003 field seasons: four perennials (*Eriophorum russeolum* var. *albidum*, *Kobresia simpliciuscula*, *Cerastium beeringianum*, *Minuartia rossii*; 2002), one annual *Koenigia islandica* in 2002, and one graminoid (*Calamagrostis purpurascens*) in 2003. So far, 153 vascular plant species from 72 Genera and 27 Families have been reported in Sirmilik National Park (Appendix 1).

Vegetation classification

Classification of the vegetation based on the Twinspan analysis dendrogram of the 507 plots (beach and wetland samples not included, see methods) yielded eight vegetation types (Figure 7). The first division separates vegetation types with a high abundance of *Alopecurus alpinus* (3-15% cover, 79-100% frequency of occurrence) and *Saxifraga cernua* (0.3-0.6% cover; 70-81% frequency of occurrence) from types with a high abundance of *Dryas integrifolia* (6-29 % cover; 86-100% frequency of occurrence). Also, with the first division, the first group of vegetation types (III, IV, V, IX) has a higher cover of forbs (7-33%) whereas the second group (II, VI, VII, VIII) has a higher cover of shrubs and cryptomic crust (43-63% and 28-36% respectively) than the first one (20-49% and 3-33% respectively).

Those divisions are also illustrated on the DCA (Figure 8); see Appendix 7 for a summary of the DCA). Vegetation types with a high abundance of *D. integrifolia* are clearly separated on the second axis and are segretated on the upper part of the biplot. Finally, shrub-dominated types (VI, VII, VIII, IX) are located on the right hand side of the first ordination axis.

With the wetland and beach habitats, a total of ten vegetation types (labelled I to X) and 18 plant communities were identified in Sirmilik NP (Table 11). In Table 12, vegetation types are ordered following a general moisture gradient (wet to dry) based on decreasing moss and graminoid cover and on increasing shrub cover (from I to X).

Vegetation types and plant communities

The general landscape of Sirmilik NP has a high vascular plant cover (≥61%) and, disregarding specific vegetation types, *Salix arctica* is the dominant shrub species (Table 12). When considering the vascular plant and cryptogam strata (moss, lichen, biological crust), the total vegetation cover is very high, generally >100%. Total cover exceeds 100% because the different strata of vegetation can overlap.

In the following pages, the ten major vegetation types and their respective plant communities will be described in terms of floristic composition, physiognomic structure and vegetation-environment relationships. Table 12 shows the biological and environmental characteristics of the ten vegetation types while Tables 13 to 22 provide the species composition for vegetation types I to X respectively, with their corresponding plant communities. Pictures of the vegetation types with their respective plant communities are shown in Appendix 8.

Vegetation types were separated in four physiognomic groups: Meadow, Shrub-Tundra, Heath-Tundra and Barren (Table 11). The wetter types of the gradient are represented by the two meadows Graminoid Wet Meadow (I) and Graminoid Moist Meadow (II) which are dominated by graminoids and mosses (Table 12). As for Moist Meadow and Grass Mesic Meadow (types III and V), they represent moist to mesic types. Graminoids and mosses are the dominant life forms in these two meadows but they have a higher cover of lichens compared to the precedent meadows (Table 12). Mesic to mesic-xeric types are represented by Moist Shrub-Tundra, Shrub Heath-Tundra and Shrub-Forb Tundra (types IV, VI, VII, VIII and IX). These types are dominated by dwarf-shrubs and have a low cover of graminoids and mosses compared to the precedent moist-mesic types. The driest vegetation type is the Graminoid Barren (type X) which has the lowest vegetation cover and nearly no moss.

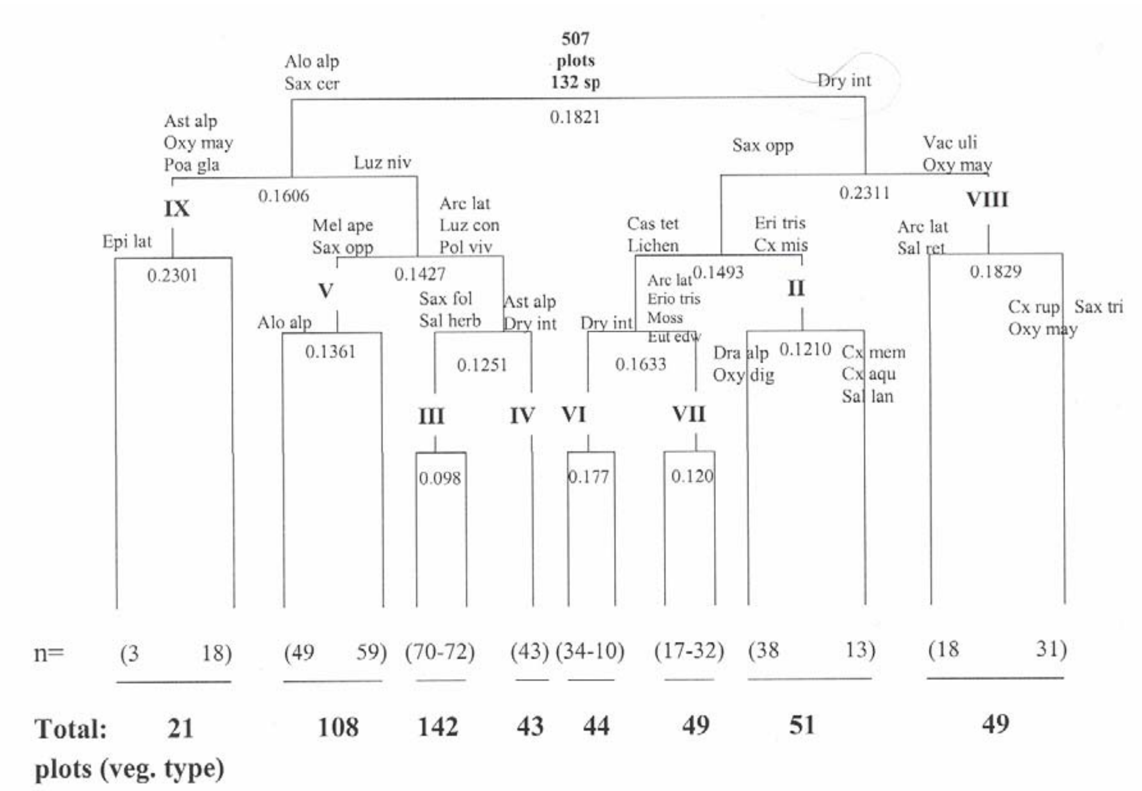


Figure 7. Dendrogram of the Twinspan vegetation classification of 507 plots, using the mean cover of 138 vascular taxa, mosses, lichens and biological crust. Eight vegetation types are represented. Eigenvalue and indicator species for each division are indicated at the dichotomy. n: the number of plots in the cluster. Species abbreviations: Alo alp: *Alopecurus alpinus*; Arc lat: *Arctagrostis latifolia*; Ast alp : *Astragalus alpinus*; Cx aqu: *Carex aquatilis*; Cx mem: *Carex membranacea*; Cx mis: *Carex misandra*; Cx rup: *Carex rupestris*; Cas tet: *Cassiope tetragona*; Dra alp: *Draba alpina*; Dry int: *Dryas integrifolia*; Epi lat: *Epilobium latifolium;* Eri tri: *Eriophorum triste*; Eut edw: *Eutrema edwardsii*; Luz con: *Luzula confusa*; Luz niv: *Luzula nivalis*; Mel ape: *Melandrium apetalum*; Oxy dig: *Oxyria digyna*; Oxy may: *Oxytropis maydelliana*; Poa gla: *Poa glauca*; Pol viv: *Polygonum viviparum*; Sal herb: *Salix herbacea*; Sal lan: *Salix lanata*; Sal ret: *Salix reticulata*; Sax cer*: Saxifraga cernua*; Sax fol: *Saxifraga foliolosa*; Sax tri: *Saxifraga tricuspidata*; Sax opp: *Saxifraga oppositifolia*; Vac uli: *Vaccinium uliginosum*.

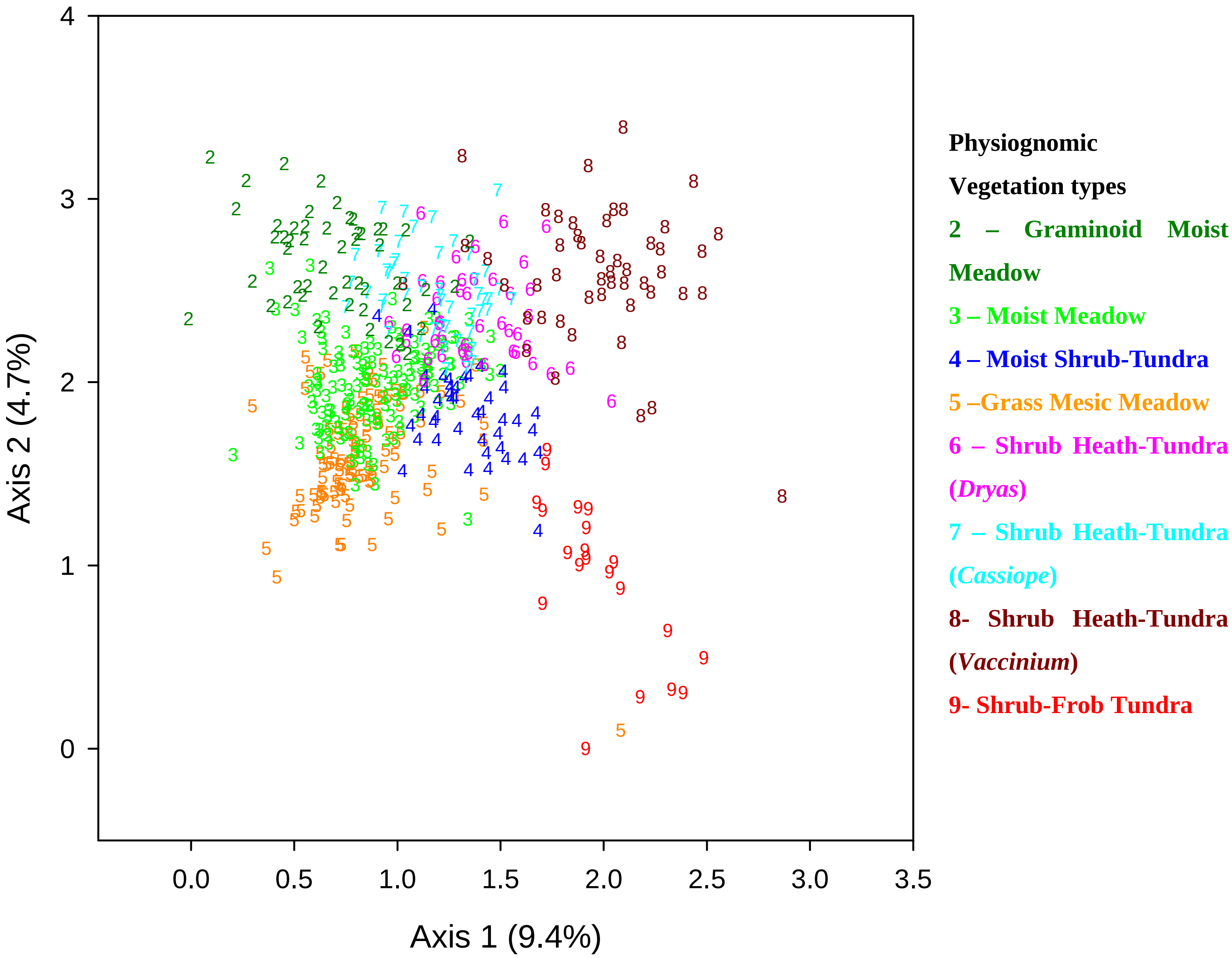


Figure 8. First and second axes of the DCA ordination for 507 plots sampled in Sirmilik NP between 2000 and 2003. Each stand is represented by the number corresponding to its vegetation type from the Twinspan classification results.

Table 11. Classification of the vegetation in Sirmilik NP. Analysed from both Duclos (2002) and Parks Canada data sets (field work of summer 2002 and 2003). Most shrubs in the region are prostrate, only some *Salix lanata* are erect.

General vegetation type	Physiognomic Vegetation type	Vegetation type (Alliance)	Plant communities (Association)
Wet-Moist Meadow	Graminoid Wet Meadow (Wetlands)	I. *Dupontia fisheri* / Moss Herbaceous Alliance	a. *Dupontia – Eriophorum /* Moss Herbaceous Vegetation b. *Eriophorum – Dupontia /* Moss Herbaceous Vegetation c. *Dupontia – Salix arctica /* Moss Herbaceous Vegetation (rims)
	Graminoid Moist Meadow	II. *Eriophorum triste - Carex* spp. Herbaceous Alliance	a. *Eriophorum triste – Dryas integrifolia – Carex misandra* Herbaceous Vegetation b. *Carex membranacea – Eriophorum triste – Carex aquatilis* var *stans* Herbaceous Vegetation
Moist Tundra	Moist Meadow	III. *Arctagrostis latifolia* Herbaceous Alliance	a. *Arctagrostis latifolia – Luzula nivalis* Herbaceous Vegetation b. Shrubs – *Arctagrostis latifolia* Dwarf-Shrubland*
	Moist Shrub-Tundra	IV. *Salix* spp. Dwarf-Shrubland Alliance	No association
Mesic Meadow	Grass Mesic Meadow	V. *Luzula nivalis* Herbaceous Alliance	a. *Alopecurus alpinus – Luzula nivalis / Saxifraga oppositifolia* Herbaceous Vegetation b. *Luzula nivalis / Saxifraga oppositifolia* Herbaceous Vegetation
Heath Tundra	Shrub Heath-Tundra	VI. *Dryas integrifolia* Dwarf-Shrubland Alliance	a. *Dryas integrifolia / Saxifraga oppositifolia* Dwarf-Shrubland b. *Dryas integrifolia - Cassiope tetragona* / Lichen Dwarf-Shrubland
	Shrub Heath-Tundra	VII. *Cassiope tetragona* Dwarf-Shrubland Alliance	a. *Cassiope tetragona* –- *Luzula* spp Dwarf-Shrubland b. *Salix reticulata* –- *Cassiope tetragona* Dwarf-Shrubland
	Shrub Heath-Tundra	VIII. *Vaccinium uliginosum* Dwarf-Shrubland Alliance	a. *Eriophorum* spp – *Vaccinium uliginosum* Dwarf-Shrubland b. *Vaccinium uliginosum – Hierochloë alpina* Dwarf-Shrubland
Dwarf-Shrub Tundra	Shrub-Forb Tundra (Mountains)	IX. *Salix arctica / Astragalus alpinus* Dwarf-Shrubland Alliance	a. *Salix arctica – Astragalus alpinus* / Forbs Sparse Vegetation (Scree slopes) b. *Salix arctica – Astragalus alpinus – Oxytropis maydelliana*/ Forbs Dwarf-Shrubland
Barren	Graminoid Barren (Beaches)	X. Graminoid Sparse Vegetation Alliance	*Alopecurus alpinus – Luzula confusa – Poa arctica / Stellaria longipes* Sparse Vegetation

*This plant community is a transition between vegetation type III and IV. See text for details.

Table 12. Physiognomic, floristic and environmental characteristics of the ten vegetation types identified by Twinspan classification. Mean cover (%) was calculated for vascular plants, cryptogams and ground cover; mean altitude and slope angle are presented with standard errors (SE); when specified, frequency is given in parenthesis (freq. %).

	Wet	**Wet-mesic**		**Mesic**			**Mesic-xeric**		**Xeric**	
Vegetation Types	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
	Graminoid Wet Meadow	**Graminoid Moist Meadow**	**Moist Meadow**	**Moist Shrub-Tundra**	**Grass Mesic Meadow**	**Shrub Heath- Tundra (*Dryas*)**	**Shrub Heath- Tundra (*Cassiope*)**	**Shrub Heath-Tundra (*Vaccinium*)**	**Shrub-Forb Tundra**	**Graminoid Barren**
Biological characteristics										
Vascular plants										
Total species richness	60	66	82	77	87	68	74	79	63	36
Total cover (%)	87	112	84	80	61	76	84	91	90	18
Dwarf-shrub	7	43	35	49	20	60	54	63	46	2
Graminoid	76	62	42	21	26	7	25	21	10	10
Forb	4	6	7	10	14	9	5	6	33	6
Cryptogamic cover (%)										
Moss	81	42	58	44	32	17	50	36	29	<1
Lichen	<1	2	15	21	6	19	13	10	7	3
Biological crust	5	35	19	12	33	34	28	30	3	3
Dominant Dwarf-shrubs	*Salix arctica*	*S. arctica, Dryas integrifolia*	*S.arctica, Cassiope tetragona*	*S. arctica, Salix reticulata, D. integrifolia*	*S. arctica*	*D. integrifolia, Salix spp.*	*C. tetragona, Salix spp.*	*Vaccinium uliginosum, C. tetragona, Salix spp. D. integrifolia*	*S. arctica*	*S. arctica*
Dominant Graminoids	*Dupontia fisheri, Eriophorum russeolum, E. scheuchzeri*	*Eriophorum. triste, Carex spp., Arctagrostis latifolia*	*A. latifolia, Luzula spp.*	*A. latifolia, Alopecurus alpinus*	*A. alpinus, Luzula nivalis*	*Carex spp. L. nivalis*	*A. latifolia, Carex spp. Luzula spp., E. triste*	*E. vaginatum, Hierochloë alpina, Luzula spp., Carex rupestris*	*Poa arctica, A. alpinus, Festuca brachyphylla, Poa glauca*	*A. alpinus, L. confusa, C. maritima, Poa arcitca*
Dominant Forbs	*Ranunculus hyperboreus, Pedicularis sudetica*	*Saxifraga oppositifolia*	*Oxyria. digyna, Draba spp., Stellaria longipes*	*Polygonum viviparum, Draba spp., S. longipes*	*S. oppositifolia, O. digyna, Papaver radicatum*	*S. oppositifolia, Pedicularis spp., P. viviparum, O. maydelliana*	*S. oppositifolia, P. viviparum, O. digyna*	*O. maydelliana, P. viviparum*	*Astragalus alpinus, Oxytropis maydelliana,, Polygonum viviparum*	*S. longipes, S. oppositifolia, Cerastium arcticum*
Environmental characteristics										
Ground cover (%)										
Litter	4	7	9	17	4	3	8	5	35	0.5
Bare ground	6	2	4	9	5	7	0.7	1	8	83
Gravel (freq. %)	0.1 (3)	5 (65)	0.6 (62)	2 (35)	16 (81)	11 (95)	0.4 (35)	3 (76)	0.2 (24)	6 (33)
Stone (freq. %)	0.02 (3)	2 (53)	1 (35)	0.7 (16)	5 (71)	5 (89)	0.6 (29)	5 (86)	7 (62)	0.5 (17)
Rock (freq. %)	0	0.4 (18)	1 (28)	0.3 (12)	2 (42)	1 (32)	0.5 (20)	11 (76)	1 (24)	1 (33)
Altitude (m a.s.l.; x ± SE)	60 ± 74	223 ± 142	215 ± 141	128 ± 118	428 ± 151	230 ± 171	166 ± 117	166 ± 89	182 ± 106	28 ± 13
Slope angle (°; x ± SE)	0.2 ± 0.6	5 ± 4	4 ± 4	6 ± 6	7 ± 6	6 ± 6	6 ± 4	10 ± 8	22 ± 8	1.9 ± 0.7
Main microtopography	Polygons	Hummocky Flat	Hummocky	Hummocky	Flat Stripes	Flat Hummocky Stripes	Hummocky Flat	Hummocky Undulating Net	Flat Undulating Lobes	Flat
Sampling sites (n)	30	51	142	43	108	44	49	49	21	6

Type I – Graminoid Wet Meadow (n=30)

Dupontia fisheri / Moss Herbaceous Alliance

The Graminoid Wet Meadow is the wettest vegetation type as illustrated by the high cover of mosses (generally >75%) and hydrophilic graminoids: *Dupontia fisheri*, *Eriophorum russeolum* var. *albidum*, *E. scheuchzeri* and *Carex aquatilis* var *stans* (Table 13; *E. scheuchzeri* was mostly found in the goose camp valley whereas *E. russeolum* var. *albidum* was mostly sampled outside this valley). Cyanobacteria in general, or *Nostoc* sp. in particular, were frequent but at a low cover (≤1%) in this meadow type. Shrubs and forbs, such as *Ranunculus hyperboreus* and *Pedicularis sudetica*, are a minor component whereas lichens are nearly absent in this meadow type (<1%). The cover of litter is quite low due to the high grazing pressure by geese (Table 12). All these floristic characteristics make this Graminoid Wet Meadow a unique type that shares very few species with other sampled vegetation types.

