A MULTI-SCALED APPROACH TO VEGETATION AND LANDSCAPE ASSESSMENT IN THE BARENTS REGION:

REINDEER HABITAT IN A CLIMATE OF CHANGE

A

DISSERTATION

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DOCTOR OF PHILOSOPHY

By

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PREFACE

Declaration

This dissertation is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated in the text. Certain components were connected to the BALANCE Project (http://balance1.uni-muenster.de) or to other members of the Project Team and to research done with my supervisor, Dr. Gareth Rees, as explicitly stated.

Statement of Length

The length of this dissertation does not exceed the 225-page limit (not including corrections required by the examiners and the permitted additional 50 data pages) for physical science dissertations within the Geography and Earth Sciences Department, under which physical science dissertations from the Scott Polar Research Institute (SPRI) fall.

Additional data

Supplementary information should be available through the Cambridge University DSpace website, DSpace@Cambridge (http://www.lib.cam.ac.uk/dspace/), and included within the Scott Polar Research Institute holdings, accessible from http://www.dspace.cam.ac.uk/. Included are all original botanical analysis and vegetation mapping data and results, and about 500 vegetation species, community and landscape photographs, geo-referenced and with associated metadata. The DSpace site presents the full range of data and information collected, only some of which is able to be included or analysed in the thesis, allowing all of the data to be used in additional future research or by other researchers.

Fiona S. Danks
October 2006

ABSTRACT

The circumpolar Arctic is predicted to be particularly affected by global change, including climate change. Likely ecological vulnerabilities include flora and dependent fauna. Reindeer (*Rangifer tarandus*), a keystone Arctic herbivore, are of particular importance, ecologically, as well as culturally and socio-economically. Many Arctic regions, particularly in Russia, lack critical data thereby limiting current understanding and the ability to assess consequences of change.

This research develops new botanical and spatial vegetation data for a much understudied region, increases understanding of the landscape and its relationships to reindeer habitat and climate change through multi-scale assessments, and creates the potential for analysing consequences of change. Three primary scales of vegetation analysis and their limitations, uses and value are compared within the Barents region. More detailed examinations are undertaken within study regions in the Nenets Autonomous Okrug, Russia. Plant communities, community structure and environmental influences are described.

The most detailed level of analysis uses new data derived from traditional field-based, species-level botanical assessment. Statistical analyses show distinct community divisions and the importance of particular vegetation species or species groupings in defining these communities. The intermediate scale of analysis defines vegetation communities through development of a thirty-metre resolution map, based on Landsat ETM+ satellite sensor imagery. The study region is unusually heterogeneous, complicating classification development. The third and coarsest scale comprises existing regional and global land-cover assessments, with resolutions of one to five kilometres.

Multi-scale comparison shows that the intermediate level is the most suitable for reindeer pasture and habitat assessment, and that climate-related shifts could be observed on any of the three scales, depending on the objectives, enabling assessment of patterns of change in species, communities or landscape. Long-term monitoring, however, is currently limited to coarser-scale analysis. Replication and broad regional expansion of finer-scale analysis, as developed here, are restricted by data availability, computing power, logistics and cost, amongst other factors.

The thesis ends with a discussion of the potential for habitat assessment that includes additional environmental factors critical to reindeer habitat.

All botanical and vegetation-mapping data and about 500 vegetation species, community and landscape photographs, geo-referenced and with metadata, should be archived in DSpace@Cambridge under the Scott Polar Research Institute archive.

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I would like to first express my sincere gratitude to my supervisor Dr. Gareth Rees for his time and consideration, beginning with a decision made long ago one autumn Friday afternoon, and for his near infinite patience and support over the last four years. Good advice and lessons learnt have come from areas far beyond the Arctic and remote sensing and its technical intricacies, and 'lab' discussions have taken on a new meaning.

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Funding came from many sources. The BALANCE Project supported all fieldwork costs and travel to various BALANCE meetings. The B.B. Roberts Fund's (SPRI) substantial assistance enabled me to attend meetings and make research visits in far-flung Arctic locations, as did the CAES fund early on. In particular, I owe great thanks to St John's College, Cambridge for generosity in funding research visits and conference travel, providing stipendiary support and for additional help and benefits (and for accepting and keeping me!). Finally, scholarships from the Overseas Research Students (ORS) Award Scheme, Cambridge Commonwealth Trust, and C.T. Taylor Fund (Cambridge) made my PhD possible.

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I would like to thank all the staff and my fellow colleagues at SPRI for their help and support in various capacities, and the many kind staff and fellows I had contact with over the years in St John's College, in particular my tutor Dr. Sue Colwell and the porters for their smiles and greetings on my daily mail checks.

My PhD experience would not be the same without the incredible, interesting and diverse friends and people I met along the way, on - and off! - the PhD track. I thank my SPRI friends for their great company, attentive ears and wicked humour (and long lunches); my friends from St John's and beyond for so many amazing experiences, culinary adventures, stimulating discussions and educating me in a myriad of other realms; and these and other friends in and far beyond Cambridge for great escapes, brightening days, weathering storms, enlivening my dreams and inspiring my future. I will look back on my time here with much fondness and appreciation. With particular respect to the last few months of my PhD, I would like to thank those friends whose company, patience, support, gifts of sustenance and humour were invaluable.

I would like to mention with gratitude and admiration Dr. David Klein, my former Masters advisor, mentor and friend, who helped develop my fondness for and awareness of our Arctic, exposed me to its beautiful complexity and is very much responsible for the path I have chosen to follow. I remember with respect and admiration the late Ian Ross, a former colleague in Canada, who displayed exemplary passion and dedication to research.

Finally, I would like to dedicate this dissertation to my parents to whom I owe my deepest gratitude for their unwavering support and belief, encouragement, and love (and for sometimes simply not asking!). They, and in particular my mum, have sacrificed so much and enabled me to pursue incredible educational opportunities for which I am ever grateful and without them the last few amazing, memorable years would not have been possible.

Paintings here and on end cover by Prokopy Yavtysy (1932-2005)

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GLOSSARY

AUTONOMOUS OKRUG

A Russian administrative unit for indigenous territories. The partially autonomous Okrugs belong to larger Oblast units, e.g. the Nenets Autonomous Okrug belongs to the Archangelsk Oblast.

BARENTS REGION

Area of northern Europe including regions of Norway, Sweden, Finland and European Russia north of 60 degrees

BRIGADE

Reindeer herding unit or division within a kolkhoz or sovkohz and consisting of a number, usually up to eight, of reindeer herders and their animals.

GAUSS-KRÜGER PROJECTION

A common Russian/Soviet projection for topographic maps similar to the Universal Transverse Mercator (UTM) projection. It typically uses the Krasovsky ellipsoid and coordinates are given in northings (distance from equator) and eastings (distance from central meridian of the zone) with zone numbers.

KOLKHOZ

A collective farm administration unit within an Okrug or other larger region in Russia, particularly associated with reindeer herding, e.g. Vyucheiskii Kolkhoz mentioned in this thesis belongs to the Nenets Autonomous Okrug. The term is left over from Soviet times.

LANDSAT

A series of remote sensing satellite sensors that have been in continuous orbit since 1972 and include the MSS (Multispectral Scanner), TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper) sensors. MSS has four visible and near-infrared bands, TM six visible, near- and mid-infrared and one thermal infrared band and ETM+ the same as TM. Resolution in MSS is 79m x 79m and in TM and ETM+ 30m x30m except 120m x 120m for the thermal infrared band (for additional details see Chapter 4).

MIRE

A general term for peat-forming ecosystems, which includes both fens (alkaline or neutral, mineral rich, watered by above ground water sources) and bogs (acidic, mineral poor, watered by ground/rainwater, associated with sphagnum)

OBLAST

Russian administrative unit for a large region under federal governance.

PERMAFROST

Frozen ground, continuously or semi-continuously frozen.

REINDEER

In a general sense, all *Rangifer tarandus* throughout the circumpolar north, both wild and semi-domesticated; in a specific sense only semi-domesticated animals, generally confined to Europe and Siberia.

REMOTE SENSING

Generally, the use of airborne (photographic, satellite, radar, etc.) tools to extract data about features of the Earth's surface, e.g. vegetation, ice, topography.

SOVKHOZ

A state farm administration unit within an Okrug or other larger region in Russia, particularly associated with reindeer herding, a term left over from Soviet administration.

TUNDRA

General term for Arctic (and sub-Arctic) treeless vegetation. Common species are shrubs, both deciduous (dwarf to tall) and ericaceous, graminoids (sedges and grasses), forbs (flowering plants), and mosses and lichens.

YASAVEY

Association of Nenets Indigenous People, member of RAIPON (office in Naryan Mar)

ACRONYMS AND ABBREVIATIONS

ACIA	Arctic Climate Impact Assessment
AOI	Area Of Interest
AVHRR	Advanced Very High Resolution Radiometer
BALANCE	BArents region: Linking Arctic Natural resources, Climate change and Economies
CAVM	Circumpolar Arctic Vegetation Map
DEM	Digital Elevation Model
DGVM	Dynamic Global Vegetation Model
ECHO	Extraction and Classification of Homogeneous Objects
ERDAS	Earth Resources Data Analysis System
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EU	European Union
GCP	Ground Control Point
GPS	Global Positioning System
GIS	Geographical Information Systems
GLC	Global Land Cover
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IR	InfraRed
ITEX	International Tundra Experiment
JM	Jeffries-Matusita
JRC	Joint Research Centre (of the European Commission)
Landsat ETM+	Landsat Enhanced Theamtic Mapper sensor
Landsat MSS	Landsat Multispectral Scanner sensor
Landsat TM	Landsat Thematic Mapper sensor
LAI	Leaf Area Index
LTER	Long Term Ecological Response
MODIS	Moderate Resolution Imaging Spectroradiometer
MPG	Max Planck Institute
NAO	Nenets Autonomous Okrug
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalised Difference Vegetation Index
NIR	Near InfraRed
NPP	Net Primary Productivity
PCA	Principal Component Analysis
PFT	Plant Functional Type
RAIPON	Russian Association of Indigenous Peoples of the North
RGB	Red-Green-Blue colour channels in an image
RMS	Root Mean Square
SAR	Synthetic Aperture Radar
SPOT	Satellite Pour L'Observation de la Terre
SPRI	Scott Polar Research Institute, Cambridge University
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VNIR	Very Near InfraRed
ZERO	Zackenberg Ecological Research Operations

CHAPTER 1 - INTRODUCTION

“That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly often forgotten.”

Aldo Leopold, *Sand County Almanac*

1. OVERVIEW

The earth is facing certain global change and Arctic environments are likely to be particularly affected. Specifically, climate change is predicted to have significant and far-reaching impacts on the circumpolar Arctic (IPCC 2001, ACIA 2005), with observed and potential shifts in weather patterns, sea ice dynamics and ocean circulation, rates of glacial, icecap and permafrost melting, release of methane, and vegetation dynamics (*e.g.*, Mann et al. 1999, Cornelissen et al. 2001, IPCC 2001, Jones et al. 2001, Sturm et al. 2001, Rees et al. 2003, ACIA 2005, Hinzman et al. 2005, Chapin et al. 2006, Rignot & Kanagaratnam 2006, Walter et al. 2006), thereby also affecting humans and other animal inhabitants (*e.g.*, Gunn & Skogland 1997, Krupnik & Jolly 2002, Root & Schneider 2002). Ecosystem interactions are complex, and intricate positive and negative feedback mechanisms, both within the Arctic and on a global scale, are only beginning to be understood, factors making predictions of climate impacts difficult (Callaghan et al. 1995). The Arctic is highly connected to the rest of the earth: research has uncovered the Arctic's role in affecting the heat balance of the entire planet and the Arctic is suffering detrimental effects from distant globalisation activities, directly through pollution and, research suggests, indirectly through impacts of changing climate. With increasing evidence of change, the phenomenon of global climate change is an accepted reality, including in Arctic regions (Nicholls 1996, IPCC 2001, ACIA 2005). Debate still exists, however, over defining the sources of change, *i.e.* natural or anthropogenic, and understanding potential ramifications remains challenging. The circumpolar north is sensitive to environmental change and requires attention, and thus focus must expand from simply understanding the nature of potential shifts to include assessment of likely responses in order to mitigate and cope with the consequences. Climate change research is becoming ever more complex and urgent.

Of specific relevance to this research are terrestrial ecosystem dynamics, pertaining particularly to vegetation and other ecological factors influencing one of the Arctic's primary herbivores, reindeer (*Rangifer tarandus*). Flora in the Arctic are already showing signs of climate related shifts with increases in shrub vegetation (*e.g.*, Sturm et al. 2001, Hope at al. 2003) and decreases in lichen (Cornelissen et al. 2001), and northern advancement of the tree-line is predicted (Skre et al. 2002, ACIA 2005). Existing differential local and regional precipitation and temperature regimes across the Arctic impact local plant characteristics and communities; effects of climatic change will likewise not be uniform. Arctic warming is not predicted to be universal: in some regions cooling is likely, resulting in widely different vegetation and ecosystem responses. Not all climate-related changes will necessarily be negative: some plant species may thrive under different environmental conditions and others may be resilient and unaffected, depending on the degree of change. Recent research into permafrost melting (Frey & Smith 2005) and methane (CH_4) release (Walter et al. 2006) suggests feedback mechanisms in the Arctic may be stronger than earlier research suggested and rates of change in vegetation and other systems may therefore be orders of magnitude greater. Significant unknowns remain but climate research and models are continuing to improve.

The Arctic region is home to an array of wildlife species, including about five million reindeer (http://www.adfg.state.ak.us/pubs/notebook/biggame/caribou.php, Rees et al. 2003). Reindeer are a keystone species in the circumpolar Arctic: they play an integral part in ecosystem dynamics, significantly influencing and being influenced by their surroundings; they are critical to the natural, wild ecology; and they are invaluable to the lives of numerous indigenous peoples. Reindeer add complexity to vegetation and climate change dynamics through their environmental influences: grazing pressure and forage requirements (Hobbs 1996, Manseau et al. 1996, Cooper & Wookey 2001, Moen & Dannell 2003); manuring (van der Wal & Brooker 2004, van der Wal et al. 2004); trampling of lichen (Cooper at al. 2001); and overgrazing of vegetation (Käyhkö & Pellikka 1994, Olofsson 2006, van der Wal 2006), particularly lichen (Colpaert et al. 1995, den Herder et al. 2003). Reindeer and other herbivore grazing is implicated in reducing or preventing tree-line advancement (Cairns & Moen 2004), in limiting shrub expansion and in other vegetation shifts (Van der Wal 2006) and in altering the structure of lichen communities, in serious cases the recovery of which is estimated to take decades (Cooper & Wookey 2001). While a great deal about reindeer ecology has been discovered, substantial gaps remain and the reindeer-vegetation-ecosystem dynamic is not thoroughly understood. Understanding the ecological role of reindeer in the Arctic, what factors may affect them and how any changes may be manifest is critical to understanding the dynamics of the Arctic as a whole. Even pared down to smaller, seemingly manageable issues, the Arctic system is full of inadequately understood complexity.

Reindeer play a critical role, not only ecologically but also socio-economically, culturally and historically, broadening the value of their circumpolar presence (Jernsletten & Klokov 2002). Reindeer provide an essential means and way of life and cultural identity for diverse peoples throughout the Arctic, from North American Inuit to Greenlanders and across Europe to Asia from Sámi to Chukchi. Reindeer are hunted and herded, supplying essential food, sometimes milk, clothing, transport and other lifestyle resources such as tools and cultural traditions. In some regions of Europe, reindeer herding forms the dominant occupation. Many although not all indigenous groups of the north have been subject to western influences of modernisation and change, and lifestyles and traditions have in some cases radically shifted, for example amongst Alaskan or Scandinavian cultures (Pelto & Müller-Wille 1987, Beach 1993), but the dependence on reindeer has not. In recent years a more sensitive political climate and greater cultural acceptance, at least in some regions and as a result of significant struggle, may offer hope of improved conditions and preservation of cultures in an increasingly difficult changing environment.

Ramifications of climate change are complex, reindeer ecology is not thoroughly understood despite decades-long research efforts, and for many Arctic regions their remote northern location and sometimes additional political and economic isolation has meant that ecological data are lacking, exacerbating the difficulty in research advancement. While certain regions of the Arctic such as Alaska and Scandinavia (and to a similar extent Canada) can in recent times boast of improved awareness of Arctic issues and therefore research access and funding, other regions remain substantially behind. In particular, much of northern Russia lacks critical relevant ecosystem data, limiting understanding of the current ecological situation both in general and in comparison to its neighbours, and preventing increasingly critical assessment of consequences of change. Furthermore, progress is required, not just for particular regions but for successful collaborative circumpolar efforts which need to be a focal point if potential effects of a changing climate are to be sufficiently understood throughout the vast, diverse polar region. Fortunately the situation is improving, collaboration is increasing and more initiatives, such as the International Polar Year (IPY) (http://www.ipy.org/) are being developed.

In light of the issues mentioned above, the theme of this research is to examine the value of landscape assessments, vegetation and other, in relation to potential climate change effects and reindeer habitat in an Arctic region for which previous lack of data would have rendered such analysis impossible. New data are developed as necessary.

This research aims to use a multi-scaled approach to examine landscape aspects of the reindeer environment in the Barents region of northern Europe (an area that includes regions of Norway, Sweden, Finland and European Russia north of 60 degrees (see Chapter 2 for details and maps)) providing: 1) new knowledge about local vegetation species and communities in a previously unstudied region that can contribute not only to the existing botanical knowledge but also to what is known of local reindeer habitat use; 2) a vegetation map for a region for which modern, detailed data do not yet exist and which may prove useful in reindeer habitat studies; 3) an assessment of a regional model of future reindeer habitat that incorporates potential effects of climate change, allowing for an improved perspective on the direction of future research needs and goals; and 4) an improved understanding of the relationship between detailed, fine-scale studies and broad, less detailed ones and the advantages and disadvantages of each in the context of reindeer habitat and climate change. Information from such research can be used by both local and foreign scientists; by managers within the regions; and, equally as important, by locals and reindeer herders. This project required a combination of both fieldwork, carried out over two summer seasons, and computer based work, as well as interaction with colleagues and scientists, in a variety of fields, and reindeer herders with unparalleled first-hand knowledge.

2. BACKGROUND

Basic contextual background information is provided to better understand the purpose of, and concepts and analyses in this research.

2.1 Reindeer

A note on terminology: when used in an obvious general, global sense the term ‘reindeer’ in this thesis applies to semi-domesticated (or herded) reindeer and wild reindeer, but when used in a more specific sense it applies to semi-domesticated animals in Europe. A distinction is made if reference is to wild populations only: the term ‘caribou’ applies to wild reindeer in North America, and ‘wild reindeer’ to reindeer that are not herded in Europe.

2.1.1 Population

The current global reindeer population is about five million, two million of which are in Eurasia and of those about one million are herded in the Barents region. 35% of these are in Russia while the remaining 65% are divided nearly equally between Norway (20%), Sweden (25%) and Finland (20%). The total pasture land within this region is about 700 000 km^2 with Russia containing about 50% of the total, Norway and Sweden 15% each and Finland 20%. Calculated approximate densities range from about 0.3 - 13 $animals/km^2$ with greatest densities found in northern Norway and Sweden and lowest in Russia (Rees et al. in press). Herding has a long-standing tradition in these regions, forming an integral part of the culture, economy and history of many indigenous peoples including the Sámi in Scandinavia and the Kola Peninsula and the Nenets and Komi further to the west in European Russia. In the Canadian and Alaskan north and in Greenland, reindeer are predominantly wild; in Siberia the majority are herded. Few wild herds remain in the Eurasian north, most of which are found in Siberia.

Wild herd sizes can be as large as half a million animals, *e.g.*, in the Taimyr Peninsula, Siberia, but herded groups tend to consist of no more than a few thousand animals. Reindeer populations can fluctuate over short and long time periods in both semi-domesticated and wild herds (Leader-Williams 1988) due to a number of factors including forage quality, availability and accessibility, climate and weather (short term changes), snow and ice cover, insect harassment, resource conflict, disturbance, and in the case of semi-domesticated animals, socio-economic effects that include laws governing numbers, culls, herd amalgamation, etc. Reasons behind population fluctuations, particularly significant ones, are not always clearly understood. The current decline in the Bathurst caribou herd in Canada from 472 000 animals in 1986 to 186 000 in 1983 to 128 000 in 2006 illustrates the degree to which herd size can change (http://www.cbc.ca/canada/north/story/2006/09/19/caribou-count.html). Wild populations are more likely to fluctuate significantly than domestic ones, primarily because herders have some control over their animals and can lead them away from unfavourable situations and also because traditionally regulations on numbers are set by government rules. However, shifts have been evident in recent years in European Russia and numbers of reindeer in certain regions have been declining. Reasons are most probably political and cultural, with decreased government support of herding and increased draw of younger generations to live in villages rather than sustain a difficult herding life. Required education also limits herding experience among the younger generations who have not grown up in the tundra. This trend is not uniform for all of European Russia, however. One area, the Yamal Peninsula, has actually shown increased population and economic growth within reindeer herding (Gray & Stammler 2002, Stammler 2002, Stammler 2005b), but this is unusual.

2.1.2 Herding

Specific cultural traits differ and detailed practices may vary among indigenous groups according to tradition, territory size and density, politics, etc., but the historical and current reliance on reindeer for livelihood and survival is common to all. Techniques of herding vary across the Barents region, in Russia following ‘close herding’ (Baskin 1991, Stammler 2005b) in which one or more herders maintain close contact with the herd twenty-four hours a day, taking turns on the nightshift. Fences in Scandinavia, which keep herds within their territory and limit loss of animals, have permitted ‘loose herding’ (Beach 1981, Paine 1994) where animals spread across greater areas and are not monitored constantly but are rounded up or herded more infrequently. Technology has had a significant impact: in Russia herder transport is still primarily by sledge in winter and summer while in Scandinavia snowmobiles and all-terrain vehicles (ATVs) are the norm, allowing greater coverage of territory, and helicopters may also be used (Pelto & Müller-Wille 1987).

Reindeer herding groups and territories typically follow political and administrative divisions and are divided into broad regions and within these regions into smaller sub-divisions, for government and land management. Typical terminology for the divisions differs within the Barents region among countries but is generally compatible: broad divisions in Norway, Sweden, Finland and Russia are Område, County, District and Oblast/Okrug respectively, and finer sub-divisions are Distrikt, Sameby, Paliskuntas, Kolkhoz/Sovkohz, also respectively. Still finer reindeer-specific divisions may exist in each region, such as Brigade in Russia (Klokov 2001a, Klokov 2001b, Syroechkovski 2000, Paliskuntain yhdistys 2002, Reindriftsforvaltningen 2005, Sámiid Riikkasearvi 2005).

2.1.3 Pasture and Migration

Reindeer pasture is highly managed and generally long established throughout northern Scandinavia and Russia, and reindeer are herded, utilising set pasture areas according to established rules of ownership or leased land grazing territories. Population estimates and distribution are well documented (although accuracy, particularly in Russia, varies) with records having been kept for several decades in most if not all regions. In general, herding areas in Scandinavia are smaller and populations denser. In Russia land is more plentiful, pastures are larger and consequently populations are less dense (Figure 1.1). The areas of greatest density are found in northern Norway.

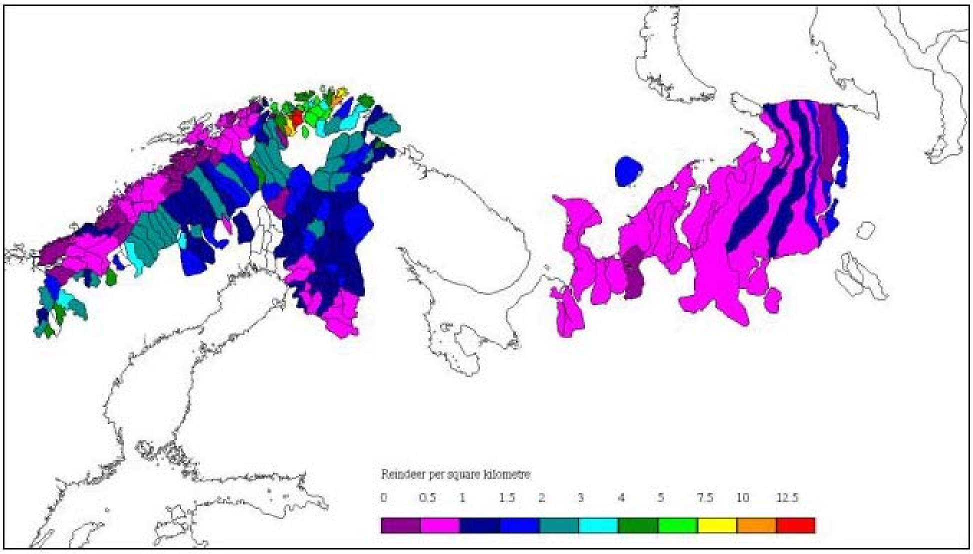


Figure 1.1. Density of reindeer in the Barents region by herding districts (missing Murmansk Oblast data)(Figure by G. Rees).

Reindeer, whether wild or herded, migrate seasonally. Herders move with their animals along firmly established and governed migration routes, outlined in detailed maps and ingrained in herders' knowledge and the animals' movements. In Soviet Russia, traditionally territory divisions were based on 'carrying capacity', a determination of what the land could support based on detailed calculations of numbers and density. The application of such regimented laws to reindeer herding is diminishing as the former Soviet regime's influence wanes but certain herding traditions such as seasonal pasture divisions and specified brigades and brigade territories remain. In Russian herding, migration typically follows delineated 6-season pasture divisions that reflect variations in vegetation distribution and seasonal dietary requirements and selection: summer, early autumn, late autumn, winter, early spring, and late spring (illustrated in the pasture map shown in Figure 5.7) (Rees et al. 2003). The most typical seasonal pattern for reindeer herd migration is to spend the summer on pastures further north, in the tundra or sometimes close to the seashore, and the winter further south, either still in the tundra or in the forest zone. Many migration routes and territories follow narrow, long corridors. There are exceptions to both latitudinal trends of use and territory shape, particularly in northern Scandinavia where sharing of territories by different herds in different seasons, moving of reindeer to discontinuous pasture and other facts complicates land use and ability to strictly define density.

2.1.4 Grazing and Forage

Reindeer, the dominant herbivore in the circumpolar north, consume vast quantities of vegetation, the Barents region reindeer alone consuming of the order of 750 kilograms of biomass per reindeer per year or ¾ million tonnes of total biomass (dry matter) per annum (Rees et al. in press). Diet varies seasonally according to vegetation distribution, availability and access. Climatic extremes limit distribution, growth and species richness of vegetation in the Arctic. In winter, senescence, leaf loss and cessation of growth limit quality and availability of vegetation, as do effects of snow and wind. In summer, drainage patterns influence vegetation communities with richer vegetation found in lower lying or riparian zones and drier species in better drained, often higher or raised locations. The result of these conditions and microclimate variables is a vegetated terrain that is heterogeneous and patchy in distribution. In general reindeer move within their seasonal habitat to locate the most suitable forage.

In summer the reindeer diet is rich and plentiful and animals take advantage of readily available food resources in order to fatten up for the energy intensive rutting season and autumn migration. In fall, food availability begins to decrease and animals graze on remaining biomass before it senesces for winter. Winter is the most difficult grazing time, in terms of food accessibility and sometimes quality: reindeer must dig through snow or find windblown areas with less snow in order to reach food resources, which have become less plentiful, except where lichens are available. Serious population crashes can occur if forage access is prevented by re-freezing or icing events (Bruland 2002), phenomena which change the typical snow characteristics and cause ice layers to form, rendering the vegetation impenetrable. Hardness and depth have been shown to be the most critical factors in the effect that snow has on the location and use of winter habitat by reindeer (Brooks & Collins 1984). Springtime signifies the return of abundant food and reindeer are able to feed on young plants and new vegetation and improve their condition. Food resources are critical at all times of year: a hot dry summer that dries out vegetation leads to poorer condition in animals, as would a harsh winter with ice crust over the snow, limiting forage access.

Seasonal diets, while variable amongst regions, follow certain trends. Summer forage consists of green biomass and rich vegetation often associated with scattered riparian communities or wetlands. Graminoids (sedges and grasses), forbs and young shrubs dominate (Klein 1990). In autumn, the animals feed on remaining summer plants and newly produced berries and in particular, where available, mushrooms. Winter vegetation is sparse and patchy and consists of whatever food reindeer are able to reach under the snow, preferably lichens if they can smell them, although certain *Equisetum* and *Carex* species provide good winter forage, remaining green under the snow (Dmitrieva et al. 1982). Grasses, forbs and dwarf shrubs may also be consumed (Gaare & Skogland 1975). In some herded regions such as Finland, winter food resources, particularly lichens, are so limited due to grazing pressure that animals are given supplemental feed to enable them to survive (Colpaert et al. 1995). In spring, reindeer take advantage of snow free patches and new growth and feed on young shoots and shrubs, forbs and grasses (Klein 1990, Ihl & Klein 2001), and forage gradually becomes plentiful again.

2.1.5 General Ecology

Unlike many other Arctic animals that rely on energy conservation for survival in harsh conditions, reindeer lead an active life and movement is critical to their survival. Reindeer search locally for valuable forage throughout the year. Larger movements in winter and summer are limited to more localised areas while in autumn and spring reindeer, particularly wild reindeer and caribou, undertake potentially significant migrations (Pielou 1994). In autumn, migration follows the rutting season and as autumn approaches the animals begin their journey to over-wintering grounds. In spring, migration is even more critical, particularly for caribou and wild reindeer: the animals must reach suitable calving grounds to give birth synchronously to maximize survival of the newborn calves by limiting predation. In herded populations migrations are generally less pronounced, distances may be shorter and herders and government policy have a say in dictating routes and pastures used. The value and necessity of substantial suitable, seasonal pasture for reindeer is evident.

To cope with the harsh environment reindeer have developed adaptive mechanisms. In winter they utilise a counter-current heat exchange system to maximize core body warmth and minimize heat loss through the extremities (legs and nose); they have special hollow hair that increases insulation and protection from the elements; the large surface area of their hooves allows easier walking over snow and soft ground, increases energy efficiency and permits digging for forage; they conserve energy by lowering their body weight thereby requiring less food, by adopting a low protein diet (lichens) which requires less water (obtained from snow melt), and by recycling waste (urea) (Pielou 1994). In summer they are able to store energy reserves during plentiful forage times; they use effects of wind to their advantage in reducing insect harassment; their thinner summer coat permits them to be cool and their heat exchange system now releases heat. Reindeer are well adapted to their environments, however, significant changes will potentially affect reindeer health and populations. For example, excess heat in summer is difficult for the animals to handle physiologically and it may also affect availability of suitable forage, both factors negatively influencing body condition and population.

2.1.6 Environmental Factors Affecting Reindeer and Reindeer Habitat

Numerous and various environmental factors affect the quality of reindeer habitat and the animals' survival and health. Vegetation and pasture quality and type is perhaps the most important, with shifting seasonal dietary requirements of reindeer, as described earlier in the chapter and expanded upon from a vegetation community perspective in Chapter 3. Topography is the underlying factor in all reindeer habitat and pasture. Reindeer are adapted to harsh conditions but require suitable topography for movement, migration and forage, *i.e.* areas with extreme topography such as very steep slopes, deep valleys and therefore little available grazing land are not suitable. Slope and terrain ruggedness indices, derived from elevation and topography (Nicholson et al. 1997, Nellemann & Reynolds 1997, Danks & Klein 2000) can give clues as to pasture suitability.

Climate is another key factor. While reindeer are suited to the severe Arctic climate and its extremes, both hot and cold, there are limitations. Negative effects of climate on reindeer can be summarized as resulting from hot summer temperatures and dry summers (Soppela et al. 1986), inducing heat stress, decreasing forage opportunities and increasing insect harassment; extreme snowfalls in winter (Johnson et al. 2001) or shifting temperatures (near freezing) causing refreezing events and icing over of ground snow layers, making movement difficult (deep snowfalls) and preventing reindeer from digging to access forage (snow depth and ice layers); and delayed onset of spring, reducing availability of and access to critical forage after a winter of decreased opportunity, and particularly affecting calves (Ropstad et al. 2001). Positive influences, on the other hand, may include cool summer temperatures, liming insect harassment and improving forage quality; windy summers, limiting mosquito harassment, warm autumn temperatures, providing longer access to forage; and an extended growing season. Climate exerts a significant influence on forage (Gunn & Skogland, 1997). Potential climate changes and anomalies, such as late springs with delayed warming and extended snow depth, will affect habitat even further. Weather, meaning short-term climate characteristics, also exerts an important influence (Soppela et al. 1986).

Insects including mosquitoes (*Culicidae*), nose bots (*Chepenemyia trompe*) and warble flies (*Hypoderma tarandi*) are a crucial factor in habitat suitability: harassment can reduce critical energy reserves in adults, reducing body weight and condition directly (Gunn & Skogland 1997, Colman 2000) or indirectly through avoidance activity and consequent decreased foraging opportunity (Downes et al. 1986, Hagemoen & Reimers 1999), possibly leading to death in calves. In particular, nose bots are thought to cause the most disturbance (Mörschel & Klein 1997, Anderson et al. 2001). Reindeer are forced to seek areas with greater wind exposure, typically elevated, or exposed areas where insect density is lower but forage is limited (Walsh et al. 1992, Pollard 1996). Insect harassment is tied to weather and climate (Helle & Tarvianen 1984, Hagemoen & Reimers 1999, Mörschel 1999, Weladji 2001, Hagemoen & Reimers 2002, Weladji et al. 2002): a positive correlation exists between temperature and harassment (Anderson et al. 1994, Mörschel & Klein 1997) while wind shows the opposite trend, a negative correlation (Anderson et al. 1994, Pollard et al. 1996, Mörschel & Klein 1997, Mörschel 1999). Studies have also examined effects of cloud cover on insect harassment with differing results of no effect of cloud cover on insect or caribou activity (Mörschel & Klein 1997) and moderate or severe harassment with cloud cover below 40% (Colman 2000).

Predators can exert a substantial influence on herd population, particularly wolves (*Canis lupus*) (hence the synchronous birthing trend in caribou, an attempt at predator swamping) and also brown bears (*Ursus arctos*), wolverine (*Gulo gulo*), lynx (*Lynx lynx*) and golden eagles (*Aquila chrysatos*), the latter of which prey on calves primarily. Predators are a greater concern with wild animals or more loosely herded semi-domesticated animals that are less protected by herders' vigilance, and effects are regional dependent according to predator populations.

Disturbance from other land use such as hydro-electricity projects and dams, mines, oil and gas development, farming, forestry, tourism, etc. or land use effects such as infrastructure, roads, traffic, powerlines, etc. can influence habitat suitability and fragment pasture, affecting energy expenditure and animal health. Numerous studies have been done on this increasingly important and relevant issue, given growth in development in the north: on powerlines (Nellemann et al. 2001, Nellemann et al. 2002, Reimers et al. 2000), on forestry and forage (Eriksson & Raunistola 1990, Helle et al. 1990, Stevenson 1990) and effects of fertilisers (Åhman & Åhman, 1984, Eriksson & Raunistola 1990); on industry and oil and resource development (Curatolo & Murphy 1986, Dau & Cameron 1986, Murphy & Curatolo 1987, Vitebsky 1990, Cameron 1994, Nellemann & Cameron 1996, Nellemann & Cameron 1998, Stammler 2002, Klein & Magomedova 2003, Rees & Rigina 2003, Tuisku 2003); on roads (Dau & Cameron 1986, Wolfe et al. 2000, Vistnes & Nellemann 2001) and traffic (Reimers 2001); on other transportation such as snowmobiles (Mahoney et al. 2001) and low-altitude planes and helicopters (Miller & Gunn 1981, Maier et al. 1998, Wolfe et al. 2000, Reimers 2001); and on human influences and tourism effects (Helle & Särkelä 1993, Sporan et al. 1999, Nellemann 2000). Pollution is an additional factor that can cause pasture degradation and loss, as in Norilsk and Dudinka for example (Klein & Vlasova 1992, Klein 1996, Tutubalina & Rees 1999, Freese 2000), although so far within the Barents region consequences have been limited with the exception of the Chernobyl accident and resultant caesium fall-out (Åhman et al. 1990, Åhman & Åhman, 1994). Causes and severity of disturbance or conflict with other land uses are highly regional dependent, for example, much more development has occurred in Scandinavian regions than in much of Russia, and within Russia, certain regions may be almost entirely immune from disturbance while others may face some, increasingly due to oil and gas development. Recent studies examine disturbance beyond effects on habitat and include implications for reindeer life history and population dynamics as well as socio-economics and the regions' peoples (Weladji & Forbes 2002).

Some of the factors above may be directly or indirectly affected by Arctic climate change, including vegetation, weather and climate trends, insect harassment and effects of other land use (if, for example, climate shifts allow increased development or development effects on the landscape). Complex interactions exist among some of the factors, such as vegetation and climate effects and insects and climate effects.

2.1.7 Resilience and Susceptibility to Change

Reindeer are highly adaptable to different conditions, climatic extremes and varied grazing pastures. Virtually all reindeer live in the northern hemisphere, in nearly all Arctic regions, occupying Boreal forests, sub-Arctic zones near the treeline with populations utilising both tundra and taiga zones, Arctic tundra regions and even the high Arctic. Separate populations live well below the Arctic, in woodland and forest, particularly in Canada and Siberia, and a translocated herd even in Scotland. European reindeer populations are found predominantly in Arctic regions. A successful translocated population survives in altogether different habitat, on South Georgia (Leader-Williams 1988). Reindeer are resilient and can survive in exceptionally harsh conditions of temperature extremes and limited nutritional resources, however, limits exist and certain basic requirements and environmental conditions must be met: food supplies must be adequate, pastures of high enough nutritional quality, and environmental conditions favourable, such as limited insect harassment, cool temperatures, etc. Understanding potential effects of climate change on the environmental variables affecting reindeer is crucial in knowing how populations may be affected.

2.1.8 Complex Ecological Interactions

Reindeer ecology is deceptively complex. Numerous studies have been done and attempts made to understand the intricate relationship of reindeer to their environment: that reindeer migrate, have seasonal nutritional requirements and require specific calving grounds (particularly in the case of wild populations) is known. Whether pasture is overgrazed, lichens are essential in the diet or exactly how reindeer influence the ecological balance remains contentious and critical questions remain. Complex interactions and feedbacks among reindeer and vegetation and now climate change present a complicated picture.

Vegetation availability and distribution clearly affect reindeer population success and their distribution in the landscape. Reindeer population size, grazing intensity, and land use effects (manuring, trampling, etc.) in turn influence the dynamics and distribution of vegetation including lichen (Käyhkö & Pellikka 1994, Kumpula et al. 2000, Olofsson et al. 2001, Theau & Duguay 2001, den Herder et al. 2003, Theau & Duguay 2004, Tømmervik et al. 2004). Primary production has been found to increase as a consequence of (heavy) grazing, which enhances nutrient cycling (Olofsson et al. 2001, Olofsson et al. 2004). Increased nitrogen deposition, leading to replacement of moss-dominated communities by graminoids (sedges and grasses), cannot be attributed to atmospheric effects alone, herbivore grazing is also implicated (van der Wal et al. 2003). In addition to the positive feedback of grazing and trampling effects which increases grass abundance by reducing depth of the moss layer and thereby increasing soil temperature (van der Wal et al. 2001), a second positive feedback of increased nutrients resulting from manure and urine deposition is evident (van der Wal & Brooker 2004). Less severe grazing pressure, by intermittent intense use, however, rather than causing a shift to graminoid dominated tundra can in fact increase pasture productivity (Olofsson et al. 2001) and grazing in productive habitats is suggested to support species richness and biodiversity (Austrheim & Eriksson 2001). Examination of soil mineralization in grazed versus ungrazed areas showed a decrease in carbon cycling, hypothesized to be a result of plant root damage from trampling effects, with the effect of reducing decomposition rates; however, grazing effects on nitrogen are suggested to potentially outweigh the effect of decreased organic decomposition (Stark et al. 2003).

Changes in tundra landscape and vegetation distribution due to climate or other causes are suggested to affect reindeer populations, grazing and pasture use (Klein 1999, Forchhammer et al. 2002). Reindeer populations may in turn affect manifestations of change, limiting northward advancement of the treeline, for example, through grazing effects (Grace et al. 2002, Cairns & Moen 2004). Examination of historical reindeer and climate data seems to show that in periods of warming and as summer temperatures increased at the end of the Pleistocene, reindeer populations decreased until they were extirpated in southern France, suggesting that increased temperatures, such as might result from future warming, may be detrimental to reindeer populations (Grayson & Delpech 2005). Studies that increase awareness and understanding of reindeer ecology and dynamics, both current and potential, are essential given predicted changes, the importance of being able to respond, the need for planning and management and the established value of reindeer populations ecologically, culturally and socio-economically.

2.1.9 Politics and Laws

Wild reindeer and caribou are less subject to influences of politics, except through decisions on culls and hunting quotas or resource development, however, semi-domesticated reindeer (and herders) may be particularly affected by political and government decisions. For example, to keep populations and numbers in check and ensure sustainability of pasture areas and herds, herding boundaries may shift, herd size and composition may be altered, or herding groups may be combined. In addition, bigger political issues that predominantly affect herders and their ability to herd reindeer exist throughout the Barents region: in recent times much controversy has resulted over land and other rights of indigenous peoples, and government and herders have often fundamentally disagreed, creating strife and resentment. The situation is particularly complicated in Scandinavia where each country has different laws about herding, who is allowed to herd, who has land rights, etc. In Norway and Sweden, only Sámi have the legal right to herd reindeer in principle (Beach et al. 1992), creating an ethnic bias. In Finland and Russia the laws are less strict though it seems it is only in Finland (and the concession area in Sweden near the Finnish border) where non-indigenous people also herd some reindeer (Jernsletten & Beach 2006). The locus of administration of the government laws also has an impact. For example, in the Barents region countries, the Minister of Agriculture oversees reindeer herding, meaning that laws often pertain to southern farming traditions and not northern reindeer herding (Paine 1992, Stammler 2005b). The implementation of European Union agricultural policy to parts of Fennoscandia has had particular effect and similar changes have occurred in Norway.

In Russia (as with elsewhere in the Fennoscandian north), issues and conflicts are primarily about economics, and government support, subsidies and level of income. Russian reindeer herding has been particularly affected by the country’s political past. Russia has undergone tremendous transformation from a communist nation to a presidential autocracy with democratic elements and a market economy, from a country where people had little or no autonomy and control to one where they have significantly more. The Russian north has on the other hand gone from a region aided by subsidies and government support to a region largely left alone in coping with the Soviet Union heritage (Wegren 1998, Krupnik 2000, Stammler & Ventsel 2003). The change has not been easy and many herders feel life was better in Soviet times (L. Taleeva, pers. comm.). As a result of Soviet political decisions such as support of sedentarisation, many herders in Russia have given up their traditional way of life and reindeer numbers have thus decreased. The herder way of life changed significantly with the sedentarisation approach and introduction of a ‘shift system’ in the 1960s whereby two groups of herders within a Brigade alternate time spent in the tundra with their animals and in the village with their families (Krupnik 2000, Tuisku 2002). In the past entire family groupings were in the tundra, families were together all of the time and herder’s knowledge was more intimate. Unpopular government rules drive some herders to turn to private herding, a complicated scheme where they can rent land from the government and choose some animals of their own or take some from the herd (Stammler 2005a). Initiative is required for this, however, and many herders are accustomed to being told how to herd their animals. With the decreased role of government in herding in Russia, traditions are likely to see more changes; the future depends on social and financial sustainability. The Russian north has always been of prime interest to every government for its resources, fur and mineral for example, and extraction of these resources has been a focus and a target for subsidies. In recent years, the Russian government has been re-exerting control in the north again, not necessarily of certain benefit to the lives of its local people, however. Throughout the Eurasian herding region a growing awareness exists among herders and policy makers of the importance of reindeer for cultural and ethnic identification. But there is a certain contradiction between the agro-industrial politics of herding and ethno-cultural conservation politics (Stammler & Ventsel 2003).

2.2 Climate Change

The body of work on causes and effects of climate change, global and Arctic, and on complexities, feedbacks, models, simulations and associated debate is substantial and cannot be covered in detail here. An overview is provided of general theories, current results and evidence, and difficulties and uncertainties, to provide a general context for this research. Where possible, details with direct relevance are provided, for example, pertaining to reindeer and vegetation.

The earth and polar environments in particular are facing increasing global change. Specifically, climate change effects are predicted to be significant and far-reaching, particularly in the circumpolar Arctic, with observed and potential shifts in temperature, precipitation and weather patterns (Overpeck et al. 1997, Mann et al. 1999, Jones et al. 2001), sea ice dynamics (Serreze & Francis 2006) and ocean circulation

(Peterson & Holmes 2002), rates of glacial (Rignot & Kanagaratnam 2006), ice-cap (Abdalati & Steffen 2001) and permafrost melting (Romanovsky et al. 2001, Hinzman et al. 2005, Hinzman et al. 2006), release of methane (Walter et al. 2006), and vegetation dynamics (IPCC 2001, Sturm et al. 2001, Epstein et al. 2004a, Epstein et al. 2004b, ACIA 2005, Sturm et al. 2005, Chapin et al. 2006). Human and animal inhabitants will necessarily also be affected (Gunn 1995, Gunn & Skogland 1997, Krupnik & Jolly 2002, Hinzman et al. 2005). Ecosystem components are complex and not fully understood in isolation; combined dynamics and interactions are even more complex and unknown. Intricate positive and negative feedback mechanisms are only beginning to be understood. The Arctic plays a global role and is in turn affected by the rest of the planet.

2.2.1 Arctic Amplification, Feedbacks and Trends

Global climate change is predicted to be greater toward the poles (polar amplification) (Manabe & Stouffer 1980, ACIA 2005), a response to change in global climate forcing, such as greenhouse gas concentrations or output of solar radiation (Moritz et al. 2002). Likely primary causes are the melting of Arctic snow and ice and release of carbon dioxide from peat thaw and associated positive feedbacks. Evidence for an amplification phenomenon exists (ACIA 2005) although it is currently less established than evidence for straightforward global climate change. However, most models support polar amplification in the future (Holland & Bitz 2003). Recent research into release of methane by thaw lakes in Siberia suggests a rate of release five times higher than previously estimated by other methods and shows that released methane is from previously stored stocks from the Pleistocene (Walter et al. 2006). Recent research into effects of snow and changing shrub conditions on albedo suggests increasing shrub vegetation may result in increases in absorbed solar radiation from 69-75%, altering the winter energy balance (Sturm & Douglas 2005, Sturm et al. 2005). These processes introduce potential additional positive feedbacks to climate warming. Other effects such as increased cloud cover may introduce negative feedbacks, counteracting the change.

While the globe and the Arctic are warming overall (Overpeck et al. 1997, Mann et al. 1999, Jones et al. 2001, Comiso 2003), climate changes are not predicted to be spatially homogeneous and in fact observed changes in the Arctic over the past three decades have not been uniform (Hansen et al. 1999). Current differences in climate and weather patterns and additional effects of change will influence dynamics and determine whether change is positive or negative. Climate change is most typically associated with warming, but in some regions of the Arctic, trends are towards cooling (Sturm et al. 2003). While on the whole glaciers are retreating, some are advancing, even those adjacent to retreating ones (B. Molnia pers. comm.)

2.2.2 Causes of Change

While the phenomenon of climate change is increasingly accepted, determining causes and sources of change is challenging and contentious. It is becoming increasingly difficult with the anomalous (over a long term, millennial context) warming in the last century, to not attribute some of the increase to anthropogenic forcing factors, with multiple simulations producing similar results of a significant increase in temperature coincident with industrialisation and increased output of greenhouse gases. The observed warming cannot be predicted without the input of anthropogenic factors (IPCC 2001). However, much uncertainty remains. The distinct roles of natural and anthropogenic factors are not understood. The exact role of greenhouse gases cannot be quantified, feedbacks are simply too complex to be fully understood currently. Production of greenhouse gases, for example, CO_2, chlorofluorocarbons (CFCs), methane and nitrous oxide, which trap heat in the earth's atmosphere, have been on the rise since the industrial revolution. Environmental efforts are attempting to slow this increase through the advent of emissions reduction programs, national and global agreements such as the Kyoto Protocol (Grubb & Brack 1999), etc. in an attempt to limit climate change effects. While rates my be slowed, it is unlikely that on a global scale greenhouse gas production will be sufficiently decreased to counteract climate change, given global activities and increasing reliance on energy sources, other global problems and concerns, and political indecision. Consequently, reduction attempts must be coupled with efforts to understand actual and potential effects of climate change.

2.2.3 Evidence of Change

Already a substantial body of data exists that provides evidence of both recent climate change and related effects. Arctic temperatures are on the rise and have increased by 0.5 degrees Celsius per decade on average over the last three decades, and evidence from lake sediment and ice and peat cores indicate current temperatures are the highest in 400 years (Sturm et al. 2003).

Lakes and rivers are frozen for shorter times (Magnuson et al. 2000), satellite data shows that since the 1970's the snow-free period has lengthened (Stone et al. 2002), and growing season length has also increased (Stow et al. 2003, Jia et al. 2003). Sea ice coverage has been shrinking by about 3% over each of the past three decades and thickness has decreased by as much as 40% in certain regions since the 1970s (Sturm et al. 2003). Ice caps are melting at record rates (for example in Greenland) (Abdalati & Steffen 2001) and many glaciers are retreating (Rignot & Kanagaratnam 2006). Glaciers in Alaska have been shrinking on average for half a century but the rate of shrinkage has increased threefold in the past decade (Sturm et al. 2003). Glacial melting results in sea level rise, which in itself has potential major consequences. Thaw of permafrost is occurring with significant far-reaching effects: for example freshwater discharge from rivers is increasing (Peterson et al. 2002, Yang et al. 2002), with potential consequences on global ocean circulation (Peterson & Holmes 2002). Release of carbon dioxide by thawing in the Arctic may transform the Arctic to a source rather than a sink for carbon dioxide, a shift with potentially significant global consequences; however, increases in shrubs and plants that fix more carbon could swing the trend in the other direction, back to a sink. This example illustrates the uncertainty that exists in understanding climate change mechanisms and overall effects, even with evidence of change.

Vegetation is one aspect of the environment already showing and likely to continue to show significant responses to climate change. Although vegetation of the Arctic regions is not known in uniform or great detail (Walker et al. 1995, CAVM Team 2003), within certain areas, detailed studies and mapping have been carried out. A number of both short- and long-term experimental studies have focused on response of vegetation to simulated climate changes, for example, the Arctic and Boreal Forest Long Term Ecological Response (LTER) Network of sites in Alaska (Chapin et al. 2006), the International Tundra Experiment (ITEX) (Henry & Molau 1997), examinations of effects of herbivory combined with simulated climate change by Klein et al. (1998) and others (*e.g.*, Chapin et al. 1995, Chapin & Shaver 1996). A study simulating temperature increases in line with climate change predictions showed differing responses among vegetation types but a general increase in abundance and height of shrubs (*e.g.*, Jonsdottir et al. 2005) and in a comparative study of experiments in Swedish (Abisko) and Alaskan (Toolik Lake) tundra systems, increase in nutrients increased biomass of deciduous and graminoid species while decreasing biomass of mosses and lichens (van Wijk et al. 2004). A further study at Toolik Lake involving warming in summer and increased snow cover in winter over an eight year period at moist and dry tundra sites showed increased graminoids; increased shrub cover and height (particularly deciduous); decreased lichen distribution and variety; and a decrease in bryophytes at the moist site, all changes concurrent with other simulation studies and with increasing documented observation (Wahren et al. 2005).

Specific changes in northern landscape and tundra vegetation have been documented. Shrub vegetation is increasing in distribution, density and size (canopy height) (Silapaswan et al. 2001, Sturm et al. 2001, Hope at al. 2003, Tape et al. 2006). Photographs of Alaskan landscape taken at approximately a fifty-year interval show clear increase of shrub vegetation (Sturm et al. 2003). Grass and graminoid tundra is increasing, occupying areas previously covered by dwarf Arctic shrubs and lichen (Rees et al. 2003, Kullman 2004) and lichen distribution and abundance are declining (Cornelissen et al. 2001). Tundra (*i.e.* treeless vegetation) boundaries are predicted to shift with the northern advancement of boreal forest species (Skre et al. 2002, ACIA 2004, Chapin et al. 2006). Evidence has not been observed yet, possibly due to lag effects present in the system dynamics or to other factors such as increased stress due to warmer temperatures, negatively affecting tree growth (Lloyd & Fastie 2002). Ecosystem responses are slow, and lag effects must be considered in vegetation dynamics, meaning that full consequences of already observed climate change may not even be known.

Additional factors complicate understanding of the response of vegetation to climate and the ability to model and predict changes accurately. Differential precipitation and temperature regimes across Arctic regions will impact plant characteristics and community responses in a non-uniform way; for example, increased rainfall, probably a localised effect, has been shown to lessen negative impacts of reindeer trampling on lichens (Cooper at al. 2001). Furthermore, studies on Arctic vegetation transition zones suggest that zones are differentially affected by environmental factors including, for example, climate, hydrology and topography, and therefore response to climate changes will vary accordingly amongst zones (Epstein et al. 2004b). In addition, synthesis of data from Alaska shows that recent summer albedo changes contribute to warming, which is correlated with the increased snow-free season which in turn has been shown to have increased atmospheric heating significantly; continued expansion of shrubs could magnify this feedback system by up to seven times (Chapin et al. 2005). Finally, as mentioned above, recent research into permafrost melting and methane release (Walter et al. 2006) suggests feedback mechanisms are even stronger than initially thought and rates of change in vegetation and other systems may be orders of magnitude greater than anticipated.

Arctic tundra vegetation has potential to be a reliable indicator of global climate change: dynamics are sensitive to change given the harsh environment and warming is expected to be amplified at the poles (Cornelissen et al. 2001, Skre et al. 2002, van Herk at al. 2002, van de Linden et al. 2003, Stow et al. 2004). Through carbon and nutrient cycling, and influences on albedo and water and weather patterns, vegetation affects climate (Betts 2000, Harding et al. 2002). Understanding these feedbacks, especially if subject to instability and change, presents a challenge. Adding additional components, such as impacts of land use change or resource development, potential pollution effects and complex ecological interactions, such as herbivory and grazing, further complicates the picture. Substantial research effort goes into understanding these northern dynamics. Reindeer, both wild and herded, with their circumpolar population of about five million are an important consideration in this complex, poorly understood dynamic.

2.2.4 Research Responses

The Arctic environment is displaying warming trends reflected in temperature increases, melting and thawing of sea ice, glaciers, permafrost and peat, shifts in vegetation cover with an increase towards shrubs and an extended growing season, amongst other factors. The exact causes and ramifications of these and other changes and the role of natural and anthropogenic factors is not yet certain but what is certain is the need to be prepared for current and predicted climate change and impacts, particularly considering the potential for lagged effects. This means developing and improving predictions so they become more accurate and more reliable, and furthering understanding of current ecosystem components so that changes can be observed and examined. Efforts must focus on required responses to mitigate consequences of change.

Reindeer populations live in a finely balanced ecological zone, more susceptible to effects of change than other more robust regions. Impacts of potential climate change are one of the most critical unknowns likely to affect the Arctic region and therefore reindeer populations and the future ecological balance. It is thus of critical importance to understand potential climate change effects, especially since change is already occurring. Research is being done to examine implications of climate change on reindeer and reindeer systems (*e.g.*, Gunn 1995, Gunn & Skogland 1997, Griffith et al. 2002, Weladji et al. 2002, Weladji & Holand 2003), including the role of the Arctic oscillation in affecting plant and reindeer population growth (Aanes et al. 2002) and effects on (caribou) habitat and calf survival (Griffith et al. 2002, Weladji et al. 2002).

3. THESIS RESEARCH QUESTIONS AND RATIONALE

General issues addressed in this thesis, brief details of which were outlined in the introductory paragraphs, are listed below:

1. the critical lack of ecological and landscape data in the north, specifically in northern Russia, which prevents current understanding of the environment and therefore renders increasingly valuable future assessment of change impossible
2. potentially transformative Arctic climate change and its effects
3. the importance of understanding complexities of reindeer habitat given their value and varied roles in the circumpolar north

Knowledge of local environments, through collection of ecological data, is of critical importance. With increasing ability to develop (and awareness of the benefits of) regional, national or circumpolar environmental assessments, the establishment of circumpolar-wide databases is also crucial. Climate change, whether natural or anthropogenic or a likely combination of the two, has the potential to significantly change the Arctic as we know it. It is essential that we try to understand and prepare for potential effects to mitigate negative consequences. Reindeer are a valuable Arctic species, important across the circumpolar north ecologically, socio-economically and culturally; understanding their complex ecological dynamic is important, particularly in an increasingly complicated, changing environment.

Certain regions of the Arctic are very poorly documented and under-researched and data are scarce. This is true for data in general but for the purposes of this project, references are to vegetation and landscape, reindeer ecology and climate change data. Within the European north, Fennoscandia (referring throughout the thesis unless otherwise stated to Norway, Sweden and Finland but not Russia) is an exception: detailed, up-to-date data are plentiful and research ongoing. In contrast, European Russia suffers from a critical lack of modern, available data. Remoteness, limited accessibility and funding shortages all contribute. This paucity of information not only impedes progress and research within the region but also limits comparisons and circumpolar efforts, an increasingly common and valuable approach.

Furthermore, documenting shifts due to climate change or other causes remains impossible without a basic knowledge base from which to work. Current situations need to be documented before effects of change can be determined. With the increasing awareness of changes facing the environment, in particular in the sensitive Arctic, this is becoming more and more critical. While technology based data are increasingly common and of significant value, other traditional data remain important. Both data forms can provide crucial information in detecting and analyzing changes.

Vegetation changes occurring or predicted to occur are probably not independent of other factors. Of relevance to this research is the complex influence of reindeer on such changes. Understanding reindeer herding and its interactions and relationships with its surrounding environment is important not just to science but also to the sustenance of the reindeer, herders, local economies and stability of the local political systems. A major disruption to the state of herding could have a potential impact on the national economy of the herding countries if herding was no longer viable and the government were forced to provide support financially and through other means. Furthermore, since reindeer are such a complex, influential and integral species in northern environments, major disruptions or changes in their population or distribution could have significant effects on other flora and fauna species whose habitat overlaps in the regions, and potential for significant ecological shifts exists. While we cannot counteract this we can be prepared for the future as best as possible by carrying out relevant research

The value in this project lies in its diversities of approach and data type and analysis, and in its coverage of the issues of climate change and reindeer habitat from different perspectives of scale for the same region. Certain aspects included in this research are well-established, for example botanical examinations and vegetation mapping. However, the use of integrative modelling and interdisciplinary feedback data to try to predict potential climate change effects on vegetation and reindeer habitat is innovative. While continued future improvements are likely there is still value in these initial approaches.

This thesis seeks to answer the following specific research questions:

1. What are the landscape characteristics, including botanical composition, vegetation communities, and environmental influences, of the study region?
2. On what scales can landscape be assessed and how does information differ among scales?
3. What is the optimal scale for examining potential effects of climate change on vegetation in the landscape?
4. What is the optimal scale for assessing reindeer habitat characteristics and suitability in terms of vegetation?

5. What factors beyond vegetation are critical for more advanced reindeer habitat analysis and where does current research stand?
6. What are future data, research and analysis considerations and needs for more advanced habitat analyses and models?

Benefits of this research are multi-fold: it provides significant new and relevant landscape description data to a much understudied region, north-eastern European Russia; it allows landscape assessments within this region that were previously impossible due to lack of data; through the provision of multi-scale data for this particular region, valuable landscape scale comparisons can be made, particularly in regard to potential climate change effects and reindeer habitat; based on this research effort, requirements of future efforts to further advance critical understanding are clarified.

In addition to the different scales, a variety of data types are employed. This project combines traditional field-based and advanced satellite-based spatial data in its efforts to better understand the vegetation and landscape of the study region.

Vegetation is the dominant focus of the research but additional habitat factors are considered, expanding the focus. Results of research efforts should advance current understanding of the landscape and its characteristics and relationship to reindeer habitat and climate change. Anticipating potential shifts in climate and resulting effects is critical for our ability to respond to changes. Understanding reindeer, reindeer herding and the potential effects of global climate change on them is no exception. Results of this research allow an improved base for future work.

4. RESEARCH CONTEXT

This research provides a characterisation of landscape on various scales and assesses the differences among them when considering climate change effects and reindeer habitat. It provides an array of essential new data without which further elaborate study cannot proceed. Working in Russia had certain restrictions, which for the time being rendered data intensive, in-depth habitat suitability studies difficult or impossible. Available ecological data, such as climate or landcover, are limited, and detailed, current data, such as botany or snow cover characteristics, more so; major gaps in appropriate, timely and detailed data prevent complex studies, particularly studies that reply on multiple sources of environmental data. Improvements in data availability, research funding and technology in other regions, such as Scandinavia, have in recent times improved research potential and made complex examinations possible. This is not yet true for Russia and consequently what is possible in Russia is still very different from what has become possible in many other Arctic regions. Even field access is difficult and may be restricted. Certain regions may be out of bounds to foreigners as I discovered when I was not allowed to carry out my final winter pasture data collection in an area considered a ‘specially designated border zone’. While working in Russia imposes certain limitations, there are merits to necessary self-collection of data, namely that the type and detail are exactly as desired, errors are known and potential constraints of existing data are irrelevant. Many regions, especially in North America or Fennoscandia, have at least some if not significant existing data, limiting justification of additional collection. The advantage of working in these more studied regions is that valuable in-depth analyses are possible. This research, while not able to develop complicated modelling or habitat analyses, helps establish the potential for such work in the future in this region of Russia by providing varied, critical needed data.

This thesis, by adopting a multi-scaled, methodologically varied approach, develops relevant data and perspectives, contributing to the increased possibility in future of a conclusive examination of Arctic climatic change and associated effects on reindeer.

- It highlights important aspects of the botanical and vegetation community characteristics.
- It produces a valuable vegetation map of the particular region studied using a variety of techniques, methods of which would probably be transferable to other studies.
- It highlights current attempts and future hopes for habitat assessment.

It does not present an authoritative botanical assessment of the region, provide the definitive vegetation map or mapping technique for this or other regions in Russia or produce a detailed model of reindeer habitat in light of climate change: an entire thesis could be written on any one of these three topics alone. This dissertation rather seeks to develop data and perspectives from multiple approaches in order to gain a more rounded, thorough understanding of a region in which little is currently known compared to other regions. In this case broad, comparative knowledge is an essential base and there is significant value in an approach requiring varied field and research experience and understanding, particularly in this age of specialisation.

5. AIMS AND OBJECTIVES

Considering the research questions summarised previously, the overall aim of this project is to characterise on multiple scales and assess under-studied landscape in the Barents region, with a particular focus on vegetation, and with potential climate change effects and reindeer habitat suitability in mind. Improved understanding of the landscape and of benefits and drawbacks of different approaches in scale are sought.

This research aims to provide a set of multi-scale data for a region in which current, detailed data have been absent, limiting assessment and understanding of the region’s ecology. A base for future additional, more in depth, complex ecological research, more akin to that possible in Scandinavian regions, is created.

Specific objectives and sub-objectives of this research are:

1. to develop a fine-scale landscape vegetation characterisation in which characteristics are understood with the most detail possible, at an individual species level
    a. to provide this data for a study region in Russia in which no existing detailed botanical data are available therefore providing new knowledge of local botany
    b. to provide an overview of regional landscape and vegetation community characteristics and influences that put the botanical data as well as the spatial data developed in the next scale in context
2. to develop an intermediate-scale spatial landscape vegetation assessment which expands the coverage region while maintaining a level of local detail and vegetation community information
    a. to provide these data for a study region in Russia in which no recent regional-specific spatial data exist and in which no spatial data on such a detailed level have been developed previously
3. to include existing coarse-scale land-cover assessments, created both as part of this research and independently, to examine broad, regional characterisation across a large area
4. to compare these three primary scales of landscape assessment in terms of
    a. individual value and data and detail lost or gained
    b. suitability for replication and future monitoring
    c. applicability to the assessment of potential effects of climate change in the landscape
    d. applicability to being able to assess reindeer habitat

5. to discuss factors other than vegetation that are critical in reindeer habitat determination in the landscape and provide an overview of current progress in habitat assessment and future potential

Implications of these research objectives include

1. provision of a database for future use of botanical analyses and spatially related vegetation community data, as well as descriptive geo-referenced photographs detailing vegetation species, communities and landscape details of this previously under-studied region in Russia
2. an improved understanding of what research is required in future to ensure we are prepared for changes that may lie ahead
3. the potential for additional, more complex research that is now possible as a result of this project's contributions

6. THESIS STRUCTURE

The thesis begins with two introductory chapters, this first one presenting the problems and overall theme, rationale, aims and objectives and relevant background information on reindeer and climate change. The second introductory chapter introduces the BALANCE Project, of which this research was a part, and details the study regions, both the BALANCE Project area and smaller field study areas within it in which field data were collected and more detailed assessments developed. Brief background information on the smaller, specific study region is provided.

The third chapter focuses on detailed botany, presenting species-level analysis data and vegetation community observations from a study area. The fourth chapter takes a step back and from a community viewpoint, develops a vegetation map of a larger study area, utilising various techniques and field data. The fifth chapter introduces broader-perspective regional and global vegetation data and compares it and approaches from the previous two chapters for a multi-scale assessment of relevance to reindeer habitat and climate change. These first three analysis chapters follow a logical progression from fine to coarse scale data, allowing differences in approaches to be readily understood. The sixth chapter expands the topic of reindeer habitat by addressing factors other than vegetation and their role in current and prospective assessments. A concluding chapter summarises the developments of the thesis and resultant advances towards resolution of the initial questions, and considers future research possibilities.

All raw botanical and vegetation-mapping field data and about 500 vegetation species, community and landscape photographs should be online, archived in the Scott Polar Research Institute files at DSpace@Cambridge. Further details about its contents are provided in Chapter 3, Section 3.1.

6.1 Overview of Analysis Chapters

6.1.1 Botanical Analysis

Plant communities, community structure and environmental influences are described, putting the study region and botanical data in context. Statistical analyses are developed to show distinct community divisions and the importance of particular vegetation species or species groupings in defining these communities. This most detailed level of analysis uses new data derived from traditional field-based, species-level botanical assessment. Fieldwork was conducted during summers 2003 and 2004 at a number of sites in the Vyucheiskii Kolkhoz in the Nenets Autonomous Okrug, northern European Russia (Figure 2.3 and 2.4). Field visits provided an understanding of 1) variation inherent in the vegetation of this tundra region and 2) details on the relationship between terrain and vegetation characteristics, important in understanding habitat use and quality. Knowledge derived from such detailed analysis is also useful in the following chapter.

6.1.2 Vegetation Classification

Vegetation communities were defined for a study region also in the Vyucheiskii Kolkhoz, through development of a thirty-metre resolution vegetation map. The study region is unusually heterogeneous, complicating classification development. To facilitate and improve the map various techniques were employed. Field data were also collected, primarily in 2004, to allow ground truthing of the classification. Statistical analyses were run on the data to examine the map's accuracy and quality. The final vegetation map produced covers an area of approximately 30 000 square kilometres and contains 26 classes of vegetation and land cover.

6.1.3 Multiscale Comparison

Introduction of existing regional and global land-cover assessments, with resolutions of one to five kilometres allows a comparison of three scales of landscape assessments when the results of the first two chapters are included. Strengths and weaknesses of each are highlighted and suitability to future analysis assessed. In particular the relevance of each scale of assessment to revealing information about potential climate change effects and reindeer habitat is discussed in detail.

6.1.4 Habitat Assessment

The final analysis chapter introduces additional environmental factors critical to reindeer habitat, beyond vegetation, which has been the focus of the previous three chapters. Factors include, for example, snow and ice cover, topography and associated characteristics, wind effects and insect harassment. The habitat assessment that was done as part of the BALANCE Project is described and suggested requirements for future, more in depth habitat studies provided.

CHAPTER 2 - RESEARCH CONTEXT AND SETTING

nalunaktuq*

*unpredictable, difficult to comprehend (Inuktituk)

1. OVERVIEW

This chapter serves two primary purposes. First it describes the greater context within which the research for this dissertation was done (a major European Union (EU) funded project) and second, it details the various study areas, ranging from the overall Barents region to smaller areas within it in northern European Russia.

2. BALANCE PROJECT

Research for this dissertation was developed in conjunction with the BALANCE Project (Contract number EVK2-2002-00169) (Climatic Change, Special Issue unpublished, http://balance1.uni-muenster.de), an inter- and multi-disciplinary research project funded by the EU in which a team from the Scott Polar Research Institute (SPRI), University of Cambridge participated. Certain aspects of this thesis research were, however, primarily or partially independent of the BALANCE Project objectives, specifically the botanical analyses and vegetation map development respectively, although field studies meshed with project-specific fieldwork. Other efforts were developed in conjunction with specific BALANCE objectives, such as the habitat analysis outlined in Chapter 6. Research components that were done in collaboration and not conducted entirely independently are stated, listing names of relevant colleague/s.

2.1 Overview

The goal of the BALANCE Project was to examine the vulnerabilities of the Barents region to climate change, incorporating a multi- and inter-disciplinary approach and through the development of integrative models and incorporating a network of feedbacks. Models were developed for the present and a series of three future time slices in which potential predicted changes could be assessed. This large, three-year (December 2002 - March 2006) project involved participation of approximately fifteen different research institutions in Europe, each project team with its own area of expertise. General disciplines incorporated into the project include terrestrial ecology and biodiversity, marine ecology and oceanography, freshwater ecology, forestry dynamics, socio-economics and political aspects, anthropology, hydrology and geology, vegetation dynamics, climate modelling and the aspect examined by SPRI, reindeer and reindeer herding. The SPRI component was the only within-institution multi-disciplinary team and involved natural scientists and social scientists with combined ecological, technical, anthropological and socio-economic knowledge, working in conjunction. The BALANCE study was an attempt to utilise integrative assessment modelling to begin to understand potential climate change dynamics and vulnerabilities across an entire region and all of its components.

2.2 Study Area

The overall Barents Region, including both terrestrial and marine areas, was the study area for the BALANCE Project as shown in Figure 2.1. The terrestrial area included most of Norway and Sweden, Finland and European Russia and the marine region included coastal and ocean waters off the coast of Norway around into Russian waters and stretched to Iceland. Models were developed on a grid with half a degree resolution and a Plate Carée Projection.

Figure 2.1. Outline of the BALANCE study region in the Barents region of Europe.

In assessing vulnerability of reindeer, only areas inhabited by reindeer were relevant, generally the regions of Norway, Sweden and Finland and European Russia from the Kola Peninsula and the Murmansk Oblast to the Ural Mountains above 60 degrees. Actual borders of reindeer herding lands can be seen in Figure 1.1, which shows the density of reindeer in the Barents region.

Detailed geographic, political, economic, cultural and ecological information about the Barents region is not included due to space constraints but limited general background information, as it pertains to reindeer, is included in Chapter 1. A few details on the specific area in Russia that is a focus of this thesis research are, however, included later in this chapter.

2.3 Objectives and Products

The primary objective of BALANCE was to assess the vulnerabilities of the Barents Region to climate change based on a common modelling framework for major environmental and societal components as well as on the quantification of linkages between these components through an integrated assessment model.

More specific objectives included the following:

- specification of environmental and societal vulnerability indicators and estimates of present environmental and societal vulnerabilities;
- refinement/development of impact models for specific components of the Barents system and (re-)assessment of the nature and strength of links between components and their quantification through an integrated assessment model;
- implementation of a regional climate model for the study region and assessment of climate change impacts for different time slices: 2020, 2050 and 2080;
- estimates of future environmental and societal vulnerabilities to climate change;
- implementation of a stakeholder-scientists collaborative and assessment of perceptions and views of local residents on climate change.

The BALANCE Project results reflected the objectives and included:

- present and future environmental and societal climate change vulnerability indicators and quantified vulnerabilities to climate change;
- various individual models describing major components of the Barents Region;
- an integrated assessment model for the Barents Region,
- a regional climate model for the Barents Region and expected climate change impacts for 2020, 2050 and 2080;
- a WebGIS based information system representing major results of BALANCE; a prototype of a decision support system addressing climate change vulnerabilities of the Barents system.

2.4 Vulnerability of Terrestrial Ecosystems

2.4.1 Objectives

Specific objectives of the terrestrial ecosystems component were determined:

1. To identify relevant components of terrestrial ecosystems and vegetation, reindeer husbandry, socio-economic parameters, and policies and regulations, and construct models of the interactions between them.
2. To predict northern ecosystem vulnerability to climate change in different global change scenarios and at different geographical scales within the Barents Region.
3. To link predicted future ecosystem distribution and properties to hydrological, reindeer husbandry and forest pest models.
4. To estimate the influence of changing vegetation distribution and patterns on the hydrological response to climate change.
5. To assess the impact of changing hydrological conditions on the sub-arctic ecosystem and economic activities in Northern Scandinavia.
6. To construct a model of spatial reindeer demographics on the project's common 20 km grid, based on reindeer responses to predicted changes in vegetation, which will in turn generate scenarios for reindeer feedbacks to vegetation
7. To assess presently observable shifts in biodiversity of major species and to utilise this information for the specification of past and present ecosystem vulnerability.

2.4.2 Components

A requirement for all tasks dealing with environmental and societal vulnerabilities was development of future climate change scenarios that provided information on appropriate temporal and spatial scales. The necessary climate parameters were provided by the Max Planck Institute (MPG) in their Regional Climate Model. Baseline models were developed with a spatial resolution of 0.5° and 0.16° for present day (1990) situations in order to provide a test of the model success, and at 0.5° for future climate change scenarios in 2020, 2050 and 2080. The feedbacks between changes in land surface conditions and the regional climate were investigated in a re-run of the scenario using new surface conditions derived by the BALANCE model partners specified for the expected climate around 2020 and 2050.

Relevant details from the vegetation, hydrology and climate model components are explained in Chapter 6.

2.4.3 Reindeer Component

Research at SPRI was unique within the BALANCE project in that the SPRI project team represented both natural science and social science, indicative of the intricacies inherent in examinations of reindeer and reindeer habitat. Interactions pertaining to the reindeer component only are shown in Figure 2.2. The fine vegetation distribution, a primary focus of this thesis, is addressed in Chapters 3 and 4, while the coarse vegetation distribution and the relationships between it and the fine distribution are addressed in Chapter 5 (the right hand components in the diagram). Chapter 6 expands the focus beyond vegetation and opens up the assessment to climate, hydrology and other variables (the left hand components of Fig. 2.2 and also represented in Figure 6.1).

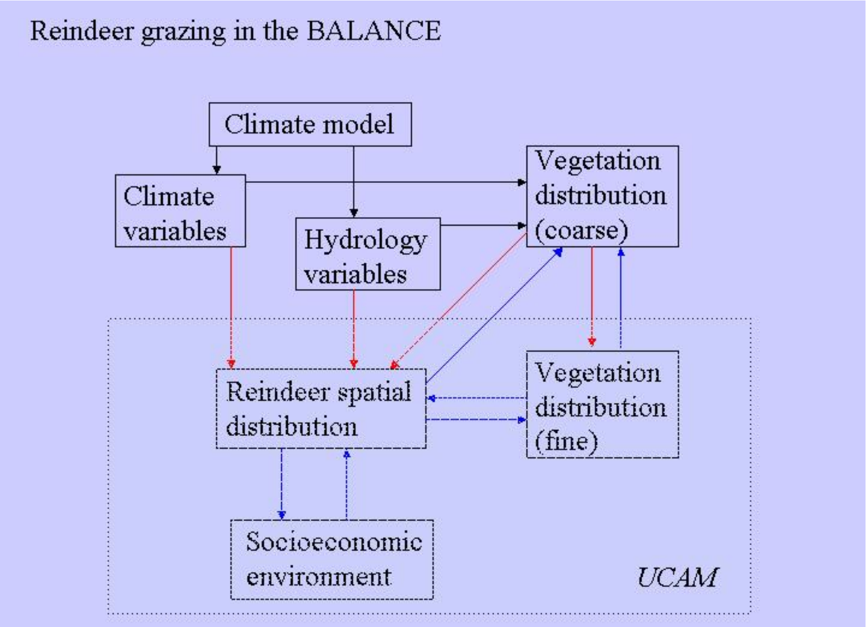


Figure 2.2. Schematic diagram of reindeer component within the BALANCE research and associated connections and model feedbacks.

Linkages between the components shown in Figure 2.2 are essential. Physical factors of climate, hydrology and vegetation all directly impact reindeer and reindeer herding as does the socio-economic environment which includes politics and shifts in government, changes in laws, effects of economic changes, social structure and trends, etc. Temperature is the primary climate variable, with effects of temperature changes differing among seasons. Hydrological variables are highly correlated with climate and specific variables of relevance to reindeer and herding are snow and ice cover and river flow. Shifts in vegetation distribution and abundance would both impact reindeer. Just as these three physical components and the one socio-economic component affect reindeer, the reindeer component will in turn affect each of these four components, providing the key feedbacks in this part of the Barents region terrestrial ecosystem. Additional factors such as forestry or insect pests and diseases could add complexity to the system.

Natural Sciences

The natural science component of the SPRI work focused on collection of herding and pasture data for reindeer in the region based on existing government and other statistics; on development of vegetation mapping data from the field and a resultant vegetation classification (on a more detailed level), to serve as a comparison of scales to the BALANCE regional model assessment; on collection of detailed botanical and vegetation data, separate from the BALANCE project but able to be collected coincident with the other field data; and on development of model interactions with climate, hydrology, vegetation and biodiversity primarily.

Social Sciences

The social science component consisted of anthropological field research on a number of field visits to study areas within the NAO in the Barents Region and subsequent analysis of data and findings to determine driving forces behind the current and potential future socio-economic situation. Within the BALANCE model, socio-economic linkages were of equivalent concern to physical ones.

2.5 Summary

The BALANCE Project was an innovative, complicated attempt to utilise integrative modelling to begin to understand potential climate change dynamics. Opportunity for improved, further developed work that can build knowledge and better prepare us for what may lie ahead exists with this as a foundation.

3. THESIS RESEARCH

The multi-scale approach to landscape assessment in this thesis requires study areas and analysis of three primary different sizes and scales: 1) fine scale, small area (Chapter 3), 2) intermediate scale, local regional area (Chapter 4) and 3) coarse scale, broad regional or global area (Chapter 5). Field data were collected in summers 2003 and 2004.

3.1 Study Areas

The broadest level of assessment did not require fieldwork or provision of personally derived or collected data but instead relied on existing spatial data at regional, *i.e.* Barents and circumpolar, and global levels. Subsets of these data, defined by the area in the intermediate scale assessment (described below), were used in comparative examination of the three scales of assessment.

The intermediate scale of assessment required a defined study area in which to develop a vegetation map and collect ground truthing data in the field. Figure 2.3 shows this study area (defined by the box) in the Nenets Autonomous Okrug and its location in northern European Russia. The NAO includes the northern area of the Arkhangelsk Oblast (north of the brown borderline) and the region between the Komi Republic (yellow region), and the coastline. It is divided into Kolkhozes for administrative purposes. The intermediate study region includes the Vyucheiskii Kolkhoz (as outlined in Figure 2.4) as well as additional land in the south of the study region and to the east of the Pechora River and delta.

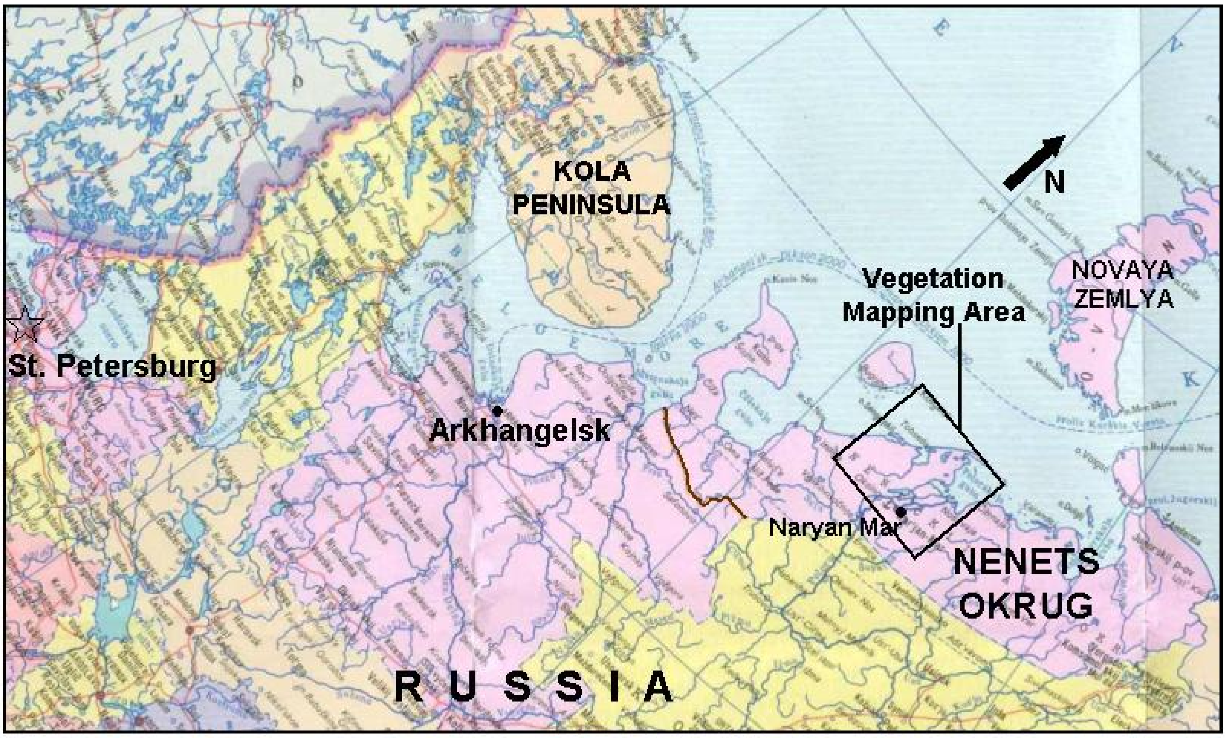


Figure 2.3. Map showing area included in vegetation mapping component, within which field sites were located.

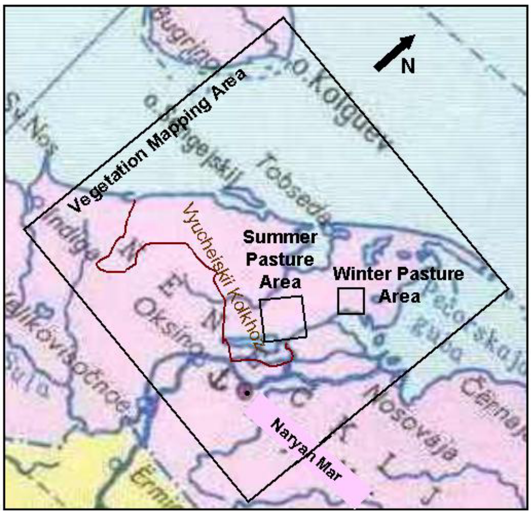


Figure 2.4. General botanical analysis study areas in the Vyucheiskii Kolkhoz territory and within the intermediate vegetation mapping study area.

Finally, the finest scale assessment comprising the field-based botanical studies was carried out within two small study areas within the vegetation mapping area, shown in Figure 2.4. The boxed outline located in the south shows the location of analyses done in summer pasture and the outline further north above Korovinskaya Bay (see Figure 2.5 for geographical details) those done in winter pasture. Each Kolkhoz is divided into brigades for reindeer herding management and administration. The botanical fieldwork was done within the territory of the Fifth Brigade in the Vyucheiskii Kolkhoz, the outline of which is shown in the map (Figure 5.7) of seasonal pasture areas.

3.1.1 General Characteristics

The Vyucheiskii Kolkhoz occupies the central northern area of the NAO and covers approximately 10 000 square kilometres. Within it, the Fifth Brigade territory occupies the easternmost region, bordering Golodnaya Guba (Lake) and the Pechora River delta and stretching northeast past Korovinskaya Bay to the coast (Figure 2.5). Naryan Mar, the capital of the NAO, lies just to the southeast of the kolkhoz and Nelmin Nos, the Kolkhoz administrative capital is located near the southeastern border along the Pechora River (Figures 2.3, 2.4 and 2.5).

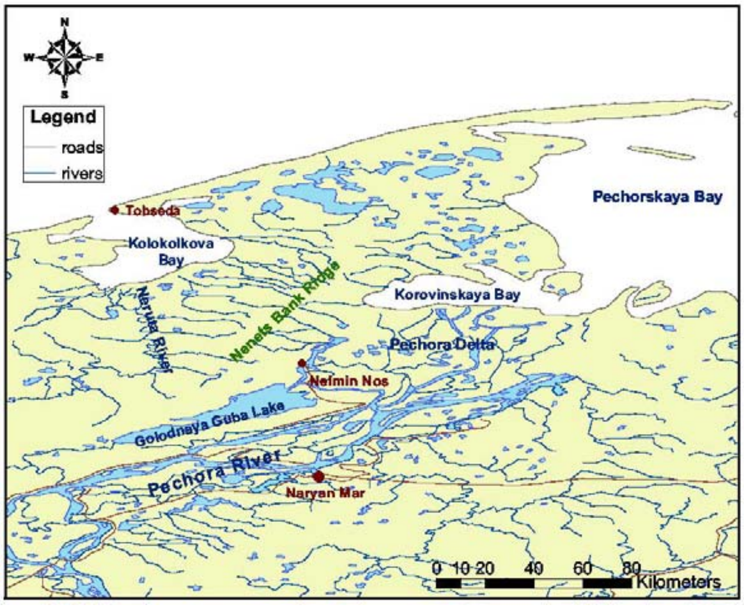


Figure 2.5. General region of the Vyucheiskii Kolkhoz showing main geographic and topographic features.

3.1.1.1 Climate

Climate in the study area is typical of southern Russian Arctic tundra regions, characterised by low winter temperatures, cool short summers and limited precipitation. It is influenced by the Arctic Ocean, ensuring cold winters and relatively short warm summers. Snow is usually present from October to June.

Regions within the NAO have different climate regimes: average January temperatures range from -12 C in the southwest to -22 C in the northeast and average July temperatures from +6 C in the north to +13 C in the south. In Naryan Mar the mean summer (July) temperature is 8.6 C, the mean winter (January) temperature is –17.5 C and the annual mean is –5.6 C. The mean annual precipitation is 338 mm and the mean depth of snow 370 mm (Virtanen et al. 1999). At the Barents Sea coast, about 100 kilometres north of Nelmin Nos, annual precipitation is 400-450 mm with a peak in August-October (http://ingrid.ldgo.columbia.edu/SOURCES/.NOAA/.NCDC/.GCPS/.MONTHLY/.STATION.cuf/, Baker et al. 1994)

Temperatures during fieldwork in July-August 2003 ranged from –2 C to 34 C but more typically from approximately 8 to 20 C, with average daytime highs of about 12 C. In July-August 2004 the absolute range was similar, extending from above 0 C to 33 C approximately and the normal range virtually the same also although the mean was probably higher due to sustained warm periods (climate station data unavailable to test). July and August are summer seasons in the Arctic tundra. Snow has essentially melted, streams and rivers are flowing, low lying areas previously flooded due to late snowmelt are drying out, the tundra is green and plants are at their peak. In July plants are flowering while in August the flowering generally ceases and it is possible to see early signs of autumn and a shift from growth to senescence. Plants may begin to produce berries in August depending on recent temperature and moisture conditions. Temperatures are above freezing, although late in August frost and below freezing temperatures can occur.

3.1.1.2 Topography and Land characteristics

The general region in which fieldwork was conducted is heavily influenced by its surrounding topography, primarily the Nenets Bank Ridge, which separates the two main drainage systems, the Pechora and Neruta (Figure 2.5). The region has a dense network of smaller rivers and lakes in addition, particularly in the north. In turn, soil moisture and drainage, microclimate, snow cover characteristics and vegetation distribution are all influenced. In the northern part of the region sea ice and winds add their influence. Other typical Arctic characteristics such as a harsh climate, short growing season, permafrost and thawing/refreezing effects play their roles. In general the region is characterised by gentle terrain, with low lying areas, plateaus and flat hilltop regions, gently sloping hills and flat or near flat tundra expanses. A few small steep stream valleys and gorges exist near the ridgeline (Nenets Bank Ridge). The range of elevation in the summer and winter study areas are roughly 0 m to 100 m and 0 m to 30 m respectively. The area is located within the zone of discontinuous permafrost (Brown et al. 1997) and permafrost is sporadic only. Bedrock is Mesozoic and underlying soil is generally sandy (fluvial) or glacial till (Virtanen et al. 1999).

3.1.1.3 Vegetation

The study area is situated in the Malozemelskaya Tundra within the low Arctic zone. Generalised vegetation communities present in the region include stands of trees (in the south only) and tall shrubs, stands of smaller and dwarf shrubs, grassland, herb slopes, mires, various moist and dry tundra heaths, scrub vegetation and wind-blown exposed or unvegetated areas. Heath communities, particularly moist heaths, dominate.

On well-drained elevations and slopes, dwarf-shrub (*e.g.*, birch (*Betula nana*)) or ericaceous heaths (with and without hummock formations) and herb-rich grasslands are found. Exposed ridges are sand or lichen-dominated. Snow beds are colonised by *Salix herbaceae*. Willow (*Salix* spp.) scrub and shrub vegetation are found alongside streams, in protected depressions with herb slopes on the side, or in patches in the tundra sometimes bordering lakes. Sphagnum and moss mires in low-lying areas are dominated by *Carex* spp. and *Eriophorum* spp. Occasional tussocky regions suggest frost influence. According to Kremenetski (1998) and MacDonald (2000), *Picea* forms the regional treeline in this part of Russia, but fieldwork was located too far north to confirm this: trees were only observed from air. More detail on vegetation is provided in Chapter 3.

3.1.1.4 Other Fauna

Other vertebrate herbivores present in the region include lemmings (*Lemmus* sp.*; Dicrostonyx* sp.), voles (*Microtus* sp.), ptarmigan (*Lagopus* spp.) and Arctic hares (*Lepus arcticus*). While present, large carnivores such as wolves (*Canis lupus*), brown bears (*Ursus arctos*), and wolverines (*Gulo gulo*), all of which are a predation threat to reindeer, are rarely seen in the territory of the Fifth Brigade. Red (*Vulpes vulpes*) and Arctic foxes (*Alopex lagopus*) are more commonly seen. Other mammals include martens (*Martes* sp.), and ermine/weasels (*Mustela* sp.). Raptor species include golden eagles (*Aquila chrysaetos*) (http://www.grida.no/ecora/pdfb/rfrs/_Toc2147526). Wild reindeer (*Rangifer tarandus)* are not found in this region of Russia.

3.1.1.5 External influences

The territory of the Fifth Brigade has not been subject to much development or other influences beyond the effects of reindeer herding, which include reindeer tracks, human made trails from sledges, and old or recent tank roads that connect the territory to Nelmin Nos. Presence of oil and gas in this particular region of the NAO is limited (see Figure 3.4). Other regions of the NAO, and indeed Russia, by contrast have significant existing or potential resources.

3.1.1.6 Politics and Economics

The NAO is a semi-autonomous region, belonging to the Archangelsk Oblast. It forms a border to the south with the Komi Republic, to the southwest with the Arkhangelsk Oblast, to the north-east with the Yamalo-Nenets Autonomous Okrug and has shorelines on the White, Barents, and Kara seas. It covers a total area of 176 700 km^2. The NAO was formed in 1929 and includes one city, Naryan-Mar (pop. 18 611, 2002 census) (http://www.world-gazetteer.com) founded in 1939, two towns, and sixteen rural administrations. The population is 48 100 (59.7% urban) (2004), and the population density is 0.3 people per km^2 (http://www.kommersant.com/page.asp?idr=370&id=-27) The Governor heads the Administration of the Okrug and is the region's highest official.

The NAO is part of the Northern economic district of the Russian Federation. The leading economic activities are reindeer herding, fishing, and hunting. Fur farming, forestry (further south) and the fuel and food industries are other developed sectors. Oil, gas, and coalfield developments are growing (see Figure

3.4) and the presence of oil companies is increasing. Only a small portion of the agricultural land is cultivated with limited crops: dairy farming and reindeer herding are the most important sectors. Tourism is beginning to develop.

3.1.1.7 Culture

The Nentsy have a population of 34 190 (1998) (Gall 1998) and live both east and west of the Ural mountains, dividing them into an European and a Siberian group (Dolgany). Reindeer herding is their primary occupation and cultural identity marker.

3.1.2 Reindeer in the Vyucheiskii Kolkhoz

(Information taken from an interview with Lidia Mikhailovna Taleeva, Director of the Vyucheiskii Kolkhoz Reindeer Herding Unit, in August 2003 (L. Taleeva pers. comm.))

The Vyucheiskii Kolkhoz pasture can support about 11 000 reindeer, about 1% of the Barents region reindeer population, although herders believe the number is higher. At the time of fieldwork in 2003/2004 about 9 000 reindeer occupied the territory. Each year about 1 500 reindeer, or 10-20% of the total in the Kolkhoz are reported ‘lost’ due to poaching, theft, and herders losing track of the animals due to animals wandering or becoming stuck in shrubs or mires, or herders affected by alcohol and unable to manage their animals. Of the 9 000 animals, 1 500 or so are privately owned animals of which the Second, Fifth and Seventh Brigades own a disproportionately high number (a herder’s salary depends on the number of animals he has, private or Kolkhoz owned). The reindeer number estimates are, however, not accurate: a census is supposed to be conducted twice a year, in September and in June, but a full count was not successful in June of 2003 as there was not enough money to support it and only Brigades Two and Seven managed a count.

Currently there are five brigades in the Kolkhoz: The first, second, fifth, sixth and seventh (comprising the combined third and fourth brigades who united in 2000 because individually they did not have enough reindeer to sustain a brigade). In 1991 or 1992 there were seven brigades with a total of about 12 500 reindeer but the number of animals and brigades has declined. Each brigade has a similar territory size and similar distances for migration, however the direction differs: brigades generally migrate from north to south in winter but the fifth brigade moves in the opposite direction, from south to north in winter.

All of the kolkhoz pasture is thought to be in good condition, especially since the number of reindeer has been declining in recent years. The Fifth brigade in fact has some of the worst land because of the large amounts of sand and the prevalence of mires (see Chapter 3 for landscape description). Other Brigades have better pasture for a number of reasons: proximity to the sea (more wind and fewer insects; higher salt content (believed to be good for the reindeer); more hills (better for wind and insects); and on the whole better pasture in terms of forage type and quality. Despite this disadvantage, the fifth brigade is currently the most successful in terms of number of reindeer.

Seasonally, summer is a time of very low pasture stress: forage is plentiful and pastures large. In autumn the stress increases but the herds migrate so no pressure is put on any particular pasture area and there is still enough forage. Even in winter, a time of typically greater pasture stress, the current reduced number of animals ensures that winter pasture quality remains high and lichens are available. Furthermore, fewer animals results in less trampling of lichens that may not be eaten in a particular season.

There is no longer enough money for support of the herders. In Soviet times things were easier: there was support with subsidies and helicopters available for transport. Oil and mineral development would bring in money and provide support (*e.g.*, resumed helicopter use) but there is no current activity on the Kolkhoz territory and so the Kolkhoz, unlike other regions in the NAO receives no oil income.

Some herders have tried to go private and separate themselves from the Kolkhoz. They are entitled to take their own private reindeer (most herders have a few) and a certain number of the Kolkhoz animals that form each herder's individual 'stock' and can rent pasture from the Kolkhoz for their personal use. The 'stock' number is determined by the number of years a herder has worked for the Kolkhoz and the total number of reindeer (and herders) in the herd.

Each brigade has a chief, or head herder. The chief decides how many herders are in his brigade, up to a maximum of eight. Fewer herders mean more money for each but more work. With the shift system, *i.e.* herders spending half of their time in the tundra and half in the village, there will be a maximum of four herders with the herd at a time. The shift system was implemented in 1975 and has not changed since then.

The future of reindeer herding is uncertain. Reindeer numbers are declining and young people are less interested in herding when they see how difficult the life is. Also, they are required to study and go to school until the age of sixteen now, and consequently are only exposed to herding methods and traditions before school age and later, in summers when they go to the tundra with their family or fathers (when they too are not 'off shift' in the village). Loss of knowledge and expertise can result, potentially problematic for the future of herding if herders lose vital skills and awareness. Government and other socio-economic factors will influence the direction of reindeer herding in the region in the future.

3.1.2.1 Afterword

I received word in May 2006 from Dr. Florian Stammler (Arctic Centre, Rovaniemi; formerly SPRI) who had returned to the NAO and the Vyucheiskii Kolkhoz for additional work (on a different project) that the Kolkhoz had just become bankrupt and the herders no longer had an administration.

CHAPTER 3 – BOTANICAL ASSESSMENT AND ANALYSIS OF TUNDRA SPECIES IN A REGION OF THE VYUCHEISKII KOLKHOZ

> “...The lovely arctic daisy with many blessed companions; charming plants, gentle mountaineers, Nature's darlings, which seem always the finer the higher and stormier their homes.”
>
> John Muir, *Our National Parks*

1. INTRODUCTION

1.1 Background

As stated in Chapter 1, there is a scarcity of current environmental data in Russia, which in contrast to other Arctic countries, in particular Scandinavia, limits the potential for understanding and analysis of ecosystem components and dynamics. There remain expansive areas for which basic ecological data are not available, or are out of date, having been collected during Soviet times. Alternatively, if data exist they may be inaccessible, never analysed or of insufficient detail or technically outdated for current demands. The excerpt below from the Caspian Environment Programme Report 2005, Part 2.2-Status of Flora and Fauna (National CBD Report Russia) (http://www.caspianenvironment.org/biodiversity/rus/part21.htm) confirms the situation.

> Till now no special master files to characterize flora diversity of Russia at a species level have existed. That is why our judgment had to be based, as a rule, on materials of a more general scope which deal with the territory of the former USSR. (p. 1)

Given the global changes that northern ecosystems are facing and will face, in particular, climatic change with its predicted Arctic magnification and feedbacks (ACIA 2005), the provision of basic ecological data is likely to become even more critical as we require not simply an understanding of current and typical Arctic ecosystem processes and interactions, but the ability to assess potential shifts and mitigate problems.

In particular, knowledge of flora is important, not only in considering environmental change, but reindeer as well. Reindeer are a major ecological, socio-economic and cultural component of the circumpolar north (as detailed in Chapter 1), and a primary herbivore in much of the Arctic. The roughly one million reindeer living in the European Arctic consume substantial biomass, roughly estimated as 760 kg/animal/year, more than ¾ of a million tonnes (dry matter) over the Barents region as a whole (Rees et al. in press).

In this chapter, previously undetermined detailed, baseline botanical data for the study region in the Vyucheiskii Kolkhoz are presented and analysed and specifics on species and community structure and influences are described. Where substantial gaps exist in even basic knowledge, traditional field-based data collection can provide valuable information, allowing an understanding of the basic ecology of a region. To further the utility of baseline data, complex analyses can be developed.

1.2 Rationale and Applications

Detailed botanical assessment provides valuable, new, specific data on vegetation species, communities and their composition for this region of Russia where currently none exist.

First, detailed species and community data enable a fine-scale assessment of vegetation and the landscape, as part of the overall multi-scale assessment of this research. Observations and details described here about vegetation community composition and structure can also provide information useful to the following vegetation mapping chapter (4) which will build on this detail and broaden the scale of analysis.

Second, botanical analysis data provide information necessary in understanding the composition of reindeer habitat. Knowing regional botanical characteristics is important in the process of understanding the pasture lands of these herbivores, examining vegetation availability and considering how potential changes in the environment and plant communities may affect reindeer in the future.

Third, knowing current vegetation species distribution and community composition, thus establishing a baseline, is important when trying to assess potential or actual ecological change. Climate change, for example, in the longer term, has the potential to shift the vegetation species balance; there is growing evidence that this is already occurring with northern advancement of shrubs (Sturm et al. 2001, Hope at al. 2003) and increases in grasses and decreases in lichens (Cornelissen et al. 2001, Rees et al. 2003, Kullman 2004).

Detailed, recent botanical information does not appear to be available for this region of the NAO. The only spatial botanical information found is a vegetation map from 1974 (presented in more detail in Chapter 4 and shown in Figure 4.3). Botanical data are only available for a small region at the northern tip of land north of Korovinskaya Bay, beyond our specific study area (Figure 2.5). General plant species lists do exist but they cover a broader region, which supports additional species not found within our specific study area. Sparse local information is available in the form of notes, glass slides and an amateur book (handmade) of pressed plants but is generally outdated and not readily accessible.

Given the lack of botanical data for the region, limited in both detail and coverage, and the multi-fold applications for new, up to date, detailed data as part of and beyond this research, the provision of detailed botanical data has significant value.

1.3 Objectives

The primary objectives of this research component are to

1. examine, through fieldwork observations and traditional field-based vegetation analysis, the detailed botany of the study region within the NAO;
2. document and explore relationships between vegetation species and community composition, and structure of the communities as a whole through observation and statistical analysis;
3. create a detailed assessment that can be analysed as part of the overall multi-scale assessment;
4. provide previously unexplored or unavailable data and material collected as part of this research for future work and analysis, to augment the scarcity of recent ecological information in parts of Russia.

The observational and analysed information that will be provided and developed in this chapter is useful by itself for understanding the region's botany and botanical communities and also in conjunction with other types of vegetation data to develop a more complete understanding of the landscape. It also can provide data relevant to reindeer habitat and potential climate change, as explored in later chapters. The data from this chapter allow an assessment of the value of highly detailed, traditional field based analyses.

All species found in the region are identified wherever possible to create a comprehensive list of plants in the area. It is acknowledged that the list may not be complete but it successfully identifies most local species. Plant species are documented using a variety of means - identification, collection, illustrations and photography.

Sufficient information on community composition will be collected to provide details about vegetation communities and the species within them. Such information can be applied within and beyond the scope of this project following statistical and general analyses.

All raw data and some processed data (as appropriate) will be made available in suitable form for future application and development.

2. METHODS

2.1 Outline

Available information (as books, plant collections, notes and photos) on plant species in the region was located. Knowledge from herders relating to reindeer vegetation and forage was gathered, and insight gained through observations during fieldwork was documented. Botanical analyses were conducted over two seasons of fieldwork in the study region in the NAO during summer 2003 and 2004. The data were compiled and analysed both qualitatively and quantitatively to illustrate species found, general vegetation communities and their composition, and characteristics of the region affecting plant distribution.

2.2 Supporting information

2.2.1 Existing Data

Searches were done prior to going to and in Russia for existing botanical data in the Vyucheiskii Kolkhoz region of the NAO. Detailed research was conducted by a team of ornithologists from the Netherlands working on geese wetland habitat near Tobseda and Kolokolkova Bay (van der Graaf et al. 2004) and other vegetation work has been done within the protected reserve at the tip of the northern land area north of Korovinskaya Bay (Yasavey pers. comm.)(Figure 2.5). These areas, however, are markedly different from our study area as they are further north, on an exposed coast, and subject to great influence from sea ice, ocean winds and other maritime influences. The landscape is different, in addition, comprising primarily wetlands, which support the substantial bird life found there. A vegetation map from 1974 (Isachenko et al. 1974) (described in more detail in the following chapter) exists but the data it provides are on too general a scale (half a kilometre resolution approximately) to be of application in a botanical study. The class divisions are clearly designed from a botanical viewpoint and relevant data must have been used to create the map, however, these data are not known.

A number of general Russian botany books exist, easily obtained in Moscow’s academic and scientific bookshops, but none were found with an explicit focus on our region. Books found, including those in Naryan Mar and Nelmin Nos (Dmitrieva et al. 1982, Karev 1952, Karev undated, Anon) were too general and outdated. ‘Green Books’ such as the ‘Green Book of Siberia: Rare and Requiring Protection Plant Communities’ (Koropachinsky 1996) do exist but again coverage is more general than the study region. In Naryan Mar a few days were spent in the library within the research building that housed our host, Yasavey (Association of the Nenets People). We discovered old unpublished scientific notes from the 1950s and 1970s detailing some of the plant species of the region, two collections of glass slides of plants and of lichens, and additional information with drawings and photos of some plant species. Detailed notes were made of all of this information and illustrations drawn. In Nelmin Nos a pamphlet on local medicinal plants were obtained. Following our fieldwork, we found a book of pressed local plants produced by a local woman in Naryan Mar. This unofficial, unpublished information was perhaps the most useful, at least providing a glimpse of what to expect in the field, although its potential is limited: the notes and slides are outdated and nearly impossible to find, located in unarchived storage at the research library in Naryan Mar, and the pressed plant book was made from plants collected south of the study region in the vicinity of Naryan Mar and contains misidentifications.

2.2.2 Reindeer Herder Knowledge

Botanical and plant species details, particularly as they relate to reindeer, were sought from the herders to supplement the scientific quantitative (and qualitative) data collection. Formal and informal discussions were held with herders of the Fifth Brigade.

Upon our arrival in the tundra in 2003, Tanya Nogatisy, the chumrabotnitsa (tent/camp worker) accompanied us on a reconnaissance and species collection visit and contributed her knowledge and opinions on plant uses, reindeer habits and plant preferences. Upon learning that we were examining vegetation, herders sometimes approached us with information or a plant in hand, where to find it and information about it. Interviews were held with the herders of the Fifth Brigade in both 2003 and 2004 to learn more about the reindeer’s vegetation habits and requirements from the herders’ perspectives. To enable our work to be better understood our data collection methodology was explained to the herders.

2.2.3 Reconnaissance and Species Collection

The primary field task in this part of the project was to carry out detailed vegetation analyses in the study region. However, there was value and necessity in gaining familiarity with the region first: its topographic features and influences on vegetation; its vegetation communities and their distribution patterns; and species diversity and particularities. Observing reindeer, and their grazing patterns and selections, was also important in understanding botanical relevance to reindeer.

Two initial reconnaissance trips of the surrounding region to gain familiarity with species present and observe general vegetation communities were made in 2003 prior to beginning data collection, one on my own and one with T. Nogatisy (mentioned above). A similar trip was made in 2004 so that botanist Dr. Christian Bay (Botanical Museum, Copenhagen) could develop an understanding of the vegetation during his first field visit to the region. During the 2003 trips, specimens of each different species encountered were collected for immediate labeling and compilation into both a photographic and plant press collection. Where possible flowering parts, leaves and roots were included to make identification and confirmation of species easier. Additional specimens were collected throughout fieldwork in both 2003 and 2004 to add to the photographic and plant press collections. Figure 3.1 shows a random selection of photographed and pressed species. A few species were not collected for photographing but instead photographed in the field. Understanding of the vegetation communities present in the region and of the general trends in composition and species distribution was improved throughout the periods of fieldwork and by the end of two seasons, an awareness that allowed a general assessment of the botanical characteristics of the region was gained. Observations of reindeer pasture use were made whenever possible over the two field seasons.

All of the species observed and identified in the field in both 2003 and 2004 were noted and a species list compiled. Some final identifications were made upon returning from the field after additional consultation with botanical references. A few identifications to species remained impossible. The following additional information was also noted: presence in summer and /or winter reindeer pasture, habitat type found in (*e.g.,* mire, moist heath, herb slope), and any additional notes or comments such as grazing evidence.

Figure 3.1. Assortment of plant species photographed and pressed to create a resource collection (Photo IDs clockwise from top left: 11-09; 13-33; 11-03; 11-06; 13-37; 11-07).

2.3 Vegetation Analyses

2.3.1 Study Sites

Data for the detailed botanical analyses were collected in summer 2003 and 2004 from two primary study areas within the territory of the Fifth Brigade of reindeer herders belonging to the Vyucheiskii Kolkhoz in the NAO (Figure 2.4), the first in part of the brigade’s summer pasture and the second in their winter pasture. The summer pasture area was visited during fieldwork in 2003 and 2004, from July 13 to July 27 and July 17 to July 31 respectively, and the winter area only during the latter few days of the 2004 period from August 2 to August 5. Additional details about the study region (geography, topography, climate, flora and fauna, land use) are provided in Chapter 2.

Field camp coordinates in 2003 were 68.1302 N and 52.7507 E (Datum WGS84). In 2004, two summer field camps were used as we migrated with the reindeer herders: the first at 68.154 N and 52.760 E (Datum WGS84) and the second at the previous year’s camp. The coordinates of the 2004 camp in winter pasture were 68.385 N and 53.469 E (Datum WGS84). The summer camps were approximately thirty kilometres northwest from the town of Nelmin Nos and the winter camp approximately 70 kilometres northeast across Korovinskaya Bay. The summer pasture study area, about 700 km^2 in total, was occupied by reindeer and herders at the time of fieldwork while the winter pasture study area, about 300 km^2 in total, was not and had not been occupied since the previous winter (2003-2004).

Vegetation analyses were done within radial walking distance of the camps as no other form of transport was available. Due to the difficult often hummocky or wet terrain, large tracts of impassable shrub and mire vegetation and the presence of many lakes, travel across the tundra was slow, typically approximately 2 km/hour walking speed. Routes were almost never direct. The closest analyses were done at or near to the camps, where vegetation was often disturbed or affected by reindeer, and the furthest at a distance of approximately 15 km in summer pasture and 10 km in winter pasture. Some of the more distant summer sites chosen were in abandoned pasture no longer used for reindeer grazing while many of the sites showed some grazing influence.

2.3.2 Data Collection

All visually different major vegetation communities that were able to be distinguished and that, where possible, appeared to occur in patches large enough (at least 100 x 100 metres) to be distinguishable in the process of developing vegetation maps (Chapter 4) were analysed. By considering the vegetation mapping process in this botany component, collected data could be applied to both research components, increasing field efficiency, and providing the same data foundation, potentially valuable in the comparisons of scale that will follow (Chapter 5). Multiple analyses in each major vegetation community were done, with two or three being the bare minimum but additional analyses preferred where possible, time and accessibility being the limiting factors.

Vegetation analysis data were collected in both 2003 and in 2004. In 2003 only summer pasture could be visited and a total of 56 analyses were completed. In 2004 summer pasture (in the same region) was revisited and winter pasture was also analysed. A total of 19 analyses were completed in 2004, 7 in summer pasture and 12 in winter for a sum total of 75 total analysis sites. Figure 3.2 shows the location of the analysis sites, the larger cluster further to the south the sites in summer pasture and the smaller cluster to the north the sites in winter pasture.

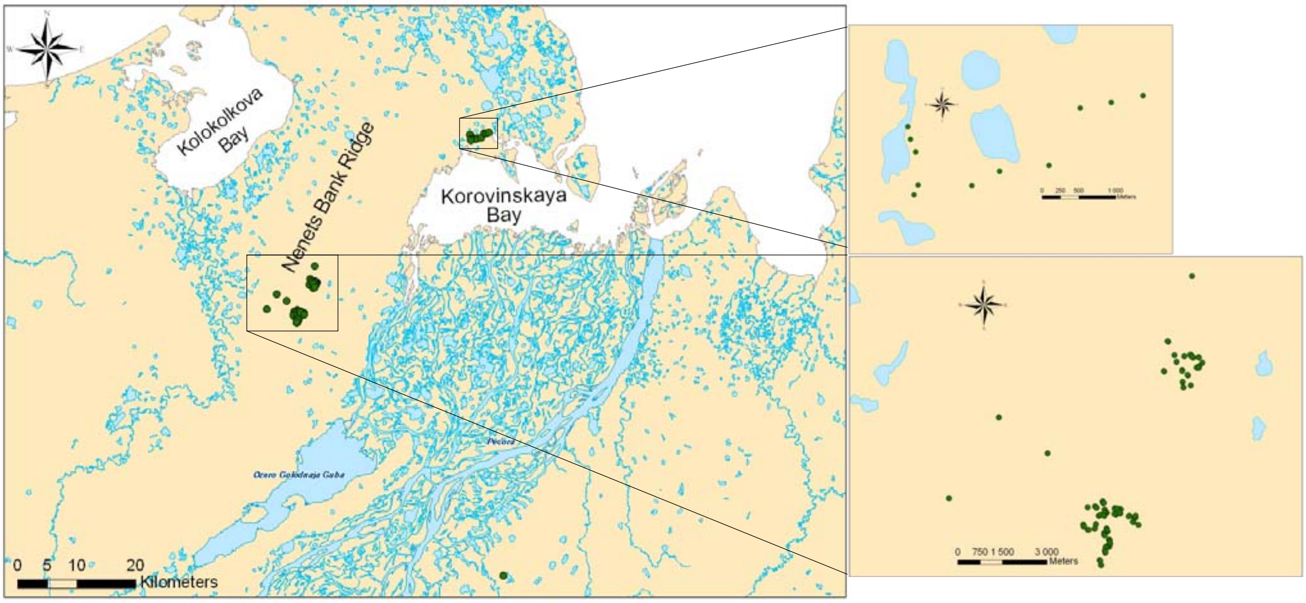


Figure 3.2. Location of the 75 botanical analysis sites in summer pasture (southern cluster) and winter pasture (northern cluster).

Data collection protocol was based on botanical fieldwork done in 1997 at Zackenberg Ecological Research Operations (ZERO) Station in Northeast Greenland (74° 28’ N) (Bay 1998) as part of a long-term monitoring programme of the vegetation communities and structure, on fieldwork done for Masters research on Alaska’s north slope in 1997 and 1998 (Danks 2000, Danks & Klein, 2002) and on further ecological and vegetation studies (O’Brien 1988, Wilson 1992).

At each analysis site, in addition to the botanical data collected, the following additional site characteristics and information were recorded: unique site ID, plant community or vegetation type, date, geographic coordinate location from a handheld GPS, aspect, slope (graded value of increasing steepness from 1-4), soil moisture (value of 1-3 of increasing moisture), average vegetation height (cm) and the primary vascular plant species present. Photographs of each site were taken and any evidence of disturbance or presence of reindeer was noted, *e.g.*, feces, footprints, browsed or grazed plants. Each analysis site contained two transects and this information was recorded for each transect. All analysis information was recorded by hand into field notebooks.

The two transect lines within each analysis site were oriented from south to north for consistency (unless a deviation was necessary and noted, *e.g.*, due to specific site characteristics such as flow orientation of a stream). Transect starting points were chosen at random within the vegetation site but near to the centre. A collapsible point frame constructed of PVC piping and string (dimensions 0.6m by 0.6m) and with 25 intersections for vegetation hits (5 rows by 5 rows of string, each 10 cm apart) was used in the vegetation analyses. The point frame was laid down every 5m along the two transects, on alternating sides of the line and beginning on the west. The total transect width was therefore 1.2m and length 25.6m. Figure 3.3 illustrates the sampling technique at a vegetation analysis site and Figure 3.4 shows the actual point frame used.

Two methods of data collection were employed, point hit counts and percent cover estimates. Point hits were recorded for the plant species (or other terrain description/object) found immediately below the intersections of the point frame strings when looking from directly above the intersection. With 25 point hits per frame and 6 frames per transect, each transect sample therefore consisted of 150 vegetation hits, for a total of 300 hits per sampled vegetation site. In the majority of cases the specific species of plant was identified. If field identification was not possible, the plant was collected for later identification by myself and/or by C. Bay and a temporary unique identifying name was given in the meantime. In the cases of lichens and mosses, broader categories were used and species level identifications were not made. Moss was divided into moss and sphagnum (living mosses) and dead moss, and lichens into fruticose, foliose, rock and dead lichens in vegetation communities where lichen was present but not dominant. In analyses of lichen heaths or any other vegetation community containing greater lichen cover, additional refinements were made and information collected included identification down to the genus level where possible, *e.g.*, *Cetraria* sp., *Cetraria* ‘brown’, *Thamnolia*, *Stereocaulon*, etc. Additional point hit results included the categories ‘water’, ‘algae’, ‘litter’, ‘dead’ (for general dead plant material), ‘organic matter’, ‘rock/gravel’ and ‘sand’. For use in the later statistical analysis, the number of hits of each plant species or other hit result was summed and recorded for each point frame analysis, then each transect and finally each analysis site.

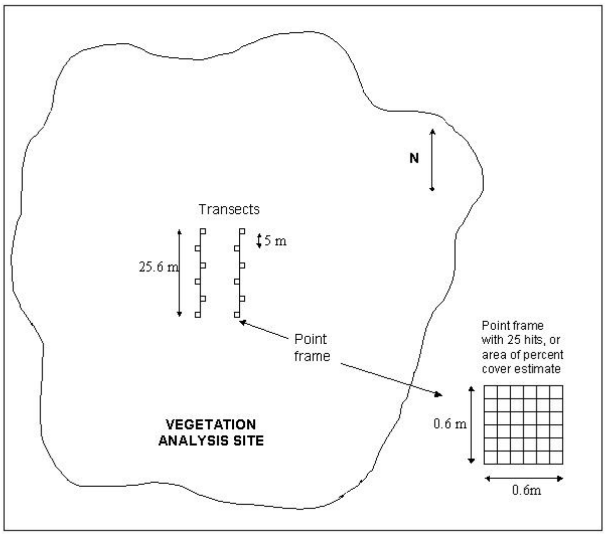


Figure 3.3. (left) Schematic representation of methodology for vegetation analysis, showing vegetation site area, two transects and their orientation, point frame locations along the transects and point frame details.

Figure 3.4. (right) Actual vegetation frame and transect tape measure (on moist heath vegetation showing *Rubus chamaemorus* and *Empetrum nigrum* dominating) (Photo ID 2,4-09).

In addition to the point hit counts, percent cover estimates were made for each point frame sample along each transect for 6 results per transect and 12 per vegetation site analysis. The degree of cover (%) of the dominant plant species and any others present to a degree of at least 1% of the total and also of mosses and lichens was recorded. Identification of species and categories was the same as in the point hit data collection. In mires and wet areas, the percentage of water was also recorded if applicable and likewise for sand in exposed areas. For consistency, independent estimates were made by the author and field assistant (E. Ilinova in 2003 and C. Bay in 2004), and a consensus reached before a final value was recorded. Percentages were summed to 100 for each point frame. However, some data collection inconsistency exists in the 2003 data: in cases where moss and lichen cover was great, separate 100% sums were recorded for moss and lichen. Individual percent cover values for each plant species or other ground cover identified (in the 6 point frame areas) were averaged across each transect yielding two averages per vegetation site.