This type of vegetation was found at different altitude (generally <200 m) but large concentration of wetlands are generally <40m a.s.l.. Observed wetlands developed exclusively on flat terrain where polygons are formed on eolian deposits (Klassen 1993). Water table is at or above the soil surface during most of the growing season. Small lakes or ponds are common in this meadow type. Goose families intensively use this habitat during the brood rearing period because of the high availability of graminoids (high quality food) and of lakes and ponds acting as refuges (Hughes *et al*. 1994, Duclos 2002).

Three plant communities are recognised in this vegetation type. The first two plant communities are either dominated by *D. fisheri* or *E. russeolum* var. *albidum* and usually grow in the centre of polygons. The water-saturated nature of these communities results in a relatively homogeneous species composition with a low species diversity (12-34 and 3-24 species respectively). The third community is found on elevated polygon rims. Species composition is similar but the cover of mesic species such as *Salix arctica*, *Arctagrostis latifolia*, biological crust, *Poa arctica* and *Alopecurus alpinus* are higher in this plant community.

The Goose research team has previously studied wetlands on Bylot Island. Gauthier *et al*. (1995) described two communities of wetlands found on polygon fens and pond margins. The first one, named grass/cottongrass community and typical of young polygons, is dominated by *Dupontia fisheri* and *Eriophorum scheuchzeri* (sometimes mixed with *E. angustifolium*). The second community called sedge/grass community is dominated by *Carex aquatilis* var. *stans* and *Dupontia fisheri* and develops on old undisturbed polygons. This last community was not sampled by Parks Canada in the course of the field seasons of 2002 and 2003. For more details on Bylot Island wetland's, see work of Manseau and Gauthier (1993), Hughes *et al*. (1994), Massé (1998) and Massé *et al*. (2001).

Table 13. Mean percent cover and frequency of occurrence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type I (Graminoid Wet Meadow). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.4% or frequency ≥0.7) is presented.

Vegetation type I *Dupontia fisheri* / Moss Herbaceous Alliance				**Plant communities**					
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=14)** *Dupontia-Eriophorum* / Moss Herbaceous Vegetation		**b (n=10)** *Eriophorum-Dupontia* / Moss Herbaceous Vegetation		**c (n=6)** *Dupontia-Salix arctica* / Moss Herbaceous Vegetation (rims)	
Shrub	*Salix arctica*	6.30	0.87	Moss	78	Moss	85	Moss	83
	Salix reticulata	0.76	0.27	*Dupontia fisheri*	52	*E. russeolum*	39	*Dupontia fisheri*	37
	Dryas integrifolia	0.11	0.07	*E. russeolum*	12	*/E. scheuchzeri*		*Salix arctica*	28
	Salix herbacea	0.03	0.07	*/E. scheuchzeri*		*Dupontia fisheri*	32	*E. russeolum*	10
	Salix lanata	0.01	0.07	*E. angustifolium*	6	*C. aquatilis var stans*	8	*/E. scheuchzeri*	
	Cassiope tetragona	0.01	0.03	*Biological crust*	4	*Biological crust*	5	*Arctagrostis latifolia*	9
Graminoid	*Dupontia fisheri*	42.27	1.00	*Ranunculus hyperboreus*	1	*Arctagrostis latifolia*	0.5	*Biological crust*	8
	Eriophorum russeolum	20.94	0.97	*Salix arctica*	1	*Pedicularis sudetica*	0.5	*C. aquatilis var stans*	7
	/Eriophorum scheuchzeri			*Deschampsia pumila*	1	*Hierochloë pauciflora*	0.4	*Eriophorum angustifolium*	2
	Carex aquatilis var stans	4.34	0.87	*Salix reticulata*	1	*Saxifraga cernua*	0.4	*Poa arctica*	0.8
	Eriophorum angustifolium	3.03	0.60	*Arctagrostis latifolia*	0.8	*Saxifraga foliolosa*	0.3	Lichen	0.7
	Arctagrostis latifolia	2.27	0.80	*Pedicularis sudetica*	0.7			*Astragalus alpinus*	0.7
	Deschampsia pumila	0.65	0.17	*C. aquatilis var stans*	0.6			*Pedicularis sudetica*	0.7
	Pleuropogon sabinei	0.38	0.27	*Pleuropogon sabinei*	0.6			*Stellaria longipes*	0.4
	Hierochloë pauciflora	0.35	0.60	*Hierochloë pauciflora*	0.4			*Saxifraga foliolosa*	0.4
	Poa arctica	0.24	0.50	*Saxifraga hirculus*	0.3			*Alopecurus alpinus*	0.3
	Festuca brachyphylla	0.23	0.33	*Cardamins pratensis*	0.3			*Hierochloë pauciflora*	0.3
	Alopecurus alpinus	0.20	0.30	*Stellaria longipes*	0.2			*Saxifraga cernua*	0.3
Forb	*Ranunculus hyperboreus*	0.70	0.77						
	Pedicularis sudetica	0.62	0.60						
	Saxifraga foliolosa	0.30	0.70						
	Saxifraga cernua	0.29	0.63						
	Saxifraga hirculus	0.27	0.63						
	Stellaria longipes	0.26	0.73						
	Cardamine pratensis	0.22	0.50						
	Chrysosplenium tetrandrum	0.20	0.43						
	Astragalus alpinus	0.16	0.23						
	Senecio congestus	0.08	0.27						

Type II –Graminoid Moist Meadow (n=51)

Eriophorum triste - *Carex* spp. Herbaceous Alliance

In this meadow type, hydrophilic graminoid species are absent and are replaced by species (mostly Cyperaceae) specific to moist to mesic conditions such as *Eriophorum triste*, *Carex* spp. (*Carex misandra, Carex membranacea, Carex aquatilis* var *stans, Carex bigelowii*) and *Arctagrostis latifolia* (Table 14). *Salix arctica*, *Dryas integrifolia* and *S. reticulata* form the shrub layer (4-23%). *Saxifraga oppositifolia, Equisetum variegatum, Pedicularis arctica/P. hirsuta, Polygonum viviparum, Draba* spp. and *Melandrium apetalum* are the most dominant and frequent forbs. Mosses and biological crust are also an important component of the ground cover (42% and 35% cover repectively) whereas lichen is nearly absent (2% cover). Hummocks and flat are the predominant microtopography. This type grows at variable altitudes (35-580 m; valley bottoms, terraces or plateaus) and at different slope angles (0-20°) but mostly on gentle slopes (mean: 5 ± 4°). Gravels and stones were frequently noted (Table 12).

Two plant communities are recognised within this type. The first plant community is dryer than the second one considering its lower cover of graminoids and mosses, and its higher cover of shrubs. Graminoid and shrub composition are similar within the two types but the dwarf-shrubs *S. arctica* and *D. integrifolia* have a higher cover in the first type whereas *C. membranacea* and C. *aquatilis* var *stans* have a higher cover in the second community. The first plant community also has a higher cover and frequency of gravels (6% and 76% respectively) and stones (3% and 58% respectively) than the second community (<1% cover and <38% frequency for both gravels and stones).

Table 14. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type II (Graminoid Moist Meadow, n=51). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type II *Eriophorum triste - Carex* spp. Herbaceous Alliance				**Plant communities**			
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=38)** Eriophorum triste – Dryas integrifolia – Carex misandra Herbaceous Vegetation		**b (n=13)** Carex membranacea – Eriophorum triste – Carex aquatilis var stans Herbaceous Vegetation	
Shrub	*Salix arctica*	23.33	0.98	Biological crust	40	Moss	63
	Dryas integrifolia	13.35	1.00	Moss	35	*Carex membranacea*	28
	Salix reticulata	4.23	0.67	*Salix arctica*	26	*Eriophorum triste*	23
	Salix lanata	1.42	0.33	*Eriophorum triste*	20	Biological crust	19
	Cassiope tetragona	0.44	0.22	*Dryas integrifolia*	16	*Carex aquatilis var stans*	17
Graminoid	*Eriophorum triste*	20.48	0.84	*Carex misandra*	13	*Salix arctica*	14
	Carex misandra	12.62	0.90	*Arctagrostis latifolia*	10	*Carex misandra*	11
	Carex membranacea	10.54	0.65	*Carex membranacea*	5	*Salix reticulata*	7
	Arctagrostis latifolia	9.05	0.90	*S. oppositifolia*	4	*Arctagrostis latifolia*	6
	Carex aquatilis var stans	4.44	0.16	*Salix reticulata*	3	*Salix lanata*	5
	Carex bigelowii	2.72	0.25	*Carex bigelowii*	3	*Dryas integrifolia*	4
	Luzula nivalis	0.88	0.57	Lichen	3	*Equisetum variegatum*	4
	Juncus biglumis	0.54	0.76	*Luzula nivalis*	1	*Carex bigelowii*	2
	Poa arctica	0.15	0.25	*Juncus biglumis*	0.6	Lichen	1
	Alopecurus alpinus	0.14	0.25	*Pedicularis arctica /P. hirsuta*	0.5	*Saxifraga oppositifolia*	0.6
Forb	*Saxifraga oppositifolia*	2.81	0.92			*Cassiope tetragona*	0.3
	Equisetum variegatum	1.11	0.47	*Carex rupestris*	0.5	*Juncus biglumis*	0.3
	Pedicularis arctica /P. hirsuta	0.46	0.96	*Cassiope tetragona*	0.5	*P. arctica/P. hirsuta*	0.3
				Polygonum viviparum	0.4	*C. integrifolium*	0.3
	Polygonum viviparum	0.36	0.75	*Salix lanata*	0.3		
	Chrysanthemum integrifolium	0.29	0.43	*Oxyria digyna*	0.3		
	Oxyria digyna	0.23	0.43	*C. integrifolium*	0.3		
	Draba alpina/D. corymbosa	0.21	0.61	*Draba alpina /D. corymbosa*	0.3		
	Melandrium apetalum	0.16	0.61				
	Eutrema edwardsii	0.13	0.43				
	Pedicularis capitata	0.13	0.33				
	Draba lactea	0.11	0.47				
	Papaver radicatum	0.10	0.31				
	Stellaria longipes	0.08	0.37				
	Braya purpurascens	0.06	0.24				
	Cerastium alpinum	0.05	0.22				

Type III – Moist Meadow (n=142)

Arctagrostis latifolia Herbaceous Alliance

Compared to the previous meadow, the graminoid layer is not dominated by Cyperaceae but by a mixture of Poaceae and Juncaceae (Table 12). Species adapted to mesic conditions such as *Arctagrostis latifolia* (dominant graminoid species), *Luzula nivalis*, *Alopecurus alpinus*, *Eriophorum triste* and *Luzula confusa* comprise the graminoid layer (Table 15). *Salix arctica*, which is the dominant shrub, *Cassiope tetragona* and *S. herbacea* form the shrub layer (4-21%). Diversity of forbs is high in this type (50 species) where *Oxyria digyna, Potentilla hyparctica, Stellaria longipes, Draba* spp., *Polygonum viviparum* and *Cardamine bellidifolia* are amoung the most dominant and frequent forbs. Hummocks are the predominant microtopography (64% of the plots). This type grows at a range of altitudes (15-615 m) on relatively flat terrain (mostly on terraces, also in valley bottoms).

The Twinspan analysis devides this cluster (Type III) in two plant communities with a high cover of mosses (58%). The first plant community is characteristic of meadows with its high cover of graminoids (58%, with *A. latifolia* and *L. nivalis* being the dominant ones). It grows at higher altitudes then the second one (250 vs 180 m). The second community has a higher cover of shrubs (37%) compared to graminoids (27%) which is more characteristic of shrub-tundra. However, its graminoid and moss cover is higher than in the Moist Shrub-Tundra (<25% and <50% respectively), the next vegetation type in this moisture gradient. This community has thus characteristics of both meadows and shrub-tundra. This type is likely a transition between these two types of vegetation (III and IV) .

Table 15. Mean percent cover and frequency of occurence for the frequent vascular plant species (frequency ≥0.20) of vegetation type III (Moist Meadow, n=142). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type III *Arctagrostis latifolia* Herbaceous Alliance				**Plant communities**			
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=70)** Arctagrostis latifolia- Luzula nivalis Herbaceous Vegetation		**b (n=72)** Shrubs - Arctagrostis latifolia Dwarf-Shrubland	
Shrub	*Salix arctica*	21.05	1.00	Moss	58	Moss	58
	Cassiope tetragona	8.14	0.51	*Arctagrostis latifolia*	29	Lichen	17
	Salix herbacea	4.38	0.61	*Salix arctica*	27	Biological crust	17
	Salix reticulata	0.71	0.40	Biological crust	21	*Arctagrostis latifolia*	16
	Dryas integrifolia	0.61	0.36	*Luzula nivalis*	15	*Salix arctica*	15
	Salix lanata	0.01	0.02	Lichen	13	*Cassiope tetragona*	14
	Vaccinium uliginosum	<0.01	0.01	*Alopecurus alpinus*	4	*Salix herbacea*	7
Graminoid	*Arctagrostis latifolia*	22.34	0.93	*Eriophorum triste*	3	*Luzula nivalis*	5
	Luzula nivalis	10.26	1.00	*Cassiope tetragona*	2	*Luzula confusa*	2
	Alopecurus alpinus	2.66	0.79	*Carex membranacea*	2	*Alopecurus alpinus*	0.9
	Eriophorum triste	1.79	0.50	*Luzula confusa*	2	*Oxyria digyna*	0.8
	Luzula confusa	1.65	0.69	*Salix herbacea*	1	*Eriophorum triste*	0.7
	Carex membranacea	1.16	0.13	*Carex misandra*	1	*Poa arctica*	0.7
	Carex misandra	0.74	0.21	*Dryas integrifolia*	1	*Salix reticulata*	0.7
	Poa arctica	0.60	0.75	*Luzula confusa*	1	*Polygonum viviparum*	0.5
	Juncus biglumis	0.24	0.52	*Salix reticulata*	0.7	*Pyrola grandiflora*	0.5
Forb	*Oxyria digyna*	0.72	0.88	*Oxyria digyna*	0.7	*Stellaria longipes*	0.4
	Potentilla hyparctica	0.47	0.70	*Potentilla hyparctica*	0.6	*Cardamine bellidifolia*	0.4
	Stellaria longipes	0.46	0.95	*Carex aquatilis var*	0.5	*Draba lactea*	0.4
	Polygonum viviparum	0.44	0.59	*stans*		*Carex bigelowii*	0.3
	Draba lactea	0.39	0.87	*Poa arctica*	0.5	*Potentilla hyparctica*	0.3
	Cardamine bellidifolia	0.38	0.88	*Stellaria longipes*	0.5	*Saxifraga cernua*	0.3
	Cerastium alpinum	0.32	0.62	*S. oppositifolia*	0.5	*Saxifraga nivalis*	0.3
	Saxifraga oppositifolia	0.32	0.59	*Cerastium alpinum*	0.4	*/S. tenuis*	
	Saxifraga cernua	0.31	0.70	*Draba lactea*	0.4		
	Draba alpina	0.30	0.65	*Ranunculus nivalis*	0.4		
	/D. corymbosa			*Juncus biglumis*	0.4		
	Ranunculus nivalis	0.29	0.58	*Saxifraga foliolosa*	0.4		
	Pedicularis arctica	0.28	0.65	*Polygonum viviparum*	0.4		
	/P. hirsuta			*C. bellidifolia*	0.4		
	Saxifraga foliolosa	0.28	0.68	*Saxifraga cernua*	0.4		
	Papaver radicatum	0.26	0.66	*Papaver radicatum*	0.4		
		0.26	0.61	*Draba alpina*	0.3		
				/D. corymbosa			
	Saxifraga hieracifolia	0.24	0.56	*Pedicularis arctica*	0.3		
	Eutrema edwardsii	0.19	0.44	*/P. hirsuta*			
	Ranunculus sulphureus	0.12	0.30	*Festuca brachyphylla*	0.3		
	Saxifraga caespitosa	0.12	0.32	*Saxifraga nivalis*	0.3		
	Melandrium apetalum	0.10	0.25	*/S. tenuis*			
	Sagina intermedia	0.08	0.23	*Saxifraga hieracifolia*	0.3		

Type IV – Moist Shrub-Tundra (n=43)

Salix spp. Dwarf-Shrubland

This vegetation type is typical of drier, yet still moist, tundra with a decreasing cover of mosses (<50%) and graminoids (<25%) and nearly 50% cover of shrubs (Table 12). *Salix* spp. (mainly *Salix arctica* and *S. reticulata*) and *Dryas integrifolia* are the dominant shrubs (Table 16). Diversity of forbs is high in this type (50 species) where the legumes (*Astragalus alpinus* and *Oxytropis maydelliana*), *P. viviparum*, *Saxifraga oppositifolia*, *Stellaria longipes* and *Draba* spp. are the most dominant and frequent forbs. This type has a high cover of litter (17%) mainly because of the high cover of *S. arctica* and *S. reticulata*. Hummocks are the predominant microtopography (58% of the plots) and a few plots had mud-boils (19%) or large polygons (14%). This type grows at a range of altitudes (20-490 m) on relatively flat terrain (mostly on terraces, also in valley bottoms) like the precedent type III- Moist Meadow.

This type is not subdivided further.

Table 16. Mean percent cover and frequency of occurence for the frequent vascular plant species (frequency ≥0.20) of vegetation type IV (Moist Shrub-Tundra, n=43). All dwarf-shrub species present are shown. The plant community is the same as the vegetation type.

Vegetation type IV
Salix spp. Dwarf-Shrubland

Life Form	Species	Cover (%)	Frequency
Shrub	*Salix arctica*	30.25	1.00
	Salix reticulata	10.33	0.70
	Dryas integrifolia	7.04	0.95
	Salix lanata	1.09	0.30
	Cassiope tetragona	0.23	0.23
	Salix herbacea	<0.01	0.02
	Vaccinium uliginosum	<0.01	0.02
Graminoid	*Arctagrostis latifolia*	7.85	0.88
	Alopecurus alpinus	3.79	0.95
	Carex bigelowii	2.3	0.28
	Luzula confusa	1.78	0.81
	Poa arctica	1.77	0.88
	Luzula nivalis	1.34	0.95
	Festuca brachyphylla	0.45	0.86
	Juncus biglumis	0.14	0.30
Forb	*Astragalus alpinus*	1.67	0.74
	Oxytropis maydelliana	1.22	0.42
	Polygonum viviparum	1.09	0.88
	Saxifraga oppositifolia	0.63	0.72
	Stellaria longipes	0.44	0.95
	Draba lactea	0.38	0.86
	Papaver radicatum	0.37	0.63
	Cerastium alpinum	0.35	0.81
	Draba alpina /D. corymbosa	0.33	0.70
	Oxyria digyna	0.30	0.35
	Saxifraga cernua	0.29	0.72
	Eutrema edwardsii	0.25	0.60
	Saxifraga caespitosa	0.25	0.67
	Saxifraga nivalis /S. tenuis	0.25	0.60
	Pedicularis arctica /P. hirsuta	0.24	0.60
	Saxifraga hieracifolia	0.21	0.58
	Cardamine bellidifolia	0.17	0.37
	Saxifraga hirculus	0.11	0.26
	Potentilla hyparctica	0.11	0.28
	Minuartia rubella	0.09	0.26

Type V Grass Mesic Meadow (n=108)

Luzula nivalis Herbaceous Alliance

This type is the driest of the meadows in this study with a moss cover of only 32% (Table 12). This meadow has also the lowest cover of graminoids (26%) and a low cover of dwarf-shrubs (20%). However, this type has the highest vascular plant species richness of all vegetation types with 87 species. *Luzula nivalis* and *Saxifraga oppositifolia* are highly characteristic of this type (Table 17). *Alopecurus alpinus, Poa arctica* and *Juncus biglumis* are frequently observed within this type. The cover of forbs is particularly high in this meadow (14%) compared to the other vegetation types with *Saxifraga oppositifolia*, *Oxyria digyna*, *Papaver radicatum* and *Saxifraga cernua* among the dominant. The cover of biological crust is variable (0 to up to 50%) but relatively frequently observed in the field (26% of the plots). Finally, the cover of litter is low in this type with only 4%.