An exception in methodology occurred with medium and tall shrub sites. Vegetation in these cases was both too tall and the individual plants too large for the point frame to be used effectively and so only percent cover data were recorded. Percent cover technique was also modified. The point frame area was too small and the point frame could not be placed on the vegetation and so two transects were walked. The shrub transects were approximately the same length but 5 large steps (author’s) were measured between assessment sites along the transect because it was not possible to use a tape measure. Percent cover was estimated for a 4m x 4m square (author standing in centre) (as in O’Brien 1988). Only shrub cover was estimated, ground cover was not included.

An example of all of the data collected at a vegetation site can be found in Appendix 1. The general site information, point hit data and percent cover data from an actual site are all shown with a key to the abbreviations used in data collection provided.

Two primary flora were used in the species identification (nomenclature) in this study, Tolmachev (1995-2000) and Böcher et al. (1978).

Additional flora and botany books were consulted as necessary. The two Russian botany books purchased in Moscow prior to the 2003 field season were utilised in the field as was ‘Flowers of Greenland’ by Feilberg et al. (1984) for its photographs. The notes and illustrations made from materials in the Naryan Mar library and Yasavey building offices were also consulted. For any questions on systematics or general plant information, Woodlands (1997) was consulted.

Even with the use of various flora and the plant collection it was not possible to identify to species every single plant found during fieldwork. Fourteen of a total 166 species (not including hybrid *Salix* spp. or mosses and lichens) remained unidentified to species. All plants were identified to genus, however. Some specimens were not in suitable condition to identify once out of the field because they lacked flowers, fruit or other distinguishing diagnostic characteristics, and other times a gap in the botanical literature caused problems. The three volumes of Russian flora (Tolmachev 2000) accessible do not cover all of the plant families. Additional flora were consulted to address particularly problematic or difficult identifications. These included Hultén (1958), Hultén (1968), and Mossberg and Stenberg (2005). Willow (*Salix*) shrub species were not all identified to species due to hybridization that was evident. Moss and lichen data were not recorded to species level due to gaps in the author’s botanical knowledge and experience in this area. Furthermore, more detailed information was not required by the project. Differentiating lichen species is important when considering reindeer; however, general distinctions in lichen species or species groups were made to the extent that the lichen's or lichen group's suitability for reindeer could be determined. Fruticose lichen is impacted by grazing while foliose and crustose lichen distribution is controlled by other factors (van der Wal et al. 2001a)

The total number of species contained in the vegetation analyses is not equal to the total number of species listed in the complete list that was developed since not every species observed was found during vegetation analysis.

Upon returning from fieldwork, all vegetation analysis data and any other information and notes were transferred onto computer. Analysis data was copied into Microsoft Excel spreadsheets and other field notes into Microsoft Word documents or other formats as appropriate.

2.3.3 Data Preparation

All vegetation analysis (point hit and percent cover) data from 2003 and 2004 were combined to analyse all vegetation community sites together. Transects 'a' and 'b' for each site were also combined. (The purpose of two transects versus one per site was to increase the area sampled and add randomness; the two transects are not independent and cannot be considered as separate sites.) The descriptive community names given to the vegetation sites in the field were added alongside the site ID and then according to this information, and using the site photographs to double check, each site was assigned a vegetation community classification type (a number) according to the hierarchical scheme used in the vegetation mapping procedure (Chapter 4). This classification is presented later in this chapter (Table 3.5, Section 3.6). For the purposes of the statistical analyses in this chapter, an additional order was added to the scheme representing disturbed vegetation ('18' in the table). These sites were distinct and while they could belong to existing vegetation groups in the scheme, it was decided to separate them in order to see if there was any statistically significant difference in vegetation at sites disturbed by reindeer.

Site data were divided into a four-level division scheme, the first and most detailed being the original site ID, the second the numerical classification type described above, the third a coarser numerical classification type, obtained by reducing the degree of hierarchy, and the fourth level grouping a word based description as follows: Exposed, Forb, Grassland, Mire, Heath-Mire, Heath, Shrub, and Disturbed.

For point hit data, the total number of vegetation sites (site ID) is sixty-eight and not the total seventy-five as it is for percent cover data. The seven missing point hit sites are tall and medium shrub sites. (As described previously it was not possible to analyse this vegetation with a point frame, and only percent cover data, using the modified methodology, were recorded for these sites.) When point hit sites were grouped into the detailed hierarchical scheme, twenty-two vegetation groups resulted. When grouped further into the broad numerical scheme the total was reduced to twelve. Finally the basic word description yielded eight groups. The percent cover data (75 site IDs) contained twenty-five vegetation groups at the highest level, fourteen at the next and then the same eight in the coarsest grouping, with the shrub sites that were not included in the point hit data accounting for the extra groups.

A similar procedure to create a five level vegetation type (versus site) division was applied to the vegetation species data from the vegetation analysis sites. The most detailed level contained all of the species level data or other land characteristic (*e.g.*, litter, water, clay). Next, data were separated into

Genus and after that Family. From there, broad (word based) vegetation type categories were used for the fourth and the fifth level groupings (Table 3.1). The categories were selected because they separated the plant species out into accepted botanical groupings and, in addition, each category has relevance to reindeer habitat suitability and selection.

The number of distinct vegetation type groupings at each level for the point hit data are as follows: Species, 85; Genus, 61; Family 35; Vegetation type category I, 11; Vegetation type category II, 7. For the percent cover data the equivalent groupings in respective order are 75, 53, 31, 11 and 7.

Table 3.1. Fourth and fifth level species type divisions (for point hits and percent cover estimates) into which all identified species were sorted.

VEGETATION TYPE CATEGORY I	VEGETATION TYPE CATEGORY II
Sedges	Graminoids
Grasses	
Ericaceous shrubs	Ericaceous shrubs
Deciduous shrubs	Deciduous shrubs
Forbs	Forbs and Equisetum
Equisetum	
Lichen	Lichen
Moss	Moss
Litter	Unvegetated
Trampled	
Unvegetated	

In the fourth level divisions, sedges included all *Carex* and *Eriophorum* species (Cyperaceae), Grasses members of the Juncaceae and Poaceae families as well as ‘standing dead’ which was not assigned to species categories. Ericaceous shrubs included the families Empetraceae, Ericaceae and Vacciniaceae, while Deciduous shrubs included Betulaceae and Salicaceae. Forbs included Boraginaceae, Caryophyllaceae, Compositaceae, Geraniaceae, Lilliaceae, Onagraceae, Orchidaceae, Plumbaginaceae, Polemoniaceae, Polygonaceae, Ranunculaceae, Rosaceae, Saxifragaceae, Scrophulariaceae, Violaceae, and a general forbs category for any unidentifiable species. Equisetum comprised the Equisetaceae species. The Lichen division, containing terricolous lichens only, included all of the Crustose, Foliose and Fruticose lichen as well as lichen noted as dead (generally Fruticose). Fruticose lichens are the most important for reindeer habitat and also the most dominant when present and so it was decided there was not a need to distinguish between lichens in this categorization since the presence of other types was so limited. Important dominant lichens include *Cetraria* and *Cladina* species, such as *Cetraria islandica* and *C. nivalis*, generally preferred and more highly digestible than less preferred *Stereocaulon* species for example (Storeheier et al. 2002). Moss included moss, sphagnum moss and dead mosses. Litter was simply vegetation that was no longer rooted in the ground or living, and trampled was vegetation that was dying or dead but due to reindeer trampling only. The Unvegetated component included sand, rock and gravel; bare and clay patches; and water and organic matter.

In the broadest seven-group division (fifth level), the Graminoid category includes all *Carex* and *Eriophorum* species (the Sedges) as well as all Juncaceae and Poaceae species and standing dead (the Grasses). The Forb and Equisetum classes are grouped as are the Litter, Trampled and Unvegetated divisions into simply Unvegetated. This Unvegetated category includes a wide variety of components but the broad grouping can be justified: although water and rock, for example, clearly represent different vegetation communities, the value of all of the unvegetated components for reindeer is low and any community in which any unvegetated component is present to a high degree is unlikely to be suitable for reindeer (except for insect avoidance as described later).

2.3.4 Statistical Analysis of Botanical Data

While general trends can be explained based on field experience and observation alone, statistical analyses allow a quantitative assessment of otherwise qualitative descriptions and can offer certainty in trends and relationships among species and vegetation types and vegetation community characteristics.

2.3.4.1 Point Hit vs. Percent Cover Data

While all of the vegetation data for both point hit and percent cover were categorized for analysis, given the complication that some of the percent cover data in 2003 were not summed in an identical way to the rest, only the point hit data were completely analysed. Sixty-eight of the seventy-five vegetation analysis sites were assessed using point hit counts. When considering the results of the analyses it is important to take into account the absence of the taller shrub communities, the seven missing sites. Potential effects of differences in the two collection techniques should also be considered. A single level point hit method (as used here) can more commonly identify top layer vegetation, focussing less on underlying cover, *e.g.*, mosses and lichens (Danks 2000). Percent cover analyses may better represent underlying vegetation cover which can be important: first, underlying vegetation may form a significant component of the overall vegetation cover within specific vegetation communities, significantly influencing remotely sensed data, which could be important in vegetation mapping; second, when specifically considering reindeer habitat selection, underlying vegetation may be important as well as top layer vegetation. A double level point hit method that records both a top and bottom layer hit (Bay 1998) can resolve this but was too time consuming to be applied in this case. Based on examination of the two data types, however, there is no reason to think either of the data are doubtful and they are consistent with each other. Point hit and percent cover data represent 85 and 75 species respectively. Both show similar divisions among genera. A calculation of percentage of moss (which may have a higher potential likelihood of discrepancy) as a proportion of the total vegetation in the transect yielded values of 13.0% for the point hit data and 13.5% for the percent cover data. Consequently, analysis of point hit data is satisfactory.

2.3.4.2 Data Analyses

A selection of specific analyses of vegetation communities was performed to explore relationships among vegetation communities. Statistical tests chosen included Chi Square and Principal Component Analysis (PCA). The analyses can not only provide botanical and vegetation composition details that further understanding of the nature of the study region, but can also yield information useful in understanding the vegetation map classification development (Chapter 4).

Chi Square and PCA analyses were run on all of the data as prepared above, *i.e.* on each of the five levels of detail in vegetation type and on each of the four levels of detail in vegetation sites for a total of twenty possible combinations/analyses. All were assessed but only the most useful were selected for inclusion in the results.

The Chi Square test for normal association is a non-parametric test (therefore more flexible than equivalent parametric tests such as ANOVA or t-tests) for statistical significance in difference of samples (Davis 1986), in this case species (or plant category) composition among vegetation sites. Generally, it tests whether two samples are different enough in a defined characteristic to suggest that the populations are also different according to this characteristic. The Chi Square explains the extent to which one variable can predict the other and assumes from the sample data that the population (tundra vegetation region) displays the same trends. Expected values are derived from calculations of the tabular data in which marginal totals (sum of the specific row values multiplied by the sum of the specific column values divided by the tabular total) are expected to be the same as the observed data values in the table (for a given column or row). Any variation in these expected values reflects non-random variation in the observed values. Chi Square is a measure of how different these values are and any non-random variation shows statistical difference.

A Principal Component Analysis (PCA) (Davis 1986) shows statistically significant differences, *i.e.* results that are non-random, by reducing the dimensionality of the data to extract important patterns. Only components that contribute to the variance in the data are kept. Data are transformed so that the two largest (*i.e.* the first and second principal components), or other chosen, explanations of variance (eigenvalues) lie along two coordinate axes. Eigenvectors (and resulting eigenvalues) correspond to the dimensions of the data. Typically only a handful of components are required to reach a 95% or otherwise satisfactory explanation of variance. In the PCA here, vegetation type (*i.e.* species, Genus, Family or Category I /II) is the explanatory variable used to explain differences or similarities among vegetation sites.

Chi Square and PCA analyses were run by and using statistical programs written by Dr. Gareth Rees (my PhD supervisor at SPRI). Results of all statistical analyses were examined and trends in the vegetation communities and species composition described. Any relevance between the results and reindeer habitat and potential climate or global change was considered.

3. RESULTS

3.1 General Data

Substantial data were collected as part of this research and only some of it can be presented and detailed here. There remains a significant amount of information that could be of further interest. Consequently, all data collected in the field should be available on the DSpace@Cambridge archival website.

The botanical analysis data consist of 75 detailed vegetation analysis sites, 56 assessed in 2003 and 19 in 2004, and 53 in summer pasture and 12 in winter pasture. An example of the raw data collected at one of the 75 sites is found in Appendix 1 and Appendix 2 lists the 75 sites and associated general information. Data archived (generally in Microsoft Excel) include:

1. General site information- site ID, descriptive name, date, GPS location, photo number, slope, aspect, moisture, average plant height, key vascular species, other species and other notes (similar to Appendix 2);
2. Point Hit Data- 300 species identifications per site (2 transects, 6 frames per transect and 25 hits per frame);
3. Percent Cover Data- Data summing to 100% for each frame (6) along each transect (2) and summed for each transect.

One or more photographs were taken at each site. Some are included within this chapter to illustrate vegetation communities and landscape influences, however, a substantially larger collection is available on the DSpace site. The photograph collection also includes images taken at the vegetation mapping ground truthing sites, methods described in Chapter 4. Photographic information includes:

1. Photo Database- unique photo ID, date photo taken, vegetation analysis site (if appropriate), site name/description (if appropriate), and waypoint number (if appropriate);
2. Photographs- (~500) named and contained in folders to match ID in database.

Finally, the list of all plant species found in the region is included in the archived material to make the collection complete.

Information available on the DSpace@Cambridge archival website should also include an electronic version of this thesis and a separate presentation of any relevant data and results from this botanical analysis chapter (3), and data and maps from the following vegetation mapping chapter (4).

3.2 Field Observations of Reindeer

During 2003 and 2004 fieldwork, we lived in summer herder camps with the reindeer herders of the Fifth Brigade of the Vyucheiskii Kolkhoz and their reindeer. The herd totalled approximately 1600 animals (F. Stammler pers. comm.). No wild reindeer are found in the region and no reindeer from other brigades strayed into the territory we covered. Animals were herded intensely and closely, with a herder within a few hundred metres of the main group of animals at all times. On occasion a lone or a few reindeer would become temporarily separated from the herd. They generally rejoined the group unless they were crippled due to injury or lost in dense shrub. The herd and herders moved within an approximate 10 kilometre radius of the camp. Although the herders talked of predation by wolves being a problem, no wolf sightings or evidence (in the form of droppings or footprints) were seen in the areas covered during fieldwork. No other predator signs were seen, *e.g.*, bears or wolverine. At the corral area, animals grouped closely together, all circling or resting for up to a few hours at a time. Average corral diameter was approximately 100-200 m.

A number of methods exist to gain insight into reindeer use of pasture and forage preferences. First, reindeer could be observed (most usefully with binoculars) moving across the tundra and grazing and their selection of plants noted. Second, careful observation of the ground revealed browsed plants and evidence of consumption. Finally, reindeer droppings and trampling effects in sites provided evidence of site visits, and the condition and type of droppings (*i.e.* season) some degree of suggestion as to time of visit.

Reindeer movement and forage patterns were observed. When being herded reindeer moved swiftly over the ground, rarely stopping except on occasion to briefly forage. When the herd was allowed to forage and rest, they were most commonly observed grazing on the edges of low mires (*i.e.* on ground that was firm enough to not sink into), in low or medium (sometimes tall) willow shrub or on moist heath vegetation (on forbs or berries for example), as available. Image 3.1 shows reindeer grazing in all three vegetation communities: moist heath in the background higher region, shrub vegetation below this and just below the shrub vegetation hidden in the elevation dip, a mire area. Birch (*Betula*) shrub was less favoured than willow shrub, which reindeer grazed substantially (Image 3.2). Herb slopes offer preferred vegetation but are not common in the landscape.

Image 3.1. Reindeer herd feeding on summer pasture: moist heath, shrubs and mire vegetation (Photo ID 06-15).

Image 3.2. Reindeer foraging in *Salix* stand (Photo ID 03-15)

Weather affected reindeer behaviour. On windy days with fewer insects they were less agitated, and on days with little wind they were restless and appeared bothered by increased insect harassment as noted in previous studies (*e.g.,* Anderson et al. 1994, Mörschel & Klein 1997). Within the corral area they circled almost constantly. In the open tundra they faced the wind and were less likely to rest. On hot days they seemed to limit their movement and were frequently stationary (except if suffering insect harassment).

Signs of reindeer were observed in much of the area covered during fieldwork. However, some regions showed no signs of recent reindeer presence: these observations were confirmed by the herders and by the Kolkhoz office in Nelmin Nos (L. Taleeva pers. comm.) and we learned that the Fourth Brigade had abandoned this pasture when they merged in 2000 with the Third Brigade. Lack of use of pasture was reflected in vegetation differences: lichen heaths were more common (in suitable locations) and often thick, whereas in highly used summer areas almost no lichen heath was found (see Section 3.7.5). In winter pasture visits in 2004 signs of reindeer presence were evident. Droppings were seen and on lichen heaths feeding craters were common (see Sections 3.6.2.6 and 3.7.5).

3.3 Reindeer Herders' Knowledge

Much discussion was had about plants, what reindeer prefer to graze on, and other issues involving tundra vegetation (S. Vyucheiskii, T. Nogatisy, Fifth Brigade pers. comm.). Additional data were collected on changing climate, herders' knowledge and perceptions of change, socio-economic changes and other relevant issues affecting reindeer herding. The most relevant information is presented here.

Reindeer herders agree that unused pasture offers high quality forage, especially if left ungrazed for a number of years, but they say that it is problematic using it again: even if Kolkhoz laws on Brigade territories could be adjusted, it is difficult to convince reindeer to utilise areas they are not accustomed to. Reindeer are set in their ways and prefer to follow traditional migration patterns and routes.

Changing shrub presence may complicate this. Herders attest to increasing and taller shrubs over the last forty years in their environment- previously shrubs were not taller than half a metre and now they are more than two metres in height. Although they agree that willow forage is highly desirable for reindeer, an increase in shrubs has negative consequences overall. First, herders lose reindeer in the taller and more prevalent shrub vegetation, and second, herders cannot navigate through the dense shrub with their sledges and are forced to go around or follow different routes.

Reindeer adjust their forage consumption seasonally. In summer they prefer rich, green vegetation, and wet vegetation like sedges in mires. They also graze on young shrubs, grass, lichen if present, and berries in late summer. In autumn they continue to feed on grasses before senescence, shrubs and berries, particularly berries of *Rubus chamaemorus*, which is a common species in much of the heath vegetation. Autumn is also typically mushroom season. Mushrooms are the reindeer’s favourite food, to the animals’ detriment, however, as they run wild in search of mushrooms and expend valuable energy before the harsh winter season (Fifth Brigade pers. comm., Vitebsky 2005 p. 138). The herders’ viewpoint is that mushrooms are like chocolate- they have little nutritional value. In winter reindeer dig for lichen and eat some grass or salt grass if near to the coast (as is the Fifth Brigade’s winter pasture). Spring forage consists of new, young shoots and other vegetation, such as sedges, when it greens up.

Seasonal trends are shifting and the herders find it increasingly difficult to predict weather patterns in the seasons as they traditionally have done. Temperatures are shifting and moisture regimes changing and this affects vegetation and in turn reindeer. In 2003, a somewhat typical summer (though with highly fluctuating extreme temperatures), no berries or mushrooms were observed while we were still in the field in August. In 2004, however, a particularly hot, dry summer, berries were out much earlier than normal and mushrooms were plentiful. Reindeer condition was poorer and the animals were thin; the land was drier and rich vegetation less abundant.

In general, spring is longer, with temperatures warming earlier in the year than before, in April for example. However, cycles of warm and cold are the result, and this then affects snow and ice and causes thawing and refreezing (discussed in greater detail in Chapter 6). In early summer it becomes hotter more quickly. Summer temperatures seem to fluctuate significantly, within and between summers. In 2003, within a 36-hour period the temperature ranged 37 degrees, from –2 Celsius to +35 Celsius. Definitive feelings on how summers are changing are hard to ascertain. Little was said about changes in autumn. Winter seems to start at the same time but is shorter because of the earlier spring.

Moisture regimes change: some years are wetter in terms of rain and some years have heavy snowfall in winter months. Herders suggest variation has always existed. However, the dry conditions observed in summer 2004 were considered unusual (Sections 3.6.2.4 and 3.7.6)

Summer pasture is plentiful. In 2004, despite the hot summer and resultant drier conditions and likely decreased amount of available local forage, the herders spent a long time at the Vybory camp nevertheless. They felt that despite the heavy use of the land there will still be enough vegetation for the next year: using too much pasture is not seen as a problem. However, herders do believe that it will be difficult for their animals to survive in the winter without lichen even though there may be enough other forage (salt grass and grass). They say lichen abundance is decreasing in their territory, in particular in the summer territory where lichen has been trampled (and that trampling in summer is more of an issue than consumption). They agreed with our observations on the much higher presence of lichen in the unused pasture to the west of their territory, in the Fourth brigade's old lands.

Herders believe that reindeer are resilient and will adapt to changes in vegetation, or to changes in pasture. They say that the reindeer adjust their pasture use to different areas and the herders will just follow. They do believe, however, that this adaptability of reindeer is limited and some things like lichen are critical.

3.4 Plant Species

The total number of vegetation species found and noted during fieldwork is 166, not including mosses and lichens, which were less precisely identified. Club mosses are, however, included in the species list. The species belong to 100 genera and 48 families. Species richness within regions of northern Russia and Siberia varies: it is higher in Taimyr (195-200 species), intermediate in Gydan (about 170-180) and lower in Yamal (140-155) (Khitun 2002). Based on these observations, species richness determined for this study region, just west of Yamal, appears to be in line with what might be expected

The full list is presented in Table 3.2. The table includes Family, Genus and Species and the species abbreviation used during data collection and analysis. Additional information details whether the species was found in summer and/or winter pasture, a rough measure of its frequency in being sighted (on a scale of 1 to 5 with 1 rare and 5 most common) and the type of habitat in which it is commonly found. A key to the habitat abbreviations used in the two species tables is found below them in Table 3.3.

The lichen and moss species or general identifications are shown in Table 3.4. Moss and lichen identification was not an area of expertise for the fieldwork team, consequently, specific identifications were generally avoided, although enough detail was collected to be relevant to reindeer.

Specific lichen species known to be in the greater region around the study area were noted and illustrated during library and office work in Naryan Mar in the Yasavey building offices. It is likely that a number of these species were observed in the field but as we are not certain, no assumptions were made. Some of the species possibly found during this fieldwork include: *Cladonia rangiferina; Cladonia sylvatica; Cetraria cucullata; Cetraria nivallis; Cladonia stellaris; Cladonia maxima; Cladonia borealis; Cladonia furcata; Cladonia gracilis; Cladonia amaurocrae; Cladonia cegracillis;* and among brown lichens, *Arctocetraria andrejevii; Briocaulon divergens; Alectoria nigricans; Cladonia macroceras;* and *Cetraria delisei.*

Table 3.2. List of all plant species identified in field during Summer 2003 and 2004 with habitat details.

#	FAMILY	GENUS	SPECIES	ABBREV.	SUMMER PASTURE	WINTER PASTURE	FREQ. (1-5, rare=1)	HABITAT*
1	Lycopodiaceae	Huperzia	Huperzia selago	Hup sel	S	W	2	Hd
2		Lycopodium	Lycopodium annotinum	Lyc ann	S		2	Hd
3			Lycopodium clavatum	Lyc cla	S		2	Hd
4		Diphasiastrum	Diphasiastrum alpinum	Dip alp	S		2	HB
5			Diphasiastrum complanatum	Dip com		W	2	H M
6	Selaginellaceae	Selaginella	Selaginella cfr. selaginoides	Sel sel	S		1	H
7	Equisetaceae	Equisetum	Equisetum arvense	Equ arv	S	W	4	Hm Hd HB M
8			Equisetum fluviatile	Equ flu	S		2	Mw R
9			Equisetum pratense	Equ pra	S		3	M G
10			Equisetum sylvaticum	Equ syl	S		2	HB
11			Equisetum variegatum	Equ var	S		3	Hm
12	Aspleniaceae	Dryopteris	Dryopteris sp.	Dry sp.	S		1	HB
13	Cupressaceae	Juniperus	Juniperus communis	Jun com	S	W	2	HB
14	Ranunculaceae	Ranunculus	Ranunculus acris	Ran acr	S		1	HB
15			Ranunculus hyperboreus	Ran hyp	S	W	2	A
16			Ranunculus lapponicus	Ran lap	S		3	Hm(mo,*x*h) M
17			Ranunculus pallasii	Ran pal	S	W	2	Amo
18			Ranunculus repens	Ran rep	S		2	HB Ss
19		Aconitum	Aconitum septentrionale	Aco sep	S		3	Ss
20		Caltha	Caltha palustris	Cal pal	S	W	3	M Ss R

#	FAMILY	GENUS	SPECIES	ABBREV.	SUMMER PASTURE	WINTER PASTURE	FREQ. (1-5, rare=1)	HABITAT*
21		Trollius	Trollius sp.	Tro sp.	S		2	M R
22		Delphinium	Delphinium elatum	Del ela	S		3	Ss
23	Rosaceae	Rubus	Rubus arcticus	Rub arc	S		3	Ss Hw
24			Rubus chamaemorus	Rub cha	S	W	5	Hm(mo) Ssw
25		Geum	Geum rivale	Geu riv	S		2	M Ssw
26		Comarum	Comarum palustre	Com pal	S	W	5	M Ssw
27		Sibbaldia	Sibbaldia procumbens	Sib pro	S		2	HB
28		Alchemilla	Alchemilla sp.	Alc sp.	S		4	HB Ssw
29		Filipendula	Filipendula ulmaria	Fil ulm	S		3	HB Ssw
30	Saxifragaceae	Saxifraga	Saxifraga foliolosa	Sax fol	S	W	2	M
31			Saxifraga hirculus	Sax hir	S		2	M
32		Parnassia	Parnassia palustris	Par pal	S	W	2	M Ssw
33		Chrysosplenium	Chrysosplenium alternifolium	Chr alt	S		2	Ssw
34	Fabaceae	Oxytropis	Oxytropis sordida	Oxy sor	S		2	Ew
35		Astragalus	Astragalus alpinus	Ast alp	S		3	HB Ew
36	Onagraceae	Epilobium	Epilobium arcticum	Epi arc	S		2	M
37			Epilobium palustre	Epi pal	S		3	M
38		Chamaenarion	Chamaenerion angustifolium	Cha ang	S	W	3	HB Ssw
39	Hippuridaceae	Hippuris	Hippuris vulgaris	Hip vul	S	W	1	A
40	Brassicaceae	Rorippa	Rorippa islandica	Ror isl	S	W	2	Ea A
41		Cardamine	Cardamine pratensis	Car par	S		2	M
42	Violaceae	Viola	Viola biflora	Vio bif	S	W	3	HB Ssw
43	Geraniaceae	Geranium	Geranium sp.	Ger sp.	S		3	Ssw HB G
44	Callitrichaceae	Callitriche	Callitriche sp.	Cal sp.	S	W	3	A
45	Cornaceae	Cornus	Cornus suecica	Cor sue	S	W	2	HB Ssw Hw
46	Apiaceae	Angelica	Angelica archangelica	Ang arc	S		2	Ss
47	Salicaceae	Salix	Salix herbacea	Sal her	S	W	3	HB
48			Salix glauca	Sal gla	S	W	5	Sh Sm
49			Salix lanata	Sal lan	S	W	3	Sh Sm
50			Salix phylicifolia	Sal phy	S	W	5	Sh Sm
51			Salix reticulata	Sal ret	S		3	HB
52			Salix sp.	Sal sp.		W	3	Sh Sm
53			Salix sp.	Sal sp.		W	3	Sh Sm
54			Salix sp.	Sal sp.		W	3	Sh Sm
55			Salix sp.	Sal sp.		W	3	Sh Sm
56			Salix sp.	Sal sp.		W	3	Hdl
57	Betulaceae	Betula	Betula nana	Bet nan	S	W	5	Ss(d) Sd Sm
58	Polygonaceae	Rumex	Rumex acetosella	Rum ace	S	W	4	Ew
59			Rumex sp.	Rum sp.	S		4	Ssw HB G
60		Polygonum	Polygonum aviculare	Pol avi	S		2	Ea
61			Polygonum bistorta	Pol bis	S	W	4	HB
62			Polygonum vivipara	Pol viv	S		3	HB G
63	Caryophyllaceae	Cerastium	Cerastium sp.	Cer sp.	S		1	Ssw
64		Stellaria	Stellaria sp.	Ste sp.	S	W	2	Ssw
65		Arenaria	Arenaria stenophylla	Are ste	S	W	1	Ew
66		Dianthus	Dianthus superbus	Dia sup	S	W	3	HB
67		Sagina	Sagina intermedia	Sag int	S		2	E
68	Plumbaginaceae	Armeria	Armeria scabra	Arm sca	S	W	3	Ew Hdl
69	Pyrolaceae	Pyrola	Pyrola grandiflora	Pyr gra	S		2	HB
70			Pyrola minor	Pyr min	S	W	2	HB
71	Diapensiaceae	Diapensia	Diapensia lapponica	Dia lap		W	3	Hdl
72	Ericaceae	Arctostaphylos	Arctostaphylos alpina	Arc alp	S	W	5	Hdl Ew
73		Andromeda	Andromeda polifolia	And pol	S	W	3	M
74		Ledum	Ledum palustre	Led pal	S	W	4	Hm Hdl
75		Loiseleuria	Loiseleuria procumbens	Loi pro	S	W	3	Hdl
76	Vacciniaceae	Oxycoccus	Oxycoccus palustris	Oxy pal	S	W	3	M
77		Vaccinium	Vaccinium myrtillus	Vac myr	S	W	3	Hm Hw HB
78			Vaccinium uliginosum	Vac uli	S	W	4	Hm Hw
79			Vaccinium vitis-idaea	Vac vit	S	W	5	Hd Hm Hw
80	Empetraceae	Empetrum	Empetrum nigrum	Emp nig	S	W	5	Hd Hdl Hm Hw Ew
81	Gentianaceae	Gentiana	Gentiana tenella	Gen ten	S		3	G HB
82	Menyanthaceae	Menyanthus	Menyanthus trifoliata	Men tri	S	W	3	A
83	Polemoniaceae	Polemonium	Polemonium boreale	Pol bor	S	W	3	Ssw Ssd HB Ew
84	Boraginaceae	Myosotis	Myosotis palustris	Myo pal	S		3	M Ssw
85	Valerianaceae	Valeriana	Valeriana capitata	Val cap	S	W	2	M Ssw
86	Scrophulariaceae	Veronica	Veronica alpina	Ver alp	S		2	HB
87		Pedicularis	Pedicularis lapponica	Ped lap	S	W	3	Hm
88			Pedicularis oederi	Ped oed	S	W	2	M
89			Pedicularis sceptrum-carolinum	Ped sce	S		2	HB
90			Pedicularis sp.	Ped sp.	S		1	HB
91		Bartsia	Bartsia alpina	Bar alp	S	W	2	HB
92		Euphrasia	Euphrasia frigida	Eup fri	S	W	2	HB
93	Primulariaceae	Trientalis	Trientalis europaea	Tri eur	S		2	Ssw
94	Rubiaceae	Galium	Galium boreale	Gal bor	S		2	M
95			Galium sp.	Gal sp.	S		1	Ew

#	FAMILY	GENUS	SPECIES	ABBREV.	SUMMER PASTURE	WINTER PASTURE	FREQ. (1-5, rare=1)	HABITAT*
96	Caprifoliaceae	Linnaea	Linnaea borealis	Lin bor	S		2	HB Hm
97	Campanulaceae	Campanula	Campanula rotundifolia	Cam rot	S	W	2	HB Hd
98	Asteraceae/	Petasites	Petasites frigidus	Pet fri	S	W	3	M Ssw
99	Compositaceae	Erigeron	Erigeron sp.	Eri sp.	S		3	HB
100		Saussurea	Saussurea alpina	Sau alp	S		3	G
101		Antennaria	Antennaria sp.	Ant sp.	S	W	3	Hm
102			Antennaria sp.	Ant sp.	S		2	HB
103		Gnaphalium	Gnaphalium supinum	Gna sup	S		2	HB
104		Achillea	Achillea millefolia	Ach mil	S	W	3	HB Scw
105			Achillea sp.	Ach sp.		W	3	HB
106		Hieracium	Hieracium alpinum	Hiera alp	S	W	3	HB Hm
107			Hieracium cfr. umbellatum	Hie umb	S	W	2	HB Hm
108			Hieracium sp.	Hie sp.	S		2	M
109		Solidago	Solidago lapponica	Sol lap	S	W	3	HB
110		Tripleurospermum	Tripleurospermum hookeri	Tri hoo	S		2	Ea
111		Tanacetum	Tanacetum bipinnatum	Tan bip	S	W	2	HB Ew Hm
112	Lilliaceae	Tofieldia	Tofieldia pusilla	Tof pus	S		3	H
113		Veratrum	Veratrum lobelianum	Ver lob	S	W	4	HB Scw
114	Orchidaceae	Coeloglossum	Coeloglossum viride	Coe vir	S		3	HB
115	Juncaceae	Juncus	Juncus biglumis	Jun big	S		2	M
116			Juncus filiformis	Jun fil	S		1	M
117			Juncus trifidus	Jun tri	S	W	2	Hdl Ew
118		Luzula	Luzula confusa	Luz con	S	W	3	Hdl G
119			Luzula multiflora	Luz mul	S		2	H G
120			Luzula spicata	Luz spi		W	3	Ew
121			Luzula wahlenbergii	Luz wah	S	W	1	Ss Sm
122	Cyperacae	Eriophorum	Eriphorum scheucherzi	Eri sch	S	W	3	M
123			Eriphorum angustifolium	Eri ang	S	W	3	M Hw
124			Eriphorum medium	Eri med	S		1	M
125			Eriphorum russeolum	Eri rus	S		1	M
126			Eriphorum vaginatum	Eri vag	S	W	3	M Hw
127		Scirpus	Scirpus caespitosus	Sci cae	S	W	1	M
128		Carex	Carex aquatilus	Car aqu	S	W	3	M
129			Carex bigelowii	Car big	S	W	5	Hm Hd Hdl G
130			Carex brunescens	Car bru	S	W	1	Hm
131			Carex caespitosa	Car cae	S		1	M
132			Carex canescens	Car can	S		1	M
133			Carex capillaris	Car cap	S		1	M
134			Carex chordorrhiza	Car cho	S		1	M
135			Carex lachenalii	Car lac	S		1	HB
136			Carex rariflora	Car rar	S	W	4	M
137			Carex rostrata	Car ros	S	W	2	M
138			Carex rotundata	Car rot	S	W	4	M
139	Poaceae	Festuca	Festuca brachyphylla	Fes bra	S	W	1	Hdl
140			Festuca ovina	Fes ovi	S		3	Hdl
141			Festuca rubra	Fes rub	S	W	3	Hd Ew
142		Poa	Poa alpigena	Poa alpig	S	W	2	Ew
143			Poa alpina	Poa alp	S		3	HB
144			Poa glauca	Poa gla	S		1	Hd
145			Poa pratensis	Poa pra	S	W	2	H G
146		Phippsia	Phippsia algida	Phi alg	S		1	Ea
147		Arctophila	Arctophila fulva	Arc ful	S	W	1	M A
148		Dupontia	Dupontia psilosantha	Dup psi		W	2	M
149		Trisetum	Trisetum asiatica	Tri asi	S	W	1	Ew
150		Deschampsia	Deschampsia caespitosa	Des cae	S	W	2	M
151			Deschampsia flexuosa	Des fle	S	W	2	HB
152		Agrostis	Agrostis sp.	Agr sp.	S	W	2	Ew
153		Calamagrostis	Calamagrostis langsdorfii	Cal lan	S	W	2	Ssw
154			Calamagrostis lapponica	Cal lap	S	W	4	Hm G
155			Calamagrostis neglecta	Cal neg	S		1	M
156		Alopecurus	Alopecurus aequalis	Alo aeq	S		2	M
157			Alopecurus pratensis	Alo pra	S		2	M
158		Phleum	Phleum commutatum	Phl com	S		2	HB
159		Hierochloë	Hierochloë alpina	Hiero alp	S	W	3	Hm
160			Hierochloë odorata	Hie odo	S		3	HB
161		Anthoxanthum	Anthoxanthum odoratum	Ant odo	S	W	2	HB
162	Alliaceae	Allium	Allium schoenoprasum	All sch		W	2	HB
163	Sparganiaceae	Sparganium	Sparganium hyperboreum	Spa hyp	S	W	2	A
164	Potamogetonaceae	Potamogeton	Potamogeton sp.	Pot sp.	S		2	A
165			Potamogeton sp.	Pot sp.	S		2	A
166	Lemnaceae	Lemna	Lemna sp.	Lem sp.	S		2	A

Pasture: S= summer; W= winter, * for Habitat key see Table 3.3 below

Table 3.3. Habitat key showing explanation of habitat details provided in species list table.

ABBREVIATION	PRIMARY TYPE	Abbreviation	Secondary Characteristic
H	Heath		
		d	dry/xeric
		m	moist/mesic
		w	wet
		li	lichen
		h	hummocks
		t	tussocks
		mo	moss
S	Shrub		
		d	dwarf
		m	medium
		t	tall
		s	scrub/copse
		w	wet
M	Mire		
		mo	moss
		sp	sphagnum
		w	extremely wet
HB	Herb slope		
G	Grassland		
E	Exposed		
		w	wind
		a	anthropogenic
R	Riparian		
A	Aquatic		
ALL*		x_	without_

*** applicable to all habitat types**

Table 3.4. List of moss and lichen species/generalised types in field during Summer 2003 and 2004 with habitat details.

#	MOSS/LICHEN	SPECIES/GENERAL CLASS	SUMMER PASTURE	WINTER PASTURE	FREQ.(1-5,rare=1)	HABITAT*
1	Moss	Sphagnum, medium green	S	W	3	M
2	Moss	Sphagnum, light green	S	W	3	M
3	Moss	Sphagnum, red	S		1	Hw
4	Moss	Moss, general	S	W	4	M H S R
5	Lichen	Cetraria, white	S	W	3	Hdl, m
6	Lichen	Cetraria, brown	S	W	2	Hdl
7	Lichen	Cetraria islandica	S		2	Hdl
8	Lichen	Stereocaulon (paschale?)	S	W	1	Hd Ew
9	Lichen	Thamnolia sp.	S	W	1	Hdl
10	Lichen	Alectoria (ochroleuca?)	S	W	1	Hdl
11	Lichen	Fruticose – other	S	W	3	Hd, m
12	Lichen	Crustose	S	W	3	Hd
13	Lichen	Foliose	S	W	2	Hm

Pasture: S= summer; W= winter, * for Habitat key see Table 3.3 above

3.5 Vegetation Community Overview

The greater Kolkhoz region exemplifies typical Arctic tundra in a general sense but also possesses characteristics particular to the region, typically a result of the features described here. The territory is located in a topographically diverse landscape, and some of this diversity influences the vegetation community characteristics within the botanical study area. Along and near the main Pechora River delta and other smaller drainages exist low lying, wet areas; additional low, wet areas exist in depressed tundra regions inland; the prominent ridgeline that cuts through the study region affects the moisture levels through drainage and effects on weather and rain patterns and this then influences local vegetation communities; wind erosion is very active along the ridge, creating large regions of open sand and sandy substrate; well drained, sometimes steep, slopes are found in a few areas, typically above lakes or low lying areas; flat or gently sloping expanses are found in abundance.

Sedges and mosses dominate lower, wet, flat areas; forbs and grasses sand and gravel bars and well drained slopes; various heath and shrub communities flatter expanses and gentle slopes, and shrubs and graminoids (sedges and grasses) riparian communities. Various heath communities dominate the study area and surrounding region.

The summer and winter study areas contain many of the same vegetation communities; however, they are located in geographically and topographically different regions of the territory and, therefore, exhibit some differences. In general the winter pasture area is flatter, contains lower vegetation, has a smaller array of vegetation communities and is generally less complex than the summer pasture area, which has greater topographic and hydrological variation and thus more diverse communities. Small lakes are more common in winter pasture but are not necessarily bordered by mire vegetation as was typical in summer pasture. There is a sharp degradation between water bodies or wet vegetation and well-drained areas supporting dry heaths for example. Shrubs are smaller and generally less present in winter pasture while lichen is denser and more plentiful. In addition, the winter area is climatically somewhat different due to its proximity to the sea and the resulting effects of wind and even saltwater influence on coastal vegetation. No noticeable phenological differences were observed between summer and winter pasture, however, winter pasture was visited three weeks later than summer pasture so it is possible that differences were obscured by time.

The territory of the Fifth Brigade and therefore the study regions has not been subject to development or influences other than the effects of reindeer herding.

A summary of the seventy-five field sites and their characteristics is presented in Appendix 2.

3.6 Detailed Vegetation Community Descriptions

The descriptions and details below pertain not only to the topic of this chapter but are also relevant to the following chapter (4) on vegetation mapping. Not all of the images here are from vegetation analysis sites, some are from ground truthing sites for the mapping component. Both detail the same vegetation communities, however.

Vegetation communities were distinguished from one another based on field observations and data in combination with established trends and patterns in Arctic vegetation community composition. This section describes and illustrates communities found in the study region. For the purposes of consistency, the communities detailed here follow the classification scheme developed for and explained in Chapter 4 and shown below in its simplest form (Table 3.5). The scheme was developed based on observational knowledge of the variety of field sites and general knowledge of tundra communities. It should be noted that the communities could be divided in other ways: however, the key communities in the study region and their range are exemplified using the current scheme, which has undergone a number of revisions. Furthermore, other schemes may be specific to a certain region and unsuitable here (*e.g.,* ‘Renbetestyper’, the Swedish classification scheme used specifically for reindeer habitat (County Administration Boards, 2000) or they may be overly general (*e.g.,* the CAVM scheme (CAVM Team 2003)). The communities described here are not exhaustive of the entire vegetation mapping area (detailed in Chapter 4), nor possibly of the (botanical) study region explored in the field given the heterogeneity of this particular area. While much territory was covered during fieldwork and effort was made to include all vegetation communities in the study area, certain smaller, less common ones may have been inadvertently excluded. Second, it was simply not possible to visit all regions in the mapped image and certain vegetation communities (such as salt marshes or coastal vegetation) will certainly be excluded from this assessment.

Descriptions below follow the scheme in the order of presentation. Additional communities are described at the end. Certain unvegetated communities included in the classification have been shown below to improve understanding of the landscape, particularly as it relates to the vegetation map development.

Table 3.5. Vegetation community division scheme

CATEGORY	CLASS ID	VEGETATION GROUP	VEGETATION COMMUNITY
Unvegetated	000	Water	Clear water
	001	Water	Turbid and shallow water
	01	Settlement	Settlement
	02	Bare ground	Bare ground
Vegetated	11	Exposed	Exposed
	12	Forb community	Herb slope
	130	Grassland	Tundra grassland
	131	Grassland	River (Riparian) grassland
	1400	Mire	Low sedge mire with sphagnum moss (sphagnum bog)
	1401	Mire	Low sedge mire with other moss
	141	Mire	Tall sedge mire
	150	Heath-Mire	Heath-Mire without heath shrubs
	151	Heath-Mire	Heath-Mire with heath shrubs
	160000	Heath	Dry/Xeric lichen heath without *Betula*
	160001	Heath	Dry/Xeric lichen heath with *Betula*
	16001	Heath	Dry/Xeric ericaceous shrub heath
	160100	Heath	Moist/Mesic heath with hummocks & without shrubs
	160101	Heath	Moist/Mesic heath with hummocks and with shrubs
	160110	Heath	Moist/Mesic heath without hummocks & without shrubs
	160111	Heath	Moist/Mesic heath without hummocks & with shrubs
	170	Trees	Trees
	171	Shrubs	Shrubs >2 m (High)
	172	Shrubs	Shrubs >1 m (Medium)
	1730	Shrubs	Shrubs <1 m *Salix* dominated (Low)
	1731	Shrubs	Shrubs <1 m *Betula* dominated (Low)
	174	Shrubs	Scrub (open)
	18	*Disturbed*	*Disturbed (included for statistical analyses of botanical data only)*

3.6.1 Unvegetated Areas

3.6.1.1 Settlement

Settlements include any inhabited zone, the sizes of which vary from Naryan Mar, the regional capital and largest town (population 18 611 (2002 Census) (http://www.world-gazetteer.com) in the region to small villages of less than a hundred people with limited infrastructure. Shown here are two images, one aerial photo of part of Naryan-Mar and one image of the medium sized (population of approximately 1 000) village, Nelmin Nos, situated like many of the other villages in the region, along a channel of the Pechora River delta.

Image 3.3. Town of Naryan Mar, aerial view of town core looking towards port and Pechora River (Photo ID 16-05).

Image 3.4. Nelmin Nos, a typical river delta village, and the administrative centre of the Vyucheiskii Kolkhoz (Photo ID 10-35).

3.6.1.2 Bare Ground

Bare ground areas are distinguished from settlements in that they are uninhabited, and distinguished from exposed class communities in that they are (virtually) devoid of vegetation. Bare ground areas include riparian sand banks, coastal rock and sand beaches, sand craters in the tundra, large patches of gravel and rock in the tundra zone and other patches of bare earth. The sand, gravel and rock craters and natural bare patches are Aeolian in origin. Most prevalent in the study region are sand and rock craters in hilly areas and along the main ridgeline that defines the study region, and riparian and coastal sand banks along drainages and water bodies. An image of a coastal sand bank is not available but the other bare ground communities are illustrated below.

Bare ground patches can range in size from very small, of the order of 3 to 10 metres in length or diameter, to very large, and more than 500 metres in length or diameter. In particular, the sand and rock craters in the tundra tend to be largest and along the coast and riverbanks some of the sand patches very long. The frequency of these often sandy, bare ground areas and the presence of such large patches is an indicator of the underlying substrate and the main component of the soil in the region, sand, formed from aeolian processes. The sand substrate encourages drainage and will affect the vegetation species and communities in the region. Clayey soils are also present in the region but in more limited and smaller areas.

Unvegetated patches, particularly inland, may be significant for reindeer as locations free or nearly free from mosquito and insect harassment in summer (Helle & Aspi 1984). In particularly bad years, *i.e.* with a wet spring and hot summer, the importance of these regions may be even greater. Climate shifts may exacerbate the potential for extreme harassment.

Image 3.5. Riparian sand bank (Photo ID 13-25).

Image 3.6. Typical large sand crater along main ridgeline in tundra region (Photo ID 13-16).

Image 3.7. Typical rock crater near ridgeline in tundra region (Photo ID 05-12).

3.6.2 Vegetated Areas

3.6.2.1 Exposed

Exposed

Exposed communities with limited to almost no vegetation include both anthropogenic and naturally exposed regions.

Naturally exposed

Naturally exposed communities are typically partially vegetated, in dry, well-drained, sandy areas, either along a slope or in a crater region. These vegetation patches are generally large or very large, from 100-300 metres in diameter, although small patches of the order of 10 metres in diameter exist. Typical vegetation in exposed areas includes grass species (*e.g., Trisetum asiatica*, *Festuca rubra*, *Poa alpigena,* and *Luzula confusa, L. spicata* and *Juncus trifidus (*Juncaceae)), scattered dry ericaceous shrubs (*e.g., Empetrum nigrum*, *Vaccinium vitis-idaea*), occasionally low, deciduous shrubs, most commonly dwarf *Betula nana*, and possibly forbs (*Armeria scabra*, *Polemonium boreale*, *Arenaria stenophylla*, *Tanacetum bipinnatum*, *Rumex acetosella*, *Oxytropis sordida*, and *Astragalus alpinus* for example). Thin lichen cover is present in rare cases (Image 3.10).

This particular study region contains substantial amounts of naturally exposed vegetation, more than may be typical of other tundra regions (author’s experience in Alaska, Canada, Greenland and Scandinavia), the predominant reason again being the underlying sand and sandy substrate.

As with unvegetated areas, exposed sites offer refuge to reindeer from mosquitoes and other insects. Typically communities are in elevated regions with less moisture and more wind. If the climate were to shift and become drier, more unvegetated zones may exist as plants become more susceptible to wind effects.

Image 3.8. Naturally exposed dry sandy plateau with partial vegetation consisting of dwarf *Betula*, *Empetrum* and other ericaceous shrubs (Photo ID 04-29).

Image 3.9. Naturally exposed dry sandy slope with partial vegetation consisting of dwarf *Betula*, *Empetrum* and small amounts of other ericaceous shrubs, *Armeria scabra* and a few grasses (Photo ID 5,4-19).

Image 3.10. Naturally exposed open crater vegetation consisting primarily of a thin lichen (*Stereocaulon sp.*) cover and *Empetrum nigrum* (Photo ID 12-07).

Anthropogenic influenced

Anthropogenic influenced communities in the study region are the result of reindeer herding activity, primarily summer herding camps where up to a few thousand reindeer use the same corral area for a month at a time, virtually eliminating all vegetation in the corral and limiting it in the immediate surroundings. Bare earth covers the centre of the corral while on the outskirts limited grasses and some shrubs remain, in an evidently disturbed state. Corral areas are typically 100-200 metres in diameter at the core with highly affected outer areas extending another 100-200 metres or so. Grasses and a few typical forb species form the main vegetation re-growth which will rapidly disappear when the site is used again, typically the following or next after year. Common forb species in anthropogenic influenced exposed areas include *Rorippa islandica*, *Polygonum aviculare* and *Tripleurospermum hookeri*, while common grasses are *Phippsia algida*, and members of the Poa, Agrostis, and Festuca genera. Reindeer were observed to congregate in corral areas on hot summer days, presumably to avoid insect harassment, which is decreased in bare areas. The corral areas were not particularly elevated or exposed, not more so than surrounding areas and so it is unlikely that congregation was to reduce heat stress.

Image 3.11. Anthropogenic exposed site showing a typical, commonly used reindeer summer corral site, with vegetation entirely removed from the middle (approximately 200 x 150 metres area) and sparse, grassy vegetation surrounding. At the time of photo, the site had not been used for one year (Photo ID 7,2-34).

Image 3.12. Same corral site at same time showing some recovery and re-growth of grass at edges, further from central corral zone (Photo ID 7,2-36).

Image 3.13. Anthropogenic exposed site showing a second, currently in use, reindeer summer corral site, again with vegetation entirely removed from the middle (an area greater than 100 metres in diameter) and sparse, disturbed vegetation surrounding (Photo ID 10,2-05).

3.6.2.2 Forb Communities

Herb Slope

Herb or forb slopes are not a common vegetation community in the region, being very specific in their topographic and climatic requirements: well-drained typically south facing (due to earlier snow melt) or sun-exposed slopes. On well-drained slopes if the aspect is not favourable less developed forb communities may form. Patch size tends to be small (30 metres or smaller in width and 30 metres or greater in length (along the slope)) often because of the topographic nature of these areas: slopes tend to be narrow as topographic variation and rise is usually limited. On gentler slopes larger herb communities may develop. Typically, herb slopes are surrounded by moist heath expanses (generally above the slope) and mires with lakes, or moist heaths (below the slope).

Herb slopes vary in the flowering species present but within the region some common species include *Polygonum bistorta*, *Polygonum viviparum*, *Veratrum* sp., *Pedicularis* spp., *Ranunculus* sp., *Coeloglossum viride* (Orchidaceae) and a number of Compositae species. Less common species include *Viola biflora*, *Chyrsosplenum alternifolium*, *Rumex acetosa* and *R. sp.*, *Allium schoenoprasum* and still other compositae species. Rare species seen in only one or a few sites include *Bartsia alpina*, *Saxifraga foliolosa* and *S. hirculus*. Other non-forb species present include ericaceous shrubs such as *Vaccinium uliginosum* and *V. myrtillus*, deciduous shrubs such as dwarf *Betula* (*B. nana*) and small *Salix* (*Salix herbaceae* and *Salix* sp.), and grasses (*Poa alpina*, *Deschampsia flexuosa*, *Phleum commutatum*, *Hierochloë odorata* and *Anthoxanthum odoratum*.

Forb communities provide suitable grazing for reindeer when plants are young in late spring and summer but other vegetation communities provide greater biomass due to the limited presence of herb slopes versus more common communities. Herb slopes are not dominant in the study region, and whether or not their distribution might increase or decrease with potential climate change depends on a number of environmental factors: density or coverage could increase if conditions are improved with a potentially earlier snow melt; on the other hand studies suggest forbs will be negatively impacted by climate warming given their limited thermal flexibility and adaptation to cold growing conditions (Cooper 2006).

Image 3.14. Herb slope community bordering a lake showing common flowering species such as *Veratrum sp*., various Compositae species and typical patches of ground *Salix (*sp.*)* and *Betula nana* (Photo ID 7,2-13).

3.6.2.3 Grasslands

Another infrequent vegetation community in the region, though more common than herb slope, is grassland. Two types of grassland are present, tundra grassland and riparian grassland.

Tundra grassland

Tundra grasslands vary in size from very small (10 metres in diameter) to large (more than 100 metres in diameter) such as the one pictured below (Image 3.15). Grassland is typically located on gently sloping, often elevated, drained ground. Large expanses are found on elevated plateaus. Grassland distribution appeared patchy in the tundra landscape, with some regions containing very little and others more coverage.

Typical tundra grassland species include *Calamagrostis lapponica* and *Poa pratense*. Other species commonly found include *Luzula confusa, L. multiflora*, *Carex bigelowii* and *Equisetum pratense*, herbs such as *Rumex* sp., *Polygonum viviparum, Geranium* sp., *Gentiana tenella, Saussurea alpina* and *Polemonium* sp. and small amounts of sparse low *Salix* shrub.

Grassland sites provide suitable grazing for reindeer particularly in summer months when forage is rich. Studies suggest a possible increase in grassland in Arctic regions with changing climate (Rees et al. 2003, Kullman 2004). As mentioned previously, heavily grazed corral and surrounding areas encourage colonisation by grass. These changed communities, however, are not the same as undisturbed grassland in their species distribution and composition and are subject to repeated disturbance as long as reindeer pasture use and migration practices do not change.

Image 3.15. Tundra grassland on an elevated gentle slope with typical *Calamagrostis* species, forbs (particularly *Polygonum bistorta*), and low *Salix sp*. (Photo ID 07-18).

Riparian grassland

Riparian grassland sites were unable to be visited, they were observed from a boat and therefore species identification was not possible.

Image 3.16. Riparian grassland along the Pechora River delta, with shrubs beyond (Photo ID 02-33).

Image 3.17. Riparian grassland along the Pechora River delta with shrubs behind (Photo ID 2,2-27).

3.6.2.4 Mires

Mires are a dominant vegetation community in this tundra region and play a role in the heterogeneity of the landscape with varying patch size, from very small (about 10 metres in diameter) to expansive (more than 300 metres in diameter), and locations adjacent to a variety of other vegetation communities including the range of moist and dry heaths and shrub communities.

Mire communities are consistent within each mire patch but diverse between patches. Mire vegetation can be sparse or thick, low or high but is always underlain by a thick moss or sphagnum moss layer. Some mires cannot be traversed due to particularly high water content and soft moss or sphagnum layer, while others can be easily crossed, particularly in late summer as the tundra dries.

Mire vegetation is important for reindeer habitat in summer. In particular, drier and low mires are frequently visited by reindeer. High sedge mires appear to be less important. Mires are susceptible to weather and climate effects, both on short and long term scales. In hotter, drier times mire vegetation can dry out as the water layer dries or the water table sinks. During fieldwork in 2004, a particularly hot, dry summer (according to herders' perceptions and according to calculations based on daily temperature records showing an average daily July mean temperature of 14.2 in 2003 versus 18.4 in 2004 (http://meteo.infospace.ru/wcarch/html)), mire areas were vastly different to 2003 (Section 3.7.6). Mires were drier: some were passable when they were not in 2003 and others were completely dried out. If change such as this exists on a more permanent basis, shifts in mire distribution and botanical composition will be inevitable.

Low Sedge Mire

Dominant species in the low sedge mires are *Carex rotundata*, *C. rostrata* and *C. rariflora* amongst other less common Carex species. Either or both sphagnum or other moss may be present. It is not uncommon to find *Eriophorum scheuchzeri*, *E. vaginatum*, *E. angustifolium* as well as other more rare *Eriophorum* species, *Comarum palustre* and on occasion other forb species.

Image 3.18. Low sedge mire underlain by sphagnum moss (bog) (Photo ID 15-07).

Image 3.19. Low sedge mire with moss (Photo ID 13-07).

Tall Sedge Mire

Tall sedge mires are less common than low mires, tend to be smaller and are found in more specific areas, often nearby or connecting shallow lakes. Carex vegetation, typically *Carex aquatilis*, is thicker and dominant. *Comarum palustre* may also be present. Community composition is simple.

Image 3.20. Tall sedge mire dominated by *Carex aquatilis* (Photo ID 13-10).

Image 3.21. Tall sedge mire underlain by moss and dominated by *Carex aquatilis* (Photo ID 9,2-15).

3.6.2.5 Heath-Mire Mixed Complexes

Distinct community complexes of moist heath (described in detail in the following sections) and mire vegetation are present in the region. Some patches are located in typical mire areas, with low swampy areas interspersed with raised heath vegetation, while other patches contained sunken mire areas in otherwise characteristically raised heath. In some instances, patch size of heath and mire - within the complex - is large, of the order of 10-30 metres (as in Image 3.23), and in others, the two community types are simply mixed and patchy on a very small scale, of the order of more than 3 metres (as in Images 3.24 and 3.25). In all cases the vegetation community could not be identified as solely heath or mire. Overall patch size is generally large or expansive, from about 100 to more than 300 metres in diameter.

Some heath-mire complexes contained shrubs, typically *Betula nana*. Vegetation species are typical of both mire and moist heath vegetation (as described in the relative sections).

Since moist heath and mire habitats are both used by reindeer for grazing, it follows that the heath-mire complexes should also be suitable, containing appropriate forage species such as *Carex, Eriophorum, Salix* and other ericaceous shrubs and a few forbs. Furthermore, the presence of firmer heath vegetation should make movement easier than in wet mires.

Heath-mire without shrubs

Image 3.22. Heath-mire with elevated heath hummocks (without deciduous shrubs) and patches of *Carex Eriophorum* mire (Photo ID 04-31).

Image 3.23. Heath-mire with sunken *Carex* mire depressions surrounding low moist heath (without deciduous shrubs) (Photo ID 08-24).

Heath-mire with shrubs

Image 3.24. Heath-mire showing hummocky heath with *Betula*, interspersed with patches of mire vegetation (Photo ID 06-07).

Image 3.25. Heath-mire showing high heath hummocks (with *Betula*) mixed with typical mire vegetation (Photo ID 13-05).

3.6.2.6 Heath Vegetation

Of all vegetation communities in the study region, heath vegetation is the most prevalent and diverse, with various dry and moist heaths, shrub and shrub free heaths, hummock, tussock and flat heaths, and lichen free and lichen rich heaths. The primary division is between moist and dry heaths. Heath communities can often cover expansive areas, of the order of more than 300 metres, even up to 1000 metres, in diameter, sometimes with shifts into other specific heath-type vegetation within a greater general heath region.

Dry ericaceous heaths with or without lichen are found in dry well drained patches; moist heaths with or without shrubs and with or without hummocks and tussocks are found in less well drained areas; and wetter heaths with a high moss content in the poorest drained areas that can still support heath vegetation. Among heath types, hummocks are most typical; noticeably small amounts of tussock tundra are present, even in better-drained areas. Moist heaths are dominant overall.