Gravels, stones and rocks are frequent in this meadow and often take the form of stripes alternated with stripes of biological crust (34% of the plots). Growing mostly on gentle slopes, this meadow develops on elevated plateaux or terraces (428 ± 151 m). When this type was sampled in August 2002 on elevated plateaus or terraces near the glaciers, we noted that some plots had a fine textured soil. The soil was so saturated in water it was difficult to walk into, our feet were sinking. This was explained by the frequent periods of rain we had in 2002. Normally, the soil is saturated in water until early summer and becomes drier in the course of the summer.

The first plant community is dominated by graminoids (46% cover dominated by A. alpinus and L. nivalis), mosses (41% cover) and biological crust (31% cover). Within the second community, biological crust is the dominant life form with a cover of 35% followed by shrubs and mosses (25% and 24% cover respectively). Graminoids only have a cover of 9.5% in this community where Luzula nivalis, Eriophorum triste, Carex misandra, Arctagrostis latifolia and A. alpinus are dominant. In both communities, the forbs Saxifraga oppositifolia and Oxyria digyna are abundant (more than 2% cover) and a fair number of other forb species are also observed. The first plant community grows at much higher altitude than the second one (500m vs 370 m) while the second community has twice the cover of gravels than in the first one (20% vs 10%).

Table 17. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type V (Grass Mesic Meadow, n=108). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type V *Luzula nivalis* Herbaceous Alliance				**Plant communities**			
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=49)** Alopecurus alpinus – Luzula nivalis / Saxifraga oppositifolia Herbaceous Vegetation		**b (n=59)** Luzula nivalis / Saxifraga oppositifolia Herbaceous Vegetation	
Shrub	*Salix arctica*	18.91	0.91	Moss	41	Biological crust	35
	Salix reticulata	0.79	0.31	*Alopecurus alpinus*	33	Moss	24
	Salix herbacea	0.34	0.17	Biological crust	31	*Salix arctica*	23
	Dryas integrifolia	0.25	0.32	*Salix arctica*	14	Lichen	6
	Cassiope tetragona	0.08	0.05	*Luzula nivalis*	8	*Saxifraga oppositifolia*	4
	Salix lanata	0.01	0.05	Lichen	8	*Luzula nivalis*	3
Graminoid	*Alopecurus alpinus*	15.37	0.89	*S. oppositifolia*	7	*Eriophorum triste*	2
	Luzula nivalis	5.12	0.90	*Oxyria digyna*	2	*Oxyria digyna*	2
	Eriophorum triste	1.21	0.09	*Poa arctica*	2	*Salix reticulata*	1
	Poa arctica	0.99	0.54	*Papaver radicatum*	1	*Carex misandra*	1
	Arctagrostis latifolia	0.91	0.32	*Saxifraga cernua*	0.9	*Arctagrostis latifolia*	1
	Carex misandra	0.67	0.42	*R. sulphureus*	0.8	*Alopecurus alpinus*	1
	Juncus biglumis	0.59	0.67	*Juncus biglumis*	0.8	*Papaver radicatum*	0.8
	Festuca brachyphylla	0.39	0.37	*Arctagrostis latifolia*	0.8	*P. arctica /P. hirsuta*	0.5
	Luzula confusa	0.20	0.21	*Cerastium alpinum*	0.7	*Dryas integrifolia*	0.5
	Colpodium vahlianum	0.10	0.19	*Saxifraga caespitosa*	0.7	*Melandrium apetalum*	0.4
Forb	*Saxifraga oppositifolia*	5.51	0.82	*Stellaria longipes*	0.7	*Juncus biglumis*	0.4
	Oxyria digyna	1.83	0.82	*Festuca brachyphylla*	0.7	*Poa arctica*	0.4
	Papaver radicatum	0.90	0.88	*S. nivalis/S. tenuis*	0.6	*Cerastium alpinum*	0.3
	Saxifraga cernua	0.56	0.81	*Salix herbacea*	0.5	*D. alpina /D. corymbosa*	0.3
	Cerastium alpinum	0.49	0.77	*Melandrium apetalum*	0.5	*Saxifraga cernua*	0.3
	Melandrium apetalum	0.44	0.80	*Ranunculus nivalis*	0.4		
	Saxifraga caespitosa	0.43	0.69	*Trisetum spicatum*	0.4		
	Ranunculus sulphureus	0.42	0.46	*Draba alpina /D. corymbosa*	0.4		
	Stellaria longipes	0.40	0.62				
	Saxifraga nivalis/S. tenuis	0.37	0.64	*Luzula confusa*	0.3		
	Draba alpina /D. corymbosa	0.31	0.66	*Draba lactea*	0.3		
	Pedicularis arctica /P. hirsuta	0.31	0.42				
	Ranunculus nivalis	0.23	0.32				
	Draba lactea	0.23	0.66				
	Cerastium beeringianum	0.20	0.31				
	Saxifraga foliolosa	0.19	0.40				
	Cardamine bellidifolia	0.14	0.47				
	Polygonum viviparum	0.12	0.19				
	Sagina intermedia	0.11	0.40				
	Potentilla hyparctica	0.10	0.24				
	Saxifraga flagellaris	0.10	0.27				
	Saxifraga hieracifolia	0.09	0.24				
	Minuartia rubella	0.07	0.23				

Type VI Shrub Heath-Tundra (*Dryas integrifolia*) (n=44)
Dryas integrifolia Dwarf-Shrubland Alliance

In this mesic-xeric to xeric vegetation type, dwarf-shrubs are by far the dominant life form with a cover of 60% while the cover of graminoids is low with only 7% (Table 12). The cover of mosses is also drastically lower with 17%. The evergreen *Dryas integrifolia* is the dominant shrub followed by *Salix arctica, Cassiope tetragona* and *S. reticulata* (Table 18). Cyperaceae (*Carex misandra, C. rupestris* and *Eriophorum triste*) and the rush *Luzula nivalis* characterize the graminoid stratum. The presence of *Pedicularis lanata* is characteristic of this type whereas *Saxifraga oppitifolia* is the most frequent and abundant forb species. This heath-tundra has a low cover of litter (3%) mainly because of the dominance of the evergreen *D. integrifolia*. This type was observed mostly on exposed terraces or raised beaches at relatively high altitudes (230 ± 171 m). Gravels and stones were frequently noted. The microtopography is typically flat, hummocks or stripes.

Two plant communities are recognised. In the first community, biological crust is dominant (34%) with *D. integrifolia* as the dominant vascular plant species (28%). Forbs are co-dominated by *S. oppitifolia and Oxytropis maydelliana*. In the second community, lichen is dominant with 41% cover whereas biological crust, D. *integrifolia* and C. *tetragona* have comparable covers (around 30%) and the cover of mosses is markedly lower (5%). Topographically, these two communities grow at different places. The first one was observed at higher altitudes and steeper slopes (272m and 7°) than the second one (88m and 3°). Bare ground cover was high in the first community (10%) whereas in the second one, soil was almost completely covered by vegetation (90%). Finally, 24% of the plots sampled in the first community had stripes whereas this microtopography was not noted in the second one.

Table 18. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type VI (Shrub Heath-Tundra (*Dryas integrifolia*), n=44). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type VI *Dryas integrifolia* Dwarf-Shrubland Alliance				**Plant communities**			
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=34)** Dryas integrifolia / Saxifraga oppositifolia Dwarf-Shrubland		**b (n=10)** Dryas integrifolia - Cassiope tetragona/ Lichen Dwarf-Shrubland	
Shrub	*Dryas integrifolia*	29.11	1.00	Biological crust	34	Lichen	41
	Salix arctica	16.33	1.00	*Dryas integrifolia*	28	Biological crust	33
	Cassiope tetragona	12.42	0.62	Moss	20	*Dryas integrifolia*	32
	Salix reticulata	1.76	0.55	*Salix arctica*	20	*Cassiope tetragona*	31
	Salix lanata	0.23	0.20	Lichen	12	Moss	5
	Salix herbacea	0.01	0.02	*Cassiope tetragona*	7	*Carex misandra*	4
Graminoid	*Carex misandra*	2.80	0.84	*Saxifraga oppositifolia*	3	*Salix reticulata*	4
	Luzula nivalis	1.03	0.70	*Oxytropis maydelliana*	3	*Salix arctica*	3
	Carex rupestris	0.94	0.39	*Carex misandra*	3	*Saxifraga oppositifolia*	2
	Eriophorum triste	0.45	0.18	*Salix reticulata*	1	*Eriophorum triste*	2
	Arctagrostis latifolia	0.36	0.41	*Luzula nivalis*	1	*Carex rupestris*	2
	Poa arctica	0.19	0.48	*Pedicularis arctica /P.hirsuta*	0.8	*Oxytropis maydelliana*	1
	Alopecurus alpinus	0.14	0.36	*Carex maritima*	0.7	*Salix lanata*	1
	Juncus biglumis	0.14	0.32	*Carex rupestris*	0.6	*Chrysanthemum integrifolium*	0.5
	Colpodium vahlianum	0.11	0.23	*Polygonum viviparum*	0.6	*Luzula nivalis*	0.5
	Festuca brachyphylla	0.11	0.32	*Pedicularis lanata*	0.4	*Carex bigelowii*	0.5
Forb	*Saxifraga oppositifolia*	3.04	1.00	*Arctagrostis latifolia*	0.4	*Carex membranacea*	0.4
	Oxytropis maydelliana	2.29	0.36	*Papaver radicatum*	0.3	*Arctagrostis latifolia*	0.4
	Pedicularis arctica /P.hirsuta	0.67	0.77	*Oxyria digyna*	0.3	*Oxyria digyna*	0.3
	Polygonum viviparum	0.51	0.66	*Stellaria longipes*	0.3	*Epilobium latifolium*	0.3
	Pedicularis lanata	0.40	0.36			*Pedicularis lanata*	0.3
	Oxyria digyna	0.30	0.73			*Pedicularis arctica /P.hirsuta*	0.3
	Papaver radicatum	0.29	0.59			*Polygonum viviparum*	0.3
	Draba alpina /D. corymbosa	0.23	0.66				
	Stellaria longipes	0.22	0.52				
	Astragalus alpinus	0.18	0.30				
	Cerastium alpinum	0.17	0.41				
	Chrysanthemum integrifolium	0.16	0.27				
	Melandrium apetalum	0.14	0.43				
	Eutrema edwardsii	0.08	0.20				
	Draba lactea	0.07	0.25				

Type VII Shrub Heath-Tundra (*Cassiope tetragona*) (n=49)
Cassiope tetragona Dwarf-Shrubland Alliance

In this mesic to mesic-xeric vegetation type, dwarf-shrubs are the dominant life form with mosses (54% and 50% respectively; Table 12). The most dominant shrubs are the ericaceous species *Cassiope tetragona* and the deciduous *Salix reticulata* (Table 19). The grass *Arctagrostis latifolia*, the rushes (*Luzula nivalis* and *L. confusa*) and Cyperaceae (*Eriophorum triste, Carex misandra, C. membranace* and *C. bigelowii*) represent the dominant graminoids. The high cover of mosses and the presence of species characteristic of moist conditions such as *Carex membranacea*, *Eriophorum triste* and *Salix lanata* suggest that this community has more soil moisture availability than the former heath-tundra dominated by *Dryas integrifolia*. Indeed, part of the plots were sampled at the bottom of slopes or on gentle slopes facing north at the edge of valley bottoms or on terraces where the snow cover persists at the beginning of the growing season. This type of heath was sampled at moderate altitudes (166 ± 117 m) on gentle slopes where hummocks are typical.

Two plant communities are recognised. Within the first community, *C. tetragona* is the dominant shrub species whereas in the second one, *S. reticulata* and *C. tetragona* are dominant. The abundance of *L. nivalis* and *L. confusa* is characteristic of the first community whereas the abundance of *C. membranacea,C. misandra* and *E. triste* is characteristic of the second one. The cover of lichen is also higher in the first community compared to the second one (21% vs 9%).

Table 19. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type VII (Shrub Heath-Tundra (*Cassiope tetragona*), n=49). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type VII — *Cassiope tetragona* Dwarf-Shrubland Alliance

Life Form	**Species**	**Cover (%)**	**Frequency**
Shrub	*Cassiope tetragona*	22.32	0.86
	Salix reticulata	16.18	0.86
	Salix arctica	8.81	1.00
	Dryas integrifolia	5.75	0.86
	Salix lanata	0.60	0.31
	Vaccinium uliginosum	0.41	0.14
	Salix herbacea	0.37	0.29
	Ledum decumbens	0.001	0.02
Graminoid	*Arctagrostis latifolia*	7.83	1.00
	Carex membranacea	5.21	0.45
	Eriophorum triste	3.26	0.82
	Luzula nivalis	1.98	0.94
	Carex misandra	1.56	0.65
	Luzula confusa	1.16	0.71
	Poa arctica	0.48	0.69
	Carex bigelowii	0.42	0.26
	Alopecurus alpinus	0.37	0.37
	Juncus biglumis	0.23	0.57
Forb	*Saxifraga oppositifolia*	0.64	0.71
	Polygonum viviparum	0.63	0.90
	Oxyria digyna	0.46	0.80
	Pedicularis arctica /P.hirsuta	0.37	0.65
	Oxytropis maydelliana	0.37	0.33
	Eutrema edwardsii	0.36	0.84
	Stellaria longipes	0.31	0.80
	Draba lactea	0.23	0.61
	Astragalus alpinus	0.22	0.20
	Cardamine bellidifolia	0.19	0.61
	Saxifraga hieracifolia	0.17	0.37
	Cerastium alpinum	0.14	0.37
	Draba alpina /D. corymbosa	0.14	0.35
	Saxifraga foliolosa	0.13	0.47
	Papaver radicatum	0.09	0.43
	Saxifraga cernua	0.08	0.35
	Potentilla hyparctica	0.07	0.29
	Saxifraga nivalis /S. tenuis	0.07	0.22

Plant communities

a (n=17) Cassiope tetragona –- Luzula spp Dwarf-Shrubland		**b (n=32)** Salix reticulata –- Cassiope tetragona Dwarf-Shrubland	
Moss	46	Moss	52
Cassiope tetragona	31	Biological crust	34
Lichen	21	*Salix reticulata*	23
Biological crust	16	*Cassiope tetragona*	18
Salix arctica	11	*Arctagrostis latifolia*	10
Arctagrostis latifolia	5	Lichen	9
Dryas integrifolia	4	*Carex membranacea*	8
Salix reticulata	3	*Salix arctica*	8
Luzula confusa	3	*Dryas integrifolia*	6
Luzula nivalis	3	*Eriophorum triste*	5
Eriophorum vaginatum ssp spissum	1	*Carex misandra*	2
Eriophorum angustifolium	1	*Luzula nivalis*	2
Eriophorum triste	0.9	*Carex aquatilis var stans*	1
Polygonum viviparum	0.9	*Salix lanata*	0.9
Oxyria digyna	0.7	*Saxifraga oppositifolia*	0.9
Poa arctica	0.5	*Carex bigelowii*	0.6
Carex aquatilis var stans	0.5	*Vaccinium uliginosum*	0.6
Pedicularis arctica /P.hirsuta	0.4	*Alopecurus alpinus*	0.6
Saxifraga hieracifolia	0.3	*Polygonum viviparum*	0.5
Cardamine bellidifolia	0.3	*Salix herbacea*	0.5
Eutrema edwardsii	0.3	*Poa arctica*	0.5
Carex misandra	0.3	*Oxytropis maydelliana*	0.5
Stellaria longipes	0.3	*Luzula confusa*	0.4
Draba lactea	0.3	*Eutrema edwardsii*	0.4
		Pedicularis arctica /P.hirsuta	0.4
		Astragalus alpinus	0.3
		Stellaria longipes	0.3
		Juncus biglumis	0.3
		Oxyria digyna	0.3
		Equisetum variegatum	0.3

Type VIII – Shrub Heath-Tundra (*Vaccinium*) (n=49)
Vaccinium uliginosum Dwarf-Shrubland Alliance

This heath is the vegetation type with the highest cover of dwarf-shrubs (63%; Table 12). Except for the abundance of *Vaccinium uliginosum,* this heath shares the same shrub species composition with the previous heaths (type VI and VII), with *Cassiope tetragona, Salix arctica, Dryas integrifolia* and *Salix reticulata* being the dominant shrubs in decreasing order of cover. In addition to *Vaccinium uliginosum, Eriophorum vaginatum* ssp. *spissum*, *Hierochloë alpina* and *Saxifraga tricuspidata* are abundant and characteristic to this heath (Table 20). *Luzula confusa* and *Carex rupestris* are also an important element of the graminoid layer. Despite their low cover, *Empetrum nigrum*, *Ledum decumbens* and *Rhododendron lapponicum* are highly characteristic of this type. Mosses and biological crust cover a high proportion of the ground (34 % and 31% respectively). This heath grows at moderate altitude on moderate to steep slopes (10 ± 8°) and at the bottom of the slopes. The cover and frequency of rock are especially high (11% and 76% respectively) in those sites. Gravel and stone frequency is also high in the type. Inversely, the bare ground cover is quite low (1%). Most of the plots (82%) were sampled in or near Oliver Sound. Hummocks, undulating surface and nets are the principal patterned ground.

Two plant communities are separated by the analysis. The first community grows in moist to mesic conditions whereas the second one is more mesic-xeric/xeric. Cryptogams have a high cover in both communities but the cover of moss is higher in the first community (48% vs 28%). Shrub species and abundance are similar between the two communities. However, graminoid composition and abundance distinguish well the two communities. Indeed, the cover of graminoids is almost double in the first community (30% vs 17%). *Eriophorum vaginatum* ssp. *spissum* and *E. triste* are characteristic in the first community whereas in the second one, *Hierochloë alpina* and *Carex rupestris* are the characteristic graminoids. In addition, the legume *Oxytropis maydelliana* reaches a high cover in the second community (5%). This second community grows on steeper slopes (13°) and has a higher cover and frequency of rock (15% cover and 95% frequency) than the first community (slope: 6°; 2% cover and 39% frequency).