The value of heath communities for reindeer grazing varies; dry heaths with lichen are highly suitable as are some of the moist shrub heaths, particularly those that contain *Salix* shrubs and favourable Ericaceous shrubs. A dry ericaceous heath that contained no lichen would be of far less value except perhaps in autumn when berries and mushrooms are present.

Heath vegetation may be less susceptible to potential changes in climate given the range of vegetation and moisture content within the range of moist and dry heaths. Despite differences in specific species present or moisture content, key vegetation types such as ericaceous shrubs and *Betula* are typically common to all heaths.

Dry heaths

Dry heath communities are more rare than moist heaths and generally occupy smaller areas, with size ranging from very small (less than 10 metres in diameter) to medium (less than 100 metres in diameter) and on occasion large (more than 100 metres in diameter). Typically they are found in flat or gently sloping elevated areas on well-drained soil. Dry heaths often lie adjacent to exposed areas along ridge tops and on plateaus. Vegetation is low and deciduous shrubs are less common, particularly *Salix*, and present in limited amounts. Ericaceous shrubs dominate and lichens may or may not be present.

Lichen heath

Lichen heaths contain a variety of both light and dark coloured lichen species such as various *Cetraria* spp, *Cladina* spp., *Stereocaulon* spp., *Alectoria* spp. and *Thamnolia* spp., etc. Other vegetation consists of dry ericaceous shrubs such as *Empetrum nigrum*, *Vaccinium vitis-idaea*, *Arctostaphylos alpina* and *Ledum palustre*. *Betula nana* may or may not be present. Moss is not typically present in large amounts as it is in moist heaths and it may be virtually absent.

Image 3.26. Dry/xeric lichen heath without *Betula* (Photo ID 05-34).

Image 3.27. Dry/xeric lichen heath without *Betula* (except in depression lines) and showing cratering effects from reindeer winter foraging (Photo ID 12-12).

Image 3.28. Dry/xeric lichen heath without *Betula* (Photo ID 05-14).

Image 3.29. Dry/xeric lichen heath with *Betula* (Photo ID 05-31).

Image 3.30. Dry/xeric lichen heath with significant *Betula* (Photo ID 04-37).

Image 3.31. Dry/xeric lichen heath with *Betula* (Photo ID 05-01).

Ericaceous heath

Some dry heath contains no lichen at all but otherwise species composition is similar to the dry lichen heaths. In these cases, frost boils (as evident in Images 3.32 and 3.33) are sometimes present, revealing a dry clay substrate. Vegetation is similar but *Arctostaphylos alpina* is often present to a greater degree than in the lichen dominated dry heaths. Similar to lichen heaths, moss is not a dominant presence in ericaceous heaths and may even be less common in ericaceous heaths.

Image 3.32. Dry/xeric ericaceous shrub heath with frost boils on clay substrate (Photo ID 5,4-23).

Image 3.33. Dry/xeric ericaceous shrub heath with frost boils on clay substrate (Photo ID 4,4-28).

Moist heaths

Moist heath communities dominate the tundra landscape and form the primary vegetation community of the region. This heath category is divided according to landscape characteristics - presence of hummocks - and vegetation characteristics - presence of shrubs. Moss is present in rather to very substantial amounts in moist heath and is perhaps the primary distinguishing factor between moist and dry heaths. Size of moist heaths varies considerably: generally moist heath coverage is expansive with patches being 100-300 metres in diameter but small patches of more than 30 metres in diameter also exist. Key species in moist heaths are ericaceous shrubs such as *Empetrum nigrum*, *Vaccinium vitis-idaea*, *V. uliginosum*, *Ledum palustre*, *Arctostaphylos alpina*, *Ledum palustre*, *Rubus chamaemorus*, and to a lesser extent *Vaccinium myrtillus* and *Loiseleuria procumbens,* among others. Typical dwarf deciduous shrubs, if present, are *Betula nana* and low and ground *Salix* spp.

Hummocky moist heath

Heath vegetation with hummocks is typically wetter and species such as *Rubus chamaemorus* dominate, with a thick moss layer in the hummock depressions. Tussocks with *Carex* and *Eriophorum* species are sometimes present within the hummock heaths. Seldom is pure tussock tundra found, unlike in other circumpolar Arctic regions (*e.g.,* Alaska's north slope) where tussock tundra forms a dominant landscape component (author's previous experience). The summer study area contains more hummocky heaths than does the winter study area, which tends to contain flatter and drier heath types. Tussock tundra is no more present in winter pasture area than summer.

Image 3.34. Moist/mesic heath with high hummocks and without deciduous shrubs (Photo ID 8,2-32).

Image 3.35. Moist/mesic heath with hummocks and without deciduous shrubs (Photo ID 3,4-31).

Image 3.36. Moist/mesic heath with high hummocks and without deciduous shrubs (Photo ID 04-23).

Image 3.37. Moist/mesic heath with small hummocks and shrubs and scattered grass and *Carex* species (Photo ID 04-32).

Low moist heaths

Low (non-hummocky) heaths, whether or not they contain deciduous shrubs tend to be drier, possessing a thinner moss layer, than the hummocky heaths but otherwise vegetation is similar. Flat heaths contain more willow species while hummocky heaths are more birch dominated, in cases where deciduous shrubs are present.

Image 3.38. Moist/mesic flat heath (without hummocks) with *Salix* and *Betula* shrub (Photo ID 04-30).

Image 3.39. Moist/mesic flat heath without hummocks and with *Salix* and *Betula* (Photo ID 9,2-10).

3.6.2.7 Trees and Shrubs

Various shrub and tree communities are found throughout the region, both inland and along the river deltas (Pechora, Neruta and their tributaries) and in other drainages and riparian areas. Shrub communities are found within the tundra zone, as isolated pockets without a clear water source to follow, sometimes on gentle slopes with moist soil and other times in valleys (where water or moisture might pool) or on hillsides. Shrub communities are present to a greater extent than is true in other circumpolar tundra regions such as Alaska’s North Slope and Arctic Canada (author’s experience). Shrub patches, in particular medium and tall ones, are less common in winter pasture than summer. Shrub size and presence of trees increase to the south. Field sites are in fact located quite far north and consequently, tree communities were neither assessed nor seen except from afar in more southern regions by boat or plane.

Tall shrub communities (greater than 2 metres in height) were, however, observed, as were other shrub communities from very tall down to low dwarf shrub and open scrub communities. Shrub vegetation is dominated by birch, *Betula nana*, and by willow, *Salix,* species. Typically in shrub vegetation greater than one metre in height *Salix* dominates. Below this height, communities are either birch or willow or a combination of the two. In dwarf (very low) shrub communities, birch dominates. The primary willow species are *Salix glauca, S. phylicifolia* and *S. lanata*. Hybrids are also common, particularly in the shrub communities assessed in the winter pasture area. Hybrid species were not identified although notes were made on the differences in appearance and vegetative characteristics amongst the hybrids examined.

In shrub communities, particularly the tall, medium and low (less so dwarf) ones, an under layer of ground cover is present. While specific ground analyses were not done separately, in some of the shrub patches ground cover was examined and species recorded by using the point frame in order to get a clear idea of the species composition. Common ground cover species include *Equisetum* spp. and various forb species such as *Polemonium boreale, Ranunculus* spp.*, Myosotis palustris, Alchemilla vulgaris, Polygonum bistorta* and *P. viviparum* amongst others. Moss is common.

Patch size of shrub areas varies considerably but no patches are very large (much greater than 100 metres in diameter). Some medium and tall shrub patches are not more than a few (more than 3) metres in diameter and the largest are approximately 30-60 metres in diameter. Low shrub patches tend to be more expansive, between 30-100 metres in diameter, on occasion more. Dwarf shrub is more expansive if topography is favourable *i.e.* flat expanses. Observed but not visited patches of trees and tall shrubs further south appeared larger.

Shrub species, particularly willow, which is typically preferred as forage over birch, are very important in the reindeer diet, especially in spring when vegetation emerges and shoots are young and tender. Shrubs remain a key dietary component through the summer, however, and evidence (and observation) of browsing is clear.

A number of studies have examined effects of climate and potential climate change on shrub presence in Arctic tundra regions and conclusions generally support an increased presence of shrub with changing climate (increasing temperatures) (Silapaswan et al. 2001, Sturm et al. 2001, Hope at al. 2003). There are implications for reindeer grazing clearly but the picture is not simple. While shrubs provide valuable forage for reindeer, they also complicate migration patterns and reindeer herders’ use patterns in the tundra on a daily basis. Shrubs are difficult to navigate sledges through, slowing herders down, and reindeer easily become lost in tall shrub areas and herders effectively lose income. Also of consideration is the impact that reindeer have on vegetation through grazing and trampling: whether shifts in shrub distribution and size would be different without reindeer in this region is unknown.

Trees

No images of tree communities are available given that fieldwork locations were all north of the treeline.

Tall shrubs

Tall shrub communities have an average vegetation height of over 2 metres. Stands can be thick and impenetrable.

Image 3.40. Shrubs >2 m (high) showing a stand of tall mixed willow (*Salix* spp) (Photo ID 3,4-04).

Medium shrubs

Medium shrub patches are generally between 1-2 metres in height. Often pure *Salix* stands are thicker than mixed stands and generally taller.

Image 3.41. Shrubs >1 m (medium) with a mix of *Betula* and *Salix* spp. (Photo ID 5,4-12).

Image 3.42. Stand of medium (>1 m) *Salix* spp. shrubs (Photo ID 5,4-12).

Image 3.43. Riparian shrub cover in valley, probably medium shrub mixed with taller and smaller stands (Photo ID 05-11).

Low Shrubs

The low shrub group consists of both low shrub and dwarf shrubs. Low shrubs resemble the medium and tall shrub in growth form while dwarf shrubs grow much closer to the ground (prostrate) and are much smaller, typically 30 centimetres in height in the case of *Betula* and slightly taller for *Salix* communities.

Image 3.44. Shrubs <1 m (low) with *Salix* dominating (Photo ID 09-31).

Image 3.45. Shrubs <1 m (low) with *Salix* dominating (Photo ID 8,2-06).

Image 3.46. Shrubs <1 m (low) with *Betula* dominating (Photo ID 5,4-32).

Image 3.47. Shrubs <1 m (dwarf low) with dwarf *Betula* dominating (Photo ID 2,4-25).

Scrub

Scrub is an open habitat that is neither shrub nor clearly any other one community but generally a shrub dominated mixture with more sparse shrub vegetation than normal and other species such as ericaceous shrubs, grasses, sedges or *Equisetum*. It is found in occasional small patches (approximately 30 metres in diameter), often between other dominant vegetation communities. Sometimes, along small drainages, riparian scrub is found, typically with *Salix* rather than *Betula* dominating. Non-shrub species common in riparian scrub include *Eriophorum* spp, *Carex* spp. and *Alchemilla vulgaris* and other forbs in limited amounts. Tundra scrub habitats contain a wider variety of forb species such as *Polygonum* spp., *Ranunculus* spp., *Myosotis palustris*, etc. and *Equisetum* spp. Ericaceous species may include *Vaccinium uliginosum*, *V. myrtillus*, *Ledum palustre* and *Rubus chamaemorus* for example. Moss is also typical. The understorey of scrub vegetation resembles the ground cover of denser shrub stands.

Image 3.48. Typical mixed *Salix* and *Betula* scrub (open) with other vegetation present (Photo ID 13-06).

Image 3.49. Typical scrub (open) with *Salix* and various other vegetation including grasses and herb species (Photo ID 9,2-02).

Image 3.50. Thicker mixed shrub scrub dominated by *Betula* (Photo ID 4,4-30).

Image 3.51. Open riparian scrub (with *Salix* spp.) along a small stream (Photo ID 4,4-12).

3.6.3 Additional Vegetation Communities

A handful of other rare or otherwise different vegetation communities were observed and are described and illustrated below to complete the description of the study area communities and characteristics.

3.6.3.1 Tussock Tundra

As mentioned previously, tussock tundra is rare in this region of the Arctic; however, a few isolated patches exist. Tussock tundra is dominated by *Eriophorum* and *Carex* species and some grasses. Tussock vegetation in this region is often coupled with hummock heath vegetation. Patch size is medium, usually between 30-100 metres in diameter.

Image 3.52. Tussock and hummock tundra expanse (Photo ID 04-27).

Image 3.53. Tussock tundra with heath vegetation (Photo ID 04-10).

Image 3.54. Flatter tussock vegetation expanse with scattered heath hummocks (Photo ID 08-03).

Image 3.55. Hummock heath with scattered tussock vegetation (Photo ID 8,2-12).

Image 3.56. Tussock and hummock vegetation complex (Photo ID 2,4-22).

Image 3.57. Close up view of tussock and hummock mix, showing *Carex* spp. and *Eriophorum sp*. in tussocks (Photo ID 3,4-02).

3.6.3.2 Significantly Disturbed Vegetation

Reindeer can have a profound influence on the landscape of the tundra region, most noticeably in areas where herds are concentrated for periods of time such as the summer corral sites (seen above in the exposed vegetated community, Images 3.11 and 3.13) and surrounding area. Below are additional images of grossly disturbed vegetation due to reindeer grazing and trampling. In these cases, vegetation remains and is thicker but is heavily trampled and the community composition heavily influenced. Certain species suffer when disturbed and trampled and are less robust. Consequently, they become more rare or die out altogether within the community and other more robust species remain or take over. Grass tends to dominate regrowth of fully grazed or trampled areas while other vegetation species such as forbs become sparse and regrowth is slow (with some exceptions). Other species that may remain or colonise such areas include *Polygonum aviculare* in grassy areas, hardier ericaceous shrubs such as *Vaccinium vitis-idaea* and *Empetrum nigrum* where a more diverse heath type existed previously, and *Betula* in shrubby areas. *Salix* does not fare as well, remaining only as scattered, sparsely vegetated shrubs.

Image 3.58. Grass regrowth adjacent to a summer corral site (Photo ID 9,2-19).

Image 3.59. Highly disturbed hummock heath and shrub vegetation adjacent to a summer corral site (Photo ID 8,2-29).

Image 3.60. Highly disturbed vegetation adjacent to a summer corral site (Photo ID 10,2-04).

Image 3.61. Highly disturbed vegetation with greater shrub presence adjacent to a summer corral site (Photo ID 10,2-01).

3.6.3.3 Hummocky Lichen Heath

Lichen is most commonly found in low, flat dry heaths but an exception was found on rare occasion (not more than three examples like this were found) with the occurrence of lichen on the tops of moist hummock vegetation with moss as illustrated below. Lichen does occur commonly in heath-mire complexes on top of heath mounds but these formations are larger than the ones illustrated below.

Image 3.62. Unusual lichen hummock moist heath (Photo ID 06-03).

3.6.3.4 *Eriophorum* Expanse

Only two examples of true *Eriophorum* dominated communities were found. The extent of both is small, about 30 metres in diameter. The site illustrated below was found during an overnight visit to the region southwest of Naryan Mar while the other one is just outside the village of Nelmin Nos. An *Eriophorum* dominated community can signify previous disturbance, often growing for example on abandoned tundra transportation routes, but no obvious signs of previous disturbance were present at either of these two sites.

Image 3.63. *Eriophorum* dominated expanse (Photo ID 14-37).

3.7 Landscape Characteristics and Influences

3.7.1 Topography and Microtopography

The Vyucheiskii Kolkhoz region possesses distinct topographic features and characteristics that affect its environment and landscape characteristics: weather and precipitation regimes, snowmelt and snow characteristics, soil moisture and drainage, vegetation species and community distribution and growth are all affected. The botanical study area, within the greater Vyucheiskii Kolkhoz region, contains some of these specific topographic elements. For example, the main ridgeline, the Nenets Bank Ridge (Figure 2.5), running through the summer pasture region has a profound effect on moisture regimes, weather patterns and thus vegetation communities and composition. The presence of two major rivers, the Pechora and the Neruta, in close proximity to the study areas (and contained within the vegetation mapping study region, Chapter 4), influences low lying and riparian communities and vegetation patterns, not only at the main deltas but also along tributaries covering a much greater region.

Relief in the study region is limited and topographic variations would be considered minor compared to many other regions. However, given the fine ecological balance that exists in the Arctic, changes in elevation, slope and aspect that do occur in the Arctic can have a significant effect on the vegetation and characteristics of the land, affecting moisture, micro-climate, precipitation regimes, snow and ice cover, and ultimately vegetation and vegetation distribution and, in this case, also reindeer. The harsh environment and short growing season can mean that even small changes may have substantial effects in northern environments.

Some images in the previous section (*e.g.,* Images 3.15, 3.27, 3.37, 3.43 and 3.56) give a general impression of the region and its overall topography. Microtopography must also be considered, however, and the images below illustrate some of the microtopographic characteristics of the study area, the effects of which on vegetation patterns will be considered. The images show examples of stream valleys and gullies and relief typical of the study area.

The influence of valley microtopography on vegetation patterns is clear, with riparian shrub communities and herb slopes dominating these topographically varied areas. Other common vegetation such as heaths can be found in less rugged, more typical areas such as the plateaus above the drainages. It is not only relief that impacts the vegetation community characteristics but, as evident from these images, the width or openness of the valley also has a marked effect: in open valleys vegetation is more exposed to the elements (Images 3.64 and 3.65) and snow seems to melt similarly there as it does elsewhere, while in steeper, closed ravines (Image 3.67) snow may linger through summer months affecting vegetation growth and success and limiting species that may grow.

An additional topographic effect to consider is the influence of the large river drainages coursing through the region: in flat areas, moisture and drainage patterns are heavily influenced, affecting vegetation community types. Most noticeable in our botanical study region was the effect of the Neruta flood plain to the west of the Nenets Bank Ridge. Mire vegetation was dominant and other shrub and heath communities were only present in drier locations within this zone. Exposed vegetation on well-drained soils was only found higher up towards the ridge.

Topography and microtopography influence species presence. Some species need highly specific conditions to grow while others are hardy and can grow in a number of environments. In the case of more delicate plant species or species on the edge of their distribution, something as minor as an elevation change, the number of snow-free days or a shift in aspect or amount of sunlight can determine whether the species succeeds or not. Slight temperature fluctuations, particularly in summer may play a large role. Studies have shown effects of summer temperatures (Rannie 1986, Edlund & Alt 1989) and relationships between climate characteristics and plant species distribution (Fang & Xoda, 1989, Dahl 1998, Thompson et al. 1999). In fact plants can be used to map climate variation (Elvebakk 1990, Karlsen & Elvebakk 1996, Karlsen & Elvebakk 2003), even involving remote sensing (Brossard et al. 2002, Karlsen et al. 2005).

Image 3.64. Wide open stream valley with unvegetated or exposed vegetated zones at the top of the bluffs, herb and grass vegetation on the sides and shrub cover typical in riparian areas along the stream (old reindeer trails can be seen zigzagging along the hillsides) (Photo ID 05-07).

Image 3.65. A less dramatic stream valley with gentler herb and grass slope vegetation, riparian shrub cover, and heath vegetation on the elevated plateau regions (Photo ID 08-07).

Image 3.66. A narrower, deeper valley in a region with greater topographic variation than usual, showing snow remaining in August (photo taken during +30 C heatwave) (Photo ID 8,2-18).

Image 3.67. A narrow, deep valley showing micro-climatic effects of topography with patches of snow remaining where snow depth would have been great over winter (photo taken in August 2003 during 30 C heatwave) (Photo ID 9,2-03).

3.7.2 Heterogeneity

The vegetation community structure in this region is particularly heterogeneous, with patchy community distribution, complexes of mixed vegetation types and variable community size, both within and among vegetation types. The images below illustrate typical heterogeneity. In particular, Image 3.68 gives a clear indication of the varied landscape. In the foreground are medium shrubs (*Salix* dominated), then a small patch of grassland before the dark green patch that is moist hummock heath. This heath also contains low-lying mire depressions in narrow strips. The dark brown is a slightly different moist heath (probably with greater *Rubus chamaemorus* presence). Beyond this is probably hummock and tussock heath (the lighter patch). Finally, in the background a number of shrub stands can be seen with vegetation interspersed but too distant to identify. There are hills in the background and one nearer by, just beyond the background shrub patches in the right third of the image. Probably on the top of this hill, exposed vegetation or even sand craters might be found. Image 3.69 shows similar trends of heterogeneity but in a specifically riparian zone where vegetation shifts from dry heath, to dwarf *Betula* shrub, scrub, mire and then moist heath and *Salix* dominated low shrub. Finally, the third image, Image 3.70 depicts the heterogeneity that exists even on ridges and hilltops.

While the landscape of the study region is highly heterogeneous, there are places in which it is less so and as described earlier in the vegetation community section 3.6, some communities are expansive. However, compared to other tundra regions (*e.g.*, North Slope of Alaska, the Bathurst region in northeastern Nunavut, Canada, etc.) in which massive expanses of uniform vegetation are found, most commonly hummock or tussock tundra, this region can still be considered extremely heterogeneous (author's experience). The heterogeneity will be addressed again in the vegetation mapping chapter (4).

Reasons for heterogeneity are multiple. Topography and resulting variations in drainage, moisture, exposure and aspect play direct and major roles. Permafrost may also have an influence, although in the study area, permafrost effects are small given its limited presence. In regions with heavy reindeer presence, certain heterogeneous patterns can be attributed to disturbance and resultant changes in the vegetation community structure in response. There is often a radial effect in these cases if a central corral area is used or if the herders occupy one spot traditionally.

Image 3.68. A view of the tundra landscape, illustrative of the high degree of heterogeneity found within the vegetation distribution (Photo ID 3,4-27).

Image 3.69. A riparian tundra scene showing characteristics of heterogeneity with varied vegetation (*e.g.,* exposed, dwarf shrub, medium shrub, mire, moist heath, etc.) present in a localised area (Photo ID 2,4-12).

Image 3.70. An image depicting heterogeneity within higher, drier regions with exposed patches, grassland, stands of shrub, various heath vegetation, etc. (Photo ID 07-24).

3.7.3 Mixed Complexes

A heath-mire complex is a specific vegetation type present to a high enough degree and with a characteristic composition to merit being included in the community structure of the region, as outlined previously (3.6.2.5) However, other less well-defined complexes exist, some of which are simply a mix of all or many of the dominant vegetation types or species and are consequently difficult to categorize separately. This is an example of micro-scale heterogeneity and is illustrated in Image 3.71 with the combination of moist heath (both hummocky and flat), dwarf shrubs (*Salix* and *Betula*), tussocks with

Carex and *Eriophorum* species, mire vegetation and moss. Other complexes may contain all of these dominant vegetation types in a different ratio, or they may be missing one or two of the elements.

Image 3.71. Example of mixed vegetation complex, including typical heath, tussock, mire and shrub vegetation (Photo ID 8,2-07).

3.7.4 Shrub Presence

As mentioned briefly in the shrub community description, substantial shrub vegetation exists in this region. Not only are shrubs particularly prevalent but also their size is also remarkable, with shrubs well over two metres tall common in northern inland tundra zones, not just in major riparian areas or further south near the treeline. The image (3.72) below illustrates the heavy shrub presence in parts of the region, as do Images 3.44 and 3.46 in the previous section.

The question of potential shifts in the distribution and amount of shrub presents an interesting and complicated question from the point of view of climate change and reindeer influences and effects on them, as mentioned in 3.6.2.7.

Image 3.72. A tundra expanse covered by a variety of shrub species and communities (low *Betula* shrub, medium *Salix* or mixed shrub and tall *Salix* shrub in the distance) (Photo ID 2,4-14).

3.7.5 Influence of Reindeer

Reindeer have a profound effect on vegetation, grazing plant species and influencing vegetation communities and species presence (Käyhkö & Pellikka 1994, Kumpula et al. 2000, Theau & Duguay 2001, Theau & Duguay 2004, Tømmervik et al. 2004). Effects of reindeer overgrazing is a controversial issue, with opinions on the extent or existence of the problem differing substantially; however, there is no doubt that reindeer in large numbers significantly impact the vegetation around them, particularly lichen (Cooper & Wookey 2001), and reindeer density has been shown to explain the condition of lichen ranges in Finnish pastures (Kumpula et al. 2000). An extreme example can be seen along the fenced border between Finland and Norway in northern Scandinavia where lichens on the Finnish side where reindeer graze all year round have disappeared but are still present on the Norwegian side, used for grazing in winter only (*e.g.*, Käyhköa & Pellikka 1994). It might be argued that the problem is less of an issue in Russia than in regions of Scandinavia where reindeer density is higher and pressure on the land greater, nevertheless effects can be seen in the study region. In a zone of no grazing between Nelmin Nos and the pastures (summer) of the Fifth Brigade in the Vyucheiskii Kolkhoz (area between Nelmin Nos and box representing summer pasture fieldwork in Figure 2.4), vegetation community composition is markedly different. Almost no lichens are observed in the grazed summer pastures and any that exist are severely degraded (Image 3.73) but much lichen cover is found in suitable areas in this no-grazing zone (Image 3.74). In addition, regions beyond the heavily used summer pastures and regions no longer used as pasture (both visited during fieldwork) also contain significant lichen heaths (see lichen heath images in Section 3.6.2.6 and details in 3.2.). It is interesting to note that winter pastures, though showing grazing evidence such as craters, still contain substantial lichen vegetation. The lichen is not subject to degradation due to trampling as summer pasture lichen is, given snow cover and reduced reindeer density (L. Taleeva pers. comm.). An additional, aerial image taken near Naryan Mar shows thick lichen cover in an ungrazed area (Image 3.75).

Image 3.73. The only lichen heath found within heavily used summer pasture, showing lichen in very poor condition and much of it dead. Reindeer droppings were present (Photo ID 5,4-29).

Image 3.74. A patch of lichen heath in the ungrazed region between reindeer pasture and the village of Nelmin Nos (Photo ID 10,2-20).

Image 3.75. Aerial view of thick lichen vegetation in the area northeast of Naryan Mar, where no reindeer grazing occurs (Photo ID 01-19).

Reindeer not only affect lichen vegetation. As seen in the images below (and in other ones previously shown in Section 3.6), reindeer have a profound effect on heavily used areas such as corrals (Image 3.76) and the surrounding landscape (Image 3.77), due to grazing and trampling intensity.

Image 3.76. Reindeer in heavily used corral area with surrounding, modified landscape showing a limited variety of vegetation and substantial grass cover (Photo ID 2,4-33).

Image 3.77. Reindeer herd in area close to corral showing heavy grazing and trampling influence on the landscape, again with a shift to grass cover (Photo ID 9,2-26).

Vegetation in these heavily used areas does not begin to properly recover, even after one year's rest, as illustrated in the image (3.78) below of a corral site. The herd arrived for the first time that year (2004) just before this image was taken and within a day the earth was bare again.

Image 3.78. Reindeer herd in area close to corral showing long term effect of heavy grazing and trampling on the landscape (Photo ID 9,2-26).

Evidence of reindeer influencing the land is also seen in areas used as corridors: vegetation is trampled and permanent tracks remain evident in the landscape (Images 3.79 and 3.80). Winter vegetation sites can also be affected by reindeer when they dig under the snow for lichen as evidenced by craters, open patches of bare ground (Image 3.27) in previous section). The disturbance caused by cratering is, however, minimal in comparison to the other effects of reindeer on the landscape and lichen heaths do not seem affected.

Image 3.79. Reindeer tracks and trampled vegetation evident on edge of a mire along commonly used route in summer pasture (Photo ID 04-07).

Image 3.80. Reindeer tracks and trampled vegetation evident on a commonly used route in summer pasture (Photo ID 07-22).

3.7.6 Seasonal Effects and Anomalies and Climatic Shifts

Long-term climate change is a critical issue in the Arctic and an aspect of this research. However, seasonal climate shifts and effects can also have an impact, whether independent or connected to longer-term change. For example, the image below shows a mire expanse with a pond, what would normally be a wet, impassable (by foot) area. Instead, it is dried up and the pond mud cracked. This photo (Image 3.81) was taken in summer 2004, a particularly hot, dry summer, and scenes such as this were not uncommon (as seen in Images 3.82 and 3.83). Compared to the previous year, covering ground and traversing the landscape was far easier because everything was drier and areas that in 2003 were impassable became accessible. Beyond the effects of streams and lakes shrinking (Image 3.84) and mires and small ponds drying up, other changes occurred. Vegetation senesced earlier, berries and mushrooms were advanced, and reindeer condition was noticeably poorer.

Although seasonal effects such as this may seem minor, effects are far ranging, and ramifications of even such short-term anomalies or changes can be significant, not just for vegetation but for wildlife and other ecosystem components as well. If vegetation and other aspects of the environment affected do not recover, effects will be drawn out and could result in significant, longer term changes, irrespective of global change.

Factoring potential climate change into the equation complicates matters further: understanding the root of any shifts is a challenge in the first place. Are odd seasonal effects or shifts in weather patterns merely random or are they linked to a greater pattern of change? If separate what would be the combined effects of local and climate change? Would both types of change necessarily act in the same direction, *i.e.* towards warming or increased precipitation, or would they offset the other?

Image 3.81. A large dried mire expanse with a cracked, dry shallow pond in summer 2004 (Photo ID 04-34).

Image 3.82. A large dried shallow lake surrounded by mire expanse in summer 2004. (Photo: F. Stammler).

Image 3.83. A large dry mire expanse in summer 2004 (Photo ID 12-23).

Image 3.84. A shrinking lake, summer 2004 (Photo: F. Stammler).

3.7.7 Other Development, Infrastructure and Landscape Change

The territory of the Fifth Brigade, which includes the project study regions, has not been subject to development or influences other than direct and indirect effects of reindeer herding, which include reindeer tracks, human made trails from sledges, and old or recent vezdekhod (tank) ‘roads’ (paths) that connect the territory to the local village of Nelmin Nos. Other regions of the NAO, and indeed Russia, have had a different history: it is not atypical for infrastructure and other effects from past or recent oil drilling developments or attempts to be present, either physically or remain on the land as a scar. Many regions within the NAO face new oil and natural gas development, potentially conflicting with reindeer herding (*e.g.,* Ludviksen 1995, Habeck 2002, Tuisku 2002). Potential areas of exploitation are seen on the map (Figure 3.5) showing oil (red and black patches), natural gas (orange patches) and areas of related activity in much of the NAO. The project study regions are largely removed from any such exploration activity with the exception of a natural gas field near winter pasture area. It is not necessary therefore to take other development influences into account for the study region at this time and discussion can be limited to effects of or on reindeer and of potential climate change.

Figure 3.5. Map showing oil (red and black patches) and natural gas (orange patches) reserves and related activity in the NAO region. Photographed in Yasavey office, Naryan Mar, July 2003. ‘Regional Map. Current and Prospective Oil and Gas Development Areas of the NAO’, 2001, 1:500 000.

3.8 Statistical Analyses of Botanical Data

3.8.1 Chi Square and Principal Component Analyses

Although the vegetation communities appeared different on the ground from an observer’s viewpoint, it was necessary to examine if quantifiable statistical botanical differences did in fact exist among the vegetation communities, and if so to demonstrate these differences in order to more clearly understand the relationships among the various communities. Chi Square and Principal Component Analyses are two established statistical approaches that can provide definitive quantification and show statistical differences in botanical composition among vegetation communities. Certainly other useful multivariate analyses exist, such as Canonical Discriminant Function analysis, however, there was not scope for more in-depth assessment. A summary table below (Table 3.6) shows general information derived from the Chi square and PCA analyses and equivalency values derived from Shannon’s information theory (Columns 5 and 6) (Shannon 1949). In columns 1 and 3, and 2 and 4, the number of representative groups in each level of detail is shown for vegetation type (species or species grouping) and vegetation analysis site type (*i.e.* the community description at the field site) respectively. The equivalency values represent the number of effective classes assuming they all had the same frequency, *i.e.* there was no variation. Columns 7 and 8 deal with mutual information, an extension of Shannon’s information theory, and inform how much of Shannon’s information theory values are common to both rows and columns (*i.e.* vegetation type and site type). They describe how much information is shared, *i.e.* if one thing is known, how much does it explain. Column 7 describes how much of the site data can be explained by the vegetation type data and Column 8 describes the reverse. Logically, as the number of classes is decreased the values improve, and confusion is decreased. In the last column (10), the number of principal components (PCs) required to explain at least 95% of the variance are listed, effectively a measure of how much the data could be compressed. Variance is explained by the eigenvalues and their cumulative values used to find the 95% threshold. As the level of detail in the analyses decreases, the number of principal components does also, suggesting stronger relationships in the data.

Table 3.6. Summary of analyses made for Chi Square and PCA tests (Columns 1-4, 7-10) and other applicable statistical results.

Veg type level	Veg site type level	# Veg types	# Veg site types	Equiv Veg types	Equiv Veg site types	Veg type explains	Veg site type explains	PCs for 95%
1	1	85	68	27.045	67.988	35.68	45.65	16
2	1	61	68	19.707	67.988	29.76	42.13	13
3	1	35	68	14.383	67.988	24.42	38.65	9
4	1	11	68	8.861	67.988	19.68	38.07	7
5	1	7	68	6.418	67.988	15.59	35.39	5
1	2	85	22	27.045	18.747	38.9	34.58	9
2	2	61	22	19.707	18.747	33.42	32.86	8
3	2	35	22	14.383	18.747	26.87	29.54	7
4	2	11	22	8.861	18.747	22.46	30.18	6
5	2	7	22	6.418	18.747	18.08	28.5	5
1	3	85	12	27.045	8.646	43.37	28.37	6
2	3	61	12	19.707	8.646	38.11	27.58	6
3	3	35	12	14.383	8.646	30.48	24.66	5
4	3	11	12	8.761	8.646	25.85	25.56	5
5	3	7	12	6.418	8.646	20.76	24.09	4
1	4	85	8	27.045	5.241	42.77	21.49	4
2	4	61	8	19.707	5.241	37.52	20.85	4
3	4	35	8	14.383	5.241	32.28	20.06	4
4	4	11	8	8.861	5.241	26.68	20.26	4
5	4	7	8	6.418	5.241	20.46	18.23	4

While 166 species were identified in total in the study region, the point hit data picked up about half of this total, 85 or 51%. Considering the expanse of the field study area, this is a good indication that the extent of sampling was at least satisfactory. The species that are absent in the point hit data are more rare than common or they would have been included in the data. Therefore, they are unlikely to have an impact on the results. Major species, which are included, are much more important. In support of this, in the most detailed PCA, 95% of the variation is explained by 16 components, or vegetation species (Table 3.6), therefore, the remaining species in the 85 total play a minor role in explaining the variation, as would other rare species had they been included. Furthermore, the equivalent vegetation type value, from information theory/theoretical principles, is 27 (Table 3.6), suggesting that in effect, 27 vegetation types account for the differences (assuming unequal populations). The presence of additional, uncommon species would therefore be highly unlikely to affect the results.

General assessment of all of the Chi Square and PCA Analyses was made. The results of the Chi Square tests give the Chi value, *i.e.* the root of the Chi Square. To set a beginning threshold value for the χ, the Root Mean Square (RMS) was calculated as $\sqrt{\left(\chi^2\right)}$. The RMS gives an idea of the threshold beyond which values are unusually large. Such values can be positive or negative. If distinction using the RMS was not high enough, an arbitrary, slightly higher value was set. Results were examined to determine the Chi values with the greatest positive or negative values, signifying meaningful differences in vegetation species/category representation in the vegetation sites.

In the PCA, two coordinates at a time (for the vegetation type (species/species category) variable) were graphed and values of individual vegetation type sites or sight groupings represented by the points on the graph were identified to tease out the characteristics of each component. This was repeated after the initial pairing of the first two components, with the third, fourth and subsequent components until it seemed that there was not more to be gained from the data in distinguishing the vegetation sites. In addition, the Principal Components were examined numerically to see in which vegetation species/species categories the most pronounced differences, both positive and negative, were found. This information supported the coordinate graphs and helped clarify the results.

Based on this protocol, results of the various levels of analyses were assessed. The least detail needed to explain the variation is sufficient, *i.e.* the simplest level on which no information is lost, and so to begin with, data from the least detailed analysis level were examined. More detailed analysis levels were examined until the point at which additional data detail made results less clear and a suitable analysis level was thus established. The level of detail was suspected to be too high prior to analysis in some of the analysis combinations, and proper examination supported this. The general process of examination of the different analysis levels is described but only the most suitable analysis results are presented in detail.

3.8.1.1 Chi Square Results

The most basic, lower level Chi Square results are presented below as a starting point for the analysis in Table 3.7 and Figures 3.6, and 3.7, to provide a visual representation of the table data. Stars in the figures, representing the substantially larger (positive and negative) values, correspond to the similarly highlighted value in the table. Generally only tabular data are presented for the Chi Square analyses. The threshold value of this Chi Square analysis was set at 16.52, the RMS value.

Table 3.7. Chi values for the simplest analysis with 7 vegetation type categories and 8 vegetation site type groups.

		VEGETATION TYPE						
		Graminoids	Ericaceous	Deciduous	Forbs & Eq	Lichen	Moss	Unvegetated
VEGETATION SITE TYPE	EXPOSED	**-19.746485**	-2.240912	-11.825547	-12.597008	-13.020368	-15.379125	**64.451499**
	HERB SLOPE	-2.459033	-2.45144	-1.302377	**24.512733**	-6.740778	0.467683	-4.809051
	GRASSLAND	**20.847392**	-7.518872	-5.865275	5.568206	-4.76645	-5.91939	-7.303012
	MIRE	**36.764716**	**-24.816976**	-14.929172	5.074278	-15.808526	**17.18732**	-13.115447
	HEATH-MIRE	-7.328697	-1.13482	-5.521913	-4.409571	**17.440406**	8.173447	-1.420212
	HEATH	**-18.539378**	**32.256388**	-4.811129	-6.187863	**28.395741**	-4.24159	**-18.653094**
	SHRUB	2.274831	-15.674037	**40.024029**	8.190558	-15.239213	-2.092296	-12.042014
	DISTURBED	10.529342	-8.786807	-3.376295	-3.707169	-9.5329	6.110202	2.715596

Blue values represent positive values that are much larger than expected and red values negative ones that are much larger than expected, if association was random.

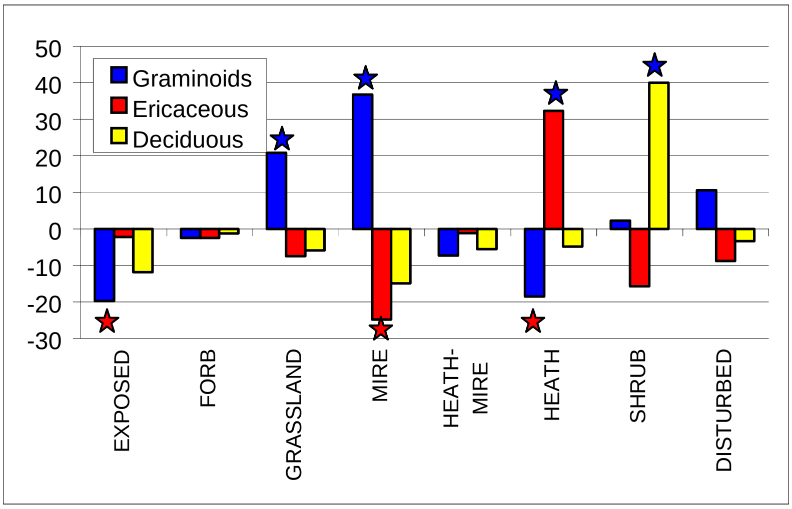


Figure 3.6. Graph showing Chi value across the 8 vegetation site type groups for Graminoids, Ericaceous shrubs and Deciduous shrubs.

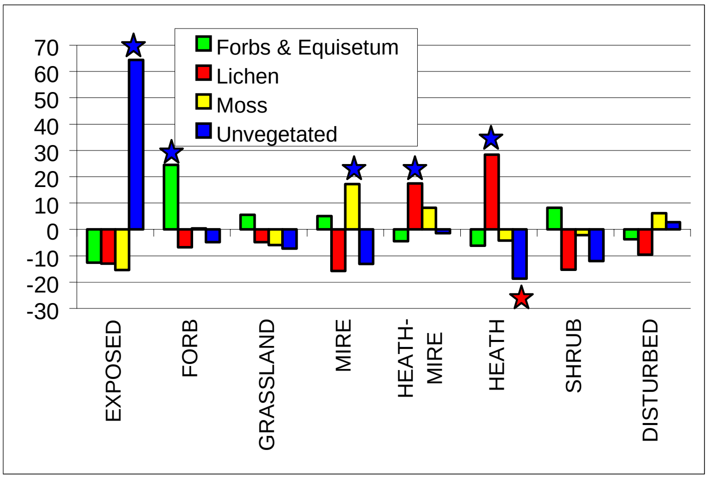


Figure 3.7. Graph showing Chi value across the 8 vegetation type groups for Forbs & Equisetum, Lichen, Moss and Unvegetated.

A number of expected trends can be seen in the data. The largest Chi value is in the Unvegetated category in the Exposed vegetation community type. The next strongest is Deciduous shrub in the Shrub community type, a good result given that data for medium and tall shrub types are missing which would presumably make this value even higher. Other significant associations are Graminoids in the Mire type, Lichen in the Heath type, a negative correlation of Ericaceous shrubs in the Mire type, Forbs & Equisetum in the Forb type and Graminoids in the Grassland type. Moss doesn't show any particularly strong associations though it is highest in the Mire type. It is interesting to note the negative correlation of Graminoids in the Heath community type: this lends support to the observation that tussock tundra was limited compared to hummock tundra. Tussock tundra would contain more graminoids than hummock tundra which consists of heath vegetation.

To check for differences in the next analysis level, Table 3.8 was produced and examined. Results show that Lichen in Dry Heath has the largest (positive) association, followed by Unvegetated in the two Exposed community types (Anthropogenic and Natural), then Deciduous shrubs in Low shrub, and nearly equally, Graminoids and Forbs & Equisetum in Low and High Mires respectively. Forbs showed a strong correlation in Grassland as did Ericaceous shrubs in Moist and Dry heaths. Again, the results seem founded at this level of increased detail.

Table 3.8. Chi values for analysis with 7 vegetation type categories and 12 vegetation site type groups.

		VEGETATION TYPE						
		GRAMINOIDS	ERICACEOUS SHRUBS	DECIDUOUS SHRUBS	FORBS & EQUISETUM	LICHEN	MOSS	UNVEGETATED
VEGETATION SITE TYPE	WIND EXPOSED	-15.911726	3.15133	-8.972752	-10.845701	-11.160077	-12.71996	**47.533421**
	CORRAL SITE	-12.115825	-10.633291	-8.294751	-6.431023	-6.740778	-8.824562	**47.766376**
	HERB SLOPE	-2.459033	-2.45144	-1.302377	24.512733	-6.740778	0.467683	-4.809051
	GRASSLAND	20.847392	-7.518872	-5.865275	5.568206	-4.76645	-5.91939	-7.303012
	LOW MIRE	**37.13425**	**-23.650588**	-13.803085	-6.313559	-15.072838	19.999445	-11.446182
	TALL MIRE	4.505962	-7.518872	-5.865275	**36.794705**	-4.76645	-6.239908	-7.303012
	HEATH MIRE	-7.328697	-1.13482	-5.521913	-4.409571	17.440406	8.173447	-1.420212
	DRY HEATH	**-22.620356**	21.431008	-12.169757	-13.873877	**63.92274**	-10.13569	-10.175769
	MOIST HEATH	-6.194072	24.244552	3.125428	2.683736	-12.508092	2.309609	-15.685866
	LOW SHRUB	-7.261282	-7.286622	**41.734128**	3.315047	-10.904517	1.333454	-13.584249
	SCRUB	11.328456	-15.26626	13.647783	8.517109	-10.658106	-4.564101	-2.980394
	DISTURBED	10.529342	-8.786807	-3.376295	-3.707169	-9.5329	6.110202	2.715596

Blue values represent positive values that are much larger than expected and red values negative ones that are much larger than expected, with bold type highlighting the largest values, if association was random.

Analysing vegetation sites at the most detailed species level data is less useful than grouping vegetation into broader clusters that are known to generally represent vegetation sites. For example, Carex species, and the Carex genus and the larger ‘Sedge’ grouping, are generally all associated with mire habitat and therefore, there would be little point in associating data on a species (or other more detailed) level if no additional information is gained that is not present at the coarser level. In cases where individual species are more uniformly distributed among vegetation site types, if there are other species within their grouping that have a strong association this uniformity will be lost, and if there are not, no strong trend will show: in neither situation are important details obscured. Analysing Chi values at the vegetation site level is not useful and this level of analysis is best left for the multivariate PCA, which has the power to group the sites through the analysis.

Conversely, analysing at too broad a level will leave out potentially interesting information and the coarsest level analyses here, as shown initially, may not show all the detail inherent in the data. Therefore, intermediate level analyses were chosen for examination using the PCA, which could be assessed with some confidence given the valid Chi square results.

3.8.1.2 Principal Component Analysis Results

The initial detailed assessment of the PCA results was made using all (68) vegetation site types and vegetation type category II (11 classes). Seven principal components explained 95% of the variation (from Table 3.6) in this case so no additional components needed to be assessed because it is unlikely that beyond the 7th any interesting trends would be evident. In fact, the 6th principal component is responsible for only 5% of the variation and brings the total to 94% and so the 7th was not examined in detail.

Vegetation site types of the furthest lying points or point clusters along the x and y axes were examined from the plots of coordinate (Principal Components) pairs, shown below in Figures 3.8, 3.9, 3.10, 3.11, 3.12, 3.13 and 3.14 with a summary of results and deductions shown in Table 3.9.

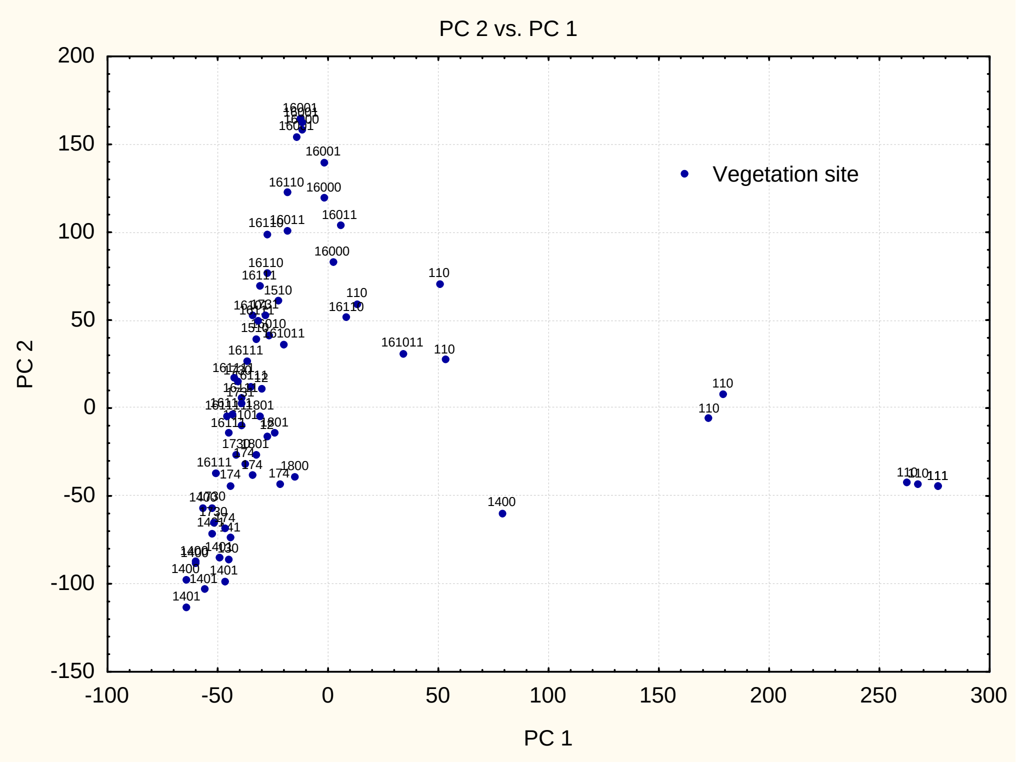


Figure 3.8. Graph of Principal Component 2 vs. Principal Component 1 and the 68 vegetation sites plotted.

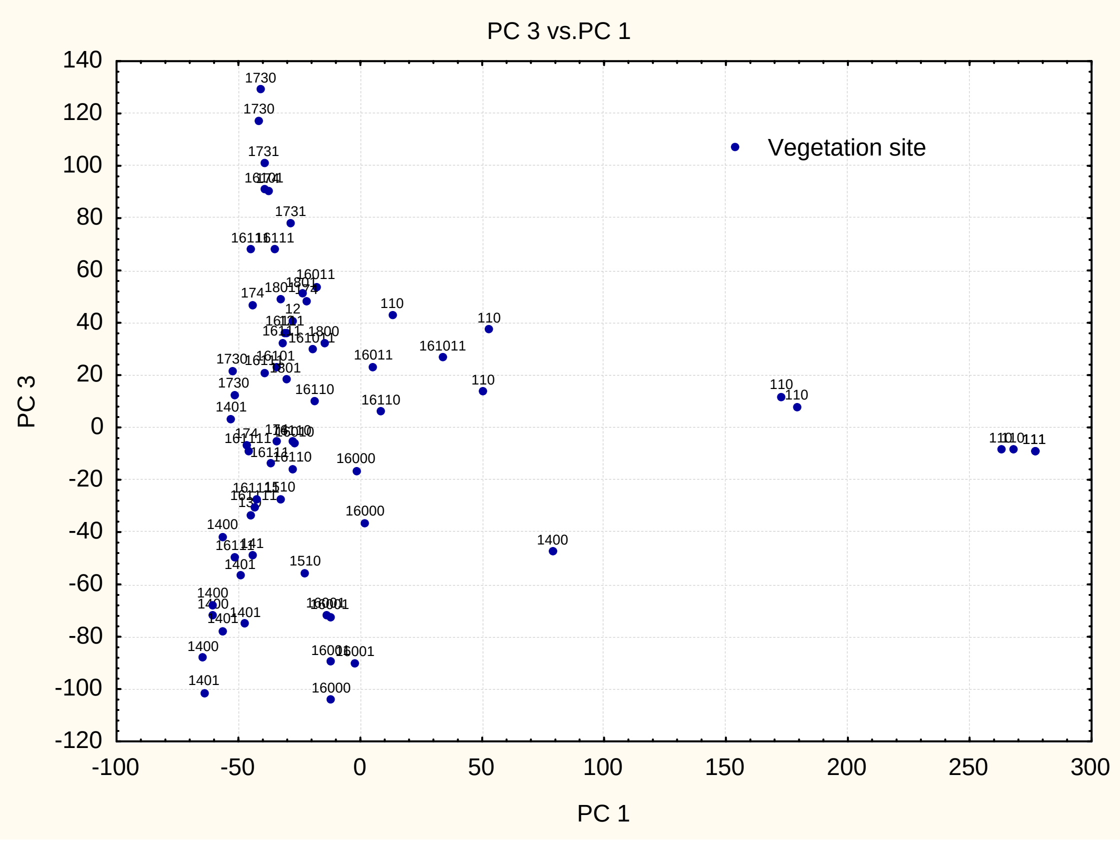


Figure 3.9. Graph of Principal Component 3 vs. Principal Component 1 and the 68 vegetation sites plotted.

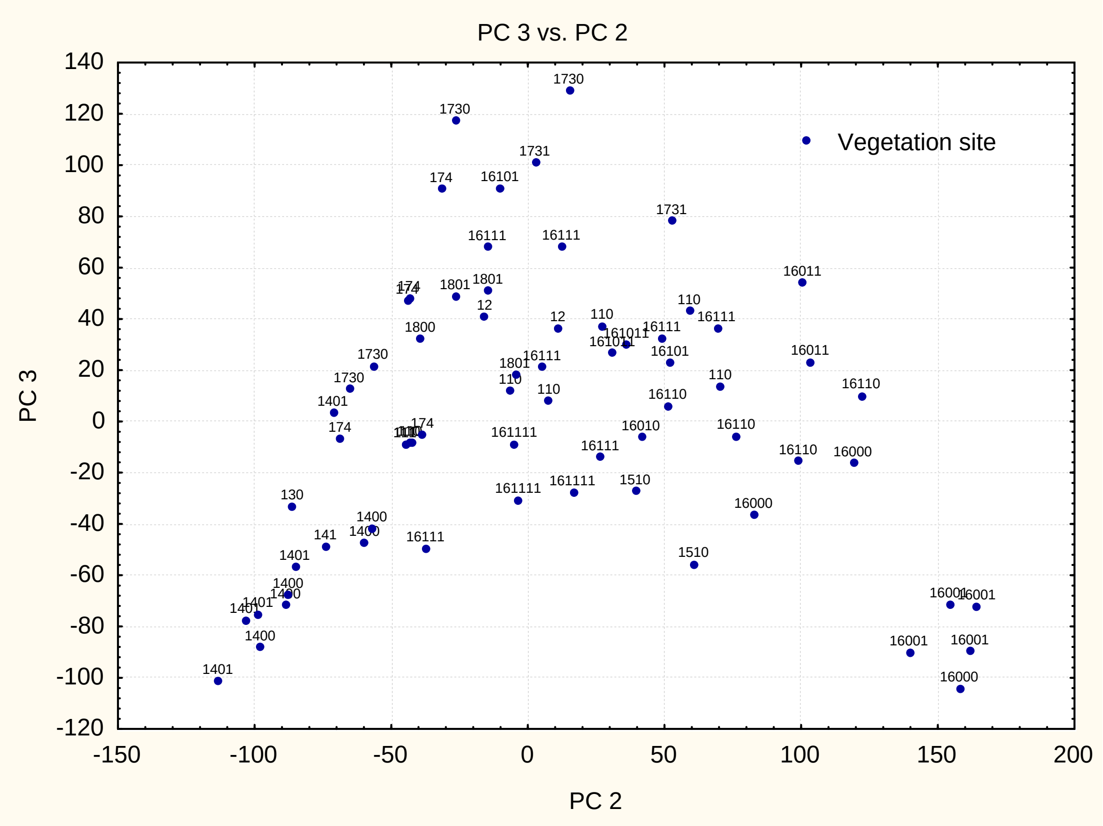


Figure 3.10. Graph of Principal Component 3 vs. Principal Component 2 and the 68 vegetation sites plotted.

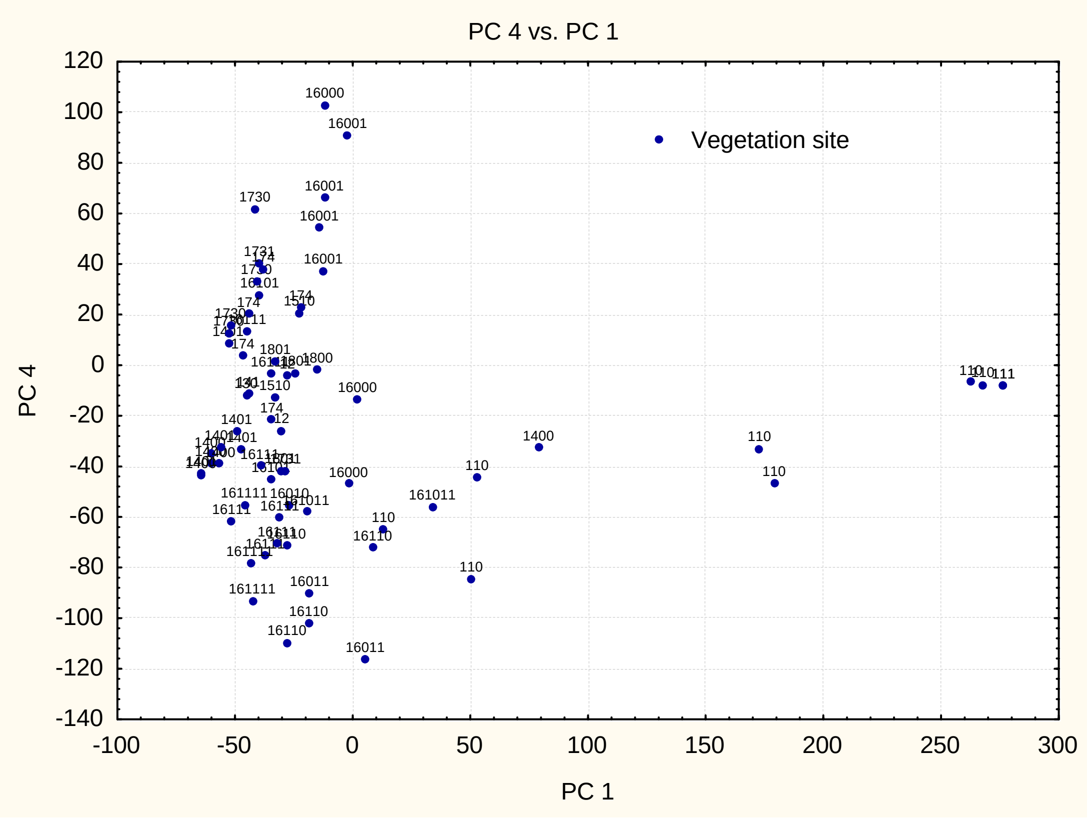


Figure 3.11. Graph of Principal Component 4 vs. Principal Component 1 and the 68 vegetation sites plotted.

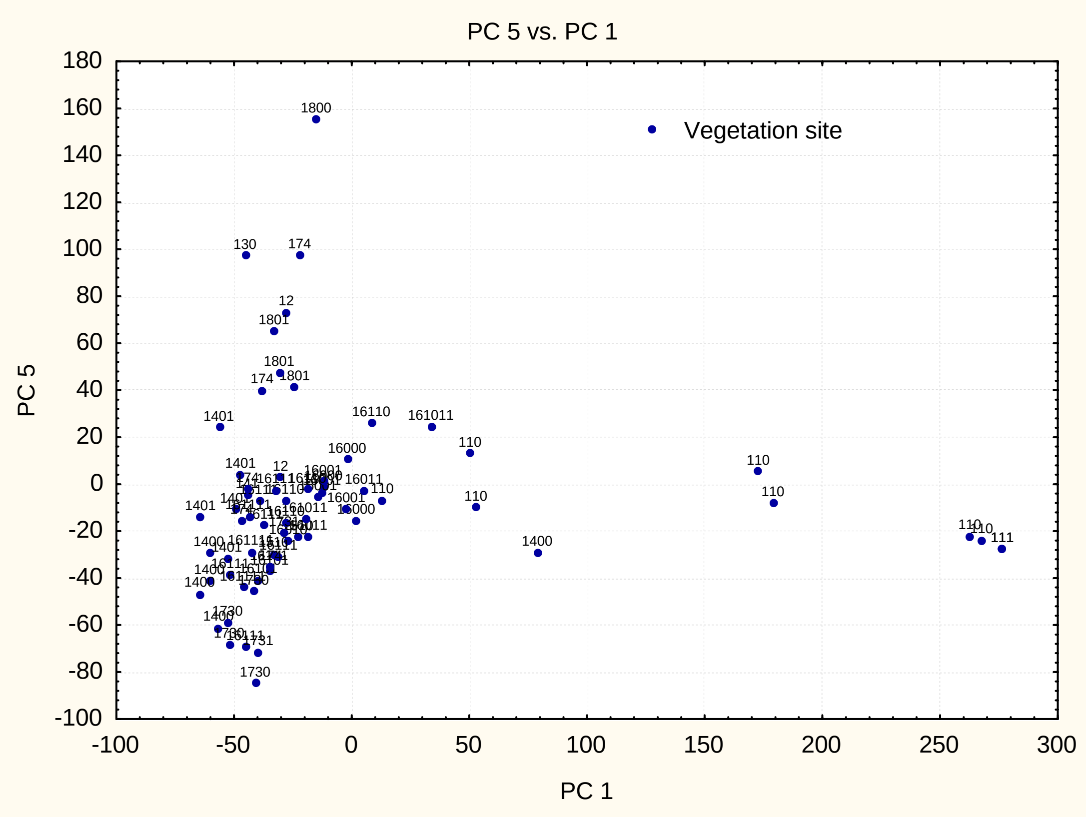


Figure 3.12. Graph of Principal Component 5 vs. Principal Component 1 and the 68 vegetation sites plotted.

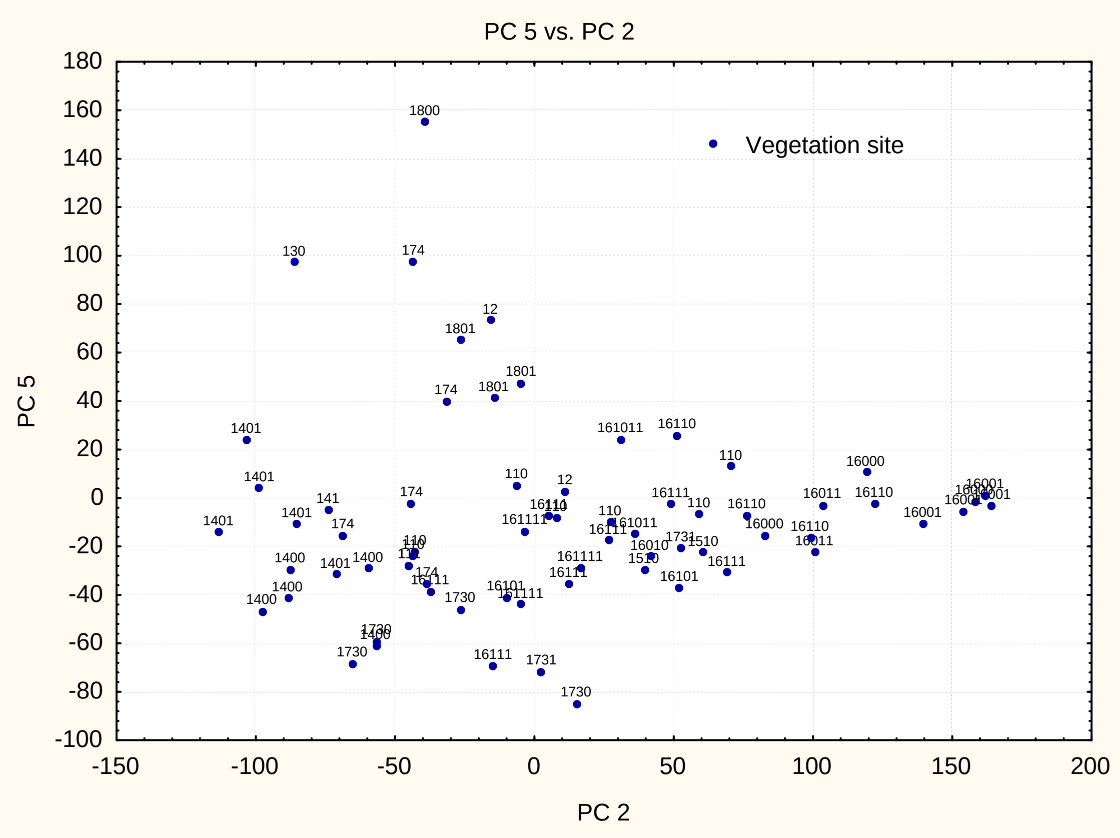


Figure 3.13. Graph of Principal Component 5 vs. Principal Component 2 and the 68 vegetation sites plotted.

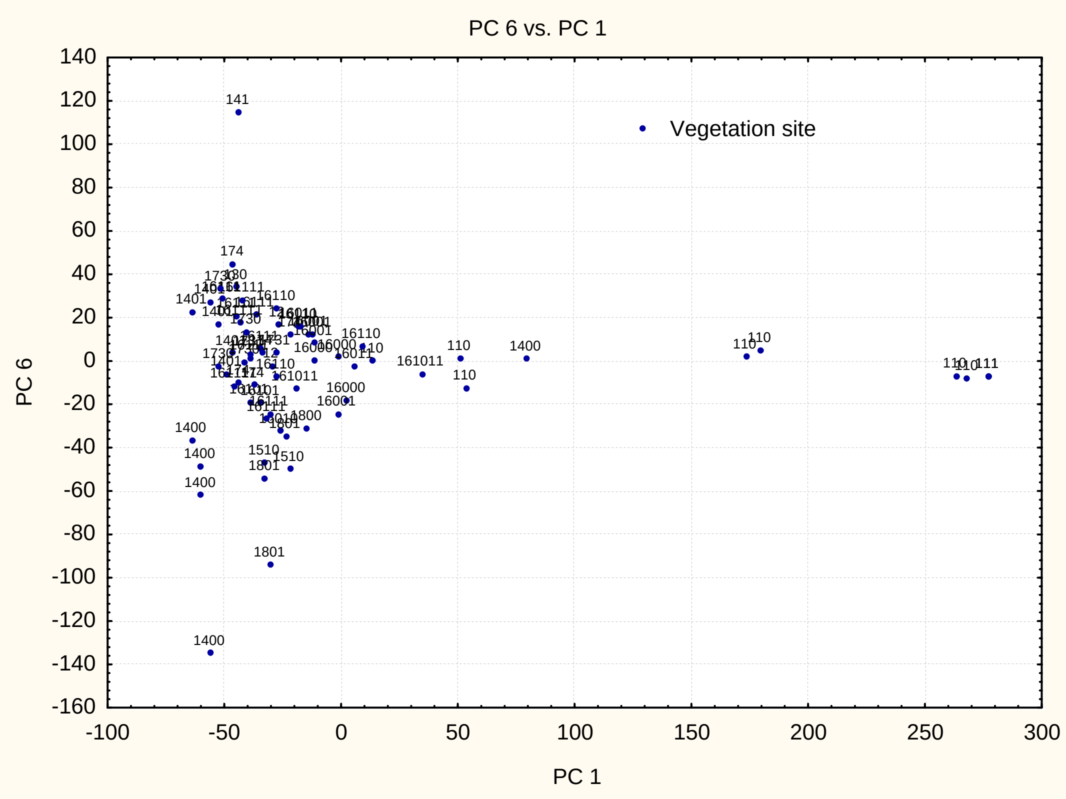


Figure 3.14. Graph of Principal Component 6 vs. Principal Component 1 and the 68 vegetation sites plotted.

Table 3.9. PCA of 1st 5 Components (89% of the variance) showing vegetation represented at extreme of x and y axes and likely vegetation group represented by the components.

PC Axes	Positive axis classes	Negative axis classes	Principle Component
1	Exposed/Corral	Dense/rich vegetation	Bare - Vegetated
2	Dry (lichen) heath	Mire	Dry - wet
3	Low Shrub/Scrub/Betula heath	Mire/Dry Lichen heath	Decreasing Shrub
4	Dry Lichen heath	Moist/Dry Ericaceous heath	Decreasing Lichen
5	Disturbed (grassy)/ Grassland/Scrub	Mire/Low Shrub	Decreasing Grass

Principle Components may or may not yield a simple interpretation to community structure although it is expected that lower components yield some explanation. Higher components account for smaller amounts of the variation and are unlikely to clarify results. In this case, the 6th PC represented the point at which additional information could not be discerned from the results (Figure 3.14). Therefore, it was eliminated from the analysis and not included in Table 3.9. The first five components provide clear information about differences in the vegetation classes, as outlined in Table 3.9. If the PC values are examined (Table 3.10) to see where the most significant extremes lie, they agree with our initial analysis that the 1st PC is bare/unvegetated cover. The second likewise agrees and separates dry from wet vegetation: it represents ericaceous shrubs and lichen in the positive and mire in the negative. The 3rd PC represents deciduous shrubs (and sedge and lichen in the negative) and the 4th, lichen in the positive and ericaceous shrub in the negative. The 5th PC shows an association with grass although less strongly than the other components and the 6th, with sedges and forbs in the positive and moss in the negative, an unclear distinction. From this point, components no longer provide information that can explain the variation in the data. It can be concluded that the level of PCA presented was useful in giving a statistical basis to the data.

Table 3.10. PCA values for vegetation type also showing Eigenvalues and Cumulative Variation explained by the PCs

		PC										
		1	2	3	4	5	6	7	8	9	10	11
		Sedges	Grass	Ericaceous	Deciduous	Forbs	Equisetum	Lichen	Moss	Litter	Trampled	Unvegetated
Eigenvalue		6602.92	5117.05	2899.47	2128.79	1633.41	1062.64	758.48	477.33	36.64	7.57	2.37
Cumulative Variation (%)		31.86	56.55	70.53	80.81	88.69	93.81	97.47	99.78	99.95	99.99	100.00
PC	1	-0.251	-0.105	-0.058	-0.157	-0.086	-0.009	-0.028	-0.196	-0.031	-0.002	**0.922**
	2	-0.477	-0.219	**0.618**	-0.066	-0.109	-0.009	**0.532**	-0.139	0.041	-0.005	-0.149
	3	-0.549	0.133	0.105	**0.644**	0.068	0.042	-0.489	-0.032	0.086	0.000	-0.030
	4	-0.212	0.048	-0.641	0.378	0.066	0.019	**0.610**	-0.096	-0.111	0.004	-0.027
	5	-0.274	**0.801**	-0.049	-0.425	0.137	0.006	0.018	-0.242	0.120	0.000	-0.093
	6	0.308	-0.082	0.159	0.169	0.429	0.019	-0.030	-0.790	-0.186	0.014	-0.022
	7	0.285	0.308	0.109	0.281	-0.806	-0.002	0.061	-0.280	0.002	0.006	0.035
	8	0.018	-0.246	-0.201	-0.051	-0.046	-0.039	-0.026	-0.255	0.906	0.011	-0.073
	9	-0.095	-0.135	-0.111	-0.154	-0.133	0.939	-0.093	-0.104	-0.075	-0.021	-0.105
	10	-0.151	-0.141	-0.139	-0.148	-0.144	-0.131	-0.135	-0.125	-0.149	0.896	-0.140
	11	0.282	0.281	0.286	0.279	0.281	0.310	0.268	0.281	0.281	0.444	0.282

Values in blue show positive association to the component and values in red negative association. Grey values do not explain variation in the PCA.

As a final data assessment, an additional Chi Square result was examined (Table 3.11): it is one level removed from the PCA, with 22 vegetation sites instead of the full 68 which as discussed above are not meaningful in a Chi Square test.

Table 3.11. Table showing Chi values across 22 vegetation site type groups for 11 vegetation types.

		VEGETATION TYPE										
		SEDGES	GRASS	ERICACEOUS	DECIDUOUS	FORBS	EQUISETUM	LICHEN	MOSS	LITTER	TRAMPLED	UNVEGETATED
VEGETATION SITE TYPE	Exposed	**-16.65**	-5.27	3.15	**-8.97**	**-10.40**	-3.23	**-11.16**	**-12.72**	-2.07	-1.57	**63.49**
	Corral	**-9.01**	**-8.10**	**-10.63**	**-8.29**	-5.95	-2.44	-6.74	**-8.82**	-6.52	-0.84	**67.35**
	Herb slope	**-9.01**	6.35	-2.45	-1.30	**23.78**	6.60	-6.74	0.47	1.92	-0.84	-7.72
	Grassland	9.63	**20.47**	-7.52	-5.87	5.06	2.34	-4.77	-5.92	-4.61	-0.59	-5.63
	Low mire-sphagnum (bog)	**26.87**	-5.07	**-16.63**	**-13.04**	-7.39	-3.85	**-10.66**	**25.47**	1.72	-1.33	-3.23
	Low mire-moss	**37.47**	**12.03**	**-16.81**	-6.48	-0.06	-1.51	**-10.66**	2.82	**-9.44**	-1.33	**-11.17**
	Tall mire	11.20	-5.73	-7.52	-5.87	**40.46**	-1.72	-4.77	-6.24	-4.61	-0.59	-5.63
	Heath-Mire	-2.58	**-8.10**	-1.13	-5.52	-3.77	-2.44	**17.44**	8.17	6.52	-0.84	-7.09
	Dry Lichen Heath	**-9.32**	-7.80	8.94	**-8.98**	-7.02	-2.98	**39.11**	-6.09	1.66	-1.03	-5.55
	Dry Lichen Heath w/ Betula	**-12.54**	**-10.99**	8.01	**-9.37**	**-8.58**	-3.23	**70.00**	**-10.13**	-7.49	-1.21	**-9.92**
	Dry Eric. Heath	-0.88	-4.50	4.45	-2.80	-3.97	-0.56	0.27	3.70	7.32	-0.59	-4.57
	Dry Eric. heath	**-9.01**	-4.15	**22.66**	-0.94	-5.95	-1.20	-4.96	-3.39	1.92	-0.84	-3.57
	Moist shrub heath	-6.13	-2.66	1.69	**13.89**	-3.60	8.24	-3.33	4.55	-1.30	-0.84	-7.97
	Moist shrub heath	-6.68	1.41	7.33	-1.78	-2.93	**17.28**	-6.59	-0.89	1.15	-0.84	0.82
	Moist hummock heath	-6.63	-5.43	**25.19**	**-11.30**	1.92	-3.44	1.06	-3.67	2.71	-1.19	**-8.16**
	Moist hummock shrub heath	0.99	-5.91	9.21	9.36	5.57	-0.60	**-10.31**	3.78	-1.95	-1.57	**-14.84**
	Moist hummock shrub heath	**13.79**	-3.26	8.86	-3.47	-3.86	-2.31	**-8.01**	1.13	-1.85	-1.03	**-9.76**
	Low shrub- mixed	1.22	-5.34	**-11.05**	**35.67**	2.16	7.88	**-9.53**	1.70	-5.86	-1.19	**-11.27**
	Low shrub- Betula	**-8.79**	-3.41	3.00	**21.84**	-0.41	-2.44	-5.41	-0.10	-0.08	-0.84	-7.46
	Scrub	1.82	**14.92**	**-15.27**	**13.65**	8.86	0.83	**-10.66**	-4.56	7.35	**15.25**	**-11.48**
	Disturbed	-6.37	**25.88**	-7.39	-5.87	-1.12	-1.72	-4.77	-5.28	**14.70**	-0.59	-3.86
	Disturbed w/ shrub	**-11.04**	**19.63**	-5.88	-0.51	-2.49	-2.65	**-8.26**	10.10	8.92	0.92	**-8.01**

Deep blue represents the highest positive association, medium blue the next highest and red highest negative associations.

Briefly, results from the final Chi Square analysis, shown in Table 3.11, are as expected, for example, low mires are the most highly positively associated with sedges, dry lichen heath shows dominant positive association with lichen as do exposed and corral areas with unvegetated. Overall, the Chi Square and PCA tests supported trends that could have been expected given vegetation community and distribution knowledge gained from the field and assessed on a qualitative, descriptive level previously.

4. DISCUSSION

4.1 Landscape

The kolkhoz territory is located in a diverse and complex landscape, with influences of an expansive, flat river delta (Pechora River) and an additional smaller delta (Neruta River), other low lying, wet areas, a ridgeline and associated plateaus, drainage valleys and slopes, and typical tundra complexes of lakes, and low and high patches of land. This diverse landscape structure is one of the major driving factors in determining the characteristics of the vegetation distribution of the region and in influencing the high heterogeneity.

4.2 Vegetation Communities

Vegetation trends are defined by the landscape characteristics and environmental influences manifested in micro-climate variability. Sedges and mosses dominate lower, wet, flat areas, forbs and graminoids sand and gravel bars and slopes, various heath and shrub communities flatter expanses and gentle slopes, and shrubs and graminoids riparian communities. Noticeably small amounts of tussock heath are present.

Various heath communities dominate the study area. Dry ericaceous heaths with or without lichen are found in dry well drained patches, moist heaths with or without shrubs and with or without hummocks and tussocks are found in less well drained areas, and wetter heaths with a high moss content in the poorest drained areas that can still support heath vegetation. Moist heaths comprise the majority of the heath communities.

Along ridge tops and on plateaus, substantial wind-blown sand and rock craters with sparse vegetation have formed. Typically, dry heaths lie adjacent to these exposed, slightly elevated areas.

Shrub patches are noticeably prevalent in drainages and in stands in the tundra, ranging in area from very small (less than 10 metres diameter) to large (around 100 metres in diameter), in height from less than one metre to more than two metres and in density from sparse to impenetrably thick.

The summer and winter study areas contain some of the same vegetation communities; however, they are located in geographically and topographically different regions of the territory and exhibit some differences. In general the winter pasture area is flatter, has a smaller array of vegetation communities and is generally less complex than the summer pasture area, which has greater topographic and hydrological variation and thus more diverse communities. In addition, the winter area is climatically somewhat different due to its proximity to the sea and the resulting effects of wind and even saltwater influence on coastal vegetation.

4.3 Land Use

Characteristics of the study region relating to land use are established. Land in the Vyucheiskii Kolkhoz has been in constant use as reindeer herding pasture for a number of decades and the territory of the Fifth

Brigade has also been used consistently during this time, unlike that of other brigades, which may have been temporarily or permanently abandoned (L. Taleeva pers. comm.). Consequently, within the study region, effects of long-term reindeer and reindeer grazing should be substantial. This is supported by evidence of lichen presence and absence in ungrazed or grazed territory. Studies suggest herbivore grazing may limit shrub expansion (Cairns & Moen 2004, van der Wal 2006) but evidence for this is not available. Herders assert that shrub distribution and size have grown but whether grazing has limited this cannot be determined. Future studies with grazing and controls could test this.

4.4 Regional Species

The species list compiled based on field identifications in 2003 and 2004 most probably identifies most of the current species in the region. Though it is unlikely to identify all of them, it is the most complete list available with 165 species and additional mosses and lichens. Other lists (*e.g.,* Plant List of the Okrug, Pamphlet (unidentified source) and notes located in the research library in Naryan Mar are not as complete, outdated and often include a broader region and therefore do not distinguish local species. Therefore, the specific species data provided here are highly relevant to this and future work in the region.

4.5 Botanical Analysis

The statistical analyses of the botanical data allowed a determination of more detailed, quantitative vegetation species and community relationships. While 165 species were found in the region, for meaningful community understanding, species are best grouped into broader divisions. Among these divisions, certain ones are more important in influencing the determination of statistically different communities. Based on the Chi Square analysis, only seven vegetation species groupings are relevant to explain most of the variation in the communities. Specifically, graminoid presence distinguishes grassland, graminoids and moss distinguish mire habitat, ericaceous shrubs and lichen distinguish heaths, forbs and equisetum distinguish herb slope communities, deciduous shrubs separate shrub communities, unvegetated cover separates exposed vegetation, and lichen plays a role in distinguishing mire-heath complexes (all non-random positive associations). Graminoid absence separates exposed and heath community sites, ericaceous shrub absence is significant in mires, and heaths are distinguished by their absence of unvegetated landcover. Results from a more detailed Chi Square analysis were in agreement with only one surprising result: forbs and equisetum were shown to be significant in separating tall mire vegetation. While tall mires can contain relatively large amounts of *Comarum palustre* for example, this result is not substantiated because based on field observation *Carex aquatilus* dominates.

Landscape and vegetation characteristics, critical in distinguishing the region’s vegetation communities from one another, were determined through the Principal Component Analysis. The primary component in separating communities was the extent or degree of vegetated cover, *i.e.* ranging from exposed, unvegetated cover to dense, rich vegetation such as mire species (containing as determined above, significant graminoids) and moist heath species (containing significant ericaceous shrubs, as determined above). The next factor in determining separation of vegetation communities was moisture, with wet mire vegetation on one extreme and dry lichen heaths and exposed regions on the other. Presence or absence of shrubs was the next most relevant factor in distinguishing community types, followed by lichen presence or absence. Finally, the presence of grass (in grassland and disturbed sites for example) versus its absence (in mire, shrub and heath communities) was a fifth factor that determined community separation.

Interestingly, three of the key vegetation groups important in both reindeer habitat suitability and climate change effect determination play critical roles in distinguishing the region’s vegetation communities: shrubs, lichen and grasses. It would be of interest to conduct future analysis of botanical data in order to determine whether trends in vegetation community separation remain the same or if potential vegetation change may cause apparent differences in results.

As mentioned in the methods section, the point hit data, which did not include medium and tall shrub communities, were used for the statistical analyses. Despite the absence of communities with probably among the highest deciduous shrub compositions, results from both the Chi Square and PCA showed the importance of shrubs in defining and separating communities. Data analysis that included additional shrub sites would be recommendable in order to see whether shrub presence would play an even stronger role in distinguishing communities, perhaps assuming a lower Principle Component, for example. Shrub vegetation is of particular importance as mentioned already for both reindeer habitat and herders’ concerns and also in assessing potential climate change. Furthermore it is thought to be expanding both in distribution and size and these changes could possibly be reflected in detailed botanical analysis.

4.5.1 Methodological Issues and Improvements

Substantial useful and widely applicable botanical data were collected, providing knowledge of species presence and distribution, and community structure and distribution for a region for which little or no detailed information was known. However, improvements in data collection are possible: additional sites in winter pasture would be an advantage, impossible in this case due to not being allowed by law to carry out additional work; a two layered point frame would remove the potential bias of point hit data more strongly representing top layer vegetation; consistent percent cover sampling would have allowed a complete analysis and data comparison of two collection methods; permanent markers or pegs that established the precise point frame positions would improve accuracy and usefulness of potential future reassessment; and more explicit notes on community size in every site analysed would have allowed a stronger connection between vegetation mapping (Chapter 4) and botanical analysis work.

The methodological discontinuity in the percent cover data collection between 2003 and 2004 was a problem in that data could not be combined for both seasons. However, both methods are valid. The 2004 data with only a single 100% ‘surface’ total can perhaps be more directly related to satellite mapping since it uses an overview of the vegetation plot. The method with moss and lichens counted separately merely separates out the plant types and accounts for the existence of an underlayer, part of plant community structure. While the point hit method is more precise, the data depending on a ‘hit’ with the crossed string, the percent cover method is an estimate. However, in the data collected as part of this study, independent estimates were made by two individuals and a consensus reached, giving the data a stronger basis. Consistency was maintained by the author having the final say and collecting data in both seasons.

There is a small issue of circularity within the botanical statistical analyses: vegetation species and sites are divided into groups prior to analysis in order to allow more useful results, reducing the independence of the data. However, the groups into which sites or species were divided are established botanical groupings with known species associations, and results from the current analyses do support the separation of the vegetation types based on a variety of botanical and site characteristics. More in depth statistical analysis, however, could better resolve this issue and shed more light on the botanical classification.

Suggestions for future development include expansion of the number of analysis sites, particularly into other seasonal pastures, and, collection of biomass data, which would yield information with particular relevance to assessment of climate or grazing related shifts and would be of particular use in monitoring programs. Measurements of soil pH would also help in establishment and separation of precise vegetation communities. Particularly useful, but requiring substantial effort, would be the development of bioclimatic maps (Elvebakk 1990, Karlsen & Elvebakk 1996, Karlsen & Elvebakk 2003), of benefit in assessment and understanding of climate, and in perceiving changes on a specific level. Data collected so far provide detail that would allow basic development of such work but additional data collection, made easier by having established species presence in the region, would vastly improve this avenue of research.

4.6 Assessing Change and Implications for Reindeer

The detailed assessment and analysis of the species and botanical communities of the study region allow not only knowledge of these aspects but also a perspective for understanding potential shifts due to climate or other factors and resulting consequences on reindeer habitat and forage.

The situation is complex, with vegetation and vegetation communities influencing and in turn being influenced by reindeer. Without reindeer, the tundra vegetation patterns and community composition would probably be different. What remains unknown is the effect that reindeer may have on slowing or reducing any climate driven changes in shrub cover, size and presence, or indeed altering any effects on lichens or grasses or other species. The situation is poorly understood currently and greater insight is required before future shifts can be clearly understood.

4.6.1 Shrub Expansion

The specific question of potential shifts in the distribution and amount of shrubs presents an interesting and complicated question. Shrub growth and distribution is determined by a number of abiotic and biotic factors: drainage patterns, moisture regimes and precipitation, climate and seasonal shifts, and effects of reindeer grazing. Should climatic shifts occur, all of the abiotic factors are likely to be impacted. Reindeer grazing may likewise also be affected. In addition however, others factors beyond climate are potentially important in characterising grazing effects on shrubs and vegetation. Reindeer populations are subject to change, both due to natural fluctuations (possible to an extent among herded reindeer) and to decisions made by herders or the government officials in control. Such changes, in population density or in regions grazed by reindeer can have resultant effects on the landscape, independent of other changes such as climate. Teasing apart the factors in a clear fashion is so far not possible. The precise effect of reindeer grazing on shrub and vegetation distribution is not understood currently, complicated climate effects such as increased shrub presence aside. The question that remains is to what extent reindeer influence shrub growth and how might reindeer alter the effects of a changing climate. These questions can be extended to grass and lichen as well. Disturbance by reindeer is known to increase grass distribution, as seen in Section 3.7 in the areas surrounding the corral sites and in the results from the PCA. Unlike the situation with shrub growth in which reindeer and climate change effects are at odds with each other, reindeer grazing and climate change are acting in the same direction in this case, both encouraging grassification. The questions therefore are to what extent each plays a role and what is the combined impact of the two influences, is it additive or synergistic. Finally, lichen distribution is likewise influenced by reindeer and potentially changing climate though different again to the previous two cases, both effects are thought to be detrimental, with reindeer grazing and trampling reducing lichen cover and climate change effects having the same result. Further study into the relationships between certain vegetation communities and climate change and grazing effects are needed to better understand the implications of change.

4.7 Climate Change Effects

Vegetation in this region is highly heterogeneous and patchy. Assessing effects of climate change on this characteristic would be an interesting study. Would the patchiness and fragmented distribution allow easier change or the opposite. More detailed examination into distribution shifts is necessary in future. Further examination of the relation between climate change and reindeer habitat will be detailed in Chapter 6.

5. CONCLUSIONS

Substantial data were collected on the vegetation and botanical characteristics of the study region, adding new information and filling in critical gaps in knowledge. The collection of raw botanical data from vegetation analyses, other botanical observations, and the associated photographs form a substantial data source on which others can draw. Additional analyses in future, particularly assessment of change, would be of certain interest.

The data collected on species presence and distribution in the communities of the study region allowed a thorough understanding of the vegetation of the region, with the role of specific species groups (*e.g.,* graminoids, lichens, shrubs) in separating communities clarified and the role of specific characteristics and species groups distinguishing communities (such as moisture, degree of vegetatedness and shrub and lichen presence). General trends were established based on fieldwork and observation, however, statistical analyses allowed a certainty of interpretation and a determination of non-random trends.

With the greater understanding of the botany and vegetation communities of the region came interpretation and discussion of specific factors and elements of change affecting the region: reindeer and potential climate change. Much remains uncertain about the future of both of these things, but that there is substantial potential for influence is certain.

Finally, the information provided in this chapter has purposes and uses beyond the scope of this research. It can be applied to further botanical assessments, used in other ecological studies, habitat assessments of wildlife and in conservation research. As with all data from this project, the raw botanical data will be available for other interested parties: public, government, industry and private.

Far more data than could be analysed in this chapter exists and additional analyses on the provided data would be beneficial for improving the understanding of the vegetation characteristics of this region.

CHAPTER 4 – VEGETATION CLASSIFICATION OF THE VYUCHEISKII KOLKHOZ

> “If we knew what it was we were doing, it would not be called research, would it?”
>
> Albert Einstein

1. INTRODUCTION

1.1 Background

Chapter 3 presented the first level of landscape assessment in this thesis, the detailed botanical analysis. With particular relevance for this chapter, it also provided detailed, illustrated vegetation community descriptions, and information on the landscape influences in the Vyucheiskii region. This chapter takes a step back from the detail of the previous and develops a spatial classification of the vegetation of the region, ultimately producing a vegetation map and a second level of landscape assessment for later multi-scale analysis (Chapter 5).

As detailed in Chapter 1 reindeer are a keystone herbivore in the circumpolar Arctic, both affecting and being affected by components of their ecosystems, in particular vegetation. Therefore, knowledge of vegetation and vegetation distribution is key to understanding their habitat and pasture suitability and requirements. Furthermore, knowledge of vegetation community spatial distribution is critical in assessing potential changes, due to reindeer influences, climate, other factors or a combination of them, and ultimately in assessing how the animals may be affected by shifts in their environment.

Given the changes that are occurring and will continue to occur in the north, in particular, climatic change with its predicted greater magnitude in Arctic regions and influence on vegetation (IPCC 2001, ACIA 2005), and the value of reindeer, the provision of modern data for Arctic ecosystem assessments is essential for ecosystem understanding. This is particularly true in many Arctic regions for which little recent and/or detailed data, including on vegetation distribution, are available, for example, Russia (Walker et al. 1995, Rees et al. 2002, Virtanen et al. 2004). Valuable vegetation mapping efforts have been developed in Russia and important contributions such as in phytogeography have resulted (Alexandrova 1980, see Walker et al. 1995, p. 431-2), but in general methods have been traditional and maps are not current or highly detailed.

Traditional field based data collection and analysis is useful, providing relevant information that broadens understanding of a region and improves perspective (as demonstrated in Chapter 3). More modern technologies and applications can further this process, expand areas of coverage more easily and cheaply, and advance knowledge in ways previously not possible (Walker at al. 1995, Barnsley et al. 1997, Franklin & Wulder 2002, Rees et al. 2002, Virtanen et al. 2004). Remote sensing and spatial mapping technology can provide information relating to vegetation, snow and ice, topography and other land characteristics, and allow increased ease of expansion and replication of data. In particular, a number of studies have examined and documented the use of satellite based vegetation mapping in circumpolar regions, more recently for use in large scale coverages (*e.g.,* Cihlar 2000, CAVM Team 2003), and for a longer time at a regional mapping level (*e.g.,* Walker et al. 1982, Markon 1989, Bay 1992, Ducks Unlimited 1998, Muller et al. 1999, Virtanen et al. 2004) and more specific local or fine-scale levels (*e.g.*, Talbot & Markon 1988, Spjelkavik & Elvebakk 1989, Virtanen et al. 2004)(and see Walker et al. 1995). In this chapter, spatial data are used to develop an understanding of previously unknown, detailed vegetation community distribution. The previous chapter provided detailed botanical information on vegetation community species composition; the work in this chapter will build on that by providing geographical distribution information for these communities.

1.2 Rationale and Applications

A modern detailed vegetation map that provides spatial data for the study region in the NAO, intermediate between the highly detailed, species-specific botany data (Chapter 3) and the coarse resolution, regional and global vegetation models (Chapter 5), is necessary 1) to provide new data for the region and 2) for a multi-scale comparison of the utility of landscape assessments. This new, widely applicable data also has significant extended value.

The spatial representation of vegetation provides valuable and previously unknown distribution information for specific botanical communities, potential changes in which can then theoretically be assessed. Furthermore, there is opportunity to assess reindeer pasture and examine established seasonal divisions within pasture land according to specific community composition. Of significant note is the opportunity to develop a vegetation classification for an unusually complex and diverse region with particularly influential topographic and associated characteristics and highly heterogeneous vegetation distribution.

Currently, no detailed or recent mapping information is available for the study region. Basic printed 1:1000000 topographical maps from 1990, 1:200000 topographical maps from 1977 and a 1:1000000 vegetation classification produced in 1974 have been the only data found. Given the overall scarcity and age and limited detail of the little existing data, and the wide variety of applications for improved, modern, and detailed data both within and beyond the scope of this research (as expanded upon late in the chapter), the development of a detailed vegetation map for the region is of certain benefit and need.

1.3 Objectives

The overall objective of this research component is to develop a current, moderately high resolution (approximately 50m) detailed vegetation classification of the Vyucheiskii Kolkhoz to provide new information on spatial vegetation community distribution. Such information would then aim to be 1) used in a multi-scale landscape assessment later in this work (Chapter 5), 2) applied to assess reindeer pasture characteristics in the region and 3) examined for its potential in elucidating any climate related changes. Specific, more involved habitat or climate change impact assessments could be developed in future with these data as a base, but fall beyond the scope of this research.

A second objective, specific to vegetation mapping techniques rather than to direct applications of the results, is to develop a classification for a particularly challenging and difficult region whose vegetation distribution and communities are heavily influenced by surrounding complex topography, river drainage systems, and effects of sea ice and winds (as described in further detail in Chapter 3), in addition to typical Arctic vegetation influences such as a harsh climate and short growing season, and phenomena such as permafrost and thawing and refreezing effects on soil. The result of these characteristics is a region of particularly heterogeneous, and therefore difficult to classify, vegetation and vegetation community distribution. Other arctic regions can have more homogeneous landscapes, large swaths of single vegetation communities (such as tussock tundra) or simple topographic influences (such as gentle expansive slopes) on distribution (Walker et al. 1994, author's experience) and, therefore, to adequately classify an unusually complex region is valuable in terms of both methodological technique and data value.

2. METHODS

2.1 Outline

Appropriate data and other supporting information were obtained for use in the vegetation map development. Preliminary work on geometric rectification of the selected remote sensing data was followed by development of initial unsupervised and hybrid classifications. Ground truthing data from two seasons of fieldwork in summers 2003 and 2004 were incorporated in the development of a supervised satellite vegetation classification. The classification was refined a number of ways and statistical analyses carried out to assess accuracy. A final vegetation map representing the study region was produced.

2.2 Data Collection and Preparation

Data for the study region in the NAO (Figure 2.4) were located for assessment and potential application to vegetation map development. The limited data found included:

1. printed General Staff topographic maps of the region dated 1990, at 1:1000000, Gauss-Krüger projection, Krasovsky ellipsoid and Pulkovo 1942 datum (Figure 4.1)
2. higher resolution, printed General Staff topographic maps dated 1977, at 1:200000, Gauss-Krüger projection, Krasovsky ellipsoid and Pulkovo 1942 datum (General Staff) (Figure 4.2) and digitized versions of the maps
3. a printed, coarse generalized vegetation map from 1974, at 1:1000000 (Isachenko et al. 1974) (Figure 4.3) (unknown projection)

As seen in the section of the scanned 1:1000000 topographic map (Figure 4.1), information given in this map includes names of cities or large towns, small towns and villages, rivers and water bodies, contours (40m) and elevation points. River courses, lakes, sandy tidal areas and marshy areas define land characteristics. Roads are shown where they exist. In addition, the map has been annotated anonymously by hand (prior to obtaining it), the lines delineating the herding territories of kolkhozes and the numbers the brigade areas within the Vyucheiskii kolkhoz. Our fieldwork, as pointed out in Chapter 2, was in the territory of the fifth brigade.

The 1:200000 maps (Figure 4.2) show similar information but provide greater detail and place names for permanent settlements of any size. Basic land cover is shown, elevation points are given and contours are at 20m intervals The maps show coordinates on a 4 kilometre grid and also provide graticule intersections (as ticks) every fifteen minutes in latitude and longitude degrees.

The vegetation map (Figure 4.3) shows only names of large towns/cities, *e.g.,* Naryan Mar and the 48 vegetation community divisions (in nine broad categories), displayed using distinct shading and hatching. A simplified key for vegetation communities found in the study region is shown here alongside the map section.

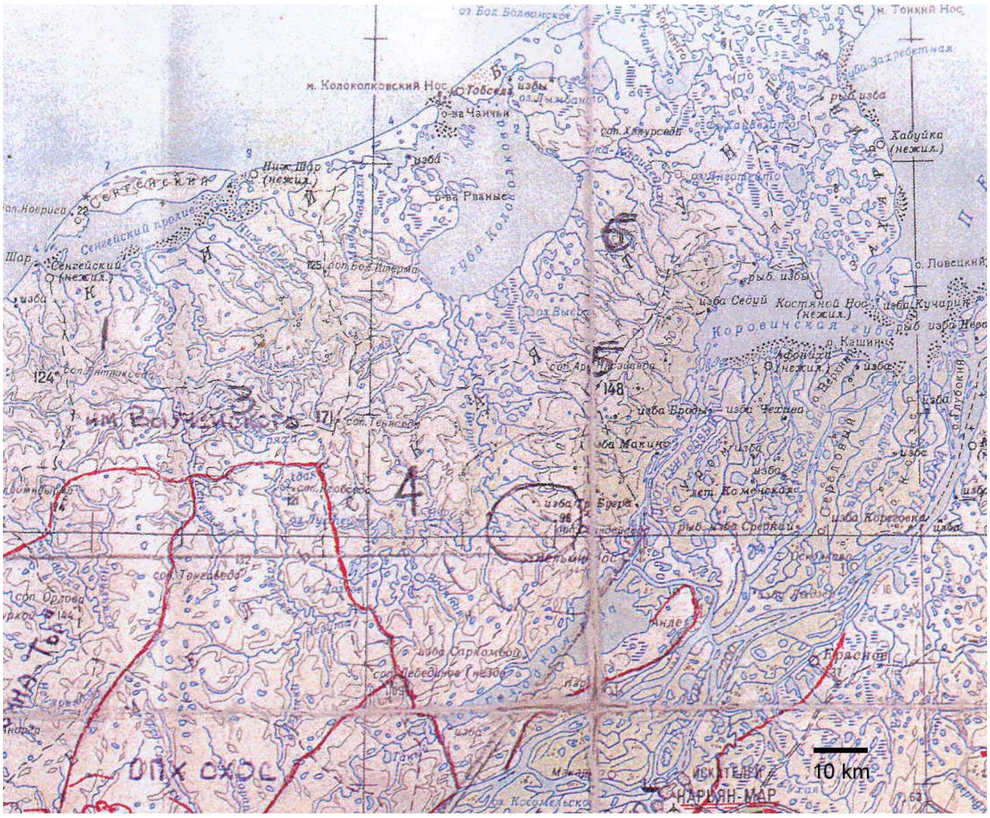


Figure 4.1. Section of scanned Russian Military Survey topographic map from 1990.

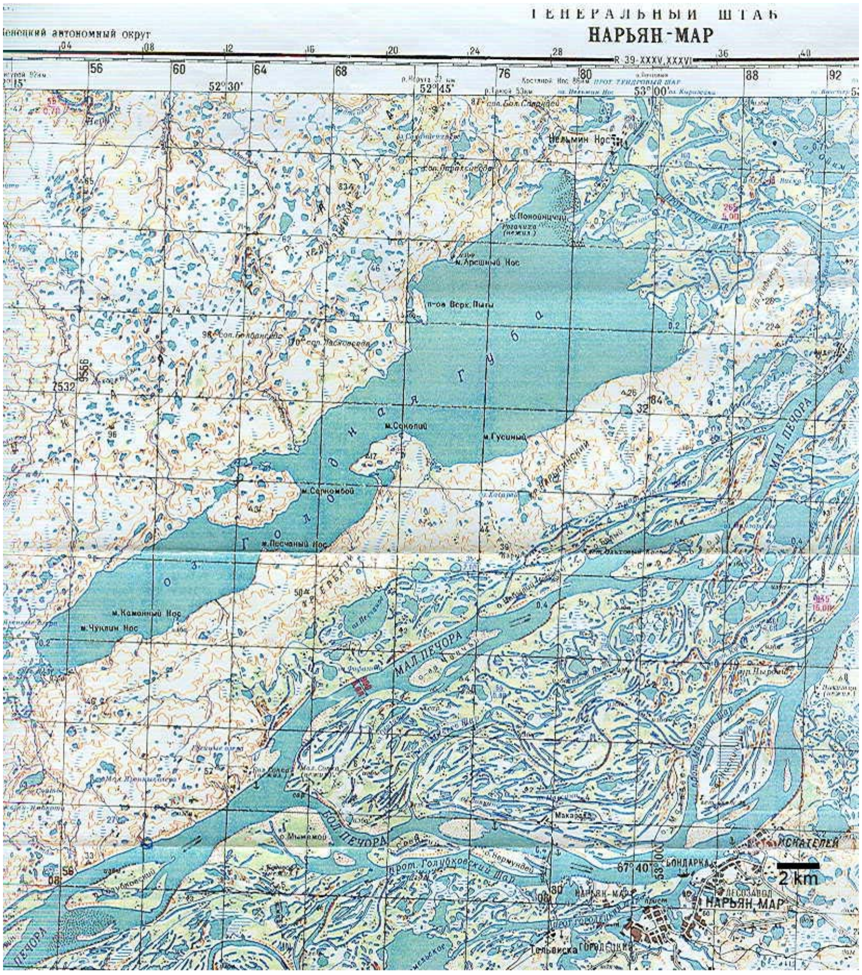


Figure 4.2. Section of digitised Russian Military Survey General Staff topographic map from 1977 (grid dimension = 4x4 km).

SELECTED KEY (Types represented in study area only)	
A	**Northern moss-herb-lichen-dwarf shrub tundra**
1	moss-sedge-herb
2	lichen-dwarf shrub
7	moss-sedge-herb with bogs and mires
B	**Southern tundra: low dwarf birch tundra with sparse shrub layer of Betula nana and willow**
8	dwarf birch-willow, dwarf shrub sedge, moss, small hummocks
9	dwarf birch willow, dwarf shrub, lichen moss, small hummock
10	dwarf birch, dwarf shrub herb, moss, with bogs
13	dwarf birch-willow-moss-dwarf shrub-sedge with bogs
14	dwarf birch-willow-lichen-moss-dwarf shrub
15	dwarf birch tundra with moss, dwarf shrub, herbs and bogs
C	**Southern tundra: tall dwarf birch tundra with dense Betula nana shrub layer**
17	dwarf birch-willow, dwarf shrub, lichen-moss
18	dwarf birch, dwarf shrub-herb, moss with bogs
20	dwarf birch-willow lichen-moss-dwarf shrub with bogs
D	**Southern tundra: willow tundra**
24	willow tundra
Mires	
36	sedge-herb coastal
37	sedge-cottongrass-moss subarctic
40	dwarf birch, herb-dwarf shrub-moss-lichen
46	**Coastal salt marsh**
47	Riparian willow thicket

Figure 4.3. Section of scanned coarse vegetation map from 1974 (reprojected plate carrée)

Attempts at finding other data sources were made but no finer scale data could be located despite enquiries within and outside of Russia. Given the limited available data, it was determined that the vegetation map would have to be developed as an entirely new project.

2.2.1 Spatial Data

Various imagery exists and was considered for use in the vegetation map development: traditional types including airborne photography and maps developed from ground observations relating specific land characteristics (such as vegetation) to topography and GCPs; and more modern types including optical remote sensing data collected from orbiting satellites and airborne radar data. No aerial photography data were found, and collecting new data was not possible due to the expense, probably strict government regulations, and logistical complexity or near impossibility, in particular in a remote region of Russia. No adequate ground-based maps existed: the only vegetation map was too coarse and more than thirty years old (Isachenko et al. 1974). High quality radar imaging data (*e.g.*, SAR) are reliable, can be finely calibrated, have sufficient resolution and are useful for penetrating cloud cover, a problem not overcome by optical remote sensing data. However, radar data are not suited to the specific vegetation mapping requirements of this research due to their limited scope for detailed classification as a result of their single channel. Multi-spectral data is superior in this regard. The remaining option, therefore, was optical remote sensing satellite data.

2.2.1.1 Satellite Remote Sensing Data

Increasingly many remote sensing satellites are in orbit around the earth, with widely varying quality, suitability and applications of their data. Satellite sensor data collection is generally based on the same principle: that features on the ground (*e.g.*, vegetation) have different and specific spectral signatures (Curran 1985). A typical approach in remote sensing interpretation is to group features according to similar reflectance (and/or thermal) values. Thermal infrared sensors, if present, measure the surface temperature of the landscape features. The process of determining reflectance is complicated by a number of factors, however, including atmospheric scatter effects (such as particulates) that affect the intensity of incoming radiation, intensity of the reflected radiation and topographic effects that can shift the seeming position of the sensor and also light source (*i.e.* the sun)(Curran 1985). For example, the same vegetation type in a flat sunny spot would yield different reflectance values than if it were on a steep slope in shadow. To correct for these factors, techniques, such as the use of digital elevation models (DEMs) in this example, can be employed and satellite data collection and interpretation can be refined.

Vegetation Classification

Satellite sensors can provide a variety of data from coarse to fine resolution, panchromatic (black and white) to multi-spectral (with a few to many bands) and infrequent to frequent temporal images. Vegetation classification often utilises multi-spectral imagery since valuable information is contained in spectral reflectance characteristics across wavelengths (*i.e.* the electromagnetic spectrum) (see Fig 2.11 in Curran 1985). While classifications are developed multi-spectrally, examination of individual bands is common during the classification refinement process. Plant physiological structure and pigments are responsible for the distinct reflectance values (across the spectrum) of different vegetation types; and, thickness, affecting both factors, is the major determinant in establishing reflectance values (Curran 1985). Leaf structure and not pigments, however, determines reflectance values in the important near-IR wavelengths (Curran 1985, Campbell 1996). The spongy mesophyll layer located between the upper and lower epidermides of a plant leaf contains air spaces between the mesophyll cell walls. These air spaces are responsible for reflecting near-IR radiation and the more air space the higher the reflectance due to scattering caused by these spaces. Reflectance values are not static but may change, decreasing in the case of near-IR, during the season as plants mature and senesce and leaf structure changes. As a consequence, examining data from different times of the year/season can provide further information for refinement.

In multi-spectral imagery, certain bands will lie in the visible wavelength range: blue, green and red. The blue band can be useful in distinguishing water, given its penetration of water bodies, and so sediment-rich water is distinguished from clear and deep water. It also separates soil from vegetation due to its light penetration qualities and it can be used in distinguishing terricolous lichens (*e.g.*, Rees & Williams 1997, Rees et al. 2004). Green can highlight the peak of reflectance for vegetation, useful at key green-up periods. Red and blue are the chlorophyll absorption bands and are useful in distinguishing types and health of vegetation, and between vegetation and soil. Infrared bands include near (reflected), mid- and thermal infrared, the latter often at a lower resolution. The near infrared (NIR) is probably the most important in vegetation classification. It highlights vegetative peaks and allows clear distinction between leafy and non-leafy vegetation types due to substantial reflectivity differences. It also clearly distinguishes vegetated from non-vegetated landcover since vegetation in general reflects highly in the NIR. Short wave or mid-infrared bands provide assessment of moisture content with wetter vegetation having lower values (also of value seasonally) while the thermal infrared, is useful for showing thermal shifts and intensity, not typically as useful in vegetation studies. However, the thermal infrared band which measures the amount of infrared radiant heat emitted from a surface is useful in disturbance studies: disturbed areas, with no, little or less dense vegetation display a warmer signal (particularly in the morning), drying out and absorbing heat more quickly than vegetated or in particular, densely vegetated sites. A panchromatic band will often have the highest band resolution (Campbell 1996).

Different combinations of the spectral bands (in the electromagnetic spectrum) of an image, when presented to the red, green and blue (RGB) channels of a computer display, yield different, colour views of the data; certain combinations allow specific features to be distinguished more clearly. An R G B combination shows the image in true colour and therefore is the most familiar and easily understood display (as seen in Figure 4.4, below). A band 4 5 3 combination in Landsat ETM+ sensor imagery, NIR (near-infrared), IR (infrared) and Blue, allows a clear distinction among vegetation types due to the physiological optical properties of plants and their chlorophyll content, and is therefore often used in image interpretation and examination of vegetation (Curran 1985). In addition, the longer the band combination wavelengths (*e.g.,* IR vs. Green), the better it is in distinguishing water classes because the water layer is not penetrated, resulting in evidently darker pixels probably representing water.

Image Processing and Geo-referencing

Before a remote sensing image can be developed into a desired classification (of landscape, elevation, vegetation, etc.) necessary radiometric (to take into account clouds or haze, system noise and satellite movement), geometric (to register the image with other images or maps or desired projections) or other (removal of extraneous data) pre-processing steps must be taken. Extent and type of pre-processing depends on data type, quality and classification needs. Resampling is a necessary step if data are to be reprojected. Three primary geometric resampling methods exist to convert an image to the desired spatial output: the simplest 'nearest neighbour' which reassigns values from one image/map to another, 'bilinear interpolation' which uses weighted averages of neighbouring cells, and the most complex, 'cubic convolution', which uses weighted averages but in a larger surrounding neighbourhood (Campbell 1996). Resampling is necessary in the registration process because pixel values need to be assigned for a coordinate that does not exist in the original image.

2.2.1.2 Project Needs

For this research a detailed, high resolution vegetation map was desired. Various satellite data were assessed for their suitability for adequately mapping the regional study area. Basic minimum criteria decided upon were as follows:

- Spatial resolution- not coarser than 100m (to ensure sufficient detail for habitat and climate consideration and assessment in the map)
- Multi-spectral characteristics -a minimum of 4 bands including visible and near infrared (required for adequate vegetation cover determination and to resolve heterogeneity in vegetation)
- Temporal availability- satellite currently operational and data chosen for mapping not more than 5 years old at time of implementation (due to higher accuracy if close in time to field data collection and the more recent the data, the lower the chance of any vegetation changes, making the map more correct)
- Temporal frequency- as high as possible with a minimum of once every 2 weeks (to increase the likelihood of a suitable scene existing with appropriate phenology (in the right season) and recent year)
- Radiometric and geometric quality- high *i.e.* geo-corrected with a known accuracy (to yield highest quality map possible)

A selection (not exhaustive) of potentially suitable satellites was made and more detailed specifications considered as outlined in Table 4.1. Some unsuitable (for explicit project needs) data are mentioned in the table to provide context because they are discussed later in the thesis. Certain imagery excluded immediately on the basis of clear unsuitability included, for example, EROS (black and white only, unsuitable for vegetation mapping) and the now available Russian High Resolution Imagery (noisy data and problems with geocorrection) (http://www.infoterra.co.uk/othersatellite.htm). Characteristics of satellite data examined included cost, suitability of resolution, time and frequency of image collection (image acquisition dates must correspond to appropriate seasonal vegetation development in Arctic regions), potential problems and applicability of information provided (*e.g.,* sensor bands). Satellite data considered for use in the vegetation map development included the long-established Landsat data (http://landsat7.usgs.gov/), the high-resolution IKONOS (http://www.infoterra.co.uk/ikonos.htm) and French SPOT (http://www.spot.com/html/SICORP/_401_402_.php) data, the newer multi-spectral thermal and near infrared ASTER data (http://asterweb.jpl.nasa.gov/index.asp) and Quickbird data (http://www.satimagingcorp.com/gallery-quickbird.html), and the lower resolution MODIS (http://daac.gsfc.nasa.gov/MODIS/index.shtml) and AVHRR data (http://edc.usgs.gov/guides/avhrr.html).

Table 4.1. Satellite imagery considered for use in this mapping project and their primary relevant characteristics.

TYPE	CHARACTERISTICS	REVISIT PERIOD#	RESOLUTION	COST (general indication%)	PROBLEMS	OTHER NOTES
ASTER	High resolution multi-spectral w/ thermal infrared visible bands (14)	4-16 days	15m; 30m; 90m	low	frequency	Imaging on request; same orbit as Landsat
AVHRR	Multi-spectral w/ visible infrared thermal bands (4-5)	3-4x/day	1100 m	free	spatial resolution	
IKONOS	Very high resolution multi-spectral w/ visible NIR panchromatic bands	3(-5) days	1m (PAN); 4m (VNIR)	high	Cost; low temporal and high spatial resolution	
LANDSAT 7 ETM+	High-resolution multi-spectral w/ visible infrared thermal bands (8)	16(-24) days	15m, 30 m, 60m+	moderate (lower after 2003 scan problem)	n/a	
LANDSAT TM/MSS	Multi-spectral w/ visible infrared thermal bands (8)	16-18 days	30–120 m	free	dated	older versions of Landsat
MODIS	Moderate resolution multi-spectral (36 channels)	1-2x/day	250-1000 m	free	resolution	
QUICKBIRD	Highest resolution multi-spectral w/ visible NIR panchromatic bands	1-3.5 days	0.7m (Pan); 2.5m(VNIR)	free* - moderate	Cost; resolution too high	largest image size (16km)
SPOT	Very high resolution panchromatic & multi-spectral (visible NIR) (SPOT XS)	3-5 days	10 m (PAN); 20m(VNIR)	high	resolution too high	

 # mean re-visit period; + additional details provided later in the section; % only an indication is given as exact prices vary and change; * available on Google Earth

Based on the information listed above, the satellite data that offered the most suitable combination of criteria was Landsat 7 Enhanced Thematic Mapper (ETM+) sensor imagery: many Landsat scenes are archived and readily available by download from the web; data are collected frequently enough for the chance of a suitable image existing; the resolution is exactly in the range sought for this project; scenes are affordable (especially compared to some of the other data types); and data for Arctic regions exist.

Most of the other data choices could be eliminated based on resolution alone: some were clearly too coarse (MODIS, AVHRR) and others too fine (SPOT, Quickbird, IKONOS) for this mapping purpose. Cost was the next most relevant factor (SPOT). Aster data, while having a number of desirable qualities, are unsuitable due to its poorer availability: Aster data are acquired on-demand, *i.e.* specifically and from scheduled rather than routine collection, meaning that scene choice and therefore quality are far more limited than Landsat data. A search confirmed that appropriate ASTER data are not available: some of the general Vyucheiskii region is covered but images do not cover the precise or entire study area, are not from appropriate times of year (summer), and/or are heavily clouded (http://edcimswww.cr.usgs.gov/pub/imswelcome/)

Landsat Data

A Landsat 7 scene size is 170 x 183 km, orbit height is 705 km and the orbit cycle lasts 16 days. The Landsat multi-spectral satellite sensor system, initially launched in 1972, is one of the oldest remote sensing data providers and has yielded the longest continuously acquired data (USGS, 2005).

Improvements and updates have occurred throughout its history, and as recently as 1999 with the launch of the Landsat 7 sensor. The Landsat Project is run jointly by the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Landsat ETM+ is a multi-spectral scanning radiometer within the Landsat 7 satellite sensor providing eight bands or channels of data, each with different wavelength ranges, and applications in image interpretation of vegetation, as outlined below in Table 4.2.

Table 4.2. Band characteristics of Landsat 7 ETM+ data

Band	Spectral band	Resolution	Wavelength	Typical characteristics/applications
1	Blue-Green	30 m	0.45 - 0.52 µm	Distinguishes soil/vegetation, and deciduous/coniferous trees
2	Green	30 m	0.52 - 0.60 µm	Highlights peak vegetation, good for assessing plant vigour
3	Red	30 m	0.63 – 0.69 µm	Highlights vegetated slopes
4	Reflected NIR	30 m	0.76 - 0.90 µm	Highlights biomass content and vegetated vs. unvegetated
5	Reflected IR	30 m	1.55 - 1.75 µm	Separates according to moisture content of soil vs. vegetation; snow/cloud discrimination
6	Thermal IR	60 m	10.4 - 12.5 µm	Used in thermal mapping and soil moisture determination
7	Reflected IR	30 m	2.08 - 2.35 µm	Useful in distinguishing according to moisture
8	Panchromatic	15 m	0.52 – 0.90 µm	Band visible through near IR; used to sharpen multi-spectral images, etc.

The Landsat database (http://edcimswww.cr.usgs.gov/pub/imswelcome/) was searched for orthorectified (already geometrically corrected for significant inaccuracies caused by topography, camera geometry, or sensor related errors for example, resulting in a planimetrically true image) scenes within the study area (68-69.5 N, 51-54 W) and acquired according to the following criteria which will be discussed in greater detail below:

1. recently (after and including 1999);
2. during optimal times of the year for vegetation development (between mid-May and mid-August);
3. during cloud-free (or virtually cloud-free) periods;
4. during daylight hours; and
5. without technical or other errors in the data.

1) Recent images are important for a number of reasons: a map representing up to date vegetation is more accurate and therefore valuable; field data used to ground truth the map could be incorporated and to obtain the highest accuracy, the chance of vegetation shifts and changes should be reduced as much as possible; to relate reindeer pasture use to vegetation types the most recent data should be used in case of any pasture shifts and potential vegetation-related reasons; 2) Arctic climate is harsh and plants have only a short growing season. Therefore obtaining an image during this short time window, when all the vegetation is out and greenness is at or near the peak is critical; 3) Radiation does not penetrate cloud cover, which therefore entirely obscures the satellite image/vegetation, and while it is possible to mosaic images or use other techniques to reduce effects of cloud cover, the superior option is to have a cloud-free or near cloud-free image. The location of cloud patches also needs to be taken into account; an image may have what seems like a high cloud cover but if this cloud is all above ocean or land that is not of interest, the image may still be suitable; 4) Vegetation and vegetation differences can only be ‘seen’ by the satellite’s sensor in daylight, and so any images acquired during dark periods (at night outside of near equinox periods) will be of no value; and 5) Finally, the chance of technical error exists in data collection. To resolve this criterion, each image, already determined to be suitable in other ways, would have to be individually examined. The original search contained 96 images but upon examination only one suitable image covering the Vyucheiskii Kolkhoz study region existed with the following details:

DATE	CLOUD %	CENTRE POINT	PATH # [#]	ROW # [#]	PROBLEMS	COMMENTS
29 Jun 2000, 07:58:36	0	68.28 N, 52.34 E	175	12	none	good, clear, right location

[#] **The path and row number refer to the Landsat World Reference System that indicates which region a scene covers**

The suitable image available was collected on June 29, 2000 and can be seen in Figure 4.4 below. While it is cloud-free there is a minor error towards the south of the image with a band 4 dropout over a few scan lines (seen in the classifications presented later in the chapter). This small fault was, however, outweighed by the other characteristics that singled this image out as the clearly suitable choice: entirely snow-free, near perfect time of year for vegetation green-up, and the optimally placed image for the study area. While the image chosen was certainly the best available, search details were kept in case other images were desired for comparison or in case of difficulty obtaining the first image.

Figure 4.4. Landsat 7 ETM+ satellite sensor imagery used in the classification (displayed here with a RGB 321 (true colour) band combination) (170 x 183km).

Imagery Details

The Landsat 7 ETM+ imagery was ordered from the United States Geological Survey (USGS) with the following specifications:

- Pixel size- 30 m (bands 1-5, 7); 60 m (band 6); 15 m (band 8)
- Resampling method- Nearest Neighbour
- Format- GeoTIFF
- Systematic correction- Level 1G (includes radiometric and geometric correction; scene is rotated, aligned and geo-referenced; geometric accuracy within 250 m (absolute potential location error) for low relief areas)
- Map projection- UTM, zone 39
- Horizontal Datum- WGS84

Reasons for the specifications are as follows. Pixel sizes in the original satellite data are 28.5m, 57m and 14.25m. During image interpolation, potential radiometric error is introduced since the geometric image properties at satellite and of the projection are not equal. Nearest neighbour resampling is applied since it prevents pixel values from changing, unlike other typical resampling methods (Section 2.2.1.1) (Campbell 1996), important if analyses of pixel values are to be conducted, as in the classification development. Pixels were resampled during the correction process to 30m (VNIR) and 60m (thermal) and 15m (panchromatic) (USGS, 2000). GeoTIFF format, which embeds geo-referencing information alongside (but without affecting) image information so that the image location and geometry are specified, was chosen for its ease of use and application in image processing software. Level 1G correction is the highest level of correction available to non-USGS users of the data. It does not use ground control or relief models to assure absolute geodetic accuracy so error is only guaranteed to be less than approximately 250m in flat areas at sea level (as is characteristic of much of our study area). The internal geometric fidelity is likely to be much better than this potential absolute location error, and in practice the error is probably lower. Atmospheric effects such as haze and scatter that can affect the satellite's recorded reflectance values are reduced during pre-processing radiometric correction, while geometric correction adjustments ensure the image fits the determined map projection. The UTM (zone 39) projection was chosen because it is common and simple to use in practice and in the field (http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html). Although the datum in the topographic maps (Pulkovo 1942) and the Landsat ETM+ satellite sensor imagery (WGS84) are different, (because the USGS does not offer Krasovsky) the projection has been matched as closely as possible, choosing the same central meridian. Any changes or shifts will therefore be minor.