Table 20. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type VIII (Shrub Heath-Tundra (*Vaccinium*), n=49). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type VIII *Vaccinium uliginosum* Dwarf-Shrubland Alliance				**Plant communities**			
Life Form	**Species**	**Cover (%)**	**Frequency**	**a (n=18)** Eriophorum spp – Vaccinium uliginosum Dwarf-Shrubland		**b (n=31)** Vaccinium uliginosum – Hierochloë alpina Dwarf-Shrubland	
Shrub	*Vaccinium uliginosum*	20.72	0.86	Moss	48	Biological crust	29
	Cassiope tetragona	17.48	0.90	Biological crust	32	Moss	28
	Salix arctica	9.17	1.00	*Eriophorum vaginatum*	20	*Vaccinium uliginosum*	23
	Dryas integrifolia	6.37	0.90	ssp *spissum*		*Cassiope tetragona*	17
	Salix reticulata	5.83	0.65	*Cassiope tetragona*	19	*Salix arctica*	12
	Ledum decumbens	1.32	0.41	*Vaccinium uliginosum*	17	Lichen	11
	Salix herbacea	1.03	0.14	*Salix reticulata*	11	*Dryas integrifolia*	8
	Empetrum nigrum	1.00	0.29	Lichen	7	*Hierochloë alpina*	5
	Salix lanata	0.01	0.04	*Salix arctica*	5	*Oxytropis maydelliana*	5
	Rhododendron	<0.01	0.02	*Dryas integrifolia*	4	*Carex rupestris*	3
	lapponicum			*Salix herbacea*	3	*Salix reticulata*	3
Graminoid	*Eriophorum*	7.41	0.14	*Arctagrostis latifolia*	2	*Luzula confusa*	3
	vaginatum ssp spissum			*Luzula confusa*	2	*Poa arctica*	2
	Hierochloë alpina	3.24	0.55	*Luzula nivalis*	2	*Ledum decumbens*	2
	Luzula confusa	2.18	0.90	*Oxytropis maydelliana*	1	*Festuca brachyphylla*	1
	Carex rupestris	2.12	0.55	*Empetrum nigrum*	1	*Empetrum nigrum*	1
	Poa arctica	1.62	0.84	*Polygonum viviparum*	1	*Luzula nivalis*	0.7
	Luzula nivalis	1.00	0.61	*Carex bigelowii*	0.9	*Carex obtusata*	0.6
	Arctagrostis latifolia	0.87	0.45	*Poa arctica*	0.8	*Poa glauca*	0.6
	Festuca brachyphylla	0.68	0.33	*Carex misandra*	0.6	*Saxifraga tricuspidata*	0.5
	Carex bigelowii	0.49	0.20	*Carex membranacea*	0.6	*Polygonum viviparum*	0.5
	Carex misandra	0.34	0.35	*Carex rupestris*	0.5	*Oxyria digyna*	0.3
Forb	*Eriophorum triste*	0.19	0.20	*Hierochloë pauciflora*	0.4	*Arctagrostis latifolia*	0.3
	Oxytropis maydelliana	3.45	0.84	*Eutrema edwardsii*	0.4	*Stellaria longipes*	0.3
	Polygonum viviparum	0.65	0.59	*Eriophorum triste*	0.4	*Carex bigelowii*	0.3
	Saxifraga tricuspidata	0.35	0.45	*Pedicularis lanata*	0.4	*Pyrola grandiflora*	0.3
	Oxyria digyna	0.27	0.43	*Ledum decumbens*	0.3		
	Stellaria longipes	0.25	0.73				
	Pyrola grandiflora	0.24	0.53				
	Eutrema edwardsii	0.22	0.47				
	Papaver radicatum	0.17	0.55				
	Draba nivalis	0.13	0.27				
	Potentilla nivea	0.12	0.20				
	Pedicularis arctica	0.07	0.24				
	/P.hirsuta						
	Cerastium alpinum	0.07	0.22				
	Draba lactea	0.07	0.27				

Type IX – Shrub-Forb Tundra (n=21)
Salix arctica / Astragalus alpinus Dwarf-Shrubland Alliance

This mesic-xeric tundra is typical of steep mountain slopes (Table 12). The dwarf-shrub *Salix arctica* and the forbs, particularly the legumes *Astragalus alpinus* and *Oxytropis maydelliana*, are the dominant life forms. The cover of grasses, mosses and biological crust are markedly lower in this type of vegetation. No species of sedge was observed in this type. Almost all the plots in this vegetation type were sampled in or in the vicinity of the Goose Camp valley.

Two distinct plant communities are recognised. The first one is a xeric community typical of scree slopes and crests. The cover of bare ground and stones is large (25% and 48% respectively) due to the steep slopes (30 ± 4°). Consequently, the cover of vascular plants (27%; mostly shrubs and forbs) and cryptogams (2%) is low. The vegetation is dominated by the dwarf-shrub *Salix arctica* and the legume *Astragalus alpinus*, and by some pioneer species such as *Epilobium latifolium*, *Festuca baffinensis*, *Taraxacum phymatocarpum*, *Trisetum spicatum*, *Erigeron eriocephalus* and *Erysimum pallasii* (Table 21). No characteristic microtopography or patterned ground was observed in this community where rocks (slab stones) are constantly present (100% of the plot).

The second community grows in mesic to mesic-xeric habitats on less steep slopes (21 ± 7°) or on plateaus. Slopes were normally facing South, East or West. The cover of vascular plants and cryptogams are higher in this community. However, moss cover is higher on slope bottom and rapidly decreasing towards the ridges. This tundra is dominated by *Salix arctica*, the two legumes *Astragalus alpinus* and *Oxytropis maydelliana*, and the grasses *Poa arctica*, *Alopecurus alpinus*, *Festuca brachyphylla* and *Poa glauca*. Forbs such as *Polygonum viviparum* and *Arnica alpina* ssp. *angustifolia* have a rather high cover in this community (Table 21). *Poa glauca* and the forbs *Saxifraga tricuspidata* and *Draba glabella* are characteristic of this community. Cover of litter on the ground is also rather high (41%) because of the high cover of vascular plants, especially *S. arctica*. Although the cover of bareground and rocks (including gravels, stones and rocks) are low (6% and <1% respectively), they are relatively frequent (94% and 61% respectively). The main microtopography are flat, undulating and lobes.

Table 21. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type IX (Shrub-Forb Tundra, n=21). All dwarf-shrub species present are shown. For the associated plant communities, only the mean percent cover of the most abundant taxa (cover ≥0.3%) is presented.

Vegetation type IX — *Salix arctica / Astragalus alpinus* Dwarf-Shrubland Alliance

Life Form	Species	Cover (%)	Frequency
Shrub	*Salix arctica*	45.50	1.00
	Salix reticulata	0.51	0.33
	Dryas integrifolia	0.32	0.52
Graminoid	*Poa arctica*	3.23	0.81
	Alopecurus alpinus	3.03	1.00
	Festuca brachyphylla	1.71	0.86
	Poa glauca	1.04	0.76
	Festuca baffinensis	0.48	0.33
	Luzula confusa	0.37	0.62
	Trisetum spicatum	0.23	0.57
	Luzula nivalis	0.09	0.24
Forb	*Astragalus alpinus*	14.20	1.00
	Oxytropis maydelliana	9.32	0.95
	Polygonum viviparum	2.45	0.90
	Arnica alpina ssp. angustifolia	1.11	0.43
	Saxifraga tricuspidata	0.88	0.76
	Stellaria longipes	0.59	1.00
	Cerastium alpinum	0.53	0.90
	Oxyria digyna	0.40	0.38
	Pedicularis arctica /P. hirsuta	0.34	0.52
	Papaver radicatum	0.33	0.62
	Draba glabella	0.32	0.67
	Epilobium latifolium	0.31	0.14
	Saxifraga cernua	0.30	0.81
	Saxifraga nivalis /S. tenuis	0.26	0.52
	Melandrium affine	0.21	0.57
	Taraxacum phymatocarpum	0.20	0.43
	Draba cinerea	0.19	0.38
	Equisetum arvense	0.19	0.14
	Saxifraga oppositifolia	0.18	0.48
	Saxifraga caespitosa	0.12	0.33
	Eutrema edwardsii	0.10	0.29
	Erigeron eriocephalus	0.08	0.24

Plant communities

a (n=3) Salix arctica – Astragalus alpinus / Forb Sparse Vegetation (Scree slopes)		**b (n=18)** Salix arctica – Astragalus alpinus – Oxytropis maydelliana/ Forb Dwarf-Shrubland	
Salix arctica	9	*Salix arctica*	52
Astragalus alpinus	4	Moss	33
Epilobium latifolium	2	*Astragalus alpinus*	16
Moss	2	*Oxytropis maydelliana*	11
Alopecurus alpinus	1	Lichen	8
Cerastium alpinum	1	*Poa arctica*	4
Papaver radicatum	1	Biological crust	3
Oxyria digyna	1	*Alopecurus alpinus*	3
Festuca baffinensis	1	*Polygonum viviparum*	3
Saxifraga tricuspidata	1	*Festuca brachyphylla*	2
Draba cinerea	0.5	*Arnica alpina ssp. angustifolia*	1
Stellaria longipes	0.5	*Poa glauca*	1
T. phymatocarpum	0.5	*Saxifraga tricuspidata*	0.9
Trisetum spicatum	0.4	*Stellaria longipes*	0.6
Draba subcapitata	0.3	*Salix reticulata*	0.6
Lichen	0.3	*Luzula confusa*	0.4
Saxifraga caespitosa	0.3	*Cerastium alpinum*	0.4
Saxifraga cernua	0.3	*Pedicularis arctica /P. hirsuta*	0.4
Saxifraga nivalis /S. tenuis	0.3	*Festuca baffinensis*	0.4
E. eriocephalus	0.2	*Dryas integrifolia*	0.4
Oxytropis maydelliana	0.2	*Draba glabella*	0.4
Festuca brachyphylla	0.2	*Saxifraga cernua*	0.3
Arnica alpina ssp angustifolia	0.1	*Oxyria digyna*	0.3
Erysimum pallasii	0.1	*Melandrium affine*	0.3
		Saxifraga nivalis /S. tenuis	0.3

Type X –Graminoid Barren (n=6)
Graminoid Sparse Vegetation Alliance

This type grows in the driest conditions we sampled. Typical of beaches, it has the lowest species richness (36 species) and lowest cover of dwarf-shrub (2%), total vascular plant (18%), mosses (<1%) and litter (0.5%; Table 12). Cover of lichens and biological crust are also rather low. Actually, the ground is covered with sand (littoral deposits), and few gravels, stones and rocks. This narrow coastal fringe vegetation type, few to 300m wide (up to 1 km on the west side of the south plain), is exposed to floods, ice scouring and sand erosion. Few graminoids and forbs can successfully establish in this unstable substrate. *Alopecurus alpinus*, *Luzula confusa*, *Carex maritima*, *Poa arctica* and *Festuca brachyphylla* are the dominant graminoids whereas *Stellaria longipes*, *Saxifraga oppositifolia* and *Cerastium arcticum* comprise the forb layer (Table 22). *Phippsia algida* was also observed in this type (Duclos, pers. obs.). This type is not subdivided further.

Table 22. Mean percent cover and frequency of occurence for the dominant or frequent vascular plant species (frequency ≥0.20) of vegetation type X (Graminoid Barren, n=6). All dwarf-shrub species present are shown. The plant community is the same as the vegetation type. *Phippsia algida* also grows on this beaches (Duclos, pers. obs.).

Vegetation type X

Graminoid Sparse Vegetation Alliance

Alopecurus alpinus – Luzula confusa – Poa arctica / Stellaria longipes Sparse Vegetation

Life Form	Species	Cover (%)	Frequency
Shrub	*Salix arctica*	1.87	0.67
Graminoid	*Alopecurus alpinus*	2.50	1.00
	Luzula confusa	1.93	1.00
	Carex maritima	1.83	0.50
	Poa arctica	1.75	1.00
	Festuca brachyphylla	1.33	1.00
	Luzula nivalis	0.67	0.50
	Elymus arenarius ssp. mollis	0.12	0.33
Forb	*Stellaria longipes*	1.33	1.00
	Saxifraga oppositifolia	1.03	0.50
	Cerastium arcticum	0.50	1.00
	Papaver radicatum	0.28	0.67
	Saxifraga rivularis	0.25	0.50
	Sagina caespitosa	0.25	0.50
	Draba cinerea	0.25	0.50
	Potentilla hyparctica	0.22	0.83
	Taraxacum phymatocarpum	0.20	0.50
	Draba lactea	0.20	0.50
	Cardamine bellidifolia	0.20	0.50
	Polygonum viviparum	0.17	0.33
	Saxifraga nivalis/S. tenuis	0.15	0.50
	Armeria maritima	0.12	0.33
	Ranunculus sabinei	0.10	0.50
	Potentilla nivea	0.07	0.33

3.3 Distribution of vegetation

In order to compare the vegetation and environmental datasets, direct ordinations were used. This approach highlights the main environmental factors influencing the distribution of the vegetation.

Overall analysis

In the first canonical correspondence analysis (CCA), all 543 plots were analysed (Figure 9). Inflation factors are all ≤ 2.4 and the total inertia is 5.292 (Appendix 7). All axes are significant ($p<0.05$) with axes 1 and 2 explaining respectively 32.1% and 26.1% of the variance of the relation between the distribution of the species and their environment. The cumulative variance rises to 80.8% with the first four axes.

Of all the measured environmental variables, slope angle, rock cover, altitude and North-South exposition influence most the distribution of the vegetation. Vegetation types in this ordination follow a moisture gradient (Figure 9). The first and second axis of the ordination clearly separates wetlands (Graminoid Wet Meadow) on the lower-left side of the biplot from dryer types dominated by dwarf-shrubs and with a low cover of graminoids on the right side (such as vegetation types Shrub Heath-Tundra (*Vaccinium*) and Shrub-Forb Tundra). These dryer types grow on steeper slopes, at higher altitude, and have a higher cover of rocks, stones and gravels than wetlands. Moist to mesic plots are gathered in the centre of the ordination.

From the biplot (Figure 9), we can notice that Graminoid Wet Meadow are restrained to flat terrain, generally at low altitude, and that rocks are nearly absent on the ground. Moreover, as we observed in the Twinspan analysis, Graminoid Wet Meadow are dominated by mosses and hydrophilic graminoids which also floristically distinguished them on the CCA biplot. Inversely, a dryer, completely different type of vegetation, dominated by dwarf-shrubs and legumes (Shrub-Forb Tundra; type IX) develops on steeper slopes at high altitudes in mountains. All sites sampled in mountains were facing South, West or East. The CCA shows that these sites have a high cover of litter, gravel, stone and bare ground. Another type of vegetation characterized by *Vaccinium uliginosum* (Shrub Heath-Tundra; type VIII) is also apart from the rest of the plots. From the biplot, we can note that this type has a high cover of rocks and grows on steep slopes (less steep than Shrub-Forb Tundra) generally facing South, but at lower altitude than the Shrub-Forb Tundra. The remaining plots, mostly mesic vegetation types are grouped in the center of this CCA.

The impossibility to clearly distinguish the remaining plots could be explained in part by the distinctive species composition and environmental characteristics of the Graminoid Wet Meadow (type I), Shrub Forb Tundra (type IX-mountains) and Shrub Heath Tundra (*Vaccinium*; type VIII). The uniqueness of these vegetation types minimise the distinction between the remaining vegetation types. Thus, another CCA was performed without the Graminoid Wet Meadow (wetlands; type I), Shrub-Forb Tundra (type IX-mountains) and Shrub Heath-Tundra (*Vaccinium*; type VIII) (see below). Beach samples (type X) were also removed from the second analysis (see methods).

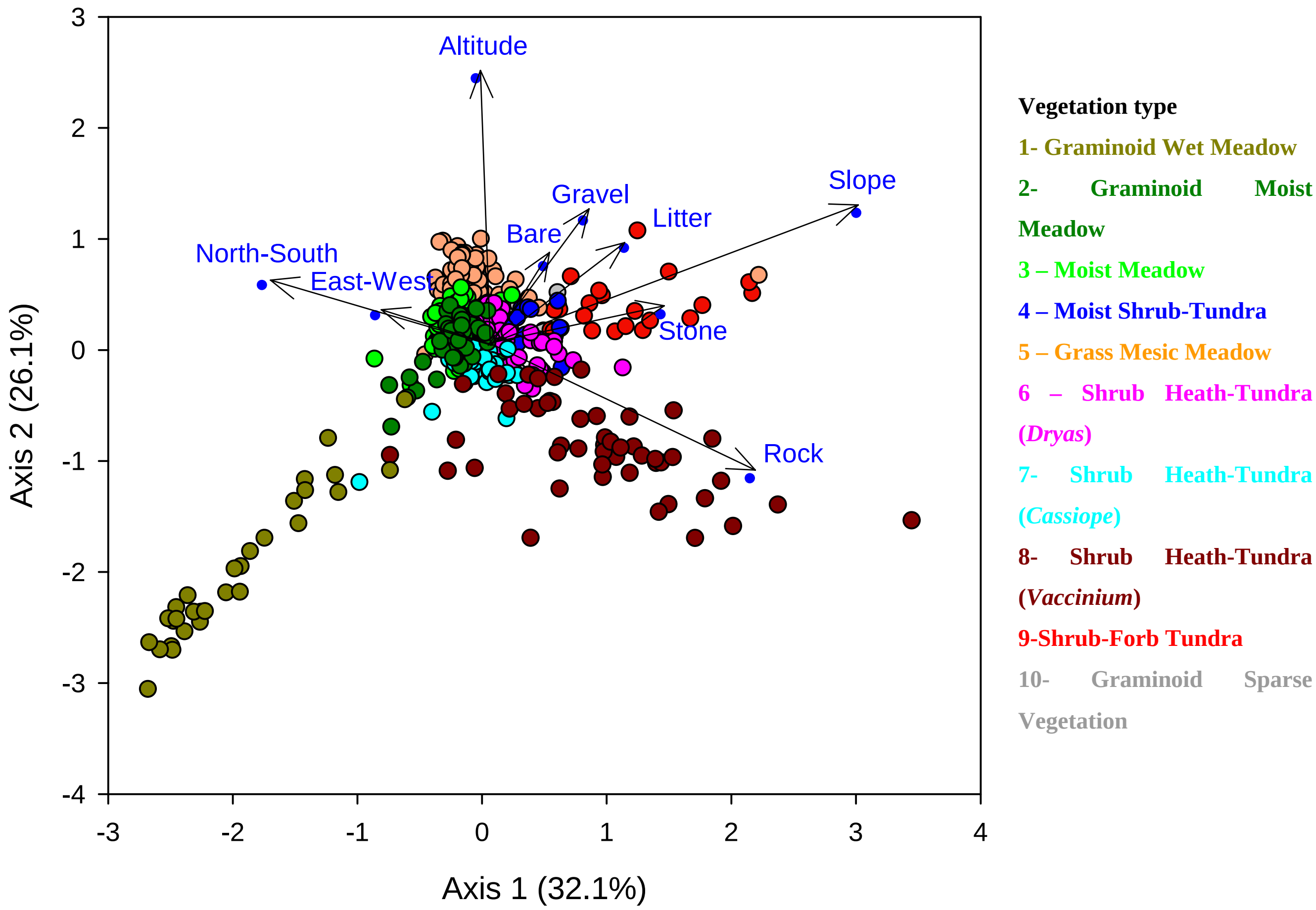


Figure 9. Distribution of 543 vegetation plots and 9 environmental variables along Axes 1 and 2 of the first canonical correspondence analysis (CCA) in Sirmilik National Park, Nunavut. Colours of symbols refer to vegetation types.

Analysis without vegetation types I, VIII, IX and X

- without Graminoid Wet Meadow, Shrub Heath-Tundra (*Vaccinium*), Shrub-Forb Tundra (mountains) and Graminoid Barren (Beaches) respectively -

In this second CCA, all axes are significant ($p<0.05$) and have a total cumulative variance of 82.3%. Inflation factors are low (≤1.6) and the total inertia is 3.596 (Appendix 7). The distinctions amongst the remaining vegetation types are more evident in this analysis but there are still some overlap (Figure 10). Moist Meadow (Type III), Grass Mesic Meadow (Type V), Shrub Heath-Tundra (*Dryas*, Type VI) and Shrub Heath-Tundra (*Cassiope*, Type VII) are more clearly distinguished on the biplot whereas Graminoid Moist Meadow (Type II) and Moist Shrub-Tundra (Type IV) remain in the center with plots overlapping with the other groups. Plots from these two last types are scattered and can not be separated clearly with the second and third CCA axis which suggest that they are found in a broad range of conditions and that their composition overlaps with the four other types.