2.2.2 Geometric Error

Procedures described below determine the error values and whether additional correction is necessary. The two primary types of error are systematic and random position error, with printed maps (topographic) and satellite image data serving as potential sources of both types of error and the handheld GPS (Global Positioning System) data (from field determination of site locations) subject to random position error.

2.2.2.1 Systematic Error

Topographic map accuracy is accepted in this case. Data from the Soviet era often had distortions deliberately added in to ensure accurate information was circulated within government circles only (Rees et al. 2003). However, these military survey maps were initially developed solely for government purposes and were previously classified (with no thought at the time of development that the data would ever be generally available): therefore, risk of distortion is probably low but was tested to be certain. Error in the satellite image data and procedures for rectifying the image to field and GPS data is dealt with below in some detail.

The Landsat 7 ETM+ satellite sensor imagery had a UTM projection, zone 39 (*i.e.* central meridian at 51 degrees longitude) and used the WGS84 ellipsoid and datum. This projection was then chosen as the standard for subsequent project work. As mentioned earlier, the Russian topographic maps use the Gauss-Krüger projection and the Krasovsky ellipsoid and datum. Consequently it was necessary to convert topographic map coordinates from the Russian maps into the satellite image projection. The Molodensky Transformation was applied (Molodensky et al. 1960).

A geometric accuracy issue (in addition to the radiometric one mentioned previously in the Image Details) exists with selection of a particular map projection for the satellite image. The existing georeferencing level (*i.e.* that done prior to obtaining the image) must be considered. Accuracy of the most advanced USGS public level pre-processing and geo-referencing option selected for this image (Section 2.2.1.2) is ± 250 metres within elevations lower than 100 m (as in the general study area) (http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html), substantially larger than the 30 m pixel size. Therefore, additional geo-referencing was required in order to satisfactorily relate field and topographic map coordinates to image pixels and gauge any offset. Since the image had already been nominally georeferenced, limiting errors in orientation and scale, it was assumed that the relationship between the image coordinates (x_i, y_i) and the true coordinates (x_f, y_f) was a simple translation:

$$x_i = x_f + \Delta x \tag{1}$$

$$y_i = y_f + \Delta y \tag{2}$$

In order to determine the values of Δx and Δy, the satellite image was referenced to the 1:200000 Russian general survey topographic maps. Sixty-five ground control points (GCPs) were identified on both the topographic maps and in the image. Suitable points included narrow points of land or distinct centres of round islands, mid-points of confluence within river channels, etc., *i.e.* features that are not subject to change and that can be identified with the most precision possible. Coastal (sea) or riparian (river) locations were avoided due to tide and erosion effects. The x and y coordinates of the clearly distinguishable points were read as precisely as possible from the paper topographic map and recorded with each location given a unique ID in case of error or lack of precision in the initial round and the need to re-visit points. Precision in estimating from the paper map was estimated to be ±50m (± 0.25mm error on paper). These same 65 locations were then located in the satellite image by scrutinizing the data at a highly magnified pixelated scale and the equivalent coordinates from the satellite image were recorded.

To guard against mistakes in this process, the set of GCP coordinates was subjected to the following procedure. Mean and standard deviations of $x_i – x_f$ and $y_i – y_f$ were calculated, and if either the value of $x_i – x_f$ or $y_i – y_f$ differed from the respective mean value by more than twice the respective standard deviation, the GCP was eliminated (if it could not be corrected upon double checking the process). This procedure was applied iteratively until no more GCPs were eliminated. The Root Mean Square error was 0.6mm on the map. Of the 65 initial points, only 5 had to be removed and so it can be inferred that the process of collection of GCPs was careful and reliable. The result of this analysis provided estimates for the values of Δx and Δy:

$$\Delta x = 20 \pm 9 \text{ m} \tag{3}$$

$$\Delta y = 12 \pm 9 \text{ m} \tag{4}$$

These mean values are smaller than the size of a pixel, and many orders of magnitude smaller than the 250 m accuracy suggested by Landsat. In addition, no correlation with position in the image or systematic variation was observed between the values of $x_i – x_f$ or $y_i – y_f$ (eliminating positional dependent distortion and other error) and the simple translational model (equations (1) and (2)) can therefore be assumed to be satisfactory. The usual and logical way to implement these analysis results would be to interpret (1) and (2) by altering the image coordinates (in this case, the GeoTIFF image header would have to be changed).

However, for overall simplicity, the image coordinates were not adjusted, and instead, the correction was applied to any true coordinates (*i.e.* from maps or GPS locations). Shifting 'reality' to fit the image may be an unusual choice but was in this case simpler and was justifiable given the small (less than one pixel) changes required.

All coordinate data collected using the handheld GPS unit during fieldwork were increased by 20m in easting value and 12m in northing value before being incorporated into or analysed with the satellite image data. Accordingly, any points read off the satellite image were decreased by 20m and 12m in the x and y directions respectively. The determination of this shift in coordinate locations yields greater certainty that pinpointed pixels in the image are in all likelihood the ones targeted in the field and recorded by the GPS unit (more on this below). Finally, a last minor point: uncertainty in the systematic error should be considered, *i.e.* the 20m latitudinal difference could be closer to 25m or to 15m. This error, however, is not of serious concern given the Landsat image resolution and the efforts made in the field to select the centre of large vegetation patches equivalent to multiple Landsat pixels.

2.2.2.2 Random Position Error

GPS error is given as ± 10 metres (under optimal conditions of an unobstructed view to the sky, low surrounding relief, etc.)(http://www.maplin.co.uk/Infocenter/gps2.htm). The accuracy of the GPS unit is dependent on a number of factors: type of unit and included technology (generally age and cost dependent); if any scrambling or selective availability is activated possibly by government or military; the clarity of position of the GPS receiver in respect to a clear, unobstructed sky and horizon; and the location of the satellites at the time of GPS location determination. Given the temporal shifts inherent in some of these sources of error, the overall error in the GPS will fluctuate. While it may be accurate to as little as 5 m, given the uncertainty the assumed general error is ± 10m in x and y directions.

The potential inaccuracies in the values of Δx and Δy presented in (3) and (4) mean that image pixel coordinates corresponding to a known GPS location cannot be precisely determined. Complicating this is the fact that in practice, the true coordinates of a location of interest (for example, a fieldwork site) cannot be exactly determined due to random position error. The most accurately determined positions in this project are from hand-held GPS units, with (as explained above) an estimated error of 10 m. In comparison, positions determined from the 1:200000 General Staff maps are accurate to not less than 50 m.) This combination of errors (spatial) yields consequences: first, field training sites must be homogeneous over an area several times larger than the combined uncertainty from the two error sources, otherwise they cannot be unambiguously located; and second, any determination of classification accuracy based on comparing the class in the image with the known class at a precise, known point on the ground should not limit its assessment to a single pixel in the classified image. There is a finite probability that the field location corresponds to a neighbouring pixel in the image, as detailed below.

Probability of hitting the intended pixel

GPS coordinates collected in the field and used in classification are located within a specific 30mx30m pixel in the satellite image. The likelihood of hitting this exact pixel must be calculated because of error inherent in the handheld GPS (~10m) and in the image geo-referencing process (~5m), potentially adding uncertainty in both the *x* and *y* directions. Accounting for these two potential error sources, it is unlikely that the GPS location is more than a pixel offset, and therefore, a 3x3 pixel neighbourhood is considered sufficient in accuracy assessment. The probability that the true position will be found within this area, centred on the intended pixel, is calculated:

The highest probability that the GPS coordinates fall at the exact centre of the intended pixel is 1. However, should the coordinate be located in a corner of the pixel, the maximum probability is reduced to ¼ (since it could fall in any of the 3 surrounding pixels). Therefore, the probability of hitting the intended pixel is between ¼ and 1. From this, given a 3x3 neighbourhood, calculations of probability with the 10 m GPS error and 5m image geo-rectification error show that the probability tends to one as the ratio of pixel size to error/uncertainty exceeds a value of about 2.6 (Rees pers. comm.). Calculations of the ratio, in this instance with Landsat data and the error values given here, show a ratio value of 2.68 (ratio = pixel dimension/ (GPS error^2 + georeferencing error^2)$^{1/2}$), greater than the value of 2.6, beyond which the probability of hitting the right pixel is above 99%. Therefore, it can be concluded that a 3x3 pixel neighbourhood is large enough within this classification procedure to provide enough certainty that the probability of hitting the intended pixel tends to 1.

However, the situation is not as simple as this result suggests. Although it was attempted, it was not always possible to record the GPS location of the vegetation site from the middle, *e.g.*, in mires, or in riparian grassland which was measured with even lower accuracy from offshore, not even on the edge of the site. At times, a ground-truthing location was recorded but not visited *e.g.*, if a large shrub patch was seen nearby it was noted by estimated distance and direction from a GPS site that could be recorded. Finally, not all vegetation ground truthing sites were necessarily an ideal 3x3 pixel shape: some were smaller and some were narrower but longer. While the AOI (Area of Interest) polygon development (detailed later in this chapter) took variation in area size and offset location into account (based on specific field notes), the accuracy assessments that were completed as part of the later classification procedure did not. The accuracy assessments took a 3x3 neighbourhood around the GPS location regardless and this necessarily introduces a degree of error. Consequently, accuracy assessment results should be interpreted accordingly. Ideally, accuracy assessments should have been based on the size and exact location of each vegetation site, something that could be achieved in more detailed, advanced remote sensing applications. Lastly, while each ground truthing location ideally had a 3x3 pixel size this was not always the case, particularly with more rare or ecologically specific vegetation sites.

In practice, error phenomena (systematic and position) can be addressed adequately by using 3×3-pixel neighbourhoods in the image. Training sites in the field need to be at least 3 pixels (90 m) across, and a ‘correct’ classification is one in which the correct image class is found within the 3 × 3 pixel neighbourhood of the expected position.

2.3 Vegetation Classification

A number of classification methods exist, ranging from automatic or unsupervised ones that require minimal input and rely primarily on information collected by the satellite sensor, to manual supervised ones that require significant field-based training data for the classification algorithms to run as well as effort by the analyst. Hybrid classifications use selected combined techniques from manual and automated methods (Campbell 1996) as appropriate for the classification purpose. Specific techniques can be employed differentially to the classes, improving the overall results. (http://cbc.rs-gis.amnh.org/remote_sensing/index.html (Remote Sensing Resources)). Additional methods and techniques, applied to classifications, such as employing masks to eliminate or focus on particular regions or classification types, and analysing specific characteristics through means such as Normalized Differential Vegetation Index (NDVI) stratification, commonly improve results (see Campbell 1996).

In this chapter a variety of classification methods will be employed or introduced and then assessed- unsupervised, supervised and hybrid variations- and other techniques incorporated, in order to address 1) the complex nature of the mapping region and 2) the limited data available for use in the mapping processes. Classifications will be compared and assessed for consistency, and refinements made until a satisfactory final classification is developed. Quantitative accuracy assessment is also included. Much of the effort in qualitative and quantitative refinement was highly iterative, and techniques were applied simultaneously. Consequently explaining the process in precise chronological order by individual method is difficult but has been done in an attempt to clarify the process. In addition, with refinement, quantitative (*e.g.,* contingency matrices) and qualitative assessments were repeated. However, for conciseness in illustration of the process, initial quantitative results (*i.e.* JM distances and contingency matrix) and more advanced, refined qualitative assessments are the steps presented in the greatest detail here.

2.3.1 Preliminary Steps

After the satellite image and ground data were rectified, preliminary steps leading to development of a vegetation classification were followed. Image processing software used throughout was ERDAS Imagine, versions 8.4-8.7 (Leica Geosystems LLC, Georgia, USA). The image data (provided as individual GeoTIFF files for each of the seven Landsat spectral bands) were compiled and the bands (1 through 7) merged into one image file (stacked) using the 'layer stack' function in the image interpreter utility. A subset of the entire image, which included the field site areas to be visited, was chosen using the utility function for ease in running preliminary assessments.

2.3.2 Per-pixel Unsupervised Classification

An initial preliminary unsupervised classification of the image was first developed: it is simplest, requires no training data and provides useful vegetation distribution information that will aid in assessing and comparing later, more complex classifications.

Using the classifier function in Imagine and the stacked Landsat image as input data, the classification process was begun (convergence threshold of 0.95 (default)) with multiple classifications produced initially to determine the optimal number of classes and iterations. The range of classes input into the classifier was between 10 and 30, and iterations between 5 and 30, with both shifting in increments of 5. When choosing the number of classes in the accepted classification, it is necessary to consider the fact that the classifier is unlikely to create a single distinct class for each separate vegetation or land cover type, for example, three classes may all represent water. The classification is presented in Section 3.1.

Generalised vegetation types were assigned to the classes in the selected basic unsupervised classification by including a small amount of field data and therefore a degree of supervision in the analysis stage (although not in the processing stage). Relevant data from the first field season's fieldwork (primarily collection of detailed botanical data (see Chapter 3)) included the basic information collected- Site ID, GPS location and vegetation type. In addition, remote sensing ground truthing data collected during a previous field visit by G. Rees in summer 1999 (and revisited in 2003 to confirm) were also used. Summer 2003 data included 67 separate locations, and original data from 1999, an additional 33. Each of these 100 GPS sites was located (having adjusted for the 20m x and 12m y offsets from the satellite image detailed in the error section previously) on the unsupervised classification image, and using the inquire cursor function in Imagine, the corresponding class assigned to the pixel was recorded.

However, due to error inherent in the GPS and spatial analyses as a general rule, a single pixel value was not sufficient for assessment of the classified image given the likelihood that the 30m x 30m pixel in which the GPS point was located would not be the intended one. However, given the consistent, undistorted offset and the low GPS spatial error value, it was not necessary to analyse a large neighbourhood of surrounding pixels, as explained previously, and a 3x3 pixel neighbourhood was determined to be sufficient. Thus, for the 100 field sites used at this stage, pixel class values were recorded systematically (*i.e.* with pixel position identification) for each of the eight surrounding pixels in addition to the central one.

Generalised vegetation type descriptions developed, based on the detailed description from the field, included the following 10 categories: W (water); B (bog & fen (mires)); E (exposed vegetation); F (forb/herb); G (grass); H (heath- with moss and shrubs); M (mud/bare ground); R (*Salix reticulata* community); S (shrub); SA (sand); and T (tundra heath- with tussocks/hummocks).

The 3x3 pixel vegetation class data for each of the 100 locations was analysed and a correspondence matrix developed. The results of this class assignment assessment were examined in tandem with the satellite image. Using information derived from a combination of features from the satellite data (such as water bodies, exposed areas, etc.), topographic maps of the region and knowledge of general vegetation distribution and characteristics, each vegetation class was examined individually, allowing a thorough assessment of the distribution of the class within the image and of the overall success of this initial classification.

2.3.3 ECHO Spectral-Spatial Unsupervised Classification

An alternative unsupervised classification, based on the Extraction and Classification of Homogeneous Objects (ECHO) procedure by Kettig & Landgrebe (1975), was developed by G. Rees, prior to the second season of fieldwork in summer 2004, primarily for its utility in the field as a tool for locating potential suitable ground truthing sites which would be required in the proceeding supervised classification stages. It is included here because of its relevance in selecting field locations for data collection and its ultimate role in providing an additional classification comparison with the eventual refined vegetation map. The ECHO method, based on pixel-neighbouring pixel relations, is based on a single pass segmentation algorithm and is object seeking. The goal of the segmentation process is to locate the homogeneous objects in the scene. Since each homogeneous object represents a statistical sample, a sample classifier (ML Sample Classifier) is used to classify the objects. In this way, the classification of each pixel in the sample is a result of the spectral properties of its neighbours as well as its own. In this ECHO-based classification, vegetation class divisions were simplified into a total of 7 and the resolution reduced to 100m in order that primary vegetation types of substantial area might be found. The classification was developed with 200 classes distinguished in the initial pass and using all seven bands (G. Rees pers. comm.). The classification is shown in Section 3.2.

2.3.4 Supervised Classification

The process of supervised classification requires the input of training data into the algorithm process of the classification (Campbell 1996). Data were obtained from the study area (detailed in Chapter 2) during the two seasons of fieldwork in summers 2003 and 2004 as described below. Refining a classification is not a simple step-by-step process; instead it is iterative and requires re-visiting the field data, any data incorporated into the classification, and the intermediate classifications multiple times until results are satisfactory and a final classification can be produced. Assessment is both qualitative and quantitative. In classification procedure and assessment, a combination of data and knowledge is incorporated beyond the computing efforts: experience gained in the field, both in the study region and in other circum-Arctic areas, information from general topographic maps, knowledge developed on the general structure of the region and its landscape characteristics and influences, and as a specific reference the approximately 500 vegetation site photographs taken during fieldwork in the region.

2.3.4.1 Training Data

Data collection for use in the vegetation map development was carried out in the same periods as fieldwork required for the botanical analyses (Chapter 3), and extended in 2004. Each botanical analysis site from 2003 (56 sites plus a few additional sites of note not included in the botanical analyses) and 2004 (19 sites) doubled as a ground truthing location for the vegetation mapping component. Fieldwork carried out in 2004 focused particularly on the collection of ground truthing data required for the supervised classification of the satellite image that would lead to the desired detailed vegetation map. Specific ground truthing data were collected from July 4 to August 12, 2004 by a team of three scientists: G. Rees, C. Bay and the author. A total of 264 ground truthing locations were collected this field season for a total of 378 locations available for use in the vegetation classification. Unlike in 2003, when only summer reindeer pasture areas were visited, in 2004, summer pasture areas were re-visited and explored to a greater extent, and winter pastures were also assessed, adding to the diversity and variation of data and potential vegetation communities included in the research.

Ground truthing data collection was simplified and made more efficient in 2004 through predetermination of general areas accessible and sites of interest based on the seven broad vegetation classes in the ECHO classification. A number of representative areas for each vegetation class were selected. While initial sites were chosen on the basis of the ECHO classification, the majority were added en route to or from ECHO-chosen locations or botanical analysis sites. Any sites that represented particular vegetation types, including mixed types, and that covered a large enough area to be believably represented in the satellite image (*i.e.* greater than 100x100m whenever possible) were assessed and included in the ground truthing data. Sites of particular interest, such as more unusual vegetation types like highly disturbed zones, corral areas or former herder campsites were also noted. We attempted to include as many sites of the same type or within the same categories or groups as possible while still ensuring we located the full range of potentially distinguishable (by visual and satellite image classification) vegetation types. The number of distinct types was of course substantially greater than the seven broad ones described in the ECHO classification.

As expected, some vegetation types are more prevalent than others and consequently had many more representative ground truthing locations than other more rare vegetation communities. Certain vegetation types are also generally less expansive, and locating a sufficiently large representative area can prove difficult. In these cases the best choices available were made.

The distribution of ground truthing data locations is seen in Figure 4.5, with the southern clustered points representative of summer pasture and the northern ones north of Korovinskaya Bay of winter pasture. Data points in the most northwesterly locations were collected by F. Stammler, during his anthropological research following our time together in summer pasture regions. I was not allowed permission from the Russian government to visit this region as it had a special controlled status. Dr. Stammler received explicit instructions on data collection methods and needs and photographs were taken at each site so that I could confirm the data. This region is now used by private herders in the Vyucheiskii Kolkhoz all year round so is both summer and winter pasture. Other specific, localised regions of data collection include a few locations east and northeast of the town of Naryan Mar in the southeast of the study region, a few clustered data sites west of Naryan Mar adjacent to a channel of the Pechora River, and finally locations taken during travel to and from field sites along the Pechora River delta channels.

Data are heavily clustered in a few specific regions due to transport, time and logistical restrictions: the only form of transport during fieldwork was by foot; fieldwork time was limited in the two seasons; and due to financial and bureaucratic restrictions, visits to other, more distant sites within the study area (e.g. to the west or north) were not possible. Travel by foot over the terrain in the study region was difficult and slow. The maximum distance possible to cover in a day taking into account the time required for collection of ground truthing and vegetation analysis data was approximately 25 km, assuming the route was familiar, or there were reindeer or sledge tracks, and it followed drier vegetation types. Typically 15km would be a more usual maximum in more difficult terrain. Average speed was roughly calculated as 2km/hour, giving an idea of the difficulty in traversing the highly variable, often very wet and boggy, very hummocky or dense shrub covered terrain. We were limited to transport by foot given the remote location of our field sites, the complete absence of any local transport infrastructure, and limited project funding which prevented us from being able to afford helicopter or other mechanized support in all but absolutely necessary cases (*i.e.* transport to and from field camps). It would have been useful to include data from the western part of the study region to broaden the field site coverage and attempt to take into account other potential landscape and environmental influences (*e.g.* topography, geology, soils, micro-climate variability, grazing influences, etc.). However, we are confident that the range of vegetation types and terrain visited is representative of the region as a whole, as in 1999, G. Rees flew hundreds of kilometres by helicopter gaining an overview of much of the area, including the western region. Despite certain limitations in the field, sufficient data were collected, a wide range of established tundra vegetation communities were visited and major vegetation types are well represented in the data. It was a challenge, however, to try to obtain an ideal number of sites within certain specific or less common vegetation types. Data along river channels were collected from the following vessels: a small ferry that travelled between Naryan Mar and the small villages in the Pechora River delta, a private skiff that we hired to allow us to access winter pasture in the north, or a private boat that we took an overnight journey on in order to access some field sites in the southwest of the study region. Consequences of data collected from boats will be described later in the chapter.

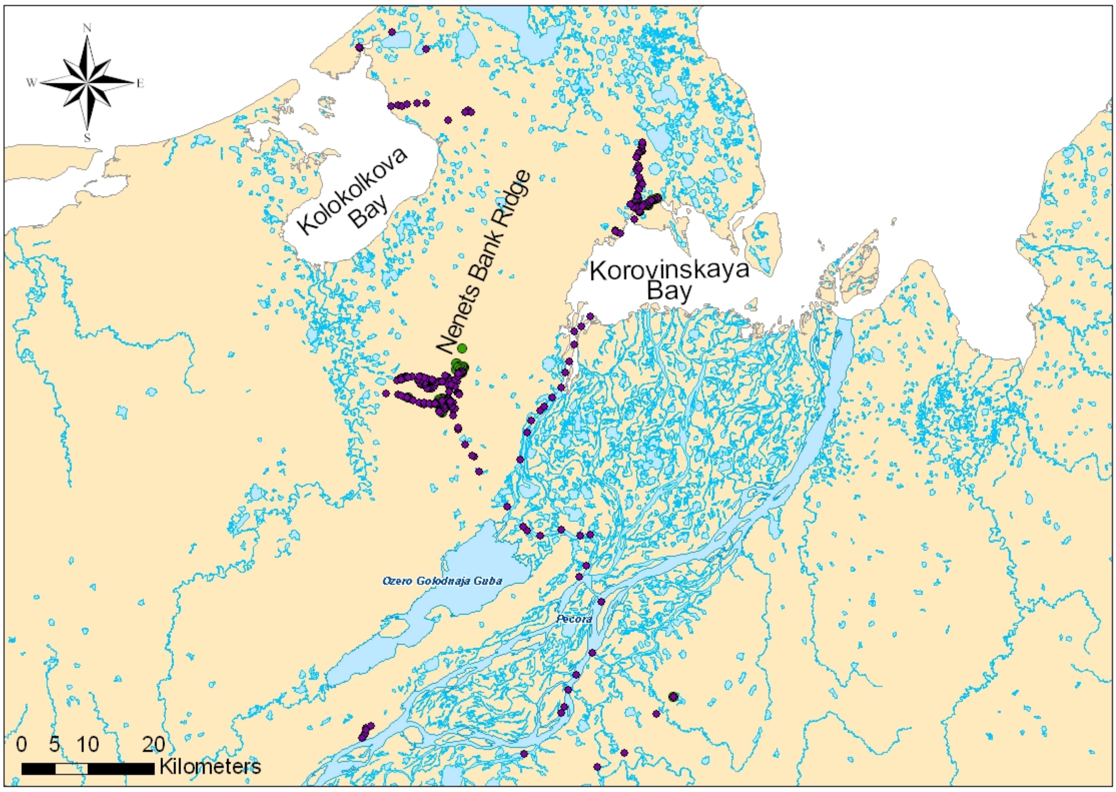


Figure 4.5. Distribution of ground truthing locations (purple markers) visited in summer 2003 and 2004, with southern cluster of locations in summer pasture and northern cluster in winter pasture. For reference, green markers signify location of botanical analysis sites.

Information collected at each ground truthing site included the date, a unique waypoint (GPS location ID), the actual GPS location written out (in case of loss or failure of GPS unit or data), photo/film number and a detailed site name which included in approximate order of presence, all major vegetation species/groups present and lastly, other relevant information such as the presence of hummocks or tussocks, a reference to height in the case of hummocks and shrubs, and an indication of wetness or presence of moss/sphagnum, or lichen, as appropriate. The author's existing knowledge of vegetation and vegetation communities allows additional interpretation and meaning to be derived from the basic seeming names. An example of a name description is 'empetrum betula ledum vaccinium heath with hummocks and moss'. This would mean that the primary or dominant species, in (visually estimated) order of presence are *Empetrum nigrum* (ericaceous shrub), *Betula nana* or dwarf birch (deciduous shrub), *Ledum palustre* (ericaceous shrub) and *Vaccinium vitis-ideae* (ericaceous shrub) and that this is an example of a typical heath; the ground is covered in noticeable but average sized hummocks (perhaps 30 cm higher than the low lying ground); and the heath tundra is moist, not dry, due to the presence of moss. Additional observations and notes were made as necessary or appropriate. For consistency all descriptive names were determined and agreed upon by C. Bay, G. Rees and the author. For details of botanical species present in the region, and descriptions and photographic examples of general vegetation communities see Chapter 3. Upon return from the field, data and notes were put into electronic form and the GPS waypoints downloaded using Waypoint+ (freeware,http://www.tapr.org/~kh2z/Waypoint/,©1996,1997Brent Hildebrand). As mentioned previously, GPS data were collected in UTM, WGS84 datum, zone 39 (Russia).

2.3.4.2 Classification of Field Vegetation Data

Based on data collected during fieldwork and on knowledge of regional vegetation types and characteristics, a hierarchical vegetation classification scheme was developed that allowed all ground truthing sites to be assigned to a particular vegetation community type with a unique hierarchical numerical identifier. The scheme was developed initially and then subsequently modified a number of times on an iterative basis, according to ground truthing data suitably fitting into the divisions, and each division having sufficient representation (greater than four sites as an absolute minimum), before being finalised. The scheme is used in the supervised method of classification. It was shown in condensed version in Chapter 3 and is presented and described here in Section 3.3 in detail.

2.3.4.3 Image Classification

In the initial stages of the supervised classification development, signature files were created using the Signature Editor function in the Classifier tool in ERDAS Imagine. To create the signature files, which are based on information from the ground truthing locations, training areas (polygons of greater than 1 pixel in size) representing the classified (*i.e.* separated into the vegetation classification scheme) ground truthing locations were created using AOI tools within the Raster tools module. A polygon consisting of the pixels defining the ground truthing location was created at all suitable ground truthing sites. For an illustration, see Figure 4.6.

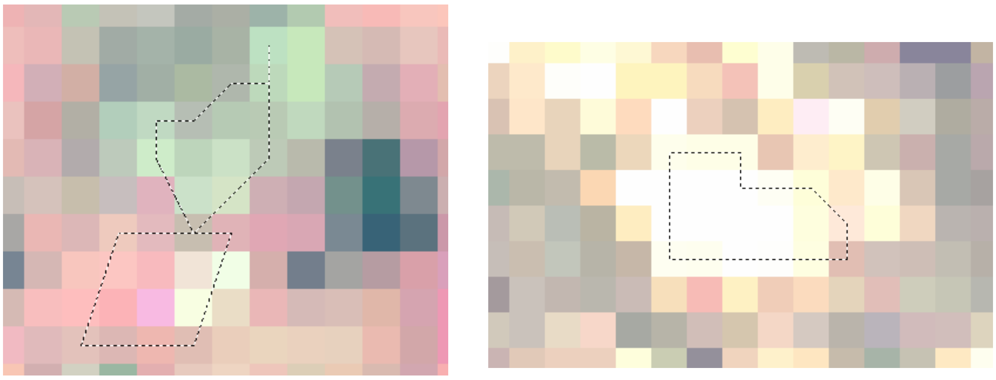


Figure 4.6. Examples of training areas (polygon) representing ground truthing sites visited and included in the signature file (within the supervised classified image) (pixel size = 30m).

Field notes were referred to closely during this stage to note and include any specific, relevant information, *e.g.,* a particularly large site (in which case the AOI polygon was enlarged) or a site that was located at a specified distance close to but not exactly at the GPS waypoint. During this process, to improve assessment of certain vegetation types, band combinations of the viewed image were adjusted to increase specific contrasts. For example, in separating out the wetter mires from grassland, near infrared with two bands (using band combination 5 4 3) was useful. All of the AOI polygon data were added into the signature editor file, which contained all of the individual ground truthing sites and their specific vegetation type classifications according to the scheme described above.

In the majority of cases for most ground cover types, the ground truthing field data were used to provide the information in the signature file creation. Water AOI polygons, however, were created by examining the satellite image directly since it was easy to see the separation of water from all other land classes and, within the water division, the distinction between clear and turbid or shallow water. Sufficient AOI polygons were developed at random for good, representative water sites within the satellite map region. In addition, while some settlement data were collected in the field, additional AOI settlement polygons were incorporated into the signature file during the process. Villages and towns were typically easily observed in the image and validated via examination of local topographic maps. Alternatively their locations were obtained from the topographic maps and the equivalent site located in the satellite image. Additional polygons for the ‘tree’ category in the scheme were also added: it was clear that in the south of the image areas were dominated by trees and increasing the number of these polygons would improve the tree and shrub classification.

Selected ground truthing sites were eliminated from inclusion in the classification upon inspection. Reasons included lack of certainty about the matching of the location with the actual satellite data, presence in a completely heterogeneous area and therefore lack of clear classification, initial uncertainty over the accuracy of the location data collected in the field. Of 343 sites, a total of 35 were not included in the classification data. Once the signature file with all its AOI polygons representing the different land cover types was complete, a supervised classification using a maximum likelihood classifier was run on the satellite image using the classify tool and a supervised version of the image classification was created.

This first supervised classification run was assessed qualitatively initially by visual examination: the distribution and overall amount of each vegetation type were individually checked using the colour table to block out other classes for clarity. When necessary, related types (*e.g.*, moist heath types or mire types) were examined in pairs or groups to further check the results. Adjustments were made if the classes didn’t seem to be accurately or logically mapping out based on two primary qualitative assessment factors: 1) relation to landscape characteristics and topography, and 2) quantity relative to other classes and to the ground truthing study region as a whole. For example, if there was too much or too little of a class based on existing notional ideas of distribution based on field experience (*e.g.,* if moist heaths were not dominant or herb slopes were) or if it appeared unconvincing in its distribution (*e.g.*, lichen heath along the Pechora delta). Knowledge of circumpolar Arctic vegetation and specifically vegetation in this region, its distribution, and of regional landscape characteristics and influences in the study region was employed in this refinement. The total landscape area observed over two field seasons when covering substantial distances by foot on a daily basis is far greater than that covered by training area sites, and presence of patterns is able to be developed unlike from localised site data. Observation-based assessment thus has a solid basis. Signature files were checked, polygons examined and redrawn if necessary or eliminated, and field data scrutinised for potential errors or weak results. When inputting field data remarks were noted about confidence in the data, or unusual or questionable sites, and so specific sites could be revisited to double check or improve and refine training data. The vegetation classification scheme divisions were changed accordingly with vegetation type names changed, or classes merged or further divided, until the concerns in classification had been rectified. This step was necessary because the vegetation and image classes do not necessarily correspond directly in all cases. A new version of the supervised classification was then developed and subsequently examined in the same way.

These steps were repeated as necessary until a classification with results in accordance with research and field-based knowledge and understanding of vegetation distribution in the region was obtained. The time-intensive, iterative nature of this approach should be emphasized: an undetermined but significant number of modifications were made by going back and forth after examining singularly and in detail each class in the classification and the classification as a whole and modifying and refining the ground truthing data and the vegetation classification scheme. At one stage, the ground truthing data was re-examined in its entirety with a focus on problematic classes to see if any discrepancies or potential problematic results could be eliminated or reduced in order to improve the vegetation classification. Multiple classifications were ultimately produced along the way to developing the final one presented in Section 3.3.

2.3.4.4 Quantitative Assessment

Accuracy assessments are necessary in order to validate and quantify the degree to which a classification can be considered true or correct. In ideal situations half of the data collected in the field is allocated for this specific purpose only. In the case of this research, however, as is more typical of efforts in remote regions, data collection in the field was difficult and limited and is best served in developing the strongest classification possible. As a consequence, however, traditional accuracy assessment (*e.g.,* Curran 1985, Campbell 1996) using field data is not possible. Instead, a variety of methods of classification and assessment of ancillary data is required (Homer et al. 1997, Franklin & Wulder 2002) and a number of classifications, each using different techniques, were developed and compared to provide confidence in results. Quantitative tests, however, were also employed to examine 1) separability between classes - Jeffries-Matusita (JM) distances (Swain & Davis 1978, Richards 1993, Schmidt & Skidmore 2003), and 2) the relationship between training data and the classified results - Contingency (Error) Matrix (Campbell 1996).

Determination of separability can provide a sound quantitative base of analysis in cases such as this where a typical accuracy assessment cannot be done. A JM distance represents the mean distance of two probability distributions, allowing a measure of separability of a pair of classes based on their signatures (and assuming normal distribution) (Richards 1996). It is often applied to remote sensing because of equivalence to the Maximum Likelihood classifier, applied here (Bruzzone et al. 1997). The highest JM value is 1.414 and lowest 0. If a pair has a value of 1.414 the signatures are separarable while the opposite holds true for a value of 0. The lower the value the less reliable any purported distinction will be. JM distances were derived and are presented in Section 3.3.2.1.

A Contingency Matrix is a table containing numbers of sample units assigned to a specific category relative to the actual category on the ground. The reference-based Producer's accuracy is determined by data across the rows (see Table 4.11). It is derived from predictions made for a vegetation class and calculating the percentage correct, *i.e.* what is the likelihood that the image correctly identifies a pixel as class *x* if the area is known to be class *x*. Consumer's accuracy is map-based and is determined from the reference data of a class and by finding the correct predictions for that subset, *i.e.* if a pixel of class *x* is selected, what is the probability that that particular pixel chosen is class *x*. It is obtained from the column data. A contingency matrix can display these and other measures, allowing a type of assessment of accuracy. A contingency matrix was created, comparing the training input and the classified output in a 3x3 neighbourhood surrounding the pixel for which the GPS location was noted. The resulting consumer's accuracy refers to the training input and the producer's accuracy to the classified output. Results are expressed as a percentage value of the proportion of the classified output to the training input (in terms of number of pixels). It should be noted that since the two water classes were added manually, directly from the satellite image, it was not necessary to include them in the quantitative assessments of the ground truthing based data. Contingency matrix values are presented in Section 3.3.2.1.

2.3.4.5 Refinement Techniques

To refine supervised classifications further and improve results, additional techniques can be employed, enabling a better understanding of the vegetation and patterns of a region. A number of refinement possibilities exist but there is scope for limited application in this research. Discussion of additional possibilities can be found in Campbell (1996), for example. The primary refinement utilised here was development of NDVI data to provide a specific assessment of shrub and tree distribution.

NDVI

NDVI is defined as,

$$NDVI = \frac{r_4 - r_3}{r_4 + r_3} \qquad (1)$$

where r_4 = reflectance of Landsat ETM/TM band 4, NIR;
r_3 = reflectance of Landsat ETM/TM band 3, red.

NDVI correlated to Leaf Area Index (LAI), is effectively ‘a measure of relative greenness’ (Raynolds et al. 2006) and uses near infrared and infrared bands to take advantage of the distinct and high reflectance (NIR) and absorption (Red) values of chlorophyll filled plant cells *i.e.* leaves. It is incorporated as part of the map development process to provide a definitive separation of trees and shrubs from other vegetation, and is a common, established approach in examination of biological production (Woodcock et al. 1997, Holmgren & Thurssen 1998, Chen et al. 2002). Multi-spectral classification makes no assumptions about relationships between classes but NDVI does through its stratification: the highest NDVI values are expected to correspond with vegetation with the highest phytomass (LAI) and the lowest values with the lowest phytomass. NDVI values range from -1 to +1 theoretically although in Arctic regions with sparse, limited vegetation it is rarely so high; the average CAVM (presented in Chapter 5) NDVI, for example, is 0.32 (Raynolds et al. 2006). NDVI results enable a check that there are no major errors in the classification with the densest vegetation classes. Should they be similar the classification results can be assumed reliable and if not, the NDVI results can be incorporated into the vegetation classification. The NDVI technique uses the same data as the classification so there is a degree of circularity in this exercise. However, the means by which NDVI derives its values are not similar and thus it can still serve as a comparison for shrub and tree classes that were classified spectrally. On a cautionary note, when considering Arctic vegetation, NDVI correlates well with leaf area index (LAI) for green leafy vegetation only. Moss, for example, may have a high NDVI value but an LAI of zero. Lichen vegetation can also cause difficulties because it has a relatively high NDVI value, and so the normal biomass-NDVI correlation is not valid (Rees et al. 1998). However, problems are more likely to occur in forested regions south of the primary study region. In general, other challenges in using NDVI due to the nature of Arctic regions exist, including short growing season, cloud cover frequency, low position of the sun at certain times of the year and fluctuating soil moisture levels (Rees et al. 1998).

The ERDAS Imagine Model Maker in the Modeller module was used to develop the model that yielded the NDVI output image. To determine NDVI certain information must be known: calibration values for the date of image collection, and atmospheric and sun radiance/reflectance values. Appropriate NDVI calibration coefficient information was downloaded from the website (http://daac.gsfc.nasa.gov/interdisc/readmes/pal_NDVI.shtml) (Table 4.3).

Table 4.3. NDVI calibration data for Landsat 7 ETM+ data on June 29 (2000).

BAND	$L_{\min}$[1]	$L_{\max}$[2]	E_{sun}[3]
1	-6.2	191.6	1969
2	-6.4	191.5	1840
3	-5.0	152.9	1551
4	-5.1	157.4	1044
5	-1.0	31.06	225.7
6			
7	-0.35	10.80	82.07

[1] $L_{\min}$=radiance for DN = 1; [2] $L_{\max}$=radiance for DN = 255;
[3] E_{sun}=irradiance from sun (mean solar exoatmospheric irradiance)

The radiometric calibration process allows a conversion between the image pixel value and the ‘at satellite radiance’, and then the ‘at satellite radiance’ and the ‘at surface radiance’ as shown in the series of equations below in order to find *r* in the initial NDVI calculation. It is necessary to do this conversion separately for each of bands 3 and 4. The need to correct for atmospheric effects results from the extra light that is involved in the satellite traversing its path and resulting scatter.

Values of *r* in equation (1) are obtained by the following sequence:

The relation between D, the measured pixel value, and the change in radiance is given by

$$L_s = \frac{D-1}{254}\left(L_{\max} - L_{\min}\right) + L_{\min} \tag{2}$$

where L_s = at-satellite radiance
D = pixel value, measured
$L_{\min}$ = minimum radiance
$L_{\max}$ = maximum radiance

Having established the at-satellite radiance, the at-ground radiance is required, derived from correction for the radiance lost to the atmosphere. In this case, the dark pixel subtraction method is applied (Campbell 1996). It assumes that somewhere in the image there is a pixel with a value of 0 (black, 0% reflectance): in most cases, given the millions of pixels in an entire image, one or a few pixels in shadow due to topography or clouds and therefore with a value of zero should be found. The dark pixel method uses the lowest non-zero radiance value occurring in the image to make the correction. In this case, in band 3 (red) it was 16 and in band 4 (NIR) it was 7. Other methods of atmospheric correction exist but this simple, frequently applied one is assumed to be sufficient. The relation between D_0, the occurring pixel value, and the change in radiance is then given by

$$L_a = \frac{D_0-1}{254}\left(L_{\max} - L_{\min}\right) + L_{\min} \tag{3}$$

where L_a = atmospheric radiance
D_0 = pixel value, occurring

Finally, from (1) and (2)

$$L_c = \frac{D-D_0}{254}\left(L_{\max} - L_{\min}\right) \tag{4}$$

where L_c = estimated at-surface radiance

Finally, the planetary reflectance formula (5) yields the reflectance values, r_3 and r_4 by normalizing to incident sunlight to get reflectance from the radiance. An assumption is made that the surface scatters radiation isotropically.

$r = \frac{\pi L_c}{E_{sun}}$ (calculated for bands 3 and 4 separately giving r_3 and r_4) (5)

Once the NDVI is calculated, one additional step is required to rescale the NDVI values from floating point to integer (8 bit) values simply in order to reduce the size of the image file (by changing the way in which data is stored within it):

$$NDVI' = \frac{NDVI + 1}{2} \times 255 \qquad (6)$$

where *NDVI*' = NDVI converted to 8 bit integer values

NDVI values were obtained and the resulting reflectance value curve (Figure 4.7) was examined to locate the beginning of the threshold shifts in reflectance (a trough and a peak pattern) as seen in the figure below at the locations of the two arrows), signifying vegetation type divisions, *e.g.* more dense or higher phytomass vegetation versus less dense vegetation or vegetation with a lower phytomass. Three threshold values (between 0-255) were set: one for the water/vegetation divide, and two for the dense vegetation types, one for smaller shrubs and less dense vegetation and the other for the large shrub/trees and most dense vegetation. This allowed more explicit separation of the trees and shrubs, which form a significant component of the regional vegetation. The water/vegetation threshold did not change but the other values were experimented with and adjusted following examination of the NDVI threshold map.

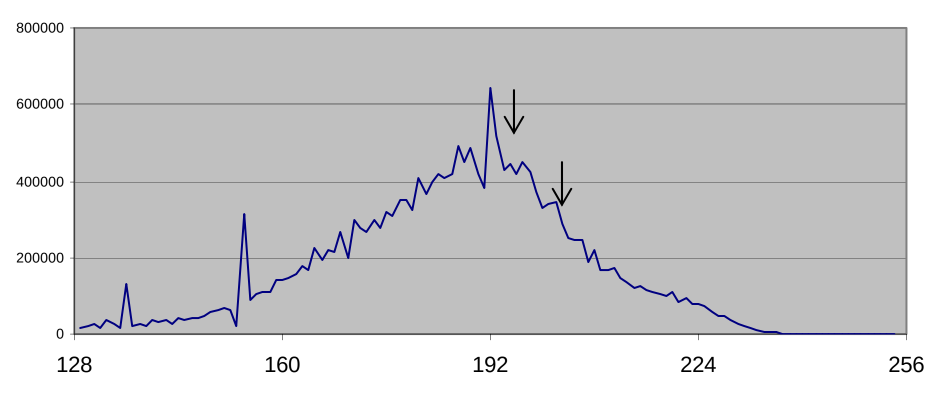


Figure 4.7. NDVI reflectance curve. Left hand arrow is at 197 and right hand arrow at 205 (discussed in Section3.3.4.1)

The map was initially examined visually at a glance, and then in more detail using the GCPs and associated vegetation type information from fieldwork. The AOI polygon layer (representing ground truthing areas) was viewed to allow examination of vegetation type size as well as location (versus just the GPS point location) and a better assessment of the NDVI threshold value. Once the NDVI threshold/s were shown to be representative, based on the ground truthing data, the shrub/tree distributions in the NDVI map and the vegetation classification were compared to assess the classification's success at mapping trees and shrubs.

2.3.5 Hybrid and Simplified Supervised Classifications

Two further classifications served to provide additional confirmation, at the broadest levels, of the vegetation trends evident in the more detailed and refined supervised classification. First, a multi-spectral classification using still different methodology- spectral purity and NDVI stratification techniques - developed by G. Rees, was included (Rees et al. in press). The spectral purity technique employs a Pixel

Purity Index endmember extraction algorithm that attempts to identify pure spectra through assignment of a pixel purity index to each image pixel (Boardman et al. 1995). Second, a simplified 12-class classification based on the 26-class supervised classification was created. Table 4.4 shows the 26-class scheme from the supervised classification broadened into the generalised 12 classes. The purpose of this exercise was to simply show more clearly the broader vegetation groups with less clutter and heterogeneity and how they are distributed in the landscape with particular regard to topography and land characteristics. Both classifications are shown in Section 3.4.

Table 4.4 Simplification of Vegetation Map Classification for development of a simplified classification

CATEGORY	CLASS ID	VEGETATION TYPE	GENERALISED CLASS
Unvegetated	000	Clear water	Water
	001	Turbid and shallow water	
	01	Settlement	Exposed/Bare
	02	Bare ground	
Vegetated	11	Exposed	
	12	Herb slope	Herb slope
	130	Tundra grassland	Grassland
	131	River grassland	
	1400	Low sedge mire (sphagnum)	Mire
	1401	Low sedge mire (other moss)	
	141	Tall sedge mire	
	150	Heath-Mire without heath shrubs	Heath-Mire
	151	Heath-Mire with heath shrubs	
	160000	Dry lichen heath without betula	Lichen/dry heath
	160001	Dry lichen heath with betula	
	16001	Dry ericaceous shrub heath	
	160100	Moist heath, hummocks, no shrubs	Moist heath
	160101	Moist heath, hummocks, shrubs	
	160110	Moist heath, no hummocks, no shrubs	
	160111	Moist heath, no hummocks, shrubs	
	170	Trees	Trees
	171	Shrubs >2 m (High)	Tall shrubs
	172	Shrubs >1 m (Medium)	Medium shrubs
	1730	Shrubs <1 m Salix dominated (Low)	Low shrubs
	1731	Shrubs <1 m Betula dominated (Low)	
	174	Scrub (open)	

2.4 Vegetation Map Production

After the above detailed multiple classification methods were employed and the results of each could be compared with the most advanced supervised classification, and after employing other data and techniques described above and conducting accuracy assessments, a final supervised vegetation map of the region was produced. This classification is presented in Section 3.6.

3. RESULTS

3.1 Per-pixel Unsupervised Vegetation Classification

After the preliminary runs and examination of the resultant classifications, the appropriate classification for the detail required at this stage of the mapping work (10 generalised classes) and the one that could be further refined with enough flexibility in class number, was determined to require not more than 20 iterations and separated the data into 30 classes. Figure 4.8 displays this initial classification.

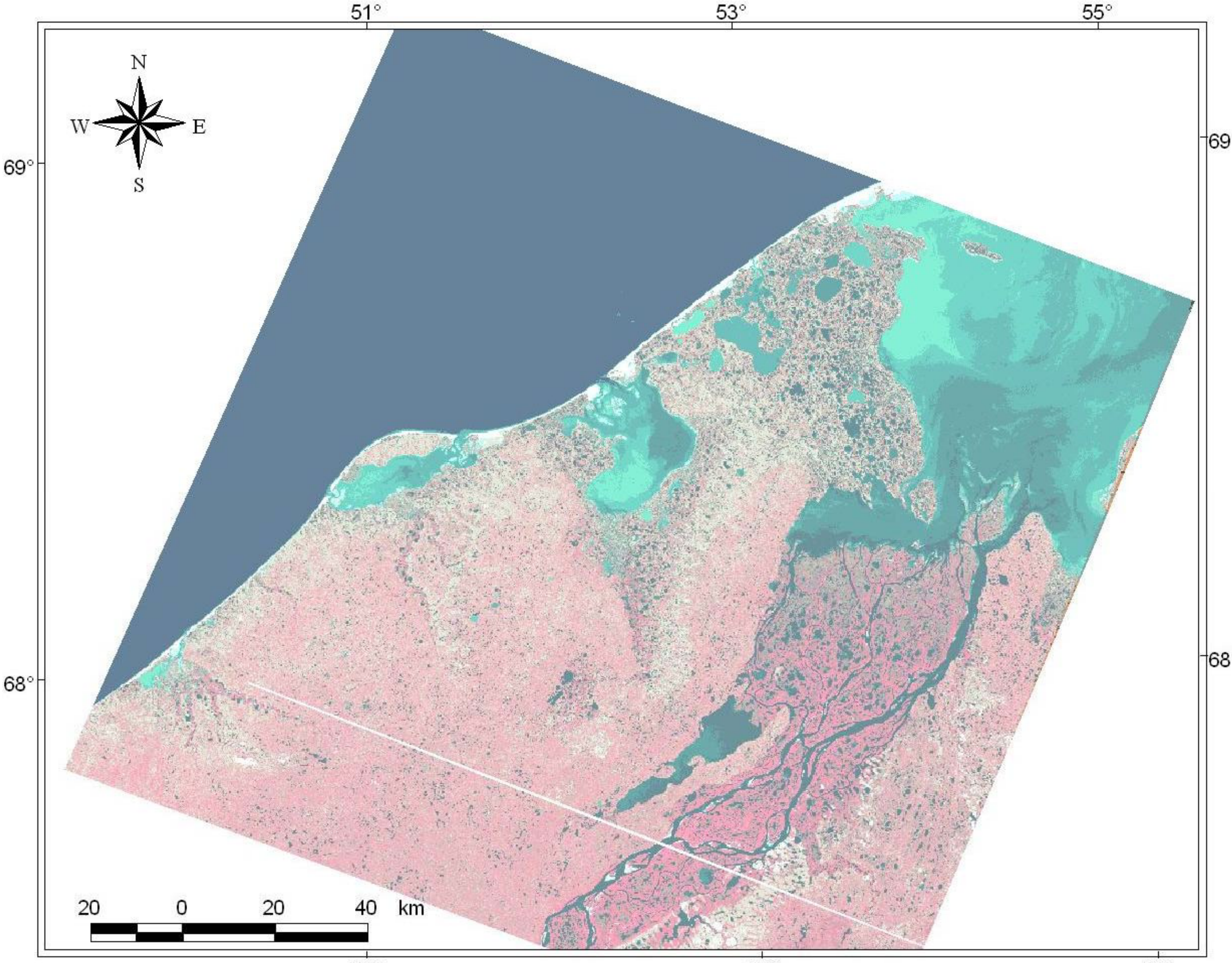


Figure 4.8 Initial unsupervised Landsat classification with 30 landcover classes.

The analysis with the 100 field site locations and neighbouring eight pixels, including a degree of supervision, gave a table of results, showing the number of pixels representing each of the ten basic vegetation types that fell within the 30 classes, providing an assessment of overall representation in each class. The row totals were normalised to 1 and are presented as percentage values for ease of understanding the value of each vegetation type in defining the class (Table 4.5). Dark red numbers indicate more than 50% representation, red more than 25%, and orange more than 12.5%. Black numbers are for anything lower. Classes 1-3, 10, 12, 20 and 21 are missing from the tables. Classes 1-3, and 12 are water and so not included in this data, Classes 10 and 20 are absent, *i.e.* not represented in any of the field locations, and Class 21 was determined from examination of the unsupervised classification to be dense shrub. The total number of pixels analysed was 873. As seen in the tally of pixels at the far right of the table, some classes were poorly represented by the field site data while others were very well represented. Class separation in cases where only a few pixels represented the class cannot be relied on given the lack of data. In the bottom half of the far right column however, pixel representation is higher and these class divisions can be accepted more readily. The column second from the right, ‘Likely Vegetation Type’ represents the vegetation type that each class seems to represent based on the relative number of pixels of each class in the vegetation types.

Table 4.5. Results of analysis showing the number of pixels representing each of the ten vegetation types (as a proportion of 1) that fell within the 30 image classes, the total number of pixels and the probable vegetation type, to which the classes were assigned.

	VEGETATION TYPE (GENERAL)											
	B	E	F	G	H	M	R	S	SA	T		
CLASS	Bog & Fen (Mire)	Exposed Vegetation	Forbs	Grass	Heath (moss, shrubs)	Mud/ Bare	*Salix Reticulata*	Shrubs	Sand	Tundra (tussocks, hummocks)	Likely Vegetation Type	TOTAL PIXELS
4			0.50					0.50			F/S	2
5			1.00								F	1
6			0.33		0.67						H	3
7	0.50							0.50			B/S	4
8	0.50							0.50			B/S	4
9	0.63							0.38			B	8
11	0.50				0.50						H	2
13			1.00								F	2
14										1.00	T	1
15	0.67		0.17					0.17			B	6
16								1.00			S	1
17	0.50		0.17	0.17		0.17					B	6
18	0.18				0.26		0.13	0.39		0.03	H/S	38
19					1.00						H	1
22	0.50		0.10		0.30			0.10			B/H	10
23	0.33		0.04	0.07	0.19	0.15		0.11		0.11	B	27
24	0.13		0.07	0.13	0.13	0.17		0.20		0.17	Mix	30
25	0.14	0.01	0.01		0.29		0.01	0.26	0.01	0.27	H/S/T	159
26	0.06	0.01			0.31		0.02	0.27	0.01	0.30	H/S/T	204
27	0.11	0.01	0.05		0.04		0.04	0.21		0.54	T	112
28	0.26	0.08	0.04	0.05	0.09		0.01	0.22	0.03	0.23	B/S/T	208
29	0.03	0.18		0.23	0.08	0.15		0.13	0.15	0.05	Mix	39
30				0.20		0.20			0.40	0.20	SA	5
TOTAL PIXELS	135	27	27	27	162	18	18	207	18	225		873
	+			+		+			+	+	+	

Preliminary determinations of the generalised vegetation type, determined from a combination of the above results, assessment of the unsupervised classification and general vegetation distribution knowledge, assigned to each of the 30 classes are shown in Table 4.6. Spectral signatures derived from field data were not used at this stage.

Table 4.6. Preliminary class vegetation determinations of the initial Landsat 7 classification based on image examination.

CLASS	VEGETATION TYPE	ADDITIONAL NOTES
1	Water	N/A
2	Water	N/A
3	Water	N/A
4	Water	N/A
5	Mire	
6	Mire	along lakes and riparian zones
7	Mire	similar to class 6 but in drier locations
8	Mire	similar to class 7 but with greater riparian associations vs. lakes (except in north of image)
9	Mire	
10	ND*	minor presence, only in north of image
11	ND*	associated with water, in delta and north, near class 16 generally
12	Water	N/A
13	Water	N/A
14	Shrub heath	in regions with water
15	Mire	uncertain
16	ND*	associated with water, in delta and north; near class 11
17	Mire	
18	Shrub	uncertain
19	Riparian	
20	Riparian grass, scrub	found in river delta & tributaries
21	Riparian grass, scrub	found in river delta & tributaries
22	Mire, wet	very wet, mostly in north and middle, not in delta
23	Mire	
24	Heath, mixed & wet	probably mossy
25	Heath, mixed	
26	Heath	in middle region
27	Heath	
28	Shrub heath	wet? but not in delta, mainly on ridge and some in north
29	Mixed	undetermined, associated with class 30
30	Sand or Lichen	undetermined whether sand or lichen

ND*= not able to be determined (assignment to a class not certain enough)

While the results for the numerical analysis (Tables 4.5) and the qualitative map based assessment are generally similar, there are a few discrepancies. For example, one of the major problems seems to lie with the meaning of the ‘Forb’ class in the quantitative analysis. Classes which represent ‘forb’ according to pixel value distribution for the vegetation type seem to in fact be water or near water. While forb communities do border lakes in regions with local topography, this is not necessarily a strong association and mires may be more likely to occupy these areas. Further examination of the classification was not done as the primary goal at this stage was simply to develop a basic classification that would give a general idea of the vegetation of the region. This initial preliminary classification allowed an overall assessment of the region and its vegetation distribution characteristics and served its purpose as a preliminary investigation tool. It will later be compared with the supervised classification.

3.2 ECHO Spectral-Spatial Unsupervised Classification

Figure 4.9 shows the ECHO 7-class vegetation map that was used initially to determine basic field site visits and routes and later as a comparison of vegetation type distribution with the more refined classifications. Landcover details, based on field observation, seem to be: red-lichen dominated dry heath; darkpink-mixed complexes/heath; light pink-heath with dwarf shrub ; yellow/orange-sand/exposed vegetation; light green-mire; dark green-mire; brown-shrub tundra; blue-water.

The classification, though generalized and on a coarser scale, was of value given knowledge of terrain characteristics and features, such as topography, river deltas, etc., and having proven its utility in the field through pre- determination of field sites. In addition, areas on the ECHO classification could in general be found in the equivalent place in the field, indicative of the classification’s soundness.

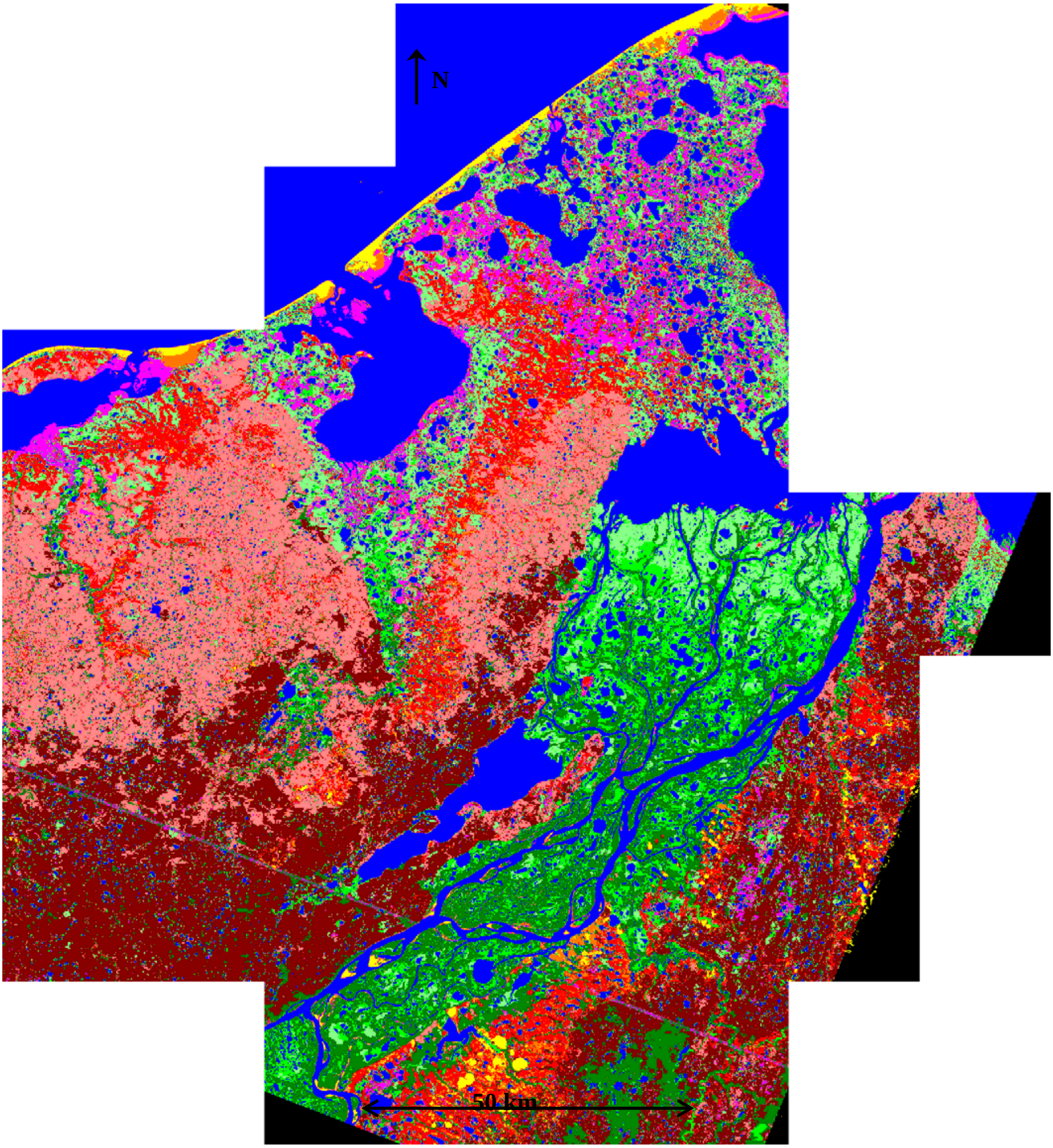


Figure 4.9. Simplified ECHO satellite-derived vegetation classification

3.3 Supervised Classification

In the process of producing the final supervised classification, a number of intermediate ones were developed as iterative modifications and improvements were made. For each new classification new signature files were created according to changes in the vegetation scheme and/or ground truthing data refinement. These intermediate stages in the vegetation classification are described in limited detail only because the process of going back and forth was repetitive with at times only minor changes. General assessments, however, are given, and key shifts and any problems detailed. Separating the development out step by step, and the qualitative and quantitative analyses, is difficult but attempts are made to present the information in a clear fashion by addressing the components on an individual basis where possible.