Grass Mesic Meadow and Shrub Heath-Tundra (*Dryas*) are both associated with a higher cover of gravel compared to the other types and grow on steeper slopes. However, Grass Mesic Meadow is found at higher altitudes than Shrub Heath-Tundra (*Dryas*). High cover and frequency of gravels and rocks is also characteristic of the Grass Mesic Meadow (Figure 10 and Table 12). As for Moist Meadow and Shrub Heath-Tundra (*Cassiope*), they grow on flat terrain and have and higher cover of litter compared to Grass Mesic Meadow and Shrub Heath-Tundra (*Dryas*). However, Moist Meadow is found at higher altitudes than Shrub Heath-Tundra (*Cassiope*). These four types of vegetation are well separated on the biplot both by their floristic and environmental characteristics.

For the two overlapping groups, Graminoid Moist Meadow (Type II) and Moist Shrub-Tundra (Type IV), although their dominant shrub species and total graminoid cover are quite distinctive as illustrated by the Twinspan analysis, these two types share many of their dominant species of graminoid and forb with other vegetation types (Tables 14 and 16). Also, they occur in a broad range of conditions without clearly distinctive environmental characteristics (Table 12).

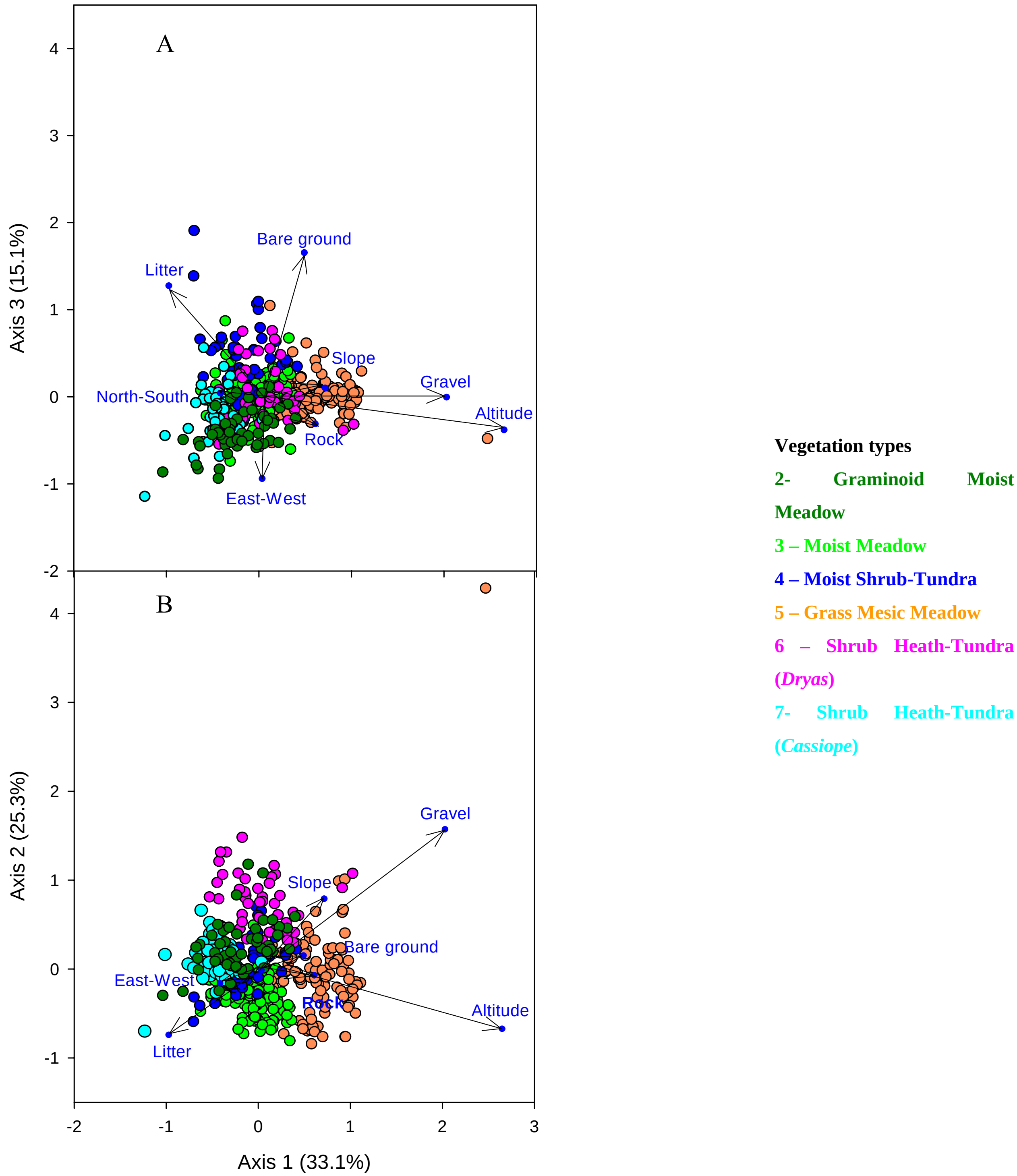


Figure 10.Distribution of 437 vegetation plots (types II, III, IV, V, VI and VII) and 8 environmental variables along: A) axes 1 and 3; and B) axes 1 and 2 of the second canonical correspondence analysis (CCA) in Sirmilik National Park, Nunavut. Colours of symbols refer to vegetation types.

3.4 Vegetation mapping

From the 10 vegetation types described previously, only the first eight were used in the following mapping exercise since vegetation types IX and X had a sparse cover and too few sites to contribute to the image classification. The vegetation cover map is presented on Figure 11.

As stated earlier, of the 389 vegetation sampling sites used for the classification, 295 were used to train the classification and 174 to test the results.

The comparison between the 174 test sites with the digital classication of the vegetation covers is performed in order to establish the accuracy of the digital map. This is presented using a confusion matrix where the first vertical column "number of sites" is the number of test sites used to evaluate the accuracy of the classification. The following vertical column separates the vegetation type class number and the NN class code used on the digital vegetation class map. While the NN classification was performed using 15 vegetation classes (same vegetation types with two groups of vegetation density, see Table 10), the final classification and resulting map regroups all NN class codes under the same vegetation class code (1 to 8, see Table 11).

The matrix is composed of the percentage of pixels which were classified under codes 1 to 8 compared to the test site pixels. In the diagonal axis is the classification accuracy for the individual class. The average accuracy is calculated at over 76%. This is established using the average percentage of test pixels classified to its corresponding class. This average accuracy does not account for the different number of reference pixels for the individual class. On the other hand, the overall accuracy, 69%, accounts for this case. Each class is normalised and the accuracy is a sum of these normalised values. The difference between the average and overall accuracy relates to the assumption that all test sites have an equal chance to be assigned to the right class. This is not always the case. A large number of test sites for a class which is usually found in clumps will usually exhibit a large overall accuracy compared to very dispersed classes.

In our analysis, the lower overall accuracy shows that the classes with a large number of test sites (i.e 64 test sites for Type III: Moist Meadows) usually relates to a vegetation class having a strong spatial dispersion. In our analysis, the 7% difference between the average and the overall accuracy is not that significant. In fact, other classes which have a large number of test sites (i.e. 31 test sites for Type V: Grass Mesic Meadows) show an average accuracy which is significaly higher (84%) than the overall accuracy. In summary, the difference between the average and overall accuracy gives an estimation of the dispersion in the digital class assignments.

An additional method to estimate the level of dispersion in the classification is the Kappa coefficient. This coefficient does not only measure the accuracy of the classification in relation to test sites, it analyses the level of miss-classification. In other words, how often is a pixel wrongly classified to a specific vegetation class. It gives us an idea of the precision of the classifcation in comparison to the accuracy. The precision is related to the probability of finding in the field a specfic vegetation class in SNP while using the map. In the case of the vegetation classification of SNP, the Kappa coefficient of 0.61933. A classification procedure which produces an average accuracy of 76% and a Kappa coefficient of 0.61933 is above average and can be used with confidence.

Table 23. The confusion matrix and classification results of the Neural Net analysis (NN). Roman numbers refer to the vegetation type numbers as in Table 11; I: Graminoid Wet Meadow (Wetlands); II: Graminoid Moist Meadow; III: Moist Meadow; IV: Moist Shrub-Tundra; V: Grass Mesic Meadow; VI: Shrub Heath-Tundra/*Dryas integrifolia*; VII: Shrub Heath-Tundra/*Cassiope tetragona*; VIII: Shrub Heath-Tundra/*Vaccinium uliginosum*. Arab numbers refer to the NN number class code used on the digital vegetation class map (Table 10).

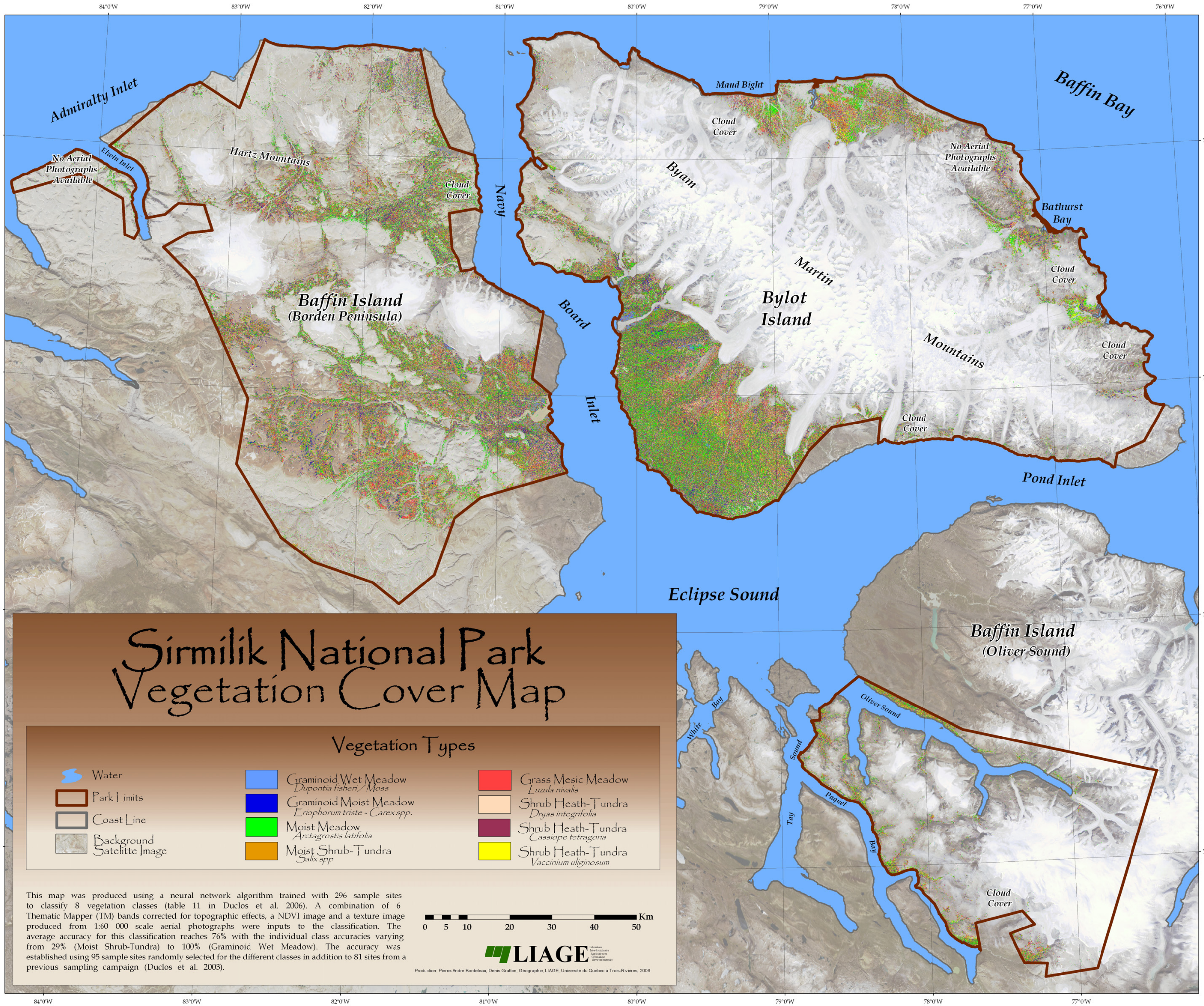
	Vegetation number	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Number of sites	**NN number**	**4**	**2**	**5**	**6**	**1**	**7**	**8**	**3**
		Percent Pixels Classified by Code							
9	**I** / **4**	**100.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	**II** / **2**	0.0	**90.9**	0.0	0.0	0.0	0.0	0.0	9.1
64	**III** / **5**	0.0	4.7	**67.2**	6.3	6.3	4.7	7.8	3.1
24	**IV** / **6**	0.0	8.3	20.8	**29.2**	20.8	4.2	16.7	0.0
31	**V** / **1**	0.0	3.2	3.2	0.0	**83.9**	6.5	3.2	0.0
6	**VI** / **7**	0.0	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0
19	**VII** / **8**	0.0	15.8	10.5	10.5	5.3	0.0	**57.9**	0.0
10	**VIII** / **3**	0.0	10.0	0.0	0.0	0.0	0.0	10.0	**80.0**

Average accuracy = 76.13%
Overall accuracy = 68.97%
Kappa Coefficient = 0.61933 Standard Deviation = 0.04265
Confidence Level :
99% 0.61933 +/- 0.11003
95% 0.61933 +/- 0.08359
90% 0.61933 +/- 0.07016

The SNP vegetation map (Figure 11), shows the 8 vegetation types classified for the areas were the NDVI values identified the presence of a vegetation cover. The classification is presented with a Thematic Mapper colour composite in the background, a water surface cover in addition to the border of SNP.

A digital file in “Geomatica” pix format is also available upon request. This file incorporates all input layers for the NN classification and the vegetation map with all sample sites and image masks.

Figure 11. The Sirmilik National Park vegetation cover map highlighting the dominant vegetation types. The printed representation does not allow as fine a resolution as the digital version and should be used with care.



This map was produced using a neural network algorithm trained with 296 sample sites to classify 8 vegetation classes (table 11 in Duclos et al. 2006). A combination of 6 Thematic Mapper (TM) bands corrected for topographic effects, a NDVI image and a texture image produced from 1:60 000 scale aerial photographs were inputs to the classification. The average accuracy for this classification reaches 76% with the individual class accuracies varying from 29% (Moist Shrub-Tundra) to 100% (Graminoid Wet Meadow). The accuracy was established using 95 sample sites randomly selected for the different classes in addition to 81 sites from a previous sampling campaign (Duclos et al. 2003).

4 DISCUSSION

4.1 Polar oasis

Total plant cover, diversity of plant communities and floristic richness all make Sirmilik National Park a polar oasis. This lush vegetation is not restricted to only one or two valley bottoms but extends to rolling hills, elevated terraces and some mountain slopes. These diverse and green habitats attract a great diversity of birds and mammals, especially on Bylot Island (Zoltai *et al*. 1983, Lepage *et al*. 1998). A number of conditions are necessary to favour the development of polar oases which explain why such rich habitats are rare in the High Arctic. The most important factor seems to be soil moisture availabitily during the growing season through favourable hydrological regime (Muc et al. 1989, Bliss 1997) and/or organic matter content (Batten and Svoboda 1994, Muc et al. 1994a). Other environmental factors such as air and soil temperature and soil nutrients also contribute significantly to the development of a lush vegetation (Bliss et al. 1994, Labine 1994, Muc et al. 1994b). It is important to note that the oases most commonly described in the literature are found in the Queen Elizabeth Island. Other oases are certainly present in the western High Arctic but have not been integrated here.

The vegetation types studied on Sirmilik NP compare well with those of other oases in the Canadian High Arctic (Table 24). Wetlands dominated by sedges are described in all polar oases whereas those dominated by grasses seem to be confined to southern oases like Sirmilik NP, Truelove Lowland and Polar Bear Pass. Similarly, moist to mesic meadows dominated by grasses (as in the Moist Meadow and the Grass Mesic Meadow) are absent in northern oases where they are principally dominated by sedges as our Graminoid Moist Meadow (Bergeron 1988, Gould 1985, Muc et al. 1989). Exceptionally, mesic vegetation types in Sirmilik NP have a high cover of mosses compared to other oasis where high cover of mosses is restricted to wetlands.

Vegetation types dominated by one or a combination of the dwarf-shrub species *Salix arctica*, *Cassiope tetragona* or *Dryas integrifolia* are common throughout the polar oases (see authors of Table 24). However, the total plant cover of these vegetation types is generally lower in higher latitude oases. The *Vaccinium*-dominated type which is relatively rare in SNP seems to be absent from other polar oases. Similarly, high cover and/or occurrence of legumes is not observed in other oases because they are North of Lancaster Sound, the limit of distribution of these species (Porsild and Cody 1980). Coastal communities reported in the literature are frequently tidal salt marshes dominated by *Puccinellia phryganodes,* as found on Truelove Lowland and Alexandra Fiord. However, such marshes are uncommon in Sirmilik NP where sandy beaches dominated by a sparse cover of graminoids characterise the coastline.

Table 24. Comparison of present and previously described vegetation types in Sirmilik National Park with those sampled in other polar oases in the Canadian High Arctic. Graminoid Barren (type X) is not shown in this table because no equivalent was found.

Parks Canada summer 2003	**Zoltai *et al*. 1983**	**Muc and Bliss 1977**	**Sheard and Geale 1983b**	**Muc *et al.* 1989**	**Bergeron 1988**	**Gould 1985**
Sirmilik National Park Types	Sirmilik National Park	Truelove Lowland, Devon Island	Polar Bear Pass, Bathurst Island	Alexandra Fiord, Ellesmere Island	Sverdrup Pass, Ellesmere Island	Lake Hazen, Ellesmere Island
I. Graminoid Wet Meadow	*Eriophorum*-Grass Wet Meadow	I. Hummocky graminoid meadow	I. Grass-moss meadow			
Not sampled	Sedge-Moss Wet Meadow	Sedge-moss meadow	Sedge meadow, Emergent meadow		*Carex aquatilis* meadow	Wet sedge meadow
II. Graminoid Moist Meadow	Shrub-Sedge Tundra			Sedge-cushion plant-dwarf shrub	*Carex aquatilis – Eriophorum triste* meadow	
III. Moist Meadow	Willow-Grass Tundra	Graminoid-moss meadow	Mesic grass meadow			
IV. Moist Shrub-Tundra		Ice-wedge polygons		Deciduous dwarf shrub-graminoid	*Salix arctica* – dominated	
V. Grass mesic Meadow			Willow-lichen meadow		*Salix arctica* – grass	
VI. Shrub Heath Tundra (*Dryas*)	*Dryas* Barrens	Cushion plant-lichen/moss	Polar desert	Dwarf shrub-cushion plant	*Dryas integrifolia* – dominated	*Dryas*–sedge meadow, *Dryas–Salix* tundra
VII. Shrub Heath Tundra (*Cassiope*)		Dwarf shrub heath-moss		Dwarf shrub-cushion plant		
VIII. Shrub Heath Tundra (*Vaccinium*)	Heath-Herb Tundra					
IX. Shrub-Forb Tundra (a-Scree slopes)[2]	*Saxifraga – Papaver* Barrens	Unvegetated scree slopes	Ridge	Herb-dominated	Herb barrens	Scree

[1] From Gauthier *et al*. 1995
[2] Only the first plant community (a) of this type can be compared to other studies. The second plant community (b) has a large cover of legumes which are absent in the other oases since they are North of Lancaster Sound.

4.2 Vegetation classification

Wetlands, mountains and beaches as well as *Vaccinium* dominated vegetation (Shrub Heath Tundra (*Vaccinium*)) were fairly easy to distinguish in the classification because of their characteristic species composition and environmental features, making them very different from the other vegetation types. The other six types were more difficult to classify. In the DCA diagram, Moist Meadow, Grass Mesic Meadow, Shrub Heath-Tundra (*Dryas*) and Shrub Heath-

Tundra (*Cassiope*) (types III, V, VI and VII) were the types that most overlapped mainly because of their similar species composition. However, these types were separated in the CCA analysis because of their different environmental characteristics. Inversely, Graminoid Moist Meadow (type II) and Moist Shrub-Tundra (type IV), which shared similar environmental features and a few vascular plant species, overlapped in the CCA biplot with other vegetation types. However, because of their different species composition when compared to other vegetation types, these two types were separated in the DCA analysis (included all types except wetlands and beaches).

Despite some overlapping, vegetation types were well defined in general with the DCA and CCA analyses. Moreover, compared to the preliminary analyses (Duclos *et al*. 2003), no vegetation type sharing most of its species composition with other types was produced.

4.3 Vegetation distribution

As in many other arctic locations, topography (Thompson 1980, Miller and Alpert 1984) and soil characteristics (Sheard and Geale 1983a, Bergeron and Svoboda 1989, Batten and Svoboda 1994, Muc *et al*. 1994a) explained a large proportion of the plant community distribution in Sirmilik National Park. Topography mostly affects moisture availability and disturbance regime (Webber 1978, Thompson 1980, Washburn 1980, Miller and Alpert 1984). In return, moisture strongly influences shifts in plant communities in the Arctic (*e.g.* Reznicek and Svoboda 1982, Sheard and Geale 1983a, Bliss *et al*. 1984, Bergeron and Svoboda 1989, Batten and Svoboda 1994). Although moisture was not measured in the field, slope is a good surrogate variable indicative of drainage conditions. Slope was retained in both ordination analyses but has a stronger effect on the distribution of the vegetation in the first ordination. In this first ordination, vegetation types were sorted along a moisture gradient where Graminoid Wet Meadow (wetlands; type I), the first community of Shrub Heath Tundra (*Vaccinium*; type VIII.a.) and Shrub-Forb Tundra (mountains; type IX) represent the extremes of this gradient. From flat habitats to steeper slopes, we observe a decrease in the cover of graminoids and mosses and an increase in the cover of dwarf-shrubs. High cover of mosses on flat terrain at low elevation can be attributed to the persistence of the snow cover in spring and to the supply in melt water from neighbouring slopes in early summer.

Soil characteristics also greatly influence the distribution of vegetation in the Arctic. In addition to high drainage (associated to steep slope and generally greater active layer depth), weak soil development and soil instability partly explained the low abundance of vegetation in the first plant communities of Shrub-Forb Tundra (referred to as ‘scree slopes’ or *Salix arctica – Astragalus alpinus* / Forb Sparse Vegetation) where many pioneer species grow. Similarly, high drainage and instability of the sandy soil of the Graminoid Barren (beaches) could explain its low plant biomass. Weak soil development, as indicated by the high cover and frequency of rocks, stones and gravels, also seems to influence the development of Grass Mesic Meadow (type V) and Shrub Heath-Tundra (*Vaccinium*; type VIII). Although not described, the type of bedrock could have favoured the growth of these vegetation types. Finally, as observed in last year’s analyses (Duclos *et al*. 2003), eolian deposits promoted the development of wetland vegetation and have influenced the formation of polygonal structures. Alternating layers of organic matter and sand contributed to the weak soil drainage favouring the establishment of hydric to moist species and the formation of these polygonal structures (Zoltai *et al*. 1983, Klassen 1993).

Exposition is another key factor associated to the topography influencing plant distribution in our study area. Vegetation dominated by *Vaccinium* (Shrub Heath-Tundra; type VIII) or growing on mountain slopes (Shrub-Forb Tundra; type IX) are greatly influenced by the exposition as shown in the first ordination. As for Shrub-Forb Tundra, many species reach their highest cover on slopes facing South, West and East such as *Salix arctica*, both species of legumes, *Polygonum viviparum*, *Poa arctica*, *Festuca brachyphylla* and many other species of forbs. Other plant species are typical of these sunny-dry habitats: *Poa glauca*, *Erigeron eriocephalus*, *Arnica alpina* ssp. *angustifolia*, *Potentilla nivea*, *Saxifraga tricuspidata* and *Erysimum pallasii* (Porsild 1957). As for Shrub Heath-Tundra (*Vaccinium*; type VIII), the legume *Oxytropis maydelliana* reaches a high cover whereas *Hierochloë alpina*, *Carex rupestris, Ledum decumbens* and *Empetrum nigrum* are typical of sunny-dry habitats. Being exposed to higher solar radiations, these slopes have higher air and soil temperatures (Reznicek and Svoboda 1982, Muc *et al*. 1994b) which stimulates the growth of some plant species and favours the activity of soil organisms essential to nutrient cycling. Those solar radiations could also be very important for the growth and maturation of *Vaccinium uliginosum* berries. Moreover, these habitats have a longer growing season being first to be snow free in spring because of lower snow accumulation (steep slopes and wind exposition) and exposition to the sun. The formation of gelifluction lobes and undulating patterns on these slopes gives evidence of high soil temperature which causes the sliding of the active layer. However, all these factors (higher temperatures and stimulation of growth) also contribute to a higher rate of evapotranspiration that reduces the moisture available in those habitats.

Altitude is another environmental variable that can influence the distribution of vegetation, and this, independently of its correlation with slope angle. Sites at high altitude are exposed to dominant winds. These strong winds decrease the availability of moisture and the temperature at the soil level during the summer while in winter, the unprotected vegetation may be damaged (Reznicek and Svoboda 1982). In our study, vegetation most exposed to dominant winds was Grass Mesic Meadow (*Luzula nivalis* Herbaceous Alliance; 428m alt.) and Shrub Heath-Tundra (Type VI - *Dryas integrifolia* Dwarf-Shrubland Alliance; 230m altitude). Communities with *Alopecurus alpinus, Luzula nivalis* and/or *Saxifraga oppositifolia* being the dominant or co-dominant vascular species are typical of polar desert or xeric conditions (Sheard and Geale 1983b, Bliss and Svoboda 1984, Bliss *et al*. 1984). Similarly, *Dryas integrifolia*, which dominate in Shrub Heath-Tundra (*Dryas*; type VI), is also well adapted to harsh environmental conditions (Reznicek and Svoboda 1982, Bliss 1997). Vegetation dominated by *D. integrifolia* commonly develops on well-drained gravel sites with shallow and sporadic snow cover in winter, such as raised beach ridges and wind-exposed slopes (Svoboda 1977, Reznicek and Svoboda 1982, Sheard and Geale 1983b, Bergeron 1988). All these three species, *A. alpinus*, *S. oppositifolia*, *D. integrifolia* are well adapted to temperature extremes and to relatively dry sites with less persistent snow-cover. The presence of specific species of *Carex* (such as *C. misandra* and *C. rupestris*) and of patterned ground such as stripes, nets and mud-boils give evidence of the harsh environmental conditions on those sites.

4.4 Vegetation mapping

The vegetation mapping using a neural network produced a map which shows a high spatial diversity of eight vegetation covers identified by the Twinspan classication. While five of the vegetation classes match the test sites with over 80% of the sites, three classes have lower class accuracy (Moist Meadows, 67.2%; Shrub Heath-Tundra, Cassiope, 57.9%; and Moist Shrub Tundra, 29.2%). Those three classes were distinguished at the 4th level of division of the Twinspan analysis (Figure 7). The two Moist Tundra Types (Moist Meadows and Moist Shrub Tundra) were mostly distinguished by the relative abundance of the grass *Arctagrostis latifolia* and the shrub *Salix arctica*, they form a continuum and can be found on a range of altitude which reduces again the ability to distinguish them by spectral classification of satellite images. Changes in hydrological conditions, plant density and background explain part of the results.

The use of Landsat TM imagery to which we applied a correction for solar incidence angle variations helped to control some of the spectral variability related to incoming radiation but also helped to separate the spatial distribution and related spectral response of the eight vegetation classes. Furthermore, the inclusion of a specific NDVI image in the Neural Net (NN) classification, permitted to enhance the importance of the background in the overall vegetation signal. This background spectral response was identified using the texture analysis which also focuses on the spatial organisation of the spectral signal. The three basic parameters, topography, spectral signal and spatial patterns, all are fundamental vegetation distribution parameters as was stated earlier. In addition, the use of these specific image parameters in the automated classification was important because specific vegetation spectral response was too "weak" to be able to apply to the overall park. In other words, it was impossible to establish specific spectral signatures for the vegetation classes over the park. The effect of topography and the background in the spectral response is very important. This is even more important because a good number of the vegetation classes are grouped in certain areas of SNP. To export a spectral signal of a specific class without "controlling" the "secondary" parameters, like topography, background spectral and spatial patterns, would have produced some classification confusion. As was pointed out in the 2003 preliminary report (Duclos *et al*. 2003). The importance of these secondary parameters also justified the generation of a neural network.

5 CONCLUSIONS AND RECOMMANDATIONS

The results obtained in this study fulfil the Phase 2 of the vegetation characterisation and mapping project of Sirmilik National Park using satellite imagery. Below are conclusions and recommandations for the vegetation sampling, mapping and environmental monitoring.

5.1 Vegetation sampling

After classification analyses of the vegetation sampled in the field, ten vegetation types and eighteen plant communities were characterised, reflecting moisture and disturbance gradients. According to a direct gradient analysis, topography (slope, altitude, exposition) and soil characteristics (cover of gravels, stones, rocks, litter and bare ground) influenced most the abundance and distribution of the vegetation. We are confident that for the sites sampled, the types and communities are well defined based on floristic and environmental characteristics because no group with high confusion or overlapping with other types have been created.

However, because the team was composed in part of people inexperienced in mapping, vegetation characterisation and/or arctic plant identification, it was difficult to adequately trained all those people for the field work, mostly because of logistic issues. Consequently, some plant identification might be erroneous. Also, descriptive information about vegetation types and plant communities are generally laking (*e.g.* description of the environmental setting in which the type or community occurs: exposed slopes, raised beaches, seepage slopes…). As a result, some descriptions of vegetation types or communities are incomplete.

As some areas of Bylot Island and Baffin Island have not been sampled yet, or have been undersampled (*e.g.* wetlands, elevated plateaux with low vegetation cover, seashore, moraines), new species or plant communities can most likely be discovered.

5.2 Vegetation mapping

Using fine spatial resolution satellite images and digital image analysis techniques to produce a vegetation map requires that we apply *a priori* controls. First, special attention must be given to the sampling sites. In many cases, the environment will control not only the plant species distribution but also the spectral measurement at the sensor. When doing the vegetation sampling, a special attention should be given in identifying the environmental parameters (relief, substrate, soil and plant moisture). Also great care must be given in the plant density and cover data. A surface with low plant density over a specific area does not make a very good data point for the image classification. For the classification of SNP we took *a priori* information like topography and texture to control the relief, subtrate and plant density parameters in the selection of the sampling plots. However, when proceeding with the vegetation classification, a further grouping of the vegetation plots into vegetation type and environmental controls will improve the accuracy of the vegetation map and this especially for vegetation types which have strong intraclass variance (many outliers). In any case, outliers should be removed. Certain specific geomorphological parameters (i.e. concave/convexe surfaces, soil grain size, slope angle/aspect,…) could be included in the vegetation classification in order to establish the grouping. Or at the least, the environmental parameters which characterise each sampling plot should be an integrated part of the training samples for the spectral image classification.

5.3 Suggestions for futur work to enhance the vegetation description and mapping

We strongly recommand that wetlands on Borden Peninsula be sampled because this type has only been sampled on Bylot Island. Moreover, as noted in Table 24, no wetland dominated by *Carex* spp. has been yet described floristically as a community in Sirmilik National Park. This type could be found either on Borden Peninsula and/or on Bylot Island. A great concentration of wetlands has developed in the area of Mala River so we recommand that this area should be sampled. We also suggest that some parts of the Park should be sampled (or further sampled):
- Eastern valleys of Bylot Island (not sampled yet);
- Oliver Sound;
- North and West part of Borden Peninsula.

Further field sampling should include areas where vegetation has not been classified by the images because of confusion, shadows or cloud cover. We recommand that in any new vegetation mapping effort at least one member of the field team should have a geographical training (geomorphology, GIS and remote sensing) to improve the quality and efficiency of data collection and interpretation. Better knowledge of the field would have helped the remote sensing analysis and inversely vegetation sampling would be benefited by geographical expertise.

Finally, the current mapping exercise was not associated with a posteriori ground truthing. It certainly would be very valuable to sample a large number of points, scattered throughout the Park (to compensate for the Bylot biais in the current analysis). Rapid visual evaluation of the vegetation type and general geomorphological caracteristics would allow to validate further the classification. Such a validation would reveal the strength and weakenesses of the image classification.

5.4 Environmental monitoring

The work accomplished in this project should contribute to the environmental monitoring of SNP. First, the images (vegetation map, NDVI and orthophotos) can be used as reference for futur analysis of change. In the future it would be possible to analyse new satellite images with the same approach and compare the level of change.

In addition, for a more direct measurement of change, the permanent plots established throughout the Park should be revisited periodically. We recommnand that an interval of 5 (2008) or 10 years (2013) should be envisionned for this monitoring. The protocols followed both in the field and for analyses should be used as a guide for futur studies. Changes in vegetation cover and/or diversity as well as changes in surface erosion, stability or other could be monitored and contribute to an evaluation of the impact of Park’s activities and environmental change on the ecological integrity of the Park.

Finally it would be important to consider establishing more permanent plots especially in sensitive areas of the Park (*e.g.* areas heavily used by visitors and/or animals, areas with unique caracteristics some stable and some less stable vegetation types).

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Appendix 1: Vascular plant list of Sirmilik National Park completed after the field work of 2002 and 2003 and from the work of Drury (1962), Zoltai *et al*. (1983), Hughes (1992) and Duclos (2002). Nomenclature follows Porsild (1957) and Porsild and Cody (1980).

* : Species only surveyed by Zoltai *et al*. (1983), not yet surveyed on Bylot Island by Drury (1962), Hughes (1992), Duclos (2002) or during the field season of 2002 and 2003. Some of these species might be found on Baffin Island only (n=5).
** : Species only surveyed by Drury (1962; n=3).
*** : Added after field survey 2002 (n=6).
**** : Added after field survey 2003(n=2).
N.B. Species list was compiled from mention based on field observations presented as species list by various authors. Confirmation using voucher specimen was not ascertained.

Taxa: 153
Genera: 72
Families: 27

POLYPODIACEAE (3)

Cystopteris fragilis (L.) Bernh. *
Dryopteris fragrans (L.) Schott.
Woodsia glabella R. Br. *

EQUISETACEAE (2)

Equisetum arvense L.
Equisetum variegatum Schleich.

LYCOPODIACEAE (1)

Lycopodium selago L.

GRAMINEAE (23)

Alopecurus alpinus J.E. Smith
Arctagrostis latifolia (R. Br.) Griseb.
Calamagrostis purpurascens R. Br. ****
Deschampsia brevifolia R. Br.
Deschampsia pumila (Trin.) Ostf.
Dupontia fisheri R. Br.
Elymus arenarius ssp. mollis (Trin.) Hultén
Festuca baffinensis Polunin
Festuca brachyphylla Schultes
Hierochloe alpina (Sw.) R. & S.
Hierochloe pauciflora R. Br.
Phippsia algida (Soland.) R. Br.
Pleuropogon sabinei R. Br.
Poa abbreviata R. Br.
Poa alpigena (Fr.) Lindm.

Poa arctica R. Br. var. *vivipara* Hook. (misidentified by Duclos (2002) as *Poa alpigena var. colpodea* (Fr.) Schol.)
Poa alpina L. **
Poa arctica R. Br.
Poa glauca M. Vahl
Poa Hartzii Gandoger var. *vivipara* Polunin **
Puccinellia langeana (Berl.) Th. Sør.
Puccinellia vahliana (Lieb.) Scribn. & Merr.
Trisetum spicatum (L.) Richt.

CYPERACEAE (22)

Carex amblyorhyncha Krecz.
Carex aquatilis Wahlenb. var. *stans* (Drej.) Boott
Carex atrofusca Schk.
Carex bigelowii Torr.
Carex glacialis Mack.
Carex maritima Gunn.
Carex membranacea Hook.
Carex misandra R. Br.
Carex nardina Fr.
Carex obtusata Liljeb. ****
Carex rupestris All.
Carex scirpoidea Michx.
Carex subspathacea Wormskj.
Carex ursina Dew.
Eriophorum angustifolium Honck.
Eriophorum callitrix Cham.
Eriophorum russeolum Fr. var. *albidum* Nyl. ***
Eriophorum scheuchzeri Hoppe
Eriophorum triste (Th. Fr.) Hadac & Löve
Eriophorum vaginatum L. ssp. spissum (Fern.) Hult.
Kobresia myosuroides (Vill.) Fiori & Paol.
Kobresia simpliciuscula (Wahlenb.) Mack. ***

JUNCACEAE (5)

Juncus albescens (Lange) Fern.
Juncus biglumis L.
Juncus castaneus Smith
Luzula confusa Lindebl.
Luzula nivalis (Laest.) Beurl.

LILIACEAE (1)

Tofieldia coccinea Richards.

SALICACEAE (5)

Salix arctica Pall. *s. lat*.

Salix herbacea L.
Salix lanata L.
Salix reticulata L.
Salix Richardsonii Hook. var. *McKeandii* Polunin **

POLYGONACEAE (3)

Koenigia islandica L. ***
Oxyria digyna (L.) Hill
Polygonum viviparum L.

CARYOPHYLLACEAE (18)

Arenaria humifusa **
Cerastium alpinum L. *s. lat.*
Cerastium arcticum Lange *s.l.*
Cerastium beeringianum Cham. & Schlecht. ***
Cerastium regelii Ostf.
Honckenya peploides (L.) Ehrh. (includes *Arenaria peploides* of Drury 1962)
Melandrium affine J. Vahl (includes *Lychnis* affinis of Drury 1962)
Melandrium apetalum (L.) Fenzl ssp. *arcticum* (Fr.) Hult.
Melandrium triflorum (R. Br.) J. Vahl
Minuartia biflora (L.) Schinzl. & Thell.
Minuartia rossii (R. Br.) House ***
Minuartia rubella (Wahlenb.) Hiern.
Minuartia stricta (Sw.) Hiern.
Sagina caespitosa (J. Vahl) Lange
Sagina intermedia Fenzl
Silene acaulis L. Jacq.
Stellaria longipes Goldie *s. lat.*
Stellaria humifusa Rottb.

RANUNCULACEAE (5)

Ranunculus hyperboreus Rottb.
Ranunculus nivalis L.
Ranunculus pedatifidus Sm. var. *leiocarpus* (Trautv.) Fern.
Ranunculus sabinei R. Br.
Ranunculus sulphureus Sol.

PAPAVERACEAE (1)

Papaver radicatum Rottb. *s. lat.*

CRUCIFERAE (15)

Arabis arenicola (Richardson) Gelert var. *pubescens* (Wats.) Gelert **
Braya purpurascens (R. Br.) Bunge
Cardamine belidifolia L.
Cardamine pratensis L. var. *angustifolia* Hook.
Cochlearia officinalis L.

Draba alpina L.
Draba cinerea Adams
Draba corymbosa R. Br.
Draba glabella Pursh

Draba lactea Adams

Draba nivalis Liljebl.
Draba subcapitata Simm.
Erysimum pallasii (Pursh) Fern.
Eutrema edwardsii R. Br.
Lesquerella arctica (Wormskj.) S. Wats.

SAXIFRAGACEAE (12)

Chrysoplenium tetandrum (Lund) Fries
Saxifraga caespitosa L. *s. lat.*
Saxifraga cernua L.
Saxifraga flagellaris Willd.
Saxifraga foliolosa R. Br.
Saxifraga hieracifolia Waldst. & Kit.
Saxifraga hirculus L.
Saxifraga nivalis L.
Saxifraga oppositifolia L.
Saxifraga rivularis L. *s. lat.*
Saxifraga tenuis (Wahlenb.) H. Sm.
Saxifraga tricuspidata Rottb.

ROSACEAE (5)

Dryas integrifolia M. Vahl
Potentilla hyparctica Malte
Potentilla nivea L. *s. lat*.
Potentilla rubricaulis Lehm.
Potentilla vahliana Lehm.