Generally the quantitative analysis is presented in detail for an early version of the classification, and the detailed qualitative assessment for a late version. In certain cases the assessments are necessarily combined.

3.3.1 Classification of Field Vegetation Data

The full vegetation classification scheme as initially developed is displayed in Table 4.7. This scheme formed the basis for the initial assignment of training data into the appropriate vegetation or land cover types. Divisions were in the first instance derived from knowledge of Arctic vegetation community types, and specifically from distinct communities observed and examined in the field. The detailed botanical analysis component (Chapter 3) was a significant help in providing intimate knowledge of community species composition and differentiation.

The left hand column in the table represents the number of ground truthing sites in each division in the scheme. Variation clearly exists with common and easily accessible vegetation community types well represented, *e.g.*, dry lichen heath. Smaller, more rare and harder to access communities are less abundantly represented *e.g.,* herb slopes (forbs) or anthropogenically influenced exposed vegetation (only corral sites). Once the training data were assigned to a class, it was apparent that the level of detail was, in fact desirably at this stage, too high since a few divisions were not represented at all by ground truthing data (value of '0' in the first column). Consequently, the scheme was modified and reduced to a level in which all classes had representation by field data. Un- and under-represented categories were grouped with others into more general divisions until each class was represented by a minimum of 4 sites. The ability of the supervised classification to distinguish between the types properly, based on visual examination of the images and the amount and distribution of each vegetation type, was also examined in detail to better develop the vegetation division scheme. It was first narrowed to 42 classes and eventually, after many adjustments, to the final version employed to produce the refined supervised classification with 26 classes. This simplified version is shown in Table 4.8.

Table 4.7 Vegetation classification scheme used to categorize and assign all ground truthing locations to a specific vegetation type for incorporation into the classification of the satellite image. Numbers in the ‘Tally’ column represent the number of training sites that were incorporated into the supervised classification.

TALLY	HIERARCHICAL CLASS ID	DIVISION					
		PRIMARY	SECONDARY	TERTIARY	QUATERNARY	QUINARY	SENARY
54	0	Unvegetated					
30	00		Water				
15	000			Clear water			
15	001			Turbid & shallow water			
13	01		Settlement				
11	02		Bare ground				
9	020			Sand			
0	021			Rock			
2	022			Sand with stones			
0	023			Bare earth			
289	1	Vegetated					
0	10		Aquatic				
14	11		Exposed				
11	110			Wind exposed			
3	111			Anthropogenic influence			
6	12		Herb slope				
24	13		Grassland				
12	130			Tundra			
12	131			River			
51	14		Mire				
15				Low sedge mire			
22	1400				Sphagnum moss		
17	14000					w/o Hummocks	
5	14001					w/ Hummocks	
7	1401				Other moss		
4	14010					w/o Hummocks	
3	14011					w/ Hummocks	
4	141			Tall sedge mire			
3	1410				Sphagnum moss		
0	1411				Other moss		
27	15		Heath-Mire				
11	150			w/o Heath Shrubs			
8	1500				w/o Mire Shrubs		
3	1501				w Mire Shrubs		
14	151			w/ Heath Shrubs			
13	1510				w/o Mire Shrubs		
1	1511				w Mire Shrubs		
106	16		Heath				
50	160			Dry			
39	1600				Lichen dominated		
16	16000					w/o betula	
23	16001					w/ betula	
11	1601				Ericaceous shrub dominated		
3	16010					w/o frost boils/bare ground	
8	16011					w/ frost boils/bare ground	
0	161			Moist			
0	1610				w/o Hummocks		
3	16100					w/o Shrubs	
2	161000						w/o tussocks/sedge/grass
1	161001						w/ tussocks/sedge/grass
28	16101					w/ Shrubs	
18	161010						w/o tussocks/sedge/grass
10	161011						w/ tussocks/sedge/grass
1	1611				w/ Hummocks		
9	16110					w/o Shrubs	
6	161100						w/o tussocks/sedge/grass
3	161101						w/ tussocks/sedge/grass
15	16111					w/ Shrubs	
8	161110						w/o tussocks/sedges/grass
7	161111						w/ tussocks/sedges/grass
61	17		Trees & Shrubs				
18	170			Trees			
6	171			Shrubs >2 m (High)			
6	1710				Salix dominated		
19	172			Shrubs >1 m (Medium)			
17	1720				Salix dominated		
0	1721				Betula dominated		
10	173			Shrubs <1 m (Low)			
6	1730				Mixed		
4	1731				Betula dominated		
8	174			Scrub (open)			
0	1740				w/o lichen		
0	1741				w/ lichen		

Table 4.8. Final vegetation classification scheme used in the final supervised classification of satellite data showing number of ground truthing locations assigned to each unique vegetation type

		DIVISION				
TALLY	HIERARCHICAL CLASS ID	PRIMARY	SECONDARY	TERTIARY	QUATERNARY	QUINARY
54	0	Unvegetated				
15	000		Water	Clear		
15	001			Turbid & shallow		
13	01		Settlement			
11	02		Bare ground			
289	1	Vegetated				
14	11		Exposed			
6	12		Herb slope			
12	130		Grassland	Tundra		
12	131			River		
22	1400		Mire	Low sedge mire	Sphagnum moss	
7	1401				Other moss	
4	141			Tall sedge mire		
11	150		Heath-Mire	w/o Heath Shrubs		
14	151			w/ Heath Shrubs		
16	16000		Heath	Dry	Lichen dominated	w/o betula
23	16001					w/ betula
11	1601				Ericaceous shrub dominated	
3	16100		Heath	Moist	w/o Hummocks	w/o Shrubs
28	16101					w/ Shrubs
9	16110				w/ Hummocks	w/o Shrubs
15	16111					w/ Shrubs
18	170		Trees & Shrubs	Trees		
6	171			Shrubs >2 m (High)	Salix dominated	
19	172			Shrubs >1 m (Med)	Salix dominated	
6	1730			Shrubs <1 m (Low)	Mixed	
4	1731				Betula dominated	
8	174			Scrub (open)		

The division process amongst and within vegetation types is described below. Degree of separation is outlined in the table headers. The primary separation is between vegetated and unvegetated classes. Within the unvegetated classes the secondary divisions are water, settlement and bare ground. Water is further divided (tertiary separation) into clear and turbid, easily distinguishable in the satellite image, and bare ground is further divided (tertiary separation) into sand, rock, sand with stones and bare earth. In the final scheme the bare ground divisions are not included, however. There are, therefore, four unvegetated classes in the final classification.

Within the vegetated category the secondary separation divided types into the following eight main, and rather typical, categories: exposed, herb slope, grassland, mire, heath-mire, heath dry, heath moist and shrub. The aquatic and herb slope divisions had no further divisions while grassland was divided on a tertiary level into tundra and riparian types which showed distinct separation upon examination of the satellite image, and exposed likewise into wind exposed and anthropogenic influenced to allow for potential effects of reindeer herding and other human activities in the region. Due to lack of ease of distinction between these two types except by manually differentiating them based on GPS locations from the field or other sources, they were combined in the classification. Rees et al. (2003) showed that anthropogenic sites such as herding camps in the tundra can be distinguished if examined in detail. The aquatic category had no field data representation and was therefore removed from the 26-class scheme.

The remaining five divisions had further levels of complexity. Mires were divided on a tertiary level into low and tall mires and then each also on a quaternary level, according to the presence of sphagnum or other moss. The low sedge mires had one further 5th order division into the presence or absence of hummocks (thought to be important because hummocks could introduce different heath type vegetation).

This final separation was removed, however, as the heath-mire complex seemed to (better) account for this characteristic. Any divisions in the tall sedge mire category were also removed due to limited numbers of representative ground truthing sites.

A distinct heath-mire category was included as there was significant evidence within the study region of a mixed complex of heath and mire that could not be clearly identified as either. It was decided that the satellite vegetation classification would probably register this as being distinct due to the very different vegetation and reflective characteristics of mires and heaths. Mixed pixels, *i.e.* those that contain different range of reflectance values according to the types of vegetation/landscape features within the pixel are a typical problem in classification; they can yield classes that are confused with uniform types or produce their own combinations (as was assumed here) (Campbell 1996, Chen et al. 2002, Foody 2002). Within the heath-mire type, the tertiary separation was into the presence or absence of heath shrubs and then for each, the final quaternary separation was into the presence or absence of mire shrubs. This final division was, however, not included in the classification applied to the final vegetation classification due to low numbers of mire shrub sites and overall limited presence (by observation).

The heath category was the most complicated and prevalent in the region. The tertiary division importantly separated out dry and moist heaths. The initial division, which included a wet heath category, was altered, as wet heaths could be included in moist heath categories or mixed heath-mire categories. Within the dry heaths the quaternary separation was into lichen versus ericaceous shrub dominated types. The lichen heaths were initially divided at a 5th order level into those with or without feeding craters indicating the presence of reindeer feeding in winter and within the uncratered heaths, there was a final 6th subdivision into heaths with and without *Betula*. However, upon examination of the vegetation classification and due to the small number of cratered heaths included in the field data, it was decided that a better final division within the lichen heaths would simply be with or without *Betula* shrubs. Initially the ericaceous shrub dominated dry heaths were separated on a quaternary level into heaths that had or did not have frost boils or exposed clay or bare spots; this division was removed, however, and dry ericaceous heaths simply formed one category.

Moist heaths were separated on a tertiary level by the presence or absence of hummocks. There was uncertainty over the quaternary separation, whether it would be according to presence or absence of shrubs or presence or absence of tussocks and sedge/grass vegetation. After qualitative assessment, it was determined that a separation according to the presence or absence of tussocks and sedge/grass vegetation would be tried. However, upon examination of the results and the discovery that some of the classification did not appear to be correct as the tussock heaths were over-represented, the divisions were rearranged and the level of division was based on shrub presence or absence instead. A 5th order division of these four moist heath types which would separate according to the presence or absence of tussocks/*Carex* and grass was not included in the final applied classification due to a lack of supporting sites of each type and previous problems separating out this vegetation distinction. Moist heaths were the most dominant general vegetation type in the region (Table 4.9) and the majority of this type comprised ericaceous hummocky heath, typically with moss and often with shrubs (*Betula nana* more commonly than *Salix* spp.). Tussock tundra, while present, was not dominant in this region and certainly appeared to have a lower presence than in some other Arctic tundra regions (author’s personal experience in Alaska, Greenland, Canada).

Very little pure tussock tundra was found; instead it was often mixed with hummock heath (see Chapter 3, 3.6.3.1).

The final of the eight initial vegetated categories, trees and shrubs, was divided at the tertiary level according to height and density with four primary types resulting: tree, shrubs greater than 2m in height (tall), shrubs between 1 – 2m in height (medium), and shrubs less than 1m in height (low). Trees and tall shrubs (*Salix* dominated) were not further divided and while medium shrubs were initially further divided on a quaternary level into *Betula* and *Salix* dominated groups, for the final scheme it was not. The only category that was quaternerally divided for the purposes of the final scheme and supervised classification according to *Betula* versus mixed shrub domination was the low shrub category. The fourth type was scrub, a less dense shrub type, generally with low shrubs. In the most detailed classification scrub was initially split into that which contained lichen and that which did not; however, in the classifications developed later it had become apparent that this separation was simply not feasible due to lack of ground truthing sites for each and it was removed. Scrub therefore formed a single category at the tertiary level.

Table 4.9. Proportion of each vegetation class represented in classified image (final version), shown per class and per class groupings.

VEGETATION CLASS	CLASS ID	INDIVIDUAL CLASS %	GROUP CLASS %	
Settlement	01	0.6	0.6	
Bare ground	02	11.3	11.3	
Exposed	11	0.9	0.9	
Herb slope	12	4.6	4.6	
Grassland- Tundra	130	1.2	2.6	
Grassland- River	131	1.5		
Low sedge mire- sphagnum	1400	8.8	12.8	
Low sedge mire- moss	1401	2.0		
Tall sedge mire	141	1.9		
Heath-Mire- w/o Heath Shrubs	150	3.5	5.9	
Heath-Mire- w/ Heath Shrubs	151	2.5		
Heath- Dry Lichen dominated w/o betula	16000	3.2	5.8	32.4
Heath- Dry Lichen dominated w/ betula	16001	2.6		
Heath- Dry Ericaceous shrub dominated	1601	2.4	2.4	
Heath- Moist w/o Hummocks w/o Shrubs	16100	4.9	24.2	
Heath- Moist w/o Hummocks w/ Shrubs	16101	1.2		
Heath- Moist w/ Hummocks w/o Shrubs	16110	3.8		
Heath- Moist w/ Hummocks w/ Shrubs	16111	14.3		
Trees	170	4.6	4.6	
Shrubs >2 m (High)- Salix dominated	171	2.1	2.1	
Shrubs >1 m (Med)- Salix dominated	172	4.1	4.1	
Shrubs <1 m (Low)- Mixed	173	2.4	2.4	
Shrubs <1 m (Low)- Betula dominated	1731	8.6	8.6	
Scrub (open)	174	6.9	6.9	

Out of the total 378 ground truthing locations collected during the two summers of fieldwork in 2003 and 2004, 343 of them (90%) were eventually used in the supervised classification process. Most land cover types in the classification were adequately represented. The representation of a few, for example, herb slopes, however, could have been improved by the addition of further ground truthing sites.

3.3.2 Quantitative Assessments of Image Classification

Quantitative and qualitative assessments were in a sense developed in conjunction, in terms of addressing specific, individual vegetation classes and problems or success in the classification. However, the two approaches will be described in general, separately.

3.3.2.1 JM Distances and Contingency Tables

Based on the initial JM distance results (Table 4.10), there existed a few problems in distinguishing or separating certain (pairs of) vegetation types. A low JM distance indicates a lack of clear separation and random differentiation. Values less than 700 ((0.8%; 5 instances) were of greater concern than those between 700-900 (1%; 8 instances). The vast majority of pairings (98%; 637/650) had values greater than 900, probably not indicative of separation problems. Other studies show a plateau of about 1000 in JM distance when sufficient classes are used (*e.g.*, Poth et al. 2001). Attention was focused on the pairs with the lowest values according to this analysis, which were then considered for merging or reassessment. Decisions were not made on the basis of JM distance results alone, however, and valid reasons for a poor separation can exist (as discussed later in the discussion). JM distances were therefore examined in conjunction with contingency matrices, the summary of an initial version shown in Table 4.11, to see where problems exist. Additional assessments of the classified image such as visual examination were also completed and field methodologies considered. Water classes were not included in the JM distance assessment below as they separated out clearly.

Table 4.10. Complete results of JM distances in assessing accuracy of supervised vegetation classification.

	01	**02**	**11**	**12**	**130**	**131**	**1400**	**1401**	**141**	**150**	**151**	**000**	**001**	**1601**	**1610t**	**1611**	**1611t**	**1610**	**170**	**171**	**172**	**173**	**1731**	**174**	**160001**	**160000**
01	0	1193	1247	1412	1414	1414	1413	1414	1412	1413	1413	1414	1414	1407	1414	1413	1414	1411	1414	1414	1414	1414	1413	1406	1406	1403
02	1193	0	1002	1398	1386	1407	1381	1398	1376	1364	1367	1414	1414	1317	1367	1364	1353	1345	1408	1404	1391	1410	1394	1392	1329	1328
11	1247	1002	0	1404	1395	1413	1389	1380	1370	1366	1381	1414	1414	1291	1385	1382	1384	1359	1414	1410	1399	1414	1376	1359	1312	1287
12	1412	1398	1404	0	1330	1409	1374	1402	1400	1375	1338	1414	1414	1250	1215	1250	1258	1204	1409	1398	1296	1412	1311	1354	1313	1352
130	1414	1386	1395	1330	0	966	1216	1288	1270	1283	1158	1414	1414	1178	1010	1029	1153	1042	1202	*837*	*809*	940	1294	1307	1283	1331
131	1414	1407	1413	1409	966	0	1290	1389	1296	1401	1372	1414	1414	1383	1358	1367	1402	1339	1275	984	912	***597***	1409	1359	1369	1398
1400	1413	1381	1389	1374	1216	1290	0	968	1001	1113	*841*	1414	1414	1156	1200	1048	1231	959	1383	1321	1147	1316	1248	1006	1157	1209
1401	1414	1398	1380	1402	1288	1389	968	0	1127	1133	969	1414	1414	1162	1285	1120	1296	1086	1384	1347	1260	1387	1269	1122	1219	1197
141	1412	1376	1370	1400	1270	1296	1001	1127	0	1075	1146	1414	1414	1083	1298	1219	1313	1104	1404	1342	1232	1334	1287	1089	1078	1130
150	1413	1364	1366	1375	1283	1401	1113	1133	1075	0	997	1414	1414	1049	1197	1108	1193	1067	1410	1365	1295	1405	1148	1170	965	940
151	1413	1367	1381	1338	1158	1372	*841*	969	1146	997	0	1414	1414	991	1051	*787*	1044	*731*	1334	1292	1102	1366	1145	1066	1039	1131
000	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	0	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414
001	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	0	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414	1414
1601	1407	1317	1291	1250	1178	1383	1156	1162	1083	1049	991	1414	1414	0	1052	934	1014	*709*	1389	1328	1189	1393	1047	1066	*819*	907
1610t	1414	1367	1385	1215	1010	1358	1200	1285	1298	1197	1051	1414	1414	1052	0	***641***	***691***	905	1362	1266	1091	1375	1134	1346	1251	1315
1611	1413	1364	1382	1250	1029	1367	1048	1120	1219	1108	*787*	1414	1414	934	***641***	0	*741*	***672***	1338	1240	1030	1372	1018	1253	1156	1261
1611t	1414	1353	1384	1258	1153	1402	1231	1296	1313	1193	1044	1414	1414	1014	***691***	*741*	0	924	1385	1335	1215	1406	1132	1342	1227	1298
1610	1411	1345	1359	1204	1042	1339	959	1086	1104	1067	*731*	1414	1414	*709*	905	***672***	924	0	1347	1260	986	1346	1035	979	933	1079
170	1414	1408	1414	1409	1202	1275	1383	1384	1404	1410	1334	1414	1414	1389	1362	1338	1385	1347	0	1082	1198	1236	1406	1396	1389	1406
171	1414	1404	1410	1398	*837*	984	1321	1347	1342	1365	1292	1414	1414	1328	1266	1240	1335	1260	1082	0	985	913	1351	1364	1348	1385
172	1414	1391	1399	1296	*809*	912	1147	1260	1232	1295	1102	1414	1414	1189	1091	1030	1215	986	1198	985	0	937	1236	1178	1205	1301
173	1414	1410	1414	1412	940	***597***	1316	1387	1334	1405	1366	1414	1414	1393	1375	1372	1406	1346	1236	913	937	0	1409	1355	1375	1401
1731	1413	1394	1376	1311	1294	1409	1248	1269	1287	1148	1145	1414	1414	1047	1134	1018	1132	1035	1406	1351	1236	1409	0	1253	1136	1200
174	1406	1392	1359	1354	1307	1359	1006	1122	1089	1170	1066	1414	1414	1066	1346	1253	1342	979	1396	1364	1178	1355	1253	0	932	971
160001	1406	1329	1312	1313	1283	1369	1157	1219	1078	965	1039	1414	1414	*819*	1251	1156	1227	933	1389	1348	1205	1375	1136	932	0	***568***
160000	1403	1328	1287	1352	1331	1398	1209	1197	1130	940	1131	1414	1414	907	1315	1261	1298	1079	1406	1385	1301	1401	1200	971	***568***	0

Numbers **are between 900-700 and *numbers* are between 700-568 (the lowest value).**

Nine Pixel Accuracy Assessment

An accuracy assessment to check the ground truthing sites' assigned vegetation class and the supervised image classification's class of the sites was done. The classes assigned to the 3x3 pixel neighbourhood (9 pixels total) with the centre pixel representing the ground truthing location were noted. As explained in the methods, training areas of various shapes and sizes were created at or near each ground truthing site according to a combination of 1) notes and observations made in the field about size, area and direction of coverage of the vegetation type and 2) logical assessment of the actual satellite image for similar or related pixels. Therefore, to assess simply the 8 surrounding pixels may not be the strongest method of assessing accuracy. Lending strength to it, however, is the fact that during collection of ground truthing data, attempts to collect data from sites that were 100m x 100m or larger were made. This was not possible in every case though, and certainly not for data collected while travelling along the rivers or noted as occurring a distance away from the GPS location. Overall it seems reasonable to assume that for the majority of cases an area of 3x3 cells would be reasonable to assess, providing that the existing faults and weaknesses of this approach are considered. A more time-intensive assessment that takes into account the shape of each training polygon would have presumably yield higher overall accuracy in the satellite image classification and so our accuracy estimate can be considered conservative.

Table 4.11. Results of 3x3 neighbouring pixel assessment and Contingency (Error) Matrix in assessing accuracy of supervised vegetation classification

Vegetation Type	# training sites incl.	# hits w/in training sites	hit rate w/in (%)	Producer's Accuracy (%)
170	5	2	40.0	99
01	3	3	100.0	92
131	12	12	100.0	62
1400	21	19	90.5	51
11	14	12	85.7	51
160001	17	13	76.5	41
1610	19	10	52.6	40
150	9	8	88.9	31
130	11	6	54.5	30
1611t	10	10	100.0	27
174	8	8	100.0	26
1401	6	6	100.0	25
1610t	11	10	90.9	25
172	19	11	57.9	22
02	9	8	88.9	22
1601	11	7	63.6	22
1611	14	12	85.7	19
173	5	5	100.0	19
171	6	3	50.0	16
141	3	3	100.0	14
1731	4	4	100.0	10
12	4	4	100.0	9
160000	16	14	87.5	4
151	13	6	46.2	1

Consumer's Accuracy

Overall consumer's accuracy based on the results that provided the summary data in Table 4.11 is 72.7%, and the average class accuracy is substantially lower at 31.6%.

Dry lichen heaths with and without *Betula* yielded a practically indistinguishable pairing (JM distance of 568). Given the similarity between these two classes from a botanical perspective, merging them would seem the correct solution. However, it was decided that the two classes should remain separate as the presence or absence of shrubs could be an important separating factor, particularly if vegetation patterns shifted in future and classification could be redeveloped. Furthermore, given the botanical similarity of these two types, it is likely that the spatial association is also high and this may be leading to the confusion rather than a direct inability to separate these types (since shrub vegetation is spectrally very distinct). Finally, from image examination, it was evident that a problem existed in the classification of coastal pixels in the northern part of the region as dry lichen heath without *Betula* only (Figure 4.10). There was no confusion of dry lichen heath with B*etula*. By keeping the two lichen heath classes separate it was hoped that this problem might be corrected. The problem for example could be corrected by using distance from the sea as a criterion for classification. These coastal types do not have associated training data and it is assumed that they most resemble dry lichen heath spectrally and are therefore classified as such. Additional training data for these regions could also help to resolve the problem but collection is beyond the means of this project. This coastal classification error is the likely cause of the very low contingency matrix value (4%) for 16000, especially considering that the 16001 class has a much higher 41% value. It is assumed that with correction of this problem the contingency value would be much higher. Consequently less weight is given to the low contingency value. One other case of botanical similarity perhaps leading to a less than optimal JM separation is between dry ericaceous heath and dry lichen heath with *Betula*. Although the lichen component might be expected to separate them, it is likely that the ericaceous shrubs common to both types, and *Betula*, typically found in the dry ericaceous heaths as well, are causing the confusion and lack of clear separation. In contrast to the JM result, the contingency matrix did not indicate a problem with these two classes. Again the classes were not merged given the potentially important (for reindeer and climate change effects) difference in lichen presence and the conflicting accuracy results.

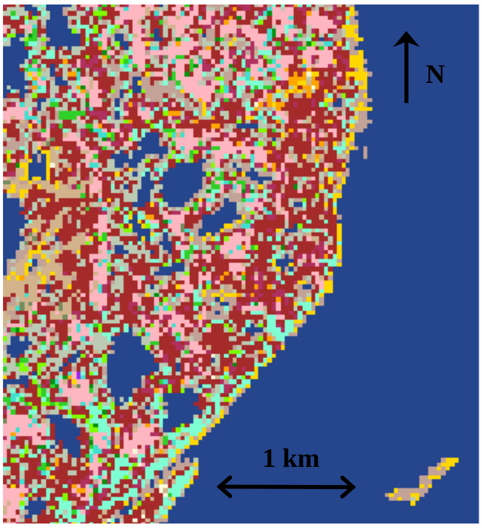


Figure 4.10. Section of classified image illustrating problem of coastal, probably tidal pixels, classified as dry lichen heath without betula (gold pixels represent dry lichen heath without betula).

The second significant separation problem existed between grassland (both riparian and tundra) and the various tree and shrub types. Some of the difficulty separating these types, at least in riparian areas can be attributed to data collection inaccuracies. Methodology for ground truthing data was sound and consistent and sites were visited on foot and the GPS location taken in the middle of the vegetation type (or as near to as was possible to assess or reach). One exception to this methodology exists in ground truthing data collected along the river. It was not possible to go ashore while travelling on the rivers to reach our shore destinations and so GPS locations were recorded from mid-river from aboard various vessels (small ferries and a small skiff with outboard motor). To improve the accuracy of the data, diagrams were drawn where appropriate, illustrating tributaries, sand banks, vegetation types, etc. and detailed and specific notes were taken for improved clarity when inputting the data for classification. Data were collected from both sides of the river courses and the bank duly noted. However, while these procedures were in place for increasing the effectiveness of these data, there still exists a greater chance of error due to movement of the boat, difficulties in viewing land clearly from a low and distant perspective and potential differences in tidal characteristics between the satellite map and the actual land areas seen at the time of data collection. Vegetation classes potentially affected by this confusion and weaker collection method are riparian grassland (131), low mires (140_ types), medium and tall shrubs (171, 172) and trees (170). Lack of separation according to the JM distance results was found between the riparian grassland type (131) and assorted shrub types (171, 172, 173). The lack of separation between tundra grassland and medium shrubs (130 and 172) and tundra grassland and tall shrubs (171) could either be due to misclassification of riparian grassland as tundra grassland or simply the similarity in the spectral characteristics of rich grassland and a rich shrub type. They probably also have close spatial association further confounding the results. The confusion involving both tundra grassland and riparian grassland, which showed an acceptable JM distance as a pair, in these cases is acceptable, given their botanical similarity when compared to a different vegetation type altogether such as shrub. In addition, the tundra and riparian grasslands and medium and tall shrub classes were examined in the classified image and their distribution appears sensible given knowledge of the landscape. Furthermore, results of the contingency matrix did not suggest separation problems. In summary, none of the grassland and tree or shrub classes were merged given their different botanical and distributive qualities.

The third poor result illustrated by this early JM distance analysis was the poor separation of moist heath types (both with and without hummocks) with and without tussocks/sedge/grass. Pairs included in this were non hummock tussock heath and hummock heath, tussock hummock and tussock non hummock heaths, tussock hummock heath and hummock heath. Tussock non hummock heath and non hummock heath was also not a particularly strong separation, falling just outside the <900 range. Upon examination of the image, it was evident that the tussock moist heath classes were over represented. It was therefore decided to restructure the vegetation type classification within the moist heath division, and the separation of tussock and non-tussock moist heaths (both with and without hummocks) was removed (as stated previously).

Finally, additional poor separations were found to exist between the heath mire types and moist heaths (two cases), and a heath mire types and mire (one case). Such a result is not surprising, however, given the botanical similarity and that the mire-heath classes are a hybrid between heaths and mires but also distinct. Therefore, no changes were made to these divisions as it was felt that the hybrid communities formed a distinct grouping.

It should be noted that the JM distances for the various exposed classes (settlement, bare ground and exposed vegetation) do not indicate problems in separation. However, assessment of the classified image shows that the classification is not entirely correct as settlement classes occur too often in uninhabited regions. Therefore the classes were merged in the final supervised classification. Although separation could be maintained by using topographic map data to classify settlements specifically, the specific separation of these classes is not critical in examination of reindeer habitat or for understanding of potential climate change effects and it was deemed unnecessary.

In cases where there is confusion shown by a low JM distance and contingency hit, spatial assessment may still suggest a value to division of classes but argument for maintaining distinction would have to be strong if both quantitative assessments suggested otherwise.

3.3.3 Qualitative Assessment of Advanced Supervised Image Classification

The classified supervised images, from the initially developed one through to the final product, were examined in detail for 1) the relative presence and 2) distribution within the landscape of each vegetation class. Individual classes were highlighted for specific examination and in certain cases, related groups were given distinct colours and examined together, in pairs or even threes if necessary. The details below from an advanced version of the classification provide a general overview of the success of the classification and details of the findings according to each class.

Results from the classification indicated that the two water categories, clear (000) and turbid or shallow (001) successfully classified the water in the mapped area. The settlement class (01) was correct within known and mapped settled regions but it intruded into bare or exposed areas in the tundra where there was no human influence or habitation. Otherwise the bare ground (which was effectively sand along river shores and some rocky and sandy craters in the tundra (02) and exposed barely vegetated (110 and 111) classes appeared to be distributed realistically given topographic associations and frequency of occurrence as observed in the field. While herb slopes (12) seemed to be present in the right areas, the class was over-represented within the map overall and contingency matrix results show a very poor 9% producer's accuracy, indicative potentially of a problem. Both tundra grassland (130) and riparian grassland (131) (which were easily distinguished and clearly occupied separate zones in the vegetation map) were successfully classified in general according to this qualitative assessment. The mire classes (1400, 1401, 141) were found in wetter areas, in the river delta and near streams and tributaries and appear to have been accurately classified according to landscape associations. The heath mire types (150, 151) occupied general tundra areas as expected although the type without shrubs (150) was more common and the shrub type was generally more prevalent in the northern area of the mapped region. The dry lichen heath with *Betula* (160001) showed good correlation with the known reality and expectations and was found near the main ridge and in the northern winter pasture area as observed. However, the dry lichen heath without shrubs (160000) while correct in inland areas is still incorrectly distributed along the northern coastline in what should have been shallow water or coastal sandy tidal zones The other heath classes, including dry ericaceous heath (1601), moist low heath without hummocks or shrubs (16100), moist low with shrubs (161001), moist hummocky without shrubs (16110) and moist hummocky heath with shrubs (16111) all appeared to be distributed in accordance with observations and knowledge of landscape association and relative abundance in the tundra. Finally, the tree and shrub categories were assessed and based on knowledge of increasing size with decreasing latitude and increased presence in riparian (*i.e.* along or near rivers and streams) zones. Trees (170) were found along the river delta, were absent in the north as observed and found increasingly towards the southern regions as expected and observed. Tall shrubs (171) showed a similar trend with an increased presence over the trees in the delta. Medium shrubs (172) were scattered throughout the map region, including in the north as observed, but were found in highest concentrations in the river delta and along other water courses as expected. Low *Betula* shrubs (1730) and low *Salix* shrubs (1731) were distributed patchily and scattered throughout the region, primarily in the main tundra zones as expected. The same was true of the scrub class (174), also as expected and observed. Overall the first attempt at creating a supervised classification was successful although a few problems needed correcting.

Requisite changes were made in generalising and reshuffling the vegetation classification scheme and in checking the accuracy and validity of the ground truthing data on an iterative basis, in order to improve the supervised classification process. Certain ground truthing data had been flagged during initial processing as potentially problematic but was nonetheless all entered initially. Subsequent checks focused particularly on rectifying problems with or removing these data in particular, though by the end, all field data was scrutinised. The herb slope classification was adjusted through this process with uncertain ground data removed, reducing the total herb slope-classified pixels but increasing accuracy of them. The total low mire area showed a slight increase though not significant, with sphagnum bog type mires (1400) increasing over the low moss type. The tall mire area showed a decrease, which was an improvement, even though the area covered in the first classification attempt was not a significant problem. In the case of the dry heath without *Betula* (160000), the amount of this type shown to be present along the coast in the north did decrease in the second classification thus showing some improvement. This issue was still, however, not totally resolved.

Only a few other problems remained outstanding after this refinement process. One was the lack of distinction between settlements and bare ground (although towns were well classified *e.g.,* Naryan Mar). A masking process could be used or known settlements manually adjusted; however, for the purposes of this research, both types have a similar value to reindeer and as they are virtually unvegetated, changes due to climate are less critical than in vegetated areas. Change could be observed however in time, coincident with climatic shifts, corresponding to either or both village/town development or increase in naturally exposed areas as a potential consequence of climate change. There is perhaps still too little classified sand and bare ground (02), more of which could improve the remaining problem of the dry lichen heath without *Betula* (160000) showing up frequently along northern shorelines. It is possible also that these tidal zones simply have a unique reflectance that is most closely matched to dry lichen heath and since no ground truthing data are currently available for this specific zone this cannot be fixed in the classification process. It could be resolved with other means such as masking or using distance qualifiers should more precise information be required. A similar problem, although less severe, is found with the heath-mire shrub class (151) which also appears in the north along the coastline.

Some modification attempts were made or considered but decided against. Combining the two dry lichen heath classes (160000 and 160001) was considered but ultimately not done as the distinction of the presence or absence of shrub in this type of tundra was felt to be important, and the issue of the coastal zone was confined to only one of these two types so mixing them may confound that problem. A modified classification was done with the merging of the four moist heath types into one large group but, after assessment of the results, this too was thought unsuitable as it was too general for such a large and significant vegetation type in the map region. The final classes for the moist heath were differentiated primarily on the basis of hummocks, as before, and secondarily on the basis of presence or absence of shrubs. The tussock separation was removed as it seemed to lead to false results and an over representation of tussock tundra as discussed above. Combining the two low mire types was considered because their separation was not seen as relevant to reindeer, but from a botanical point of view there is enough of a distinction between sphagnum bogs and other types of low sedge mires and furthermore the satellite classification was able to clearly distinguish two types. Finally the two mixed heath-mire classes were kept separate as well. It was thought that the non-shrub type might be more similar to a mire type while the shrub type might be more similar to heath vegetation; both, however, fill an in between niche in the overall vegetation characteristics of this particular region.

3.3.3.1 Comparison with Quickbird Data

Newly available Quickbird data from Google Earth (http://earth.google.com/) was found to cover some of the study area region, allowing a potential check of field data and vegetation classification results with an independent data source. The high resolution of this data allows clear visual comparison and examination.

Ground truthing GPS locations were checked against the available swaths of Quickbird data on Google Earth, revealing that in fact only three ground truthing sites, all from the winter pasture area, were covered by a Quickbird image. Two of the sites were mire types and one was dry lichen heath. Close visual examination of the Quickbird image showed that these three sites are in fact located in the recorded vegetation classes, illustrating how field data can upscale to satellite data.

While certain vegetation and landscape characteristics can be easily observed in the high resolution Quickbird data, not all vegetation classes are visually distinguishable. Bare or exposed areas, shrubs, mires and lichen heath are, however. Ten sites from each of these four classes were chosen from within the Quickbird image in the region of winter pasture area visited in 2004 and their GPS locations marked in Google Earth. The final Landsat ETM+ satellite sensor based classification was brought into ArcMAP (Version 9.1, ESRI, CA, USA) along with the 40 selected sites (as GPS points) and a Google Earth Quickbird image (jpg) containing these sites. The Quickbird image was georeferenced using control points (RMS error 3.02m) enabling it to be matched to the Landsat vegetation map. The 40 exposed, shrub, mire and lichen heath GPS points were then located in the Landsat image and the pixel class in which they were found was recorded (Table 4.12).

Correspondence was remarkably high, suggesting acceptable classification of these four vegetation types and, perhaps, more general support of the vegetation map. The exposed/bare sites matched in 10 of 10 cases and the shrub sites in 9 of 10 cases (counting as successful two cases in which the site location was on the border of a shrub and a grassland pixel but surrounded by shrub pixels) and in all 10 if the identity of the majority of neighbouring pixels is considered. The mire sites matched in 8 of 10 cases, and if the other two cases recorded as heath-mire pixels surrounded by mire pixels were considered acceptable, then in 10 of 10 cases. Finally, the dry lichen heath sites matched clearly in 6 of 10 cases but again, if the identity of the majority of the surrounding pixels is considered, then in 10 of 10 cases as well. Figure 4.11 illustrates the strength of the results for the exposed/bare class, showing five of the Quickbird bare sites centrally located in exposed/bare patches in the Landsat map. Figure 4.12 displays results typical for the shrub, mire and lichen classes. Four Quickbird shrub sites can be seen, three of them within Landsat shrub pixels and patches and the fourth lying on the border of a grassland and shrub pixel with shrub pixels surrounding suggesting correspondence for all four. The one Quickbird mire site shown appears in the midst of Landsat mire pixels but the presence (noted above and generally in Table 4.12) of heath-mire pixels in a mire patch can also be observed. Lastly, the lichen site from Quickbird appears in a dry lichen heath patch in the Landsat map. This lichen site example also illustrates, however, the general comment in Table 4.12 that dry lichen heath pixels in the Landsat image appear to be mixed with heath-mire pixels. In contrast, in the Quickbird image, lichen heath seems to appear to be more uniform although it is difficult to say by mere visual observation of the satellite picture alone exactly what vegetation is present in the lichen heath sites. It would be valuable to explore this issue further in order to determine whether dry lichen heath is being underrepresented or not in the Landsat classification.

Overall, crosschecking visually discernable vegetation type locations in the Quickbird image with the corresponding location and pixel class in the Landsat ETM+ satellite sensor based vegetation classification was successful as a simple, independent means of accuracy assessment of the vegetation map. Given greater research scope, further quantitative and more detailed analysis could prove additionally valuable.

Table 4.12. Results of comparison of selected vegetation from Quickbird image with Landsat vegetation map

QUICKBIRD CLASS	LANDSAT CLASS DESCRIPTION	LANDSAT CLASS #	COMMENTS ON LANDSAT CLASSIFICATION	
Bare 1	Exposed/Bare	11	Generally Class 11 (Exposed) with some 02 (Bare ground) pixels but without any doubt in all 10 cases	
Bare 2	Exposed/Bare	11		
Bare 3	Exposed/Bare	11		
Bare 4	Exposed/Bare	11		
Bare 5	Exposed/Bare	11		
Bare 6	Exposed/Bare	11		
Bare 7	Exposed/Bare	11		
Bare 8	Exposed/Bare	11		
Bare 9	Exposed/Bare	11		
Bare 10	Exposed/Bare	11		
Shrub 1	Shrub Medium (>1m, Salix)	172		Generally Medium (172) or High (171) Shrubs but presence of some Grassland (Riparian) (Class 131) pixels in shrub patches
Shrub 2	Grassland (riparian)/Shrub Medium (>1m, Salix)	131/172		
Shrub 3	Shrub High (>2m, Salix)	171		
Shrub 4	Shrub Medium (>1m, Salix)	172		
Shrub 5	Shrub Medium (>1m, Salix)/Grassland (riparian)	172/131		
Shrub 6	Shrub Medium (>1m, Salix)	172		
Shrub 7	Shrub Medium (>1m, Salix)	172		
Shrub 8	Shrub High (>2m, Salix)	171		
Shrub 9	Moist Heath/Shrub Medium (>1m, Salix)	16110/172	on border of 16110 & 172	
Shrub 10	Grassland (riparian)/Shrub Medium (>1m, Salix)	131/172	most pixels are 172	
Mire 1	Low Sedge Mire with sphagnum (Bog)	1400		Generally Mire types (1400 & 1400) but some Heath-Mire pixels (150/151) in the patches also
Mire 2	Heath-Mire (w/o shrubs)	150	surrounding pixels are 1400/1401	
Mire 3	Low Sedge Mire with sphagnum (Bog)	1400		
Mire 4	Low Sedge Mire with moss	1401		
Mire 5	Low Sedge Mire with sphagnum (Bog)	1400		
Mire 6	Low Sedge Mire with moss/Heath-Mire w/ shrubs	1401/151	on border of 1401 and 151	
Mire 7	Low Sedge Mire with sphagnum (Bog)	1400		
Mire 8	Low Sedge Mire with moss	1401	150 and 16000 pixels nearby	
Mire 9	Low Sedge Mire with sphagnum (Bog)	1400	some 131 (grassland) mixed in	
Mire 10	Heath-Mire (w/o shrubs)	150	mixed pixel area w/ surrounding 1400/1401 pixels	
Lichen 1	Heath-Mire (w/o shrubs)	150	but 16000 and 16001 all around	Generally Dry lichen heath (16000 & 16001) but some Heath-Mire (150) pixels in the patches
Lichen 2	Heath-Mire (w/o shrubs)	150	but 16000 and 16001 all around	
Lichen 3	Dry Lichen Heath w/o betula	16000		
Lichen 4	Dry Lichen Heath w/ betula	16001	also patchy with 150 (Heath-Mire)	
Lichen 5	Heath-Mire (w/o shrubs)	150	but 16000 and 16001 around	
Lichen 6	Heath-Mire (w/o shrubs)	150	but 16000 and 16001 all around	
Lichen 7	Dry Lichen Heath w/o betula	16000	also patchy with 150 (Heath-Mire)	
Lichen 8	Dry Lichen Heath w/ betula	16001		
Lichen 9	Dry Lichen Heath w/ betula	16001	also patchy with 150 (Heath-Mire)	
Lichen 10	Dry Lichen Heath w/o betula	16000	also patchy with 150 (Heath-Mire)	

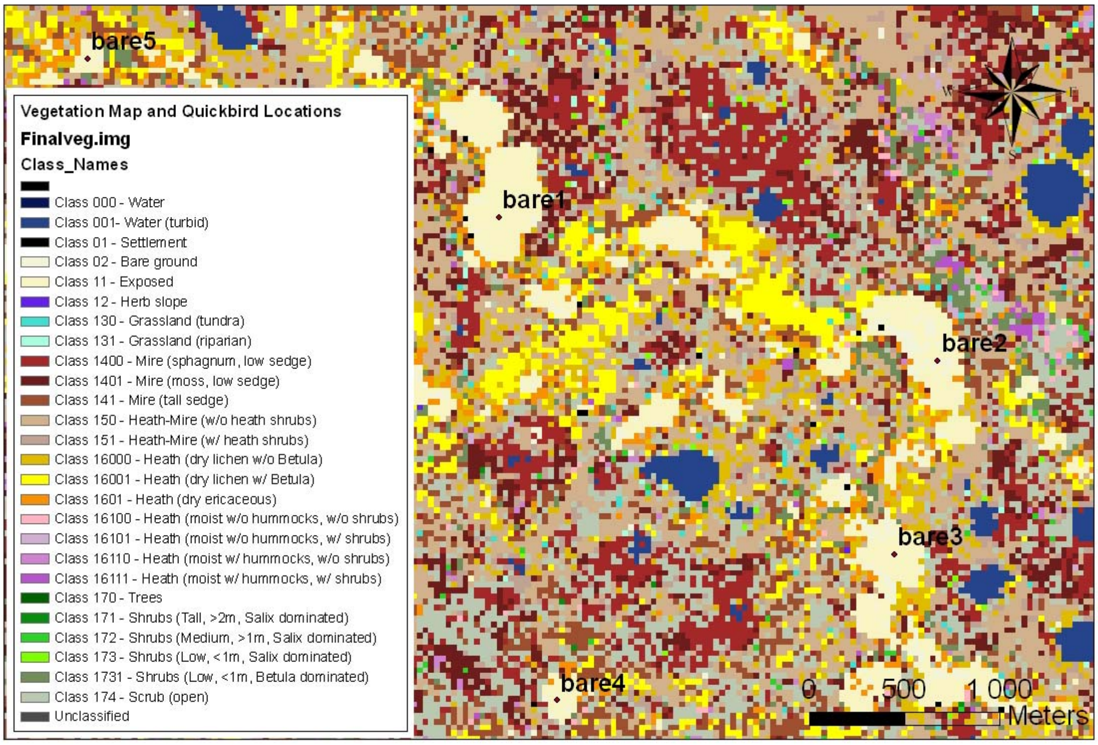


Figure 4.11. Illustration of the correspondence of visually observed Quickbird bare sites with exposed/bare classes in the Landsat vegetation classification.

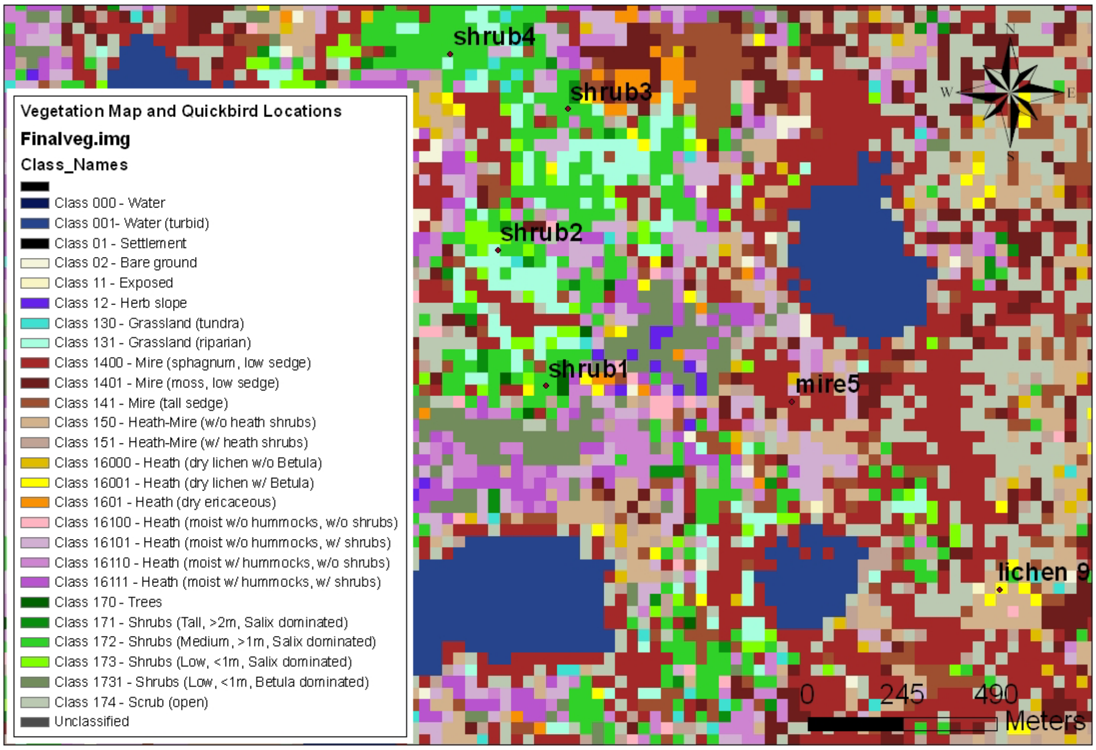


Figure 4.12. Illustration of the correspondence of visually observed Quickbird shrub, mire and lichen sites with the respective classes in the Landsat vegetation classification.

3.3.4 Refinement Techniques

3.3.4.1 NDVI

The NDVI stratification provided clear results in distinguishing shrub/tree (green leafy plants) vegetation from all other sorts of landcover. Once the NDVI image was examined, adjustments were made to the initial threshold value of 204, which was chosen based solely on the shift in pattern in the reflectance curve. This value was too high with known shrub sites from fieldwork not containing NDVI shrub/tree pixels. The threshold was gradually lowered in steps with close examination of the effects until 196 (0.77) at which point NDVI values supported all tree and shrub ground truthing sites. The two threshold values chosen improved the results, with an upper one at 205 distinctly representing riparian and larger trees and shrubs, and a lower one at 197 representing smaller shrubs, particularly in the tundra (Figure 4.7).

Thresholds were determined by close examination of the full range of ground truthing sites and all AOI polygons (excluding water). Shrub AOI polygons in the majority of cases contained mostly pixels with a value greater than 197. The threshold was not lowered further because when a lower value was tried it did not increase the number of NDVI shrub pixels in the shrub AOI polygons. Furthermore, a number of pixels in the heath polygons had NDVI values in the low to mid 190's, and further lowering the shrub threshold would result in non-shrub vegetation being defined as shrub vegetation. One shrub polygon was not well represented by pixels above the threshold value, but this particular ground truthing site had been spotted from a distance and there was probably an error in the polygon location, with NDVI shrub pixels located just adjacent to the polygon.

Heath vegetation types that contained a notable proportion of deciduous shrub vegetation, generally birch, typically contained some pixel values above the lower NDVI threshold value of 196, as might be expected. One example of *Betula Rubus* heath with a note about the particularly high density of shrub vegetation contained primarily pixels with values greater than 196. Scrub vegetation contained some NDVI-defined shrub pixels but a smaller proportion as makes sense given low shrub density in scrub. Vegetation types that contained little or no shrub vegetation likewise were not represented by NDVI pixels above the threshold value. All of these results are all accepted and contribute to verification of valid NDVI threshold values. Biomass data are not available as part of this project. Therefore, these results and any quantitative difference between scrub and shrubby heath types, for example, cannot be tested within the scope of this work. Comparisons of the NDVI stratification image and the vegetation classification's representation of shrub/tree vegetation showed a high degree of similarity, as illustrated in the examples (Figures 4.13-4.15) below which have been extracted from the full images. The first pair of extracted images provide a more generalized, coarser resolution view. Trends of increased shrub vegetation along river courses and riparian areas can be seen in both images, as can the increase in shrub vegetation in the eastern half of the images. Areas without shrub and tree classes show the same correlation trend.

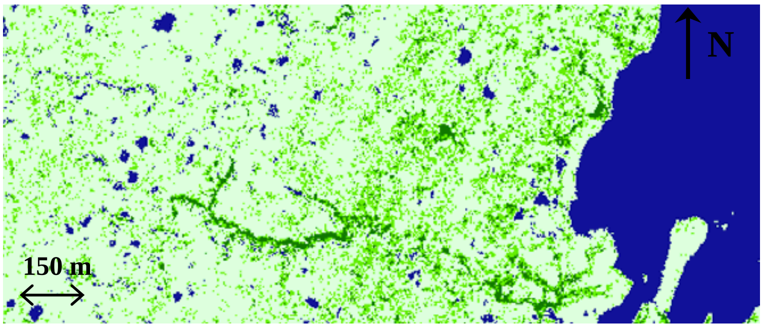


Figure 4.13a. Example of the density-sliced NDVI shrub and tree classification. NDVI values greater than 205, interpreted as trees and larger shrubs, are represented by the dark green colour, values greater than 197 but less than 205 are interpreted as smaller shrubs and shown by the medium green and values greater than 128 and less than 197 are represented by the lightest green. Deep blue represents NDVI values of less than 128, interpreted as corresponding to water or other non-vegetated classes (such as sand).

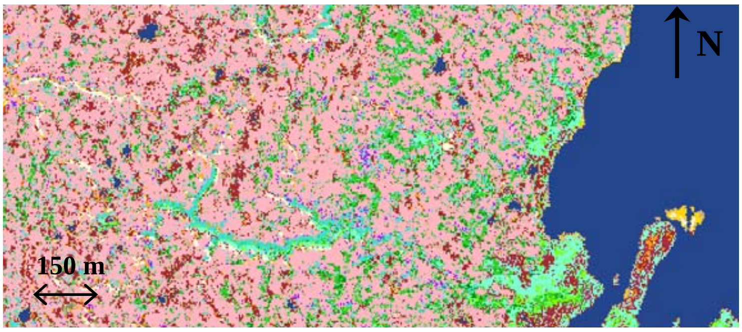


Figure 4.13b. Example of extract from the supervised Landsat vegetation classification (Figure 4.18). The various shrub and tree classes are represented by the green colours, with larger classes shown in darker shades and smaller ones in lighter shades (see Figure 4.18 for detailed vegetation key).

The second pair of images allow a more detailed comparison of the NDVI image and vegetation classification but show the same supporting trends as the first.

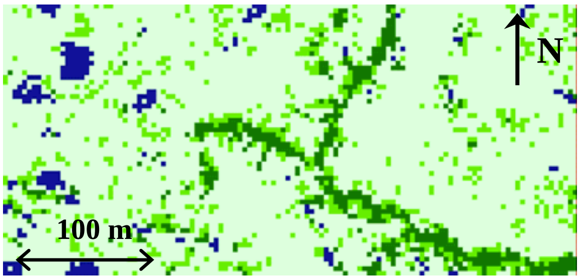


Figure 4.14a (left). Example of the density-sliced NDVI shrub and tree classification. (see Figure 4.13a for pixel colour correspondence).

Figure 4.14b (right). Example of extract from the supervised Landsat vegetation classification (Figure 4.18). The various shrub and tree classes are represented by the green colours, with larger classes shown in darker shades and smaller ones in lighter shades (see Figure 4.18 for detailed vegetation key).

The final pair of image selections come from an area of winter pasture, in the north of the study region where shrub vegetation is more sparse. Again, the NDVI and vegetation classification results correlate well even in a lower density region.

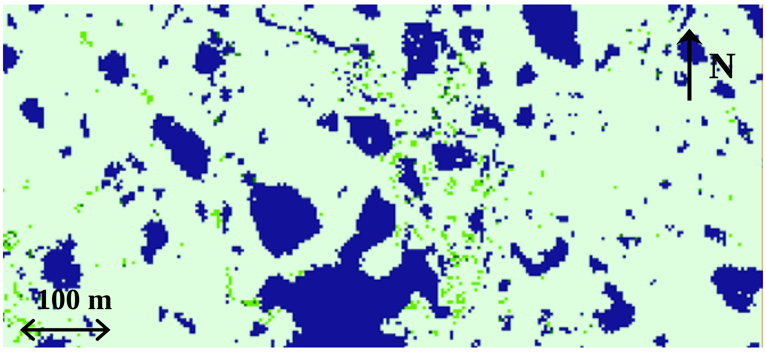


Figure 4.15a. Example of the density-sliced NDVI shrub and tree classification from winter pasture in the north. (see Figure 4.13a for details).

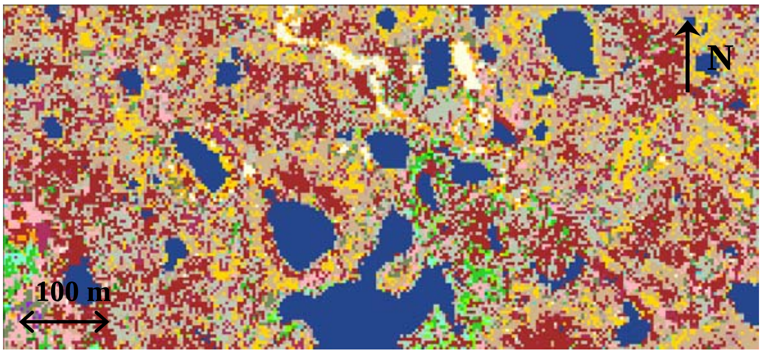


Figure 4.15b. Example of extract from supervised Landsat vegetation classification (Figure 4.18) from winter pasture in the north. The various shrub and tree classes are represented by the green colours, with larger classes shown in darker shades and smaller ones in lighter shades (see Figure 4.18 for detailed vegetation key).

It can be concluded based on these visual comparisons that the original shrub/tree delineation in the vegetation classification is representative and the classification results can, therefore, stand alone. Further modification, such as creating a mask of the NDVI stratification results to include in and improve the original classification is not necessary.

3.4 Hybrid and Simplified Supervised Classifications

The two additional classifications that provide a simple visual comparison of vegetation community distribution are shown here. The multi-spectral spectral purity NDVI classification by G. Rees is shown below in Figure 4.16.

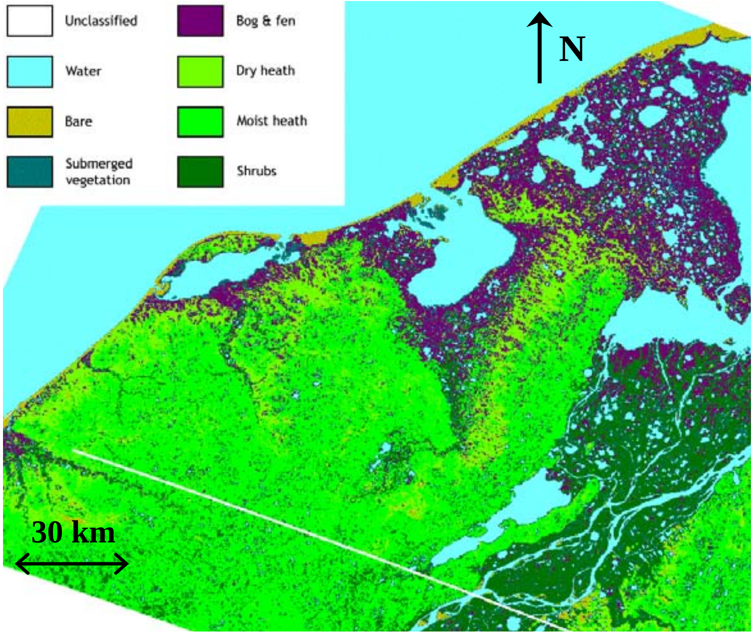


Figure 4.16. Multi-spectral spectral purity NDVI Landsat classification.

Finally, Figure 4.17 shows the simplified (from the 26-class version) 12-class map with its more homogeneous land cover. These simplified classifications clarify broad vegetation distribution trends in the region by removing some of the heterogeneity, and they illustrate some of the basic vegetation types, allowing a clearer overview assessment of vegetation in relation to land and water features of the region.