LEGUMINOSAE (3)

Astragalus alpinus L.
Oxytropis arctobia Bunge
Oxytropis maydelliana Trautv.

EMPETRACEAE (1)

Empetrum nigrum L.

ONAGRACEAE (2)

Epilobium arcticum Samuelss.
Epilobium latifolium L.

HALORAGACEAE (1)

Hippuris vulgaris L. *

PYROLACEAE (1)

Pyrola grandiflora Radius

ERICACEAE (4)

Cassiope tetragona (L.) D. Don
Ledum decumbens (Ait.) Lodd.
Rhododendron lapponicum (L.) Wahlenb.
Vaccinium uliginosum L. *s. lat*.

PRIMULACEAE (1)

Androsace septentrionalis L.

PLUMBAGINACEAE (1)

Armeria maritima (Mill.) Willd. ssp. *labradorica* (Wallr.) Hult.

BORAGINACEAE (1)

Mertensia maritima (L.) S.F. Gray

SCROPHULARIACEAE (6)

Pedicularis arctica R. Br.
Pedicularis capitata Adams
Pedicularis hirsuta L.
Pedicularis lanata Cham. & Schlecht.
Pedicularis sudetica Willd.
Pedicularis sudetica Willd. f. *alba* Cody **

CAMPANULACEAE (1)

Campanula uniflora L. *

COMPOSITAE (10)

Antennaria ekmaniana Porsild
Arnica alpina (L.) Olin ssp. *angustifolia* (J. Vahl) Maguire
Chrysanthemum integrifolium Richards
Crepis nana Richards. *
Erigeron compositus Pursh
Erigeron eriocephalus J. Vahl
Erigeron humilis Grah.
Senecio congestus (R. Br.) DC.
Taraxacum lacerum Greene
Taraxacum phymatocarpum J. Vahl. s. lat.*****

***** *Taraxacum phymatocarpum* : includes *T. alaskanum, T. hyparcticum, T. arcticum, T. lateritium, T. mackenziense* and *T. pumilum* (pers. comm. Laurie L. Consaul, Canadian Museum of Nature)

Appendix 2: Example of the sampling data sheets used during field sampling of Sirmilik National Park. The first datasheet was used to record vegetation caracteristics (cover, diversity). The second datasheet was used for environmental parameters. N.B. In order to use such data forms they should be slightly enlarged to allow more room to write.

Plot no. : Sampled by:

Date:

Species	Cover class	Species	Cover class
		Moss stratum	
		Lichen stratum	
		Cryptogamic crust	
		Litter	
		Bare Ground	
		Rocks (total)	
		<8 cm: gravel/ 8-25 cm: stone/ >25 cm: rock	
		Water	

Stratum	Cover class
Shrub	
Graminoid	
Forb	
Herb (Graminoid + Forb)	
Cryptogam (moss + lichen)	
Cryptogam (moss + lichen +crust)	

Herbivores	Occurrence
Grazing marks	
-leaves	
-inflo	
-grubbing	
Old goose faeces	
Fresh goose faeces	
Lemming	
Ptarmigan	
Hare	
Caribou	
Other	

Permanent Plot:

Yes

No

Plot no. (50 x 50m)	**Location (GPS)**			% cover Vegetation
	Lat.	Long.		

Date	**Slope (°)**	**Aspect (°)**	**Elevation (m)**	% cover Water	% cover Bare soil

Macro-Topography	**Micro-Topography or Periglacial forms**
Beach	No pattern (flat)
Terrace	Hummocky
Plateau	Mud-boils
Valley bottom	Solifluction/Gelifluction (lobes)
Lower slope	Sorted nets
Mid-slope	Sorted stripes
Upper slope	Large polygons
Crest	Small polygons
Delta	Cracks (frost fissures)
Alluvial fan	Undulating
Floodplain	Surface runoff
Ridge summit	

STONINESS -% of surface covered (fragments >15 cm)

		Distance between stones
Nonstony	< 0.01%	> 30m
Slightly stony	0.01- 0.1%	10 to 30m
Moderately stony	0.1 - 3%	2 to 10m
Very stony	3.0 - 15%	1 to 2m
Exceedingly stony	15 - 50%	0.1m to 0.5m
Excessively stony	> 50%	< 0.1 m

ROCKINESS -% occupied by bedrock

		Distance
Nonrocky	< 2%	> 75m
Slightly rocky	2-10%	25 to 75m
Moderately rocky	10-20%	10 to 25m
Very rocky	20-50%	2 to 10m
Exceedingly rocky	50-90%	< 2m
Excessively rocky	> 90%	

Herbivores		**Moisture Index**
Grazing marks	Lemming	Wet
-leaves	Ptarmigan	Wet-Mesic
-inflorescences	Hare	Mesic
-grubbing	Caribou	Mesic-Dry
Old goose faeces	Other	Dry
Fresh goose faeces		

Picture
roll no. :
slide no. :

NOTES:
A- % cover of dominant rock type:
B- % cover of dominant plant type:
C- % cover of dominant ground cover:
D- Colour of dominant plants:
E- # of goose faeces in transect #1:
F- # of goose faeces in transect #2:

Appendix 3: Example of Neural Net training output. Complete output (>200 pp) is available in PDF format of Appendices.

```
NNTRAIN Neural Network Training                 V8.2 EASI/PACE  10:01
07Jun2004

                            Normalized Total Error
 Iteration 0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   count    +----+----+----+----+----+----+----+----+----+----+
            |                                                        1.5662205
            |                                                        1.3833629
            |                                                        1.1422421
            |                                                        1.0472262
            |                                                        1.0390851
            |                                                        1.0346453
            |                                                        1.0261592
            |                                                        1.0127299
            |                                                        1.0105048
          10|                                                *       0.9932159
            |                                                *       0.9804347
            |                                               *        0.9715856
            |                                               *        0.9635860
            |                                              *         0.9541739
            |                                             *          0.9352498
            |                                             *          0.9260456
            |                                            *           0.9132617
            |                                            *           0.9036267
            |                                           *            0.8959640
          20|                                          *             0.8779410
            |                                          *             0.8744842
            |                                         *              0.8562183
            |                                         *              0.8519693
            |                                         *              0.8441402
            |                                        *               0.8323177
            |                                        *               0.8212687
            |                                       *                0.8055542
            |                                       *                0.8018164
            |                                      *                 0.7929659
          30|                                      *                 0.7804447
            |                                     *                  0.7622742
            |                                    *                   0.7560175
            |                                    *                   0.7435803
            |                                   *                    0.7378286
            |                                   *                    0.7300560
            |                                  *                     0.7162875
            |                                  *                     0.7060642
            |                                 *                      0.6914406
            |                                 *                      0.6874647
          40|                                *                       0.6767609
            |                                *                       0.6635869
            |                               *                        0.6598391
            |                               *                        0.6426914
            |                              *                         0.6352085
            |                              *                         0.6301924
            |                             *                          0.6152532
            |                             *                          0.6117201
```

```
    |                            *                           0.5956516
    |                            *                           0.5887418
  50|                            *                           0.5859235
    |                           *                            0.5739414
    |                           *                            0.5680004
    |                          *                             0.5547364
    |                          *                             0.5525758
    |                          *                             0.5454867
    |                         *                              0.5329138
    |                         *                              0.5346267
    |                         *                              0.5214433
    |                        *                               0.5175723
  60|                        *                               0.5066596
    |                       *                                0.4960999
    |                       *                                0.4975034
    |                       *                                0.4870295
    |                       *                                0.4889975
    |                      *                                 0.4765832
    |                      *                                 0.4703095
    |                      *                                 0.4697156
    |                      *                                 0.4628237
    |                     *                                  0.4560412
  70|                     *                                  0.4518375
    |                     *                                  0.4440019
    |                     *                                  0.4459942
    |                    *                                   0.4311861
    |                    *                                   0.4290601
    |                    *                                   0.4271440
    |                   *                                    0.4194751
    |                   *                                    0.4167260
    |                   *                                    0.4039233
    |                   *                                    0.4107915
  80|                  *                                     0.3980622
    |                  *                                     0.3959034
    |                  *                                     0.3905047
    |                  *                                     0.3827084
    |                  *                                     0.3817276
    |                 *                                      0.3796595
    |                 *                                      0.3750705
    |                 *                                      0.3675488
    |                 *                                      0.3665135
    |                 *                                      0.3605238
  90|                *                                       0.3537233
    |                *                                       0.3577018
    |                *                                       0.3480736
    |                *                                       0.3439146
    |                *                                       0.3425867
    |               *                                        0.3367288
    |               *                                        0.3377782
    |               *                                        0.3318335
    |               *                                        0.3251701
    |               *                                        0.3266375
 100|              *                                         0.3194653
    |              *                                         0.3180776
    |              *                                         0.3138776
```

Appendix 4: Example of environmental data file. Complete list available in PDF format of Appendices. Alt: altitude m a.s.l.; Slope: slope angle in degree; X and Y variables calculated to take into account slope angle and slope aspect (see methods); various ground cover in percent; Lat.: Latitude; Long.: Longitude. If the plot was marked as permanent plot, the appropriate number, if different from plot number is specified.

Plot	Alt. (m)	Slope (°)	X	Y	Litter (%)	Bareground (%)	Gravel (%)	Stone (%)	Rock (%)	Lat. (°N)	Long. (°W)	Date of sampling	Permanent Plot
BE-1004	541	3	-0,01	-0,05	7,5	0	7,5	0	0	72,87	80,90	July 27, 2003	
BE-1005	516	7	0,08	0,09	7,5	0	17,5	0,5	0	72,87	80,88	July 27, 2003	
BE-1006	549	4	0,02	0,07	0,5	3	62,5	0,5	0	72,87	80,89	July 27, 2003	
BE-1012	494	7	-0,04	0,12	7,5	0,5	3	0	0	72,86	80,83	July 28, 2003	
BE-1015	411	3	-0,01	0,05	0,5	0,5	0	0,5	0	72,86	80,80	July 28, 2003	
BE-1016	464	6	0,06	0,08	3	0	0	0	0	72,86	80,82	July 28, 2003	PP1016
BE-1144	536	9	-0,08	-0,13	3	0,5	7,5	3	0	72,87	81,70	July 27, 2003	PP003
BE-1164	266	12	0,21	0,03	0,5	7,5	7,5	7,5	3	72,84	80,67	August 9, 2003	
BE-1166	314	7	0,11	0,05	0,5	7,5	37,5	17,5	17,5	72,84	80,62	August 9, 2003	
BE-1169	350	13	0,17	0,14	0,5	17,5	37,5	17,5	17,5	72,84	80,59	August 9, 2003	
BE-1171	283	15	0,23	0,11	0,5	17,5	37,5	17,5	17,5	72,83	80,62	August 9, 2003	
BE-1177	301	2	0,03	0,02	0,5	0	0	0	0	72,85	80,56	August 9, 2003	
BE-1179	388	22	0,09	0,36	7,5	0,5	0	7,5	3	72,85	80,54	August 9, 2003	
BE-1180	513	14	-0,14	0,20	0,5	0	0	0,5	0	72,84	80,53	August 9, 2003	
BE-1200	548	7	-0,11	0,06	0,5	3	3	3	0	72,81	80,51	August 9, 2003	
BE-1203	480	21	0,29	-0,22	0,5	0	0	0	0,5	72,82	80,68	August 9, 2003	
BN-BARE1	182	5	-0,03	0,08	0,5	17,5	62,5	17,5	3	73,51	80,51	August 10, 2003	
BN-BARE2	135	3	-0,05	0,02	0	7,5	62,5	17,5	7,5	73,52	81,48	August 10, 2003	
BN-BARE3	178	2	-0,03	0,02	0	3	62,5	17,5	7,5	73,51	81,48	August 10, 2003	
BO-713	423	1	0,01	-0,01	0,5	0	3	7,5	0,5	73,07	80,88	August 15, 2003	
BORDEN01	110	3	-0,05	0,02	7,5	0,5	0	0,5	0	73,53	81,45	August 10, 2003	
BORDEN02	88	5	-0,06	0,06	17,5	0,5	0	0	0	73,55	81,42	August 10, 2003	
BS-1021	412	3	0,04	-0,04	0,5	3	17,5	17,5	0,5	72,87	80,79	August 21, 2003	
BS-123	415	12	-0,16	-0,13	0,5	0,5	7,5	7,5	0,5	72,90	78,55	August 3, 2003	
BS-124	407	12	0,04	-0,20	0,5	0	0,5	17,5	3	72,90	78,55	August 3, 2003	
BS-125	384	12	0,00	-0,21	0,5	0	0,5	0,5	0,5	72,90	78,53	August 2, 2003	
Cape Hay 01	208	1	0,00	0,02	0	0,5	62,5	7,5	0	73,75	80,36	July 17, 2003	
Cape Hay 02	214	1	0,00	0,02	0,2	0,2	62,5	0,5	0	73,75	80,36	July 17, 2003	
Cape Hay 03	204	1	0,01	-0,01	0,05	0,5	87,5	3	7,5	73,75	80,36	July 17, 2003	
Cape Hay 04	206	0,5	0,00	0,01	0	0,5	87,5	3	3	73,75	80,35	July 17, 2003	
PLAT-11	397	4	0,03	-0,06	7,5	0,2	0	0,5	0	72,89	78,72	July 21, 2003	
PLAT-12	409	4	0,05	0,05	3	0,2	0	0,5	0	72,89	78,73	July 21, 2003	
PLAT-13	422	5	0,08	-0,04	3	0,2	0	3	0	72,89	78,73	July 21, 2003	
PLAT-14	429	9	0,15	0,03	3	0,5	3	0,5	0,5	72,89	78,74	July 21, 2003	
PLAT-15	453	8	0,10	-0,09	3	0,2	3	3	3	72,89	78,75	July 21, 2003	
PLAT-17	357	4,5	0,05	-0,06	3	0,2	0,2	0,5	0	72,88	78,72	July 21, 2003	
PLAT-19	239	4	0,05	-0,04	3	0,2	3	0	0	72,88	78,70	July 21, 2003	
PLAT-20	278	5	0,04	-0,08	3	0,2	0	0,2	0	72,88	78,70	July 21, 2003	
PLAT-22	264	4	-0,03	-0,06	3	3	0	0	0,5	72,87	78,69	July 21, 2003	

Appendix 5: Example of vegetation data file. Complete list available in PDF format of Appendices. Species names in alphabetical order with Mosses, Lichens and Cryptogamic crust at the end; values in cells are mean percent cover for the site.

	Alopecurus alpinus	*Androsace septentrionalis*	*Antennaria ekmaniana*	*Arctagrostis latifolia*	*Armeria maritima*	*Arnica alpina ssp. angustifolia*	*Astragalus alpinus*	*Braya purpurascens*	*Calamagrostis purpurascens*	*Cardamine bellidifolia*	*Cardamine pratensis*	*Carex amblyorhyncha (C. marina)*	. . .	*Trisetum spicatum*	*Vaccinium uliginosum s. lat.*	Mosses	Lichens	Cryptogamic crust
BE-1004	37.5	0	0	0	0	0	0	0	0	0.2	0	0		0.05	0	37.5	37.5	37.5
BE-1005	3	0	0	0	0	0	0	0	0	0	0	0		0	0	37.5	37.5	37.5
BE-1006	3	0	0	0	0	0	0	0	0	0	0	0		0	0	17.5	7.5	17.5
BE-1012	3	0	0	0	0	0	0	0	0	0	0	0		0	0	37.5	3	37.5
BE-1015	0.5	0	0	0	0	0	0	0	0	0.2	0	0		0	0	0.5	7.5	87.5
BE-1016	62.5	0	0	0	0	0	0	0	0	0.05	0	0		0	0	62.5	17.5	3
BE-1144	0.2	0	0	0	0	0	0	0	0	0	0	0		0	0	17.5	7.5	37.5
BE-1164	0.5	0	0	7.5	0	0	0	0	0	0.5	0	0		0	0	62.5	7.5	62.5
BE-1166	0	0	0	0.2	0	0	0	0	0	0.5	0	0		0	0	17.5	0.5	62.5
BE-1169	3	0	0	0.5	0	0	0	0	0	0.5	0	0		0	0	17.5	0.5	37.5
BE-1171	0.05	0	0	0.5	0	0	0	0	0	0	0	0		0	0	3	0.5	17.5
BE-1177	62.5	0	0	0	0	0	0	0	0	0	0	0		0	0	87.5	7.5	7.5
BE-1179	17.5	0	0	0	0	0	0	0	0	0	0	0		0	0	87.5	7.5	3
BE-1180	17.5	0	0	0	0	0	0	0	0	0	0	0		0	0	87.5	3	0
BE-1200	7.5	0	0	0	0	0	0	0	0	0.2	0	0		0	0	37.5	3	17.5
BE-1203	7.5	0	0	0	0	0	0	0	0	0	0	0		0	0	62.5	17.5	7.5
BN-BARE1	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.5	7.5	37.5
BN-BARE2	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.5	3	7.5
BN-BARE3	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.5	0.5	0
BO-713	0.5	0	0	0.5	0	0	0	0	0	0	0	0		0	0	37.5	0.5	62.5
BORDEN01	0.5	0	0	3	0	0	0	0	0	0	0	0		0	0	37.5	3	7.5
BORDEN02	0	0	0	7.5	0	0	0	0	0	0	0	0		0	0	87.5	3	7.5
BS-1021	0.2	0	0	0.5	0	0	0	0	0	0.05	0	0		3	0	3	3	62.5
BS-123	0.05	0	0	0.5	0	0	0	0	0	0.05	0	0		0	0	17.5	3	62.5
BS-124	0.5	0	0	0.5	0	0	0	0	0	0	0	0		0	0	37.5	3	37.5
BS-125	3	0	0	0.5	0	0	0	0	0	0	0	0		0	0	37.5	3	37.5
CH01	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.5	0	37.5
CH02	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.5	0	37.5
CH03	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0.2	17.5
CH04	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.2	0.2	17.5
PLAT-11	3	0	0	0	0	0	0	0	0	0.2	0	0		0	0	62.5	7.5	37.5
PLAT-12	0.5	0	0	0.5	0	0	0	0	0	0	0	0		0	0	37.5	7.5	17.5
PLAT-13	3	0	0	3	0	0	0	0	0	0	0	0		0	0	37.5	17.5	7.5
PLAT-14	0.5	0	0	0	0	0	0	0	0	0	0	0		0	0	7.5	3	37.5
PLAT-15	7.5	0	0	3	0	0	0	0	0	0.2	0	0		0	0	3	0.5	37.5
PLAT-17	0.5	0	0	3	0	0	0	0	0	0	0	0		0	0	62.5	17.5	37.5
PLAT-19	0.5	0	0	3	0	0	0	0	0	0	0	0		0	0	17.5	3	37.5
PLAT-20	3	0	0	7.5	0	0	0	0	0	0	0	0		0	0	7.5	3	7.5

Appendix 6: Weather conditions of the Goose Camp valley area on Bylot Island (January 1995- July 20, 2001; data from Gilles Gauthier) and Pond Inlet, Baffin Island, Nunavut (January 1995- July 2001; from Environment Canada).

Goose Camp valley (Bylot Island)	J	F	M	A	M	J	J	A	S	O	N	D
Mean air temperature (°C)	-34.7	-34.9	-30.5	-19.5	-7.9	2.4	6.3	4.7	-1.1	-11.3	-19.8	-29.3
-Extreme minimum (°C)	-43.9	-44.5	-46.1	-33.4	-25.1	-6.5	2.2	-3.9	-13.2	-26.7	-35.2	-41.3
-Extreme maximum (°C)	-16.0	-15.0	-7.9	0.9	2.4	10.2	12.6	10.5	8.4	1.2	-3.7	-7.5
Mean soil temperature at 2 cm (°C)	-20.9	-23.9	-24.1	-21.0	-15.5	0.6	7.5	5.1	0.5	-2.6	-10.0	-16.5
Mean soil temperature at 10 cm (°C)	-20.6	-23.7	-23.8	-21.1	-16.2	-3.7	3.0	2.5	0.2	-1.9	-8.5	-15.4
Mean rainfall (mm)	.	.	.	.	.	21.3	35.0	26.4[1,2]	.	.	.	.
Minimum rainfall (mm)	.	.	.	.	.	0	16.5	8.5[1,2]	.	.	.	.
Maximum rainfall (mm)	.	.	.	.	.	41.8	55.1	69.6[1,2]	.	.	.	.

Pond Inlet (Baffin Island)	J	F	M	A	M	J	J	A	S	O	N	D
Mean air temperature (°C)	-33.2	-33.4	-29.1	-19.4	-8.9	2.3	7.1	4.8	-1.0	-9.7	-19.2	-27.4
-Extreme minimum (°C)	-45.5	-45.0	-41.5	-37.5	-27.5	-13.5	-5.5	-5.0	-15.0	-26.0	-42.0	-42.4
-Extreme maximum (°C)	-9.5	-9.5	-5.5	2.5	9.0	14.0	20.0	18.5	11.0	3.0	2.0	-4.5
Mean rainfall (mm)	0	0	0	0	0	18.0	23.3	39.1	1.77	0	1.83	0
Minimum rainfall (mm)	.	.	.	.	.	0.5	5	12	0	.	0	.
Maximum rainfall (mm)	.	.	.	.	.	43.2	43.4	85	6.6	.	11	.
Mean snowfall (cm)	7.9	6.4	9.5	17.2	17.7	2.4	0.7	5.5	12.9	29.3	23.3	12.6

[1] Does not include year 2002.
[2] Does not include end of August.

Appendix 7: Summary tables of the ordination analyses (DCA, CCA) performed on the vegetation dataset of Sirmilik National Park.

Summary of the DCA performed on 507 plots containing 134 taxa. All axes were significant.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues:	0.275	0.248	0.164	0.121	4.224
Lengths of gradient:	2.878	3.39	2.304	2.381	
Cumulative percentage variance					
of species data:	6.5	12.4	16.3	19.1	
Monte Carlo permutation test p value:	<0.05	<0.05	<0.05	<0.05	

Summary of the first CCA performed on 543 plots containing 141 taxa. All axes were significant.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues :	0.179	0.146	0.078	0.048	5.292
Species-environment correlations :	0.737	0.680	0.723	0.565	
Cumulative percentage variance					
of species data:	3.4	6.1	7.6	8.5	
of species-environment relation:	32.1	58.2	72.1	80.8	
Monte Carlo permutation test p value:	<0.05	<0.05	<0.05	<0.05	

Summary of the second CCA performed on 437 plots containing 125 taxa. All axes were significant.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues :	0.095	0.073	0.043	0.025	3.596
Species-environment correlations :	0.743	0.651	0.615	0.550	
Cumulative percentage variance					
of species data:	2.6	4.7	5.9	6.6	
of species-environment relation:	33.1	58.4	73.5	82.3	
Monte Carlo permutation test p value:	<0.05	<0.05	<0.05	<0.05	

Appendix 8: Illustration of dominant vegetation types from Sirmilik National Park.

Vegetation type I: Graminoid Wet Meadow

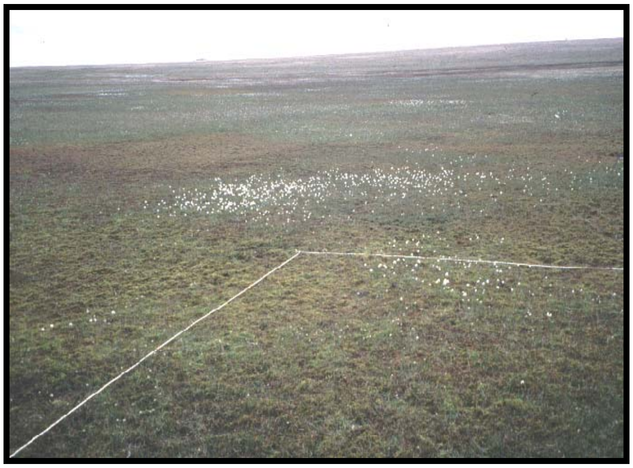
Characteristics

- Dominated by mosses and hydrophilic graminoids: *Dupontia fisheri*, *Eriophorum russeolum* var. *albidum*, *E. scheuchzeri* and *Carex aquatilis* var *stans.*

- On flat terrain, where polygons are formed on eolian deposits.

- Water table is at, or above, the soil surface during most of the growing season. Small lakes or ponds are common in this meadow type.

- Goose families intensively use this habitat during the brood rearing period because of the high availability of graminoids (high quality food) and of lakes and ponds acting as refuges.



Vegetation type II: Graminoid Moist Meadow

Characteristics

- Dominated by species specific to moist to mesic conditions (mostly Cyperaceae) such as *Eriophorum triste, Carex* spp. (*Carex misandra, Carex membranacea, Carex aquatilis* var *stans, Carex bigelowii*) and *Arctagrostis latifolia.*

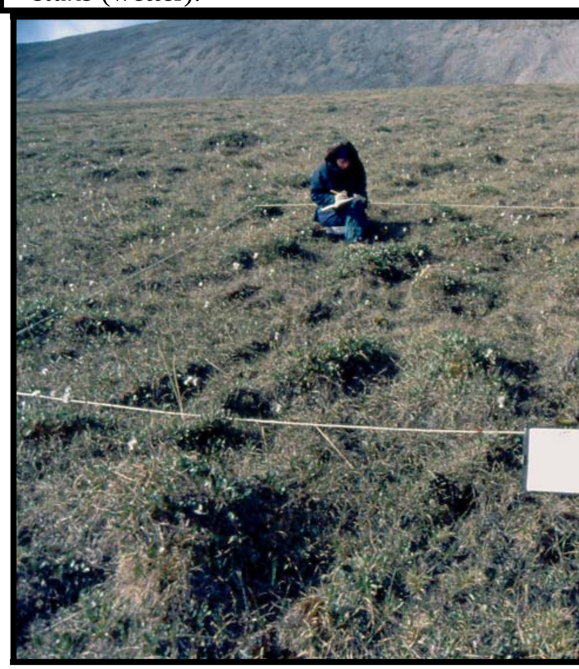
- Hummocks and flats form the dominant microtopography: Gravels and stones frequently noted.

- Variable altitudes (35-580 m; valley bottoms, terraces or plateaus) and slope angles (0-20°) but mostly on gentle slopes (mean: 5 ± 4°).

- Plant community “a”: *Eriophorum triste, Dryas integrifolia* and *Carex misandra* (dryer). Higher cover and frequency of gravels and stones than “b”.

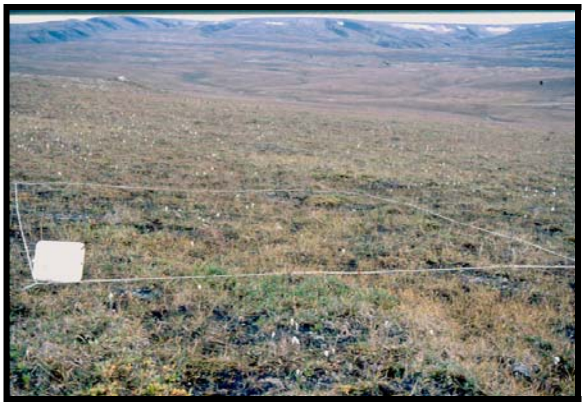
- Plant community “b”: *Carex membranacea, Eriophorum triste* and *Carex aquatilis* var. *stans* (wetter).

Plant community “a”



Plant community “b”

Vegetation type III: Moist Meadow



Plant community "a"

Plant community "b"

Characteristics

- Dominated by a mixture of Poaceae and Juncaceae adapted to mesic conditions such as *Arctagrostis latifolia*, *Luzula nivalis*, *Alopecurus alpinus*, *Eriophorum triste* and *Luzula confusa.*

- *Salix arctica*, *Cassiope tetragona* and *S. herbacea* form the shrub layer. Diversity of forbs is high in this type (50 species). High cover of mosses.

- Hummocks are the predominant microtopography. This type grows at a range of altitudes (15-615 m) on relatively flat terrain (mostly on terraces, also in valley bottoms).

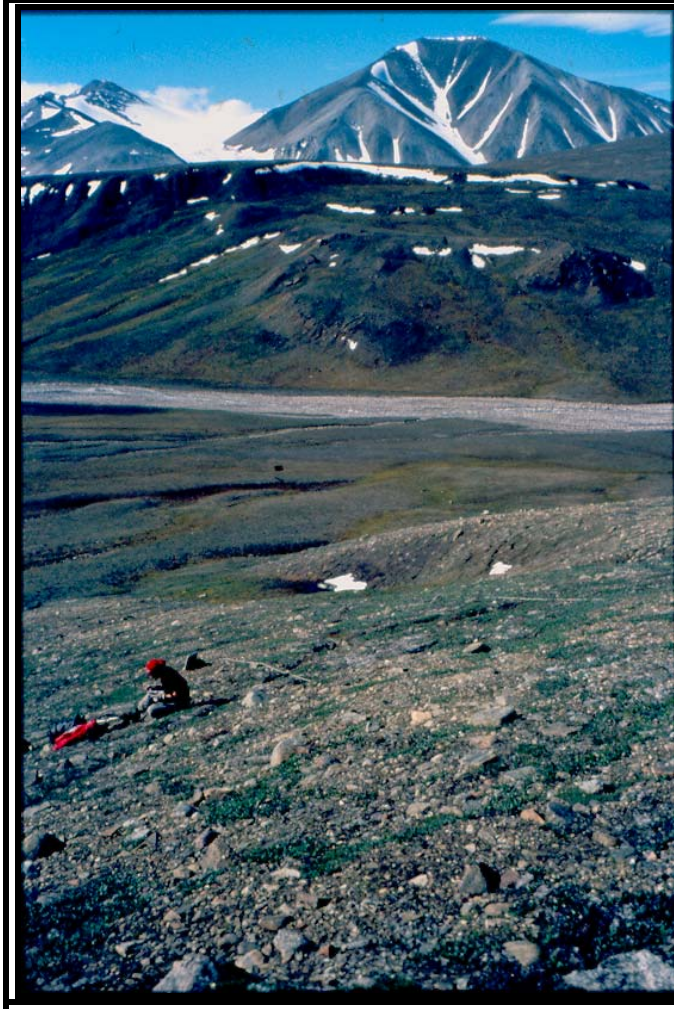
- Plant community "a": characteristic of meadows with its high cover of graminoids (58%, with *A. latifolia* and *L. nivalis* being the dominant ones). It grows at higher altitudes than "b" (250 vs 180 m).

- Plant community "b": higher cover of shrubs (37%) compared to graminoids (27%) which is more characteristic of shrub-tundra. This community has characteristics of both meadows and shrub-tundra.

Plant community "a"

Plant community "b"

Vegetation type IV: Moist Shrub-Tundra



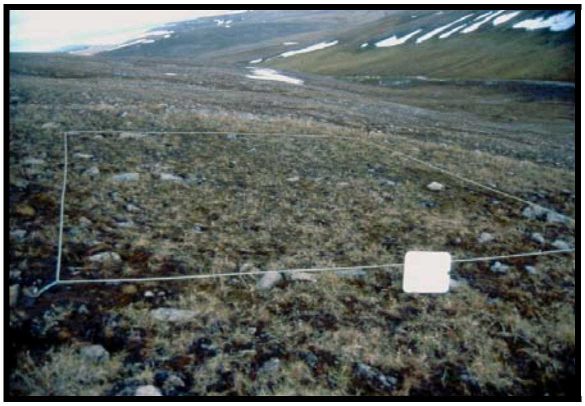
Characteristics

- Dominated by shrubs, mostly *Salix* spp. (mainly *Salix arctica* and *S. reticulata*) and *Dryas integrifolia* (cover of nearly 50%). The litter is abundant because of the *Salix* spp.

- This vegetation type is typical of drier, yet still moist, tundra with a decreasing cover of mosses and graminoids. High diversity of forbs (50 species) where the legumes (*Astragalus alpinus* and *Oxytropis maydelliana*) as well as *Polygonum viviparum*, *Saxifraga oppositifolia*, *Stellaria longipes* and *Draba* spp. are the most dominant and frequent forbs.

- Hummocks are the predominant microtopography and a few plots had mud-boils or large polygons. This type grows at a range of altitudes (20-490 m) on relatively flat terrain (mostly on terraces, also in valley bottoms) like the precedent type III- Moist Meadow.

Vegetation type V: Grass Mesic Meadow



Plant community "a"

Plant community "b"

Characteristics

- Dominated by *Luzula nivalis* and *Saxifraga oppositifolia*. The cover of forbs is particularly high in this meadow where is found the highest vascular plant species richness of all vegetation types (87 species). This meadow has also the lowest cover of graminoids and a low cover of dwarf-shrubs.

- This type is the driest of the meadows in this study with a moss cover of only 32%. Gravels, stones and rocks are frequent and often form stripes alternated with stripes of biological crust. Growing mostly on gentle slopes, this meadow develops on elevated plateaux or terraces.

- Plant community "a": characteristic of meadows with its high cover of graminoids (46%, with *A. alpinus* and *L. nivalis* being the dominant ones). Also high cover of mosses (41%) and biological crust (31%). It grows at higher altitudes than "b" (500m vs 370 m).

- Plant community "b": biological crust is the dominant life form with a cover of 35% followed by shrubs (25%) and mosses (24%). Graminoids only have a cover of 9.5% in this community. Twice the cover of gravels than "a" (20% vs 10%).

Plant community "a"

Plant community "b"

Vegetation type VI: Shrub Heath-Tundra (Dryas integrifolia)

Plant community "a"

Plant community "b"

Characteristics

- Dwarf-shrubs are by far the dominant life form (60% cover). The dominant shrub species are *Dryas integrifolia* followed by *Salix arctica, Cassiope tetragona* and *S. reticulata*.

- Mesic-xeric to xeric vegetation type with a cover of mosses drastically lower (17%). Presence of *Pedicularis lanata* is characteristic. Low cover of graminoids (7%).

- Mostly observed on exposed terraces or raised beaches at relatively high altitudes (230 ± 171 m). Gravels and stones are frequently noted. The microtopography is typically flat, hummocks or stripes.

- Plant community "a": biological crust is dominant with *D. integrifolia* as the dominant vascular plant species. Found at higher altitudes and steeper slopes (272 m and 7°) with a bare ground cover higher than "b". Stripe pattern frequent.

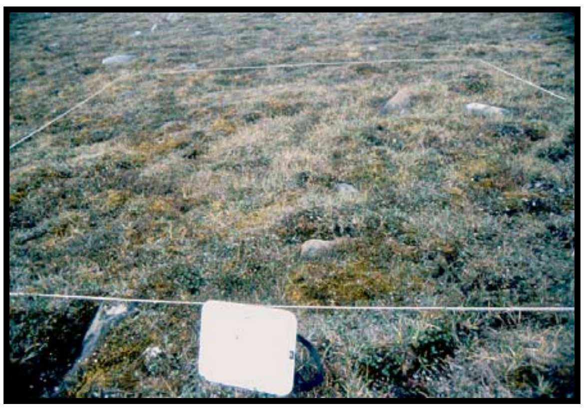
- Plant community "b": lichen is dominant followed by biological crust, D. *integrifolia* and C. *tetragona*. Found at lower altitudes and gentler slopes (88 m and 3°). Soil almost completely covered by vegetation.

Plant community "a"

Plant community "b"

Vegetation type VII: Shrub Heath-Tundra (Cassiope tetragona)

Plant community "a"



Plant community "b"

Characteristics

- Dominated by dwarf-shrubs and mosses (54% and 50% respectively). Ericaceous *Cassiope tetragona* and deciduous *Salix reticulata* are the most abundant shrubs. Typical presence of hummocks.

- Mesic to mesic-xeric vegetation type, with more soil moisture availability than type VI. Sampled at the bottom of slopes or on gentle slopes facing north at the edge of valley bottoms or on terraces where the snow cover persists at the beginning of the growing season. Found at moderate altitudes (166 ± 117 m.

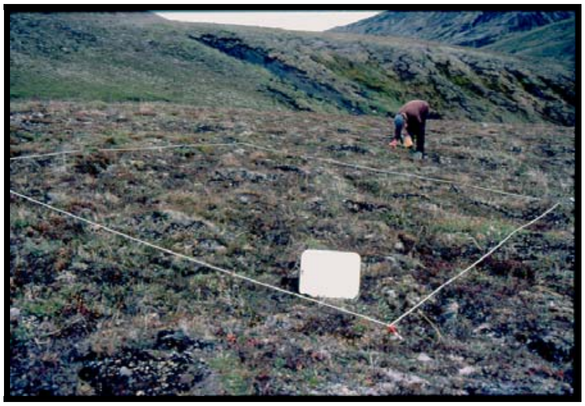
- Plant community "a": *C. tetragona* is the dominant shrub species, while *Luzula nivalis* and *L. confusa* are the most abundant graminoids. Higher cover of lichen compared to "b": (21% vs 9%).

- Plant community "b": *S. reticulata* and *C. tetragona* are the dominant shrubs while *Carex membranacea*, *C. misandra* and *Eriophorum triste* are the most abundant graminoids.

Plant community "a"

Plant community "b"

Vegetation type VIII: Shrub Heath-Tundra (Vaccinium uliginosum)



Plant community "a"

Plant community "b"

Characteristics

- This heath is the vegetation type with the highest cover of dwarf-shrubs (63%). Same shrub species composition than types VI and VII, except for the abundance of *Vaccinium uliginosum.* Other species characteristic to this heath: *Eriophorum vaginatum* ssp. *spissum*, *Hierochloë alpina* and *Saxifraga tricuspidata*.

- High cover of mosses and biological crust. Cover and frequency of rock especially high. High frequency of gravel and stone.

- Found at moderate altitude on moderate to steep slopes (10 ± 8°) and at the bottom of the slopes. Most of the plots were sampled in or near Oliver Sound. Hummocks, undulating surface and nets are the principal patterned ground.

- Plant community "a": moist to mesic conditions with a cover of moss higher in "a": (48% vs 28%) and a cover of graminoids almost double (30% vs 17%).

- Plant community "b": mesic-xeric/xeric conditions. Steeper slopes (13°) and a higher cover and frequency of rock.

Plant community "a"

Plant community "b"

Vegetation type IX: Shrub Forb-Tundra

Plant community “b”

Characteristics

- Dominated by dwarf-shrub *Salix arctica* and forbs, particularly the legumes *Astragalus alpinus* and *Oxytropis maydelliana*. No species of sedge in this type.

- Cover of grasses, mosses and biological crust markedly lower.

- Mesic-xeric tundra typical of steep mountain slopes. Almost all the plots in this vegetation type were sampled in or in the vicinity of the Goose Camp valley.

- Plant community “a”: xeric community typical of scree slopes and crests. Large cover of bare ground and stones. No characteristic microtopography or patterned ground in this community where rocks (slab stones) are constantly present.

- Plant community “b”: mesic-xeric habitats on less steep slopes or on plateaus. Higher cover of vascular plants and cryptogams than “a” and a low cover of bareground and rocks. Main microtopography are flat, undulating and lobes.

Plant community “b”

Vegetation type X: Graminoid Barren

***Armeria maritima* in bloom.**

Characteristics

- Dominated by graminoids *Alopecurus alpinus*, *Luzula confusa*, *Carex maritima*, *Poa arctica* and *Festuca brachyphylla* while *Stellaria longipes*, *Saxifraga oppositifolia* and *Cerastium arcticum* form the forb layer.

- This type grows in the driest conditions we sampled. Lowest species richness (36 species) and lowest cover of dwarf-shrub (2%), total vascular plant (18%), mosses (<1%) and litter (0.5%). Cover of lichens and biological crust also rather low.

- Typical of beaches, the ground is covered with sand (littoral deposits), and few gravels, stones and rocks. This narrow coastal fringe vegetation type is exposed to floods, ice scouring and sand erosion.