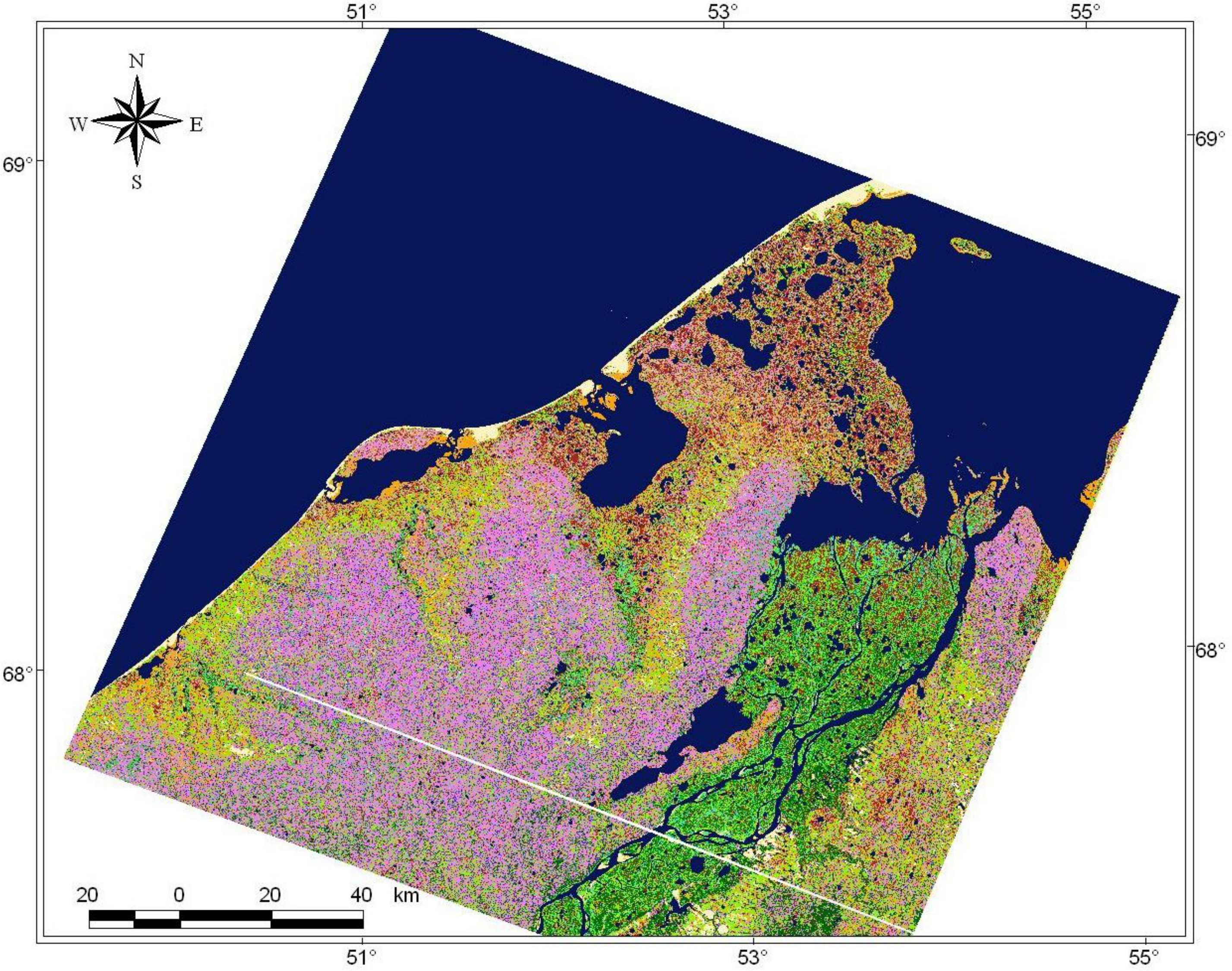


Figure 4.17. Simplified, generalised supervised Landsat classification with only 12 classes (colour scheme same as Figure 4.18 and legend generalised according to Table 4.4)

3.5 Vegetation Map Production

Based on the quantitative and qualitative assessments described above, results of NDVI development and visual comparison with a number of other classification techniques, a final vegetation classification, built on the supervised methodology, was developed (Figure 4.18) to represent the vegetation of the region.

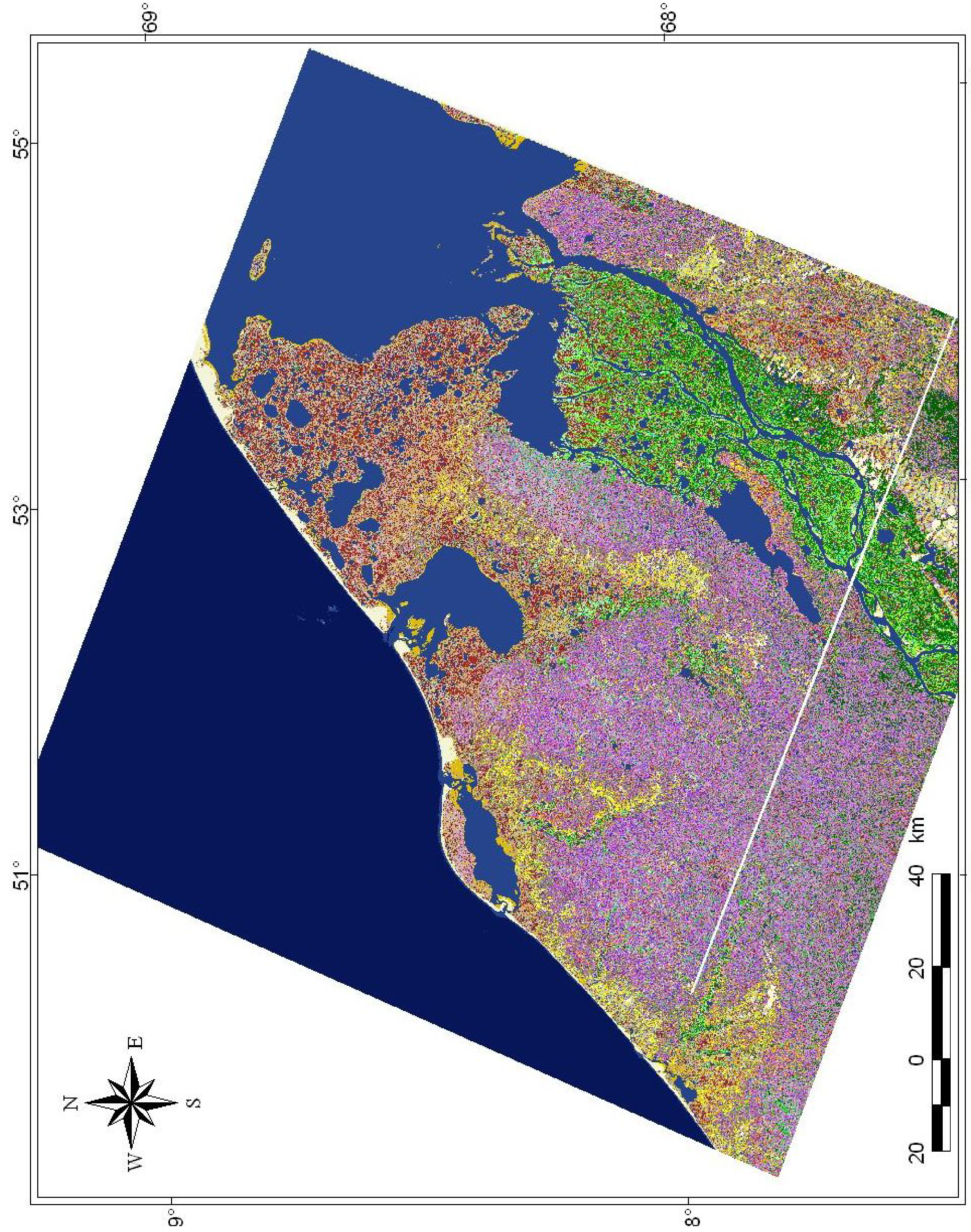


Figure 4.18 (image). Final Landsat 7 ETM+ satellite sensor based vegetation map produced for the study area within the NAO region, with a total of 26 classes (legend on following page).

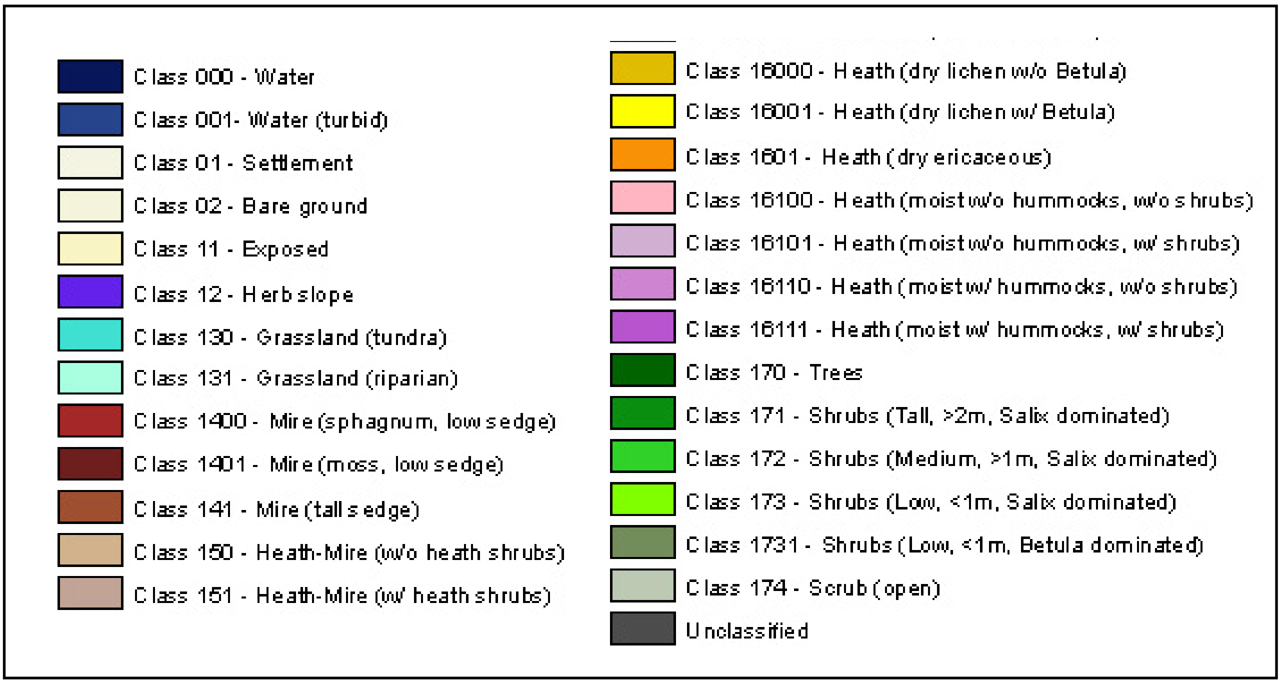


Figure 4.18 (legend). Final Landsat 7 ETM+ satellite sensor based vegetation map legend produced for the study area within the NAO region, with a total of 26 classes (image on previous page).

3.6 Classification Comparisons

A total of four classifications have been developed as part of this research and a further two included for comparison, developed by G. Rees. In general, each classification showed similar vegetation type distributions and relative proportions. The final supervised classification will be compared to other regional and global vegetation cover maps such as the Global Landcover Map (GLC) (JRC European Commission 2003), the Circumpolar Arctic Vegetation Map (CAVM) (CAVM Team 2003) and the Olson land cover map (USGS EROS) in the following chapter (5).

Detailed classifications showed more specific results with general patterns consistent across all the classifications, suggesting that each of the techniques used was appropriate. More importantly it provides confirmation for the final classification's acceptance despite the lack of traditional accuracy assessment. The simplified, ECHO and Spectral-spatial classifications were more generalised with 12, 7 and 7 classes in each respectively, whereas the unsupervised and final supervised had 30 and 26 classes each. Comparisons between all five classifications showed the same vegetation community trends: tundra heath zones in the area northwest of Nelmin Nos, shrub, riparian grassland and mire vegetation in the river deltas, with increasing shrubs and trees southwards, both along the Pechora River and inland; dry heath areas along and just west of the main ridgeline, and east of Naryan Mar. The general classifications did not of course show the same high degree of heterogeneity that the more detailed classifications did. There may be a degree of noise in the detailed supervised classification but since the classification divisions have been supported by the analysis, the amount of class detail is accepted. The supervised classification highlights the extreme heterogeneity well while at the same time allowing the general distribution trends to be seen.

Certain vegetation trends, important in reindeer habitat and potentially climate change assessment, such as lichen distribution, are not evident in the coarser classifications, giving support to the more detailed supervised classification. In the more detailed supervised classification, lichen can be distinguished in the dry heath areas, just west of the ridgeline, east of Naryan Mar and also in the winter pasture area north of Korovinskaya Bay. The heterogeneity and variety of shrub distribution is also more clearly distinguished in the supervised classification.

The effects of topography and the local drainage systems are evident when viewing all of the classifications and the resulting vegetation distribution. Micro-topography and microclimate effects are certainly partly responsible for the patterns of heterogeneity that dominate the region, in particular the inland tundra zones, and effects are more evident in the classifications with the greatest detail, reflecting the influences of landscape characteristics on vegetation on a finer scale.

4. DISCUSSION

4.1 Characteristics of Regional Vegetation Distribution

The vegetation of this particular region in northwestern Russia shows highly heterogeneous distribution. Homogeneous patches and more typically homogeneous types (such as heath expanses, mires, etc.) do exist but on the whole vegetation in the area is patchy on a fine-scale level, in some places below 30-m. On the whole, however, much of the patchiness can be resolved in a Landsat classification. Causes are probably micro-topography and micro-climate related, with small shifts in elevation, aspect, soil moisture and drainage patterns. Permafrost is patchy in the region and probably plays a smaller role in influencing vegetation distribution than in permafrost-dominated regions of the Arctic.

Taking a step back and examining the region on a coarser level, broad and easily discernable vegetation patterns begin to emerge and the landscape takes on a more homogeneous character. The study region can be divided into zones: the low lying Pechora and Neruta River deltas contain rich vegetation such as shrubs (generally not including the dwarf shrubs found in the tundra zones), which increase in size to the south (most notably in the Pechora Delta), and mires and riparian grassland; the eastern side of the Nenets Bank forms a mixed region dominated by heath vegetation, typically moist but containing shrub stands, grassland, herb slopes and mire patches; the western side of the ridge above the Neruta plain is dominated by dry heaths, often containing lichens, and exposed areas; this zone of dry vegetation extends to the north where the patterns switch and a complex mosaic of predominantly mire with heath vegetation dominates the lake covered region. As on a micro-scale level, landscape effects and topography are clearly responsible for patterns of vegetation distribution.

Vegetation types of particular importance in climate change assessment and reindeer habitat suitability are shrubs and lichen. While size and density of shrubs are shown to increase towards the south, substantial amounts of shrub vegetation is found in the northern tundra zone, interspersed in patches, along small riparian drainages or in stands near or bordering lakes or moist regions. A lichen zone develops along the Nenets Bank ridge and extends northwards above Korovinskaya Bay. Dense lichen vegetation is also present in the area east of Naryan Mar.

While topographic influences are significant, elevation gain in the region is limited to approximately 100 metres. Succession zones are found even in this fine-scale change, with valley tops dominated by exposed or dry vegetation, the sides by herb slopes, and the bases by mires or shrub vegetation.

4.2 Spatial Resolution

This issue will be addressed in more detail from a comparative perspective in Chapter 5 but briefly, the thirty-metre resolution of Landsat 7 ETM+ satellite sensor data successfully maintains a high degree of the landscape heterogeneity and differentiates between a number of vegetation classes, twenty-six in this case. As seen in the coarser resolution classifications, detail of smaller and less common vegetation types and heterogeneity are lost with decreasing resolution. However, even the more general classifications presented here remain faithful in preserving overall regional vegetation trends, as described above. A caution with over-generalisation, however, is that primary vegetation types run the risk of being over-represented (Turner et al. 1989). Very high resolution satellite imagery (such as Quickbird or IKONOS) would probably be able to show even more landscape detail, perhaps registering finer scale reindeer grazing effects such as corral and surrounding area disturbance, differences that are not immediately apparent in the Landsat classification.

The vegetation map from 1974 presented earlier in this chapter (Figure 4.3) provides detailed botanical descriptions of its classes and successfully distinguishes the regional patterns of vegetation. However, its scale is coarse and the large size of the vegetation patches does not allow the micro-scale patterns and detailed heterogeneity that exist in this complex region to be seen. The Landsat ETM+ satellite sensor imagery based vegetation map, with its thirty-metre pixel resolution does, however, while also showing the broad regional vegetation trends. There is scope for development of a more in-depth comparison of these two maps, particularly in terms of examining any potential changes or shifts in vegetation cover.

4.3 Spectral versus Spatial Confusion

Two types of confusion- spectral and spatial - can exist in vegetation classification and for a proper assessment of the classification and its value, they must be distinguished. Spectral confusion suggests problems with classification (which may or may not be solvable), whereas spatial confusion is probably simply a function of vegetation community distribution and structure. If two (or more) vegetation communities occupy the same or similar habitats (in terms of topography, slope, moisture or other characteristics) they are likely to exist in close proximity, even growing in heterogeneous patches with each other. Regardless of the strength of classification, separating such classes out will be difficult unless using highly detailed satellite data with a resolution of a few metres or less. Great potential in the future for improved and more accurate vegetation classification exists with the increasing availability of finer-scale image data.

As can be seen from examples in the JM distance results, a lack of separation may not be clearly indicative of spectral confusion. The contingency matrix can show acceptable separation as can visual knowledge-based qualitative assessment of the image. In cases of separation confusion, resolution can result through merging of the poorly separated classes. If after merging, the results still do not give a result that seems reasonable based on vegetation community and distribution knowledge it can be assumed that the classes can remain separate. Reasons for a lack of separation in JM distances include spatial confusion (versus spectral) and problems in the accuracy or amount of training data. Providing that decisions contrary to the results of the JM distance assessment can be justified by other means, decisions to maintain separation (or merge classes) may be acceptable as illustrated in the decision making process outlined in this chapter.

4.4 Methods Employed

4.4.1 Hierarchical Classification Scheme and Class Divisions

A mention of the relevance of the hierarchical scheme developed in this research to the broader picture should be made. Plant Functional Types (PFTs), which group species according to ecosystem function, are increasingly considered important in the development of vegetation models given the focus on global or broad regional wide datasets (*e.g.*, Box 1996); in particular Arctic-specific PFTs are critical given the unsatisfactory division of Arctic vegetation by global models (Walker 2000). The vegetation classification developed here did not apply an established PFT scheme because the focus was on relevance to reindeer habitat and in a general vegetation community sense to climate change, and more, and individual, division in classes was required. However, given the high number of classes and the details provided in this research regarding class content and characteristics, reclassification into a standardised PFT or other land class division scheme should not be difficult.

Landsat data are unable to accurately classify vegetation to the species and genus level and so the more detailed a classification the higher chance of error. Applying fewer classes to the final classification could mean it is accepted with greater certainty. However, while a degree of noise may exist in the final version, the quantitative and qualitative analyses conducted within this work suggest that the classification successfully distinguishes among the selected vegetation classes. There remains, however, room for improvement. Confusion exists between the grassland and herb slope types, due to limited field data, small patch size of the two types (in particular herb slopes), likely spectral similarity as registered by the satellite sensor, and possible spatial similarity. The riparian grassland and shrub communities also showed some separation confusion, due in this case in all likelihood to data collection techniques. As mentioned in the methods, all ground truthing locations were visited by foot, except those that lay along the river in which case GPS readings and detailed location notes (including diagrams) were taken from a boat in the river channel.

The issue of small patch size, brought up in the confusion between herb slopes and grassland, should be further addressed from the perspective of resolution. While the image resolution was 30 m and all vegetation types selected for inclusion in ground truthing were as large as possible, with an attempted minimum size of 100x100m, some type patches are naturally smaller (such as herb slopes in particular). Second, the error inherent in spatial analyses and data must be considered. Finally, while the resolution of an image may be 30 m, as it is here, other factors must be examined when assessing the suitability of the classification:

- landscape heterogeneity (very high in this case)
- contrast between features in near proximity
- the general level of data provided

Landscape heterogeneity can increase the difficulty in clearly distinguishing features or classes. Lack of contrast between nearby features, *e.g.,* similar and related vegetation classes such as tall shrubs and medium shrubs can increase the challenge. Finally, the level of data provided plays a role in that greater details provides greater context for interpretation and understanding.

4.4.2 NDVI

NDVI has been shown to be particularly useful for application in large, remote Arctic regions (Markon et al. 1995, Bogaert et al. 2002, Zhou et al. 2001, Jia et al. 2002, Walker et al. 2003) and was useful in providing additional detail about shrub and tree distribution and aiding classification. In long-term studies, the spatial heterogeneity of NDVI variance is suggested to reflect variety in land cover composition and consequent differences in response to climate change, and landscape features (Jia et al. 2006). Furthermore, ensuring that tree and shrub vegetation is accurately classified is of particular importance when considering reindeer herding. Herders discussed with us the changing shrub patterns on the tundra and potentially detrimental increased growth and presence of shrubs that they have noticed in recent years (Fifth Brigade pers. comm.).

While NDVI is useful, it has limitations, however, in that it does not contain information on vegetation type functional differences, and separation of vegetation types is necessary if their response to changes such as climate or treeline shifts or other disturbance differs (Kittel et al. 2000, Rupp et al. 2000, Skre et al. 2002). Lichen for example has unique spectral properties for consideration (Rees et al. 2002). A final additional small note relates to seasonal timing: NDVI values are typically most pronounced in late July in the Arctic (B. Johansen pers. Comm.) but the Landsat data used here was from late June and may, therefore, not be ideal. However, no other Landsat data were available for a more suitable period, classification of trees and shrubs was required on this level eliminating the possibility for this purpose of using MODIS data for example, and results seemed to represent the leafy vegetation as expected.

4.4.3 Accuracy

As established earlier, a typical test of accuracy using additional field data was not possible. In cases where such tests are not possible, studies have often relied on aerial photographs instead (Virtanen et al. 2004), but due to lack of availability and logistic and monetary constraints in producing any, this was also not an option. Consequently other methods were necessarily employed: JM distances, contingency matrices and multi-classification comparison. The variety of approaches used in gathering assurance of classification success and the agreement among the resulting classifications provided adequate support. Should later fieldwork in the region be possible, collection of data for typical accuracy assessment would, however, be highly valuable. Future work could further develop the coverage into a more sophisticated classification but for the purposes of this research, it is satisfactory.

4.5 Improvements and Additional Techniques

Various improvements and at a number of stages of the classification process could still be made to this classification. Additional ground truthing and training data would be useful, particularly for vegetation classes which had more limited ground truthing data or fewer and/or smaller training areas such as herb slopes, tall mires, etc. With additional time this could have been remedied, however, vegetation types that are rare will always prove difficult. Additional, more refined georeferencing could help, as could more refined classification techniques; this is likely to happen with increasing ease in the future. Finally, the addition of extra field data for use only in the accuracy assessment would have been of great benefit to understanding the limitations of the classification. However, this simply was not possible due to logistical, time and financial constraints of this project. The possibility exists for additional data collection in the future should more research be done in the region by scientists at SPRI and an accuracy assessment could be done at a later date if the vegetation classification proves highly useful. Finally, as demonstrated briefly with the recently available free online (Google Earth) Quickbird data, further analysis of correspondence between both field data and image classifications is possible with greater research scope. Such efforts are likely to become increasingly easy in addition as more and more image data become readily available.

The final classification is not without a few remaining small problems that given greater research scope, could be corrected. For example, the misclassification of tidal pixels as dry lichen heath, possibly due to a spectral similarity between coastal sand and lichen. A classification with substantially more classes (*i.e.* approximately 60) could be developed to see if some separation would result and these areas could then be classified separately.

For improved separation of rich herb (*e.g.,* grassland and herb slopes*)* and sedge vegetation and general confirmation of mire/wetland vegetation classification two techniques could be employed: 1) radar data, used in previous studies to separate wetland types (*e.g.*, van der Sanden & Ross 2001, Taft et al. 2003, Li & Chen 2005) could be utilized, and 2) a terrain map that divides classes according to elevation zones could be developed as has been done in Finnmark (B. Johansen pers. comm.). However, elevation differences in this region, while influential on a micro-topographic scale, are more limited on a regional scale and results may be less informative then in a more rugged area. For assessment and monitoring of wet conditions, particularly snow and ice, SAR data could be used, an especially interesting application potentially in this region with its coastal influences and large river systems.

The northern coastal influenced area could be refined with addition of other images from different times of the year, *e.g.,* late spring when the sea is at its highest, etc. More images would be of value in clarifying certain confusions and in ensuring reliability of currently accepted information.

A mention should be made about the potential for change in vegetation over time, due to climate, due to influential seasonal effects or due to reindeer grazing and associated effects, as has been documented in a nearby area (Rees et al. 2003). Shrubs are increasing according to herders though no explicit studies have documented it in this region (although now greater potential exists with the establishment of a baseline classification). Reindeer grazing is continuing although according to L. Taleeva (pers. comm.), numbers are decreasing. What are the overall effects of these shifts and changes and are they significant enough to alter image data? The Landsat 7 ETM+ satellite sensor imagery used in the classification development is from 2000 and field data are from 2003 and 2004. Vegetation changes may have occurred since then so there is a chance that the classification may be slightly inaccurate due to being out of date. Additional inaccuracy could result additionally if changes occurred between the image acquisition date and the application of field data to the image. However, four or six years is not long in the time scale of change and this is more likely to become a serious problem over a decade and more. To examine potential change, if Landsat data are not regularly available for new classification development, other data and techniques can be employed. For example, with Landsat data as a baseline, MODIS data could be used, providing frequent data for monitoring purposes with its 2 pass/day pass are. There is a potential issue with the less detailed spatial resolution of MODIS but derivation of NDVI and assessment of shifts should still be evident on a useful level in conjunction with the more detailed Landsat data.

Many of these improvements necessarily coarsen the level of analysis. This would be fine for certain purposes such as climate change effect examination but of more limited use potentially for reindeer habitat assessment (as will become clearer in Chapter 5).

Overall, multi-temporal data, both intra- and inter-annually, would be of great benefit. Within a year significant changes in vegetation occur (*e.g.*, in moisture, richness, senescence) from late spring to summer and through to early fall. These changes could be assessed and more precise vegetation classification could be developed as a result, by using multi-temporal post-classification change detection methods that take advantage of different reflectance values of vegetation through the growing season, for example. In addition, multi-year data would allow monitoring to be conducted. These advancements are, however, dependent on data availability.

4.6 Expansion of Coverage

For future application and study, expansion of the area covered and classified would be of certain benefit. Of note is the twenty-one-class Landsat based mapping effort by Virtanen et al. (2004) in the Usa Basin in the Komi and eastern Nenets region. It nearly neighbours this project study area and might be of relevance, limiting additional work, should the possibility for expansion of a Landsat-based regional coverage exist.

4.7 Applications

While the primary purpose of this vegetation classification development is to examine the vegetation distribution and patterns in this highly heterogeneous region, and to develop a spatial vegetation assessment particularly as it is relevant to reindeer habitat and climate change, a detailed vegetation map has significant additional potential in ecological, habitat, population and conservation studies, geological surveys and assessments, and natural resource exploitation, for example. First, no other similar, recent, detailed data like it exist for the region and given the previous lack of data, potential for further study is great. The data are made available for public, government, industry and private use, the benefit, therefore, going far beyond applicability to this research project alone. Data can be accessed by managers in the Vyucheiskii Kolkhoz and greater NAO region who have influence over the management of the region and its resources; the map and associated information can be shared with reindeer herders so that they can benefit from the new information provided if it is of help to them in their herding practices and patterns of land use and migration, particularly as they face changes ahead, natural and socio-economic potentially; and data can be given to other researchers working in the region so that research efforts are not duplicated. The developed vegetation classification could be used as a base for monitoring climate impacts should the classification data be updated, either at one or more distinct times or over a period of intervals. The same or similar methodology could be applied and modified as new (possibly better) spatial data become available. Satellite mapping is already used in studies to monitor change (*e.g.*, in Finnmark by Johansen & Karlsen (2005)) and so further application of these results should be possible.

5. CONCLUSION

The final twenty-six-class Landsat 7 ETM+ satellite sensor based vegetation classification developed for the Vyucheiskii Kolkhoz region provides valuable new spatial data that can assist in developing an understanding of reindeer habitat and potential effects of climate change in the region. Satellite based image classification, in combination with other terrain and ecological data and knowledge, is shown to produce suitable and detailed vegetation maps for a highly varied, heterogeneous region particularly affected by surrounding macro- and micro-scale landscape characteristics and influences. While typical accuracy tests using a portion of the field data could not be included here, confidence in the results is achieved through repeated and similar alternative classifications, and through the not unexpected results given field experience and vegetation knowledge. Minor classification problems do exist and the map is not without its imperfections. However, on the whole the level of detail is good and substantial new information is provided about the region's vegetation distribution, data fundamental to addressing the research questions in this thesis. Should there be scope for further development or highly detailed precise application of the classification, additional improvements would be beneficial. Substantial possibility exists for future development of this work: for refinement, expansion of areas covered and wide-ranging application. The development of a current, detailed map of vegetation distribution for a region that had no such data available is a valuable and significant contribution.

CHAPTER 5 - ASSESSMENT OF MULTI-SCALE VEGETATION AND LANDSCAPE DATA

> “Nature is ever at work building and pulling down, creating and destroying, keeping everything whirling and flowing, allowing no rest but in rhythmical motion, chasing everything in endless song out of one beautiful form into another.”
>
> John Muir, *Our National Parks*

1. INTRODUCTION AND RATIONALE

While the previous two chapters developed new vegetation data from botanical field analysis and satellite remote sensing techniques, including incorporation of ground data, this chapter synthesises these and other multi-scale vegetation data in a comparative assessment of applicability to landscape analysis, particularly pertaining to reindeer habitat and climate change, the underlying focus of this thesis. Methodologies and techniques, scale and coverage, and accuracy differ among landscape assessments. The question to be answered is what determines an optimal or suitable assessment for the needs at hand.

Three primary levels of scale are discussed: fine scale represented by the detailed botanical analysis from Chapter 3; a middle level represented by the localised vegetation mapping work from Chapter 4; and coarse scale approaches represented by 1) a vegetation model of the Barents Sea region and 2) existing global or circumpolar vegetation maps. The vegetation model was produced as part of the BALANCE project and will be described later in this chapter. Figure 5.1 presents a schematic diagram of the approach of this chapter.

As scale increases from fine to coarse (and detail generally decreases) information is lost. However, as coverage broadens, patterns and trends that were otherwise hidden by detail may emerge. The three levels of vegetation assessment each have distinct purposes and varied applications although there may be overlap. The botanical analysis provides the most detailed species level data possible, allowing species and detailed community assessment. The regional mapping allows detailed community data to be transferred to a spatial presentation of distribution and landscape patterns. The global and large regional coverages allow generalised national and global trends to be seen. Each level requires different data inputs, whether field- or satellite-based or a combination, and varied methodology and techniques of production. None is universally applicable given specific needs of ecological assessments and the inability of spatial assessments to easily translate between explicit detail and extensive coverage.

As explained previously in this thesis, there is a need for greater understanding of the Arctic environment and its components, such as reindeer, in particular due to potential climate change implications. Therefore, development of relevant data that can aid in this process is of significant value, and determining what defines relevant data, relative to the issues at hand, is a first necessary step. Factors to consider are 1) requirements of scale, 2) requirements of coverage, 3) minimum and maximum levels of required detail, and 4) potential error and its effects in limiting the value of an assessment.

Reindeer have specific, detailed habitat needs - what scales of analysis can reflect and address this? In addition, in herding regions, pasture maps have been developed that divide the land into seasonal habitats thereby dictating seasonal movements and land use patterns by reindeer and herders. Pasture maps, at least in Russia, are typically dated and the basis on which they were derived may not be known. With the development of landscape vegetation data such as this thesis provides, an assessment of pasture composition can be made once an appropriate level of landscape vegetation assessment is determined.

Climate change is predicted globally and to be even more pronounced in Arctic regions, as outlined in Chapter 1. Changes in the tundra landscape and shifts in vegetation species and communities may occur or are occurring; how, where and what patterns emerge are interesting, and crucial, questions to be answered. A number of studies have sought or are seeking answers to these questions (*e.g.*, Sturm et al. 2002, Cornelissen et al. 2001, Rees et al. 2003; ACIA 2005). What details do different analysis levels elucidate and what assessments may provide, or obscure, the most critical information? Shifts may be quick or slow, small-scale or more expansive, obvious or obscure, but change needs to be detected regardless, and how is this best achieved?

The provision of various multi-scale vegetation and landscape data, each with purpose and application, is particularly valuable for a region for which previously only sparse, non-regional-specific, generalised and outdated data existed.

Understanding dynamics and details of our complex natural environment is valuable. Understanding effects of perturbations and shifts is even more so as we begin to comprehend the potential for and extent of global change.

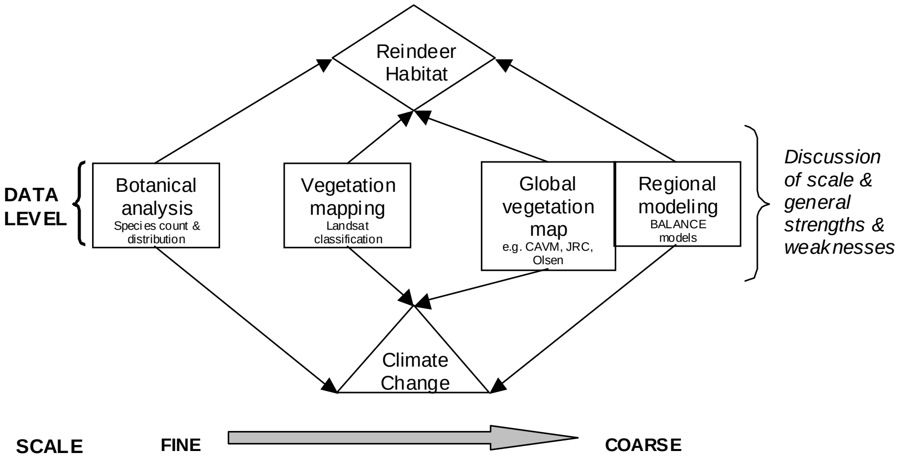


Figure 5.1. Schematic diagram showing assessment plan for the three vegetation analysis levels.

2. OBJECTIVES

The overall objective of this section of the study is to examine the three primary different landscape assessment levels, each developed on a different scale ranging from fine (small area of detailed assessment) to very coarse (large region of coarse assessment), and the information and insight provided by each. In particular they will be assessed according to 1) relevance of scale, 2) extent and flexibility of coverage, 3) inherent detail, and 4) problems of error, both in general and with specific regard to climate change and reindeer. Benefits and drawbacks of the different techniques, methodologies, and applications will be discussed. The potential for increasing coverage or for increasing detail will be assessed.

A first sub-objective is to specifically determine the applicability and relevance of the various scales to reindeer pasture and habitat, and to determine where the thresholds lie for landscape detail and scale definition in the determination of meaningful habitat assessment. The relationship between seasonal pastures and vegetation will also be examined.

A second sub-objective is to examine the extent to which each assessment or methodology can contribute useful knowledge considering potential climate change and resulting ecological effects on the study environment.

A consideration pertinent but not limited to climate change assessment is the scope for monitoring and repeated, updated data development or analysis. The feasibility of repetition or augmentation of the work or approach will be assessed. Map purposes and technical limitations will be clarified.

The overall question to be answered is what is the most appropriate scale of analysis for the given purpose (*i.e.* reindeer habitat assessment or observation of climate change effects) and at what points or under what circumstances do transitions between utility or applicability occur?

3. METHODOLOGY DESCRIPTIONS

3.1 Botanical Analyses

The detailed botanical observations, data collection and analyses are detailed in Chapter 3. In summary, data collection was site-based and at an individual species level to obtain community species composition details and quantifiable statistical results of distribution and composition. A total of 75 sites were analysed within the study area of the Fifth Brigade of the Vyucheiskii Kolkhoz using point hit and percent cover techniques. All distinguishable vegetation communities were visited with repetition of each community type to provide valid data for analysis. Data were statistically analysed with Chi square and PCA tests. All species observed in the field and their typical habitats were noted.

3.1.1 Resolution, Coverage and Scale

Spatial resolution at this scale was effectively that of an individual plant, 166 different species of which were observed in the entire region, and about 100 of which were identified within transects at study sites. Coverage was extremely limited, given the explicit detail in analysis. At each of the 75 analysis sites, species were identified within the point frame, area 0.36 m^2, at 12 sites in total. The area of coverage therefore is 324 m^2, less than 2/3 of a single 30m x 30m Landsat (ETM+ sensor) pixel. Effort to cover this area alone was spread over two summers of intense fieldwork and required significant additional post-field processing.

3.2 Detailed Vegetation Mapping

Details of the vegetation mapping component of this research are presented in Chapter 4 and the methods explained. To recount, Landsat sensor satellite imagery was the most suitable data for mapping the region of the Vyucheiskii Kolkhoz at the desired level of detail (less than 100 m resolution). Various classifications were developed and other techniques utilised for comparison and refinement. Data from approximately 340 ground truthing sites enabled a supervised classification.

3.2.1 Resolution, Coverage and Scale

The final supervised classification incorporated these ground truthing data and contained 26 vegetation or landcover classes at a 30 m pixel resolution. The vegetation map covered the Vyucheiskii Kolkhoz plus additional territory to the south and east as well as the marine environment to the north (Figures 2.3 - 2.5 and below). One Landsat ETM+ scene is 170 km by 183 km, or 31 110 km^2.

3.3 Global and Regional Coverages

3.3.1 Global Vegetation Maps

A variety of available maps are included in this analysis but methodology for each will not be detailed; the appropriate sources can be consulted for additional detail not provided here. All of the maps are static: vegetation was mapped at a point in time and cannot be updated by changing parameters as in a model. Global coverages are primarily if not entirely based on satellite data and, as a consequence, are all relatively recent, having been made within the last ten to fifteen years. Prior to the advent of widely available satellite imagery, coverage of such a large area was more limited by time, method and consistency of technique. In the circumpolar region, its vast size, remoteness and the lack of data (given requirements for site visits in botanical or aerial photo data collection) prevented this possibility.

The oldest global coverage considered is the Olson classification from 1994, developed from the database of global land cover (GLC) characteristics (downloadable from http://edcsns17.cr.usgs.gov/glcc), using AVHRR 10-day composite data from April 1992 to March 1993 (Eidenshank & Faundeen 1994), Digital Elevation Models (DEMs) (Brown et al 1993), and the Olson ecosystem classification (Olson 1994a, 1994b). The Olson map is produced by the United States Geological Survey Earth Resources Observation System (USGS EROS) Data Center, the University of Nebraska Lincoln (UNL) and the Joint Research Council (JRC) of the European Commission, and is shown in Figure 5.2.

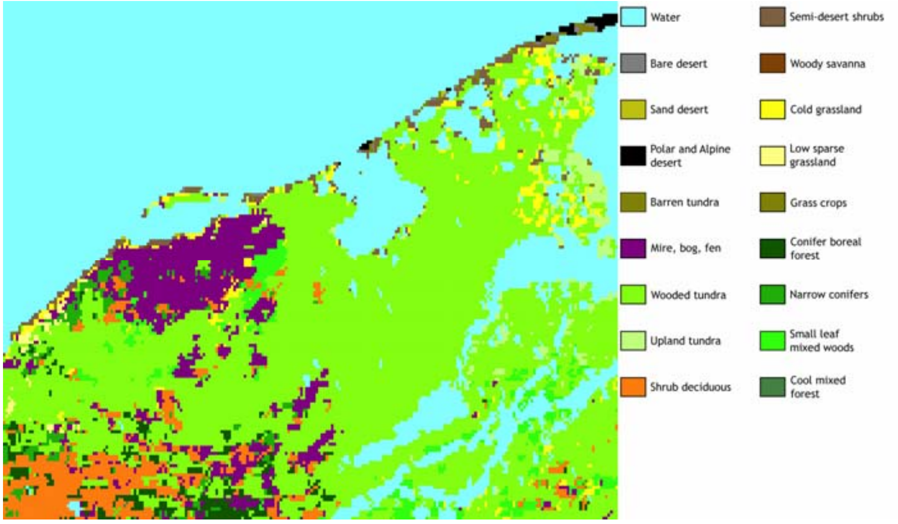


Figure 5.2. Section of the Olson global vegetation map within the Vyucheiskii Kolkhoz vegetation mapping area (excerpted by G. Rees).

The more recent JRC GLC2000, was developed by the JRC European Commission (2003). It relies on the 'VEGETATION' instrument on the SPOT-4 and SPOT-5 satellites and is shown in Figure 5.3.

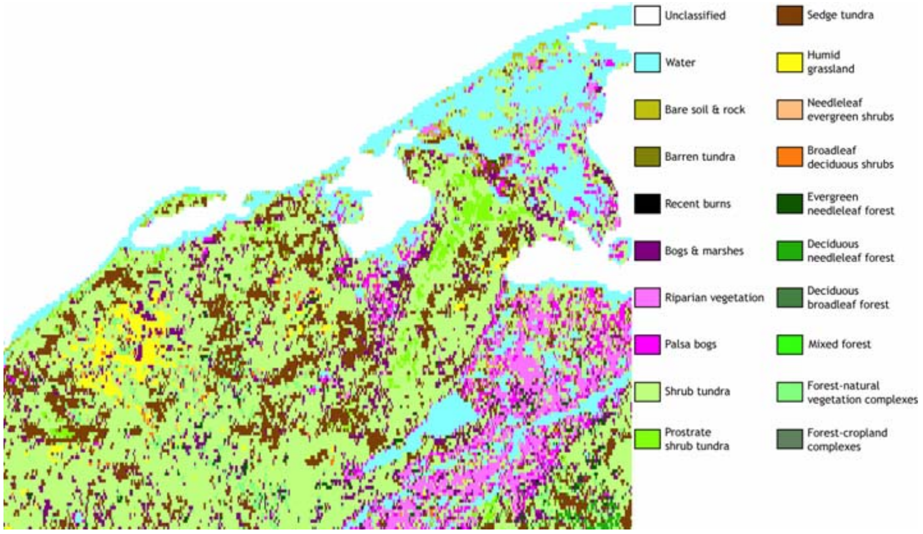


Figure 5.3. JRC global vegetation map, excerpt for the vegetation mapping region (excerpted by G. Rees).

The most recent map examined, from 2003 and based on specific circumpolar versus global coverage, is the Circumpolar Arctic Vegetation Map (CAVM) (Walker et al 2002, CAVM Team 2003) which is also developed from AVHRR imagery in combination with other ancillary field data in localised regions (Figure 5.4).

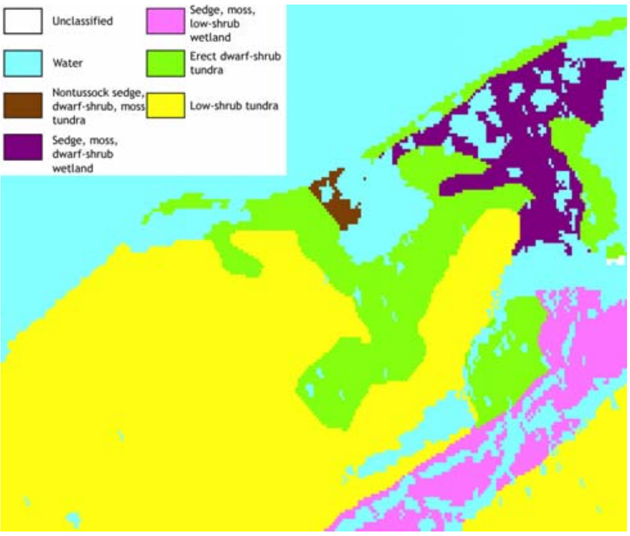


Figure 5.4. The coarser resolution CAVM in its coverage of the Vyucheiskii Kolkhoz region (excerpted by G. Rees).

In terms of vegetation class detail within the region of the Landsat vegetation map, the Olson and JRC have the most with sixteen classes each while CAVM has five. All maps as displayed here were re-projected to the plate carrée projection (Bugayevskiy & Snyder 1995) (by G. Rees) to be compatible with the BALANCE produced vegetation model shown next. Resolution of the Olson and JRC maps is similar, 925 m by 350 m and 1000 m by 380 m respectively. The CAVM was coarser with an approximate 5000 m resolution.

3.3.1.1 Resolution, Coverage and Scale

For comparison with the botanical analysis and detailed vegetation mapping, the CAVM has 5 vegetation classes (versus 100 species and 26 classes) with a resolution of approximately 5 km (versus 1 plant and 30m). Coverage is circum-Arctic, approximately 500 km from north to south, and, centred around 70 N, approximately 14 000 km in circumference. Areas of coverage of the other global maps within the same defined Arctic region are obviously the same although their resolutions are finer, as mentioned above.

The broad Arctic coverage of the global and circumpolar maps includes the equivalent of approximately 200 (3x75) Landsat scenes. In comparison, the botanical analysis covers less than one Landsat pixel and there are approximately 35 000 000 pixels in one Landsat scene. Therefore, the botanical analysis data cover approximately less than 1 billionth of the area of the circumpolar region.

3.3.2 BALANCE Vegetation Modelling

As part of the BALANCE Project work, Annett Wolf (Royal Swedish Academy of Sciences, Abisko Scientific Research Station) developed a Dynamic Global Vegetation Model (DGVM) that works in conjunction with transient climate data (modelled by the Max-Planck-Institute of Meteorology team) and other variables such as hydrological or soil nutrient data. It has outputs of leaf area index (LAI), net primary productivity (NPP), plant functional types (PFTs), biomass, and vegetation cover, the latter data presented here (Wolf & Callaghan submitted, A. Wolf pers. comm.). Additional details can be found on the BALANCE Project site or specifically http://balance1.uni-muenster.de/balance_data/stakeholder/stakeholder_index.html. Models were developed for current (1990) and future (2020,2050,2080) scenarios. The key difference between the maps described previously and this model is the model's predictive abilities, required for assessment of potential climate change effects. Given current data and time processing restraints and the large study region, the models had to be very generalized (*i.e.* coarse resolution), both spatially and categorically (vegetation types). The models have a resolution of half a degree (or about 55 km), are on the typical BALANCE oblique plate carrée projection (Bugayevskiy & Snyder 1995) and cover the entire BALANCE Barents region (Figure 2.1).

The following Plant Functional Types (PFTs) (vegetation cover) were included and biomasses for each provided (as kg carbon per square metre, above and below ground):

- BNE- Boreal Needle-leaved Evergreen Trees
    - *e.g.,* Norway Spruce, *Picea abies;* Scots Pine, *Pinus sylvestris*
- TBS- Shade-Tolerant Broadleaved Deciduous Trees
    - *e.g.,* Beech, *Fagus silvatica*; Small-leaved lime, *Tilia cordata*; Wych Elm, *Ulmus glabra*; Ash, *Fraxinus excelsior*
- IBS- Shade-Intolerant Broadleaved Deciduous Trees
    - *e.g.,* Downy birch, *Betula pubescens;* Alder, *Alnus glutinosa*; Grey alder, *A. incana*; Aspen, *Populus tremula*; Oak, *Quercus* spp.; Rowan, *Sorbus aucuparia*; Bay willow, *Salix pentandra*; Sallow, *S. caprea*
- S5W- Evergreen Shrubs up to 5m Tall
    - *e.g.,* Juniper, *Juniperus communis*; *Pinus pumila*.
- S5S- Deciduous Shrubs up to 5 m Tall
    - *e.g.,* Alder, Birch, Willow, Alder buckthorn, *Frangula alnus*
- S1W- Evergreen Shrubs up to 1 m Tall
    - *e.g.,* Cowberry, *Vaccinium vitis-idaea*; Marsh andromeda, *Andromeda polifolia*; *Cassiope*; *Ledum palustre*; Crowberry, *Empetrum nigrum*
- S1S- Deciduous Shrubs up to 1 m Tall
    - *e.g.,* Bilberry, *Vaccinium myrtillus*; Bog whortleberry, *V. uliginosum*; Large-stipuled willow, *Salix hastate*; Mountain willow, *S. arbuscula*; *Salix* spp.
- GRS- Temperate and Boreal Grassland
- GFT- Graminoid and Forb Tundra
    - *e.g., Artemisia, Kobresia*, Brassicaceae, Asteraceae, Caryophyllaceae, Gramineae, mosses
- CLM- Cushion Forb, Lichen, Moss Tundra
    - *e.g.,* Saxifragaceae, Caryophyllaceae, *Papaver*, *Draba*, lichens, mosses
- PDS- Prostrate Dwarf Shrubs
    - *e.g.,* Alpine bearberry, *Arctostaphylos alpinus*; Bearberry, *A. uva-ursi*]; Cranberry, *Vaccinium oxycoccus*; *Salix arctica*; *S. reticulata; S. herbaceae; Dryas*

The research group at SPRI worked with Dr. Wolf in trying to maximise the number of PFTs included (expanding them from the original four) and to include shrubs and lichen within the groups. While lichen is mentioned in the CLM PFT, in reality lichen is not represented properly as the CLM type does not appear in our study area where, by experience, we know it should. Shrub types are included and differentiated; however, problems exist within these classes in the modelled future scenarios (as discussed later).

The following description is summarised from information provided by A Wolf (pers. comm.) and a description in the BALANCE Newsletter No. 3, October 2004 (http://balance1.uni-muenster.de/balance_data/publication/data/BALANCE_NEWS_No_3_October_2004.pdf). The vegetation model is process-based and allows changes even outside the climate conditions initially used for parameterisation and testing. Daily photosynthetic carbon uptake and respiratory carbon loss are considered, and remaining carbon is used for reproduction or individual growth. For each grid cell a number of replicated patches (1000 square metres) of vegetation are simulated. Eleven plant functional types (PFTs) (as shown earlier) are represented in the model. Parameters are given for each PFT in determining establishment: phenology, carbon allocation, allometry, mortality, scaling of photosynthesis and respiration rates and the limits of the climate space a PFT can occupy. Precipitation, air temperature, soil type and percentage of sunshine (as monthly or daily values) are the model inputs. The range and detail of the model is restricted by model processing time and the inputted climate data. The model while developed for use at the BALANCE Barents Region scale (Figure 5.5) can be applied to local scales or even a point scale.

The key difference, therefore, between the BALANCE map of vegetation and the other global maps is in the modeling aspect that gives the former valuable predictive and dynamic abilities. The output is, however, necessarily more generalised both spatially and categorically (PFTs) given project and current computer processing constraints.

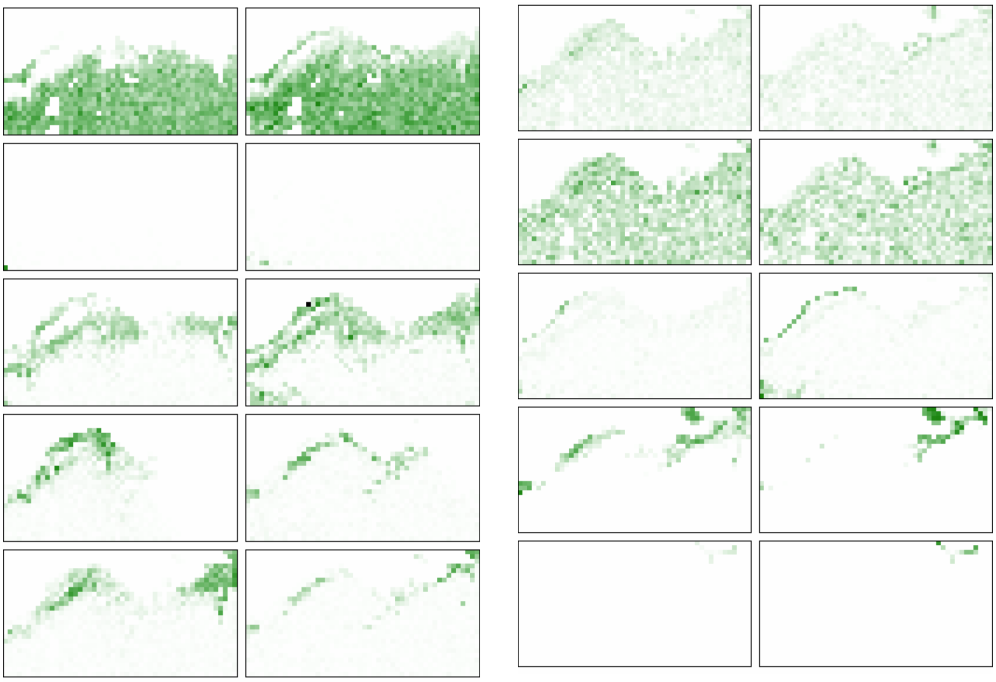
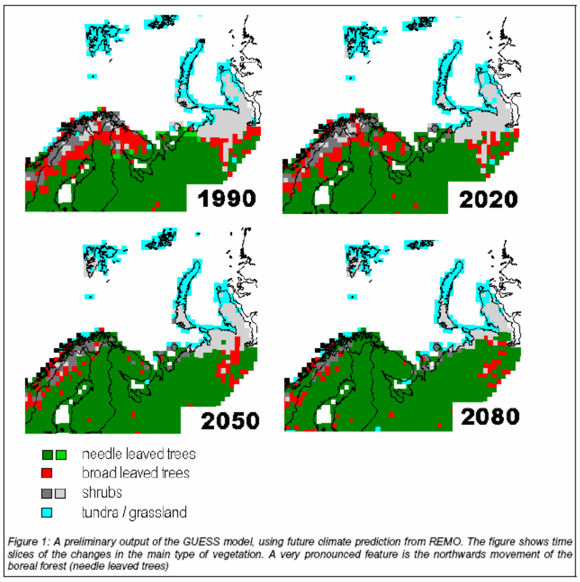


Figure 5.5. BALANCE vegetation model results for current (1990) (l.h.s.) and future (2080) (r.h.s.) scenarios. From top to bottom (left column): BNE, TBS, IBS, S5W, S5S; (right column): S1W, S1S, GRS, GFT, PDS. Darker greens correspond to greater biomasses. Scaling for 1990 and 2080 is the same but different between PFTs. CLM is not presented because the biomass is zero within the extract area shown here.



To gain a clearer picture of the general BALANCE model of predicted vegetation shifts, Figure 5.6 is included, showing the coarser four PFT model version. A northern and eastern shift in shrubs is evident, and a general advancement of needle leaved trees and an almost universal decrease (except in the far east) in broad leaf trees.

Figure 5.6. BALANCE vegetation model results for current and future scenarios. (Images extracted from the BALANCE Newsletter No. 3, October 2004 (http://balance1.uni-muenster.de/balance_data/publication/data/BALANCE_NEWS_No_3_October_2004.pdf).

3.3.2.1 Resolution, Coverage and Scale

Summary of the resolution and coverage details of the BALANCE model are as follows: 11 classes, one half degree or 55 km resolution, and area of coverage of 3 025 000 km^2, about 1000 55-km grid cells (BALANCE Region grid approximately 50 wide x 20 cells high).

4. INDIVIDUAL LEVEL ASSESSMENT

Each of the three vegetation data levels or types is discussed below in terms of their general strengths and weaknesses in methodology and application. In particular, value is considered as it pertains to one-off assessments and long-term or continuous monitoring. Relevance to reindeer and climate change are additional primary foci for discussion.

4.1 Botanical Analyses

The most detailed vegetation assessment, botanical analysis, identified plants at an individual species level and at recorded sites of known GPS location. The dataset is available and tables linking all of the data, including photographs of each site (sometimes supplemented by close-ups), can be provided.

4.1.1 Methodology Assessment

Two major methodological advantages of this analysis are 1) the high level of detail it provides and 2) the fact that sites can theoretically be revisited in time and new species-specific, detailed data collected, following the same protocol. Comparisons of species presence or absence, overall counts or percent cover and distribution among the sites would be simple, and changes and trends could be observed at the most detailed level possible. Similar statistical analyses as were carried out in Chapter 3 could be undertaken for more complex quantification of changes. The establishment of a monitoring programme is also possible with planned re-visits.

Disadvantages, however, exist in terms of 1) feasibility, 2) costs, 3) time commitment and 4) coverage. This most detailed assessment requires guaranteed future access for visits, intensive labour (including field assistance), existing botanical knowledge, significant time in the field, and substantial effort in simple data preparation. These factors amount to substantial time and monetary expense and reduce monitoring viability except in highly organised, well funded situations. Furthermore, the spatial area covered by such high intensity data collection is critically small; in this case less than one Landsat pixel. Coverage of a large (or even local regional) area, an increasingly common approach in Arctic ecological studies, would simply be impossible. Evidently, there are clear tradeoffs between the highest level of detail and feasibility and ease of repetition.

The question exists also of frequency of re-assessment: how much time is necessary for significant (quantifiable) changes to be seen at this detailed level? An answer would provide evidence of feasibility: the less frequent the field studies, the lower the cost and the higher the chance of project support or success. Such a question is perhaps being answered with BioBasis at Zackenberg (http://www2.dmu.dk/1_Viden/2_Miljoe-tilstand/3_natur/biobasis/index.asp), a long-term, detailed monitoring project in Northeast Greenland with a re-sampling frequency of five years. The project is only in its 11th year (with plans to extend to 2045 and beyond). It has been hypothesised that changes would not be seen in a monitoring cycle of less than five years and even ten years may not be enough.

Depending on potential rates of ecological change, this may of course shift in time. Over the course of the BALANCE Project timescale (present until 2080), changes should certainly be evident. An additional consideration becomes relevant over such a lengthy timeframe: the chance of sampling variation may increase or overall project priority or viability may decrease if personnel are not consistent. This issue is likely to come up in other monitoring studies in the not too distant future where individual human scientific research span is incompatible with the times needed for adequate monitoring, *e.g.,* LTER, Alaska (http://www.lternet.edu/, Chapin et al. 2006).

Additional considerations are the extent to which repetition of data collection methodology should be ‘exact’ and the robustness of the protocols. Some variation in species composition and distribution within a vegetation site and in the complete lists of species identified in a season can be expected regardless of the passing of time. However, key species will be present in sufficient quantity to show trends in the data analysis, and overall distribution of species or plant groups within a vegetation site/type should remain statistically equivalent under unchanging conditions. While methodology used in this project for botanical analysis is rigid enough and described in sufficient detail to allow repetition, established monitoring programmes ensure more precise possibilities of re-assessment, again for example, Bio-Basis at Zackenberg, Northeast Greenland (Bay 1998, http://www2.dmu.dk/1_Viden/2_Miljoe-tilstand/3_natur/biobasis/index.asp). As stated in Chapter 3, the botanical analysis methodology used in this study was simplified, based on methods used in the Zackenberg area of Greenland. Protocol for the Zackenberg-based Bio-Basis requires a point frame with spirit levels on it and a double layer of intersecting strings on the frame; the frame to be ‘planted’ in the ground at established (by a permanent peg) sites; the height of each corner of the stable frame measured; the height of each point hit species measured; and biomass data collected (at sites off the transects). These strict rules ensure the most reliable, accurate reassessment of a site possible. While these methods are superior to the simplified version used in this study, replicating them is not possible given time, monetary, and personnel restrictions nor feasible in the absence of established future visits or monitoring plans.

In summary, while scope clearly exists for repetition and even monitoring at this most detailed analysis level, consideration must be given to potentially substantial costs, intensive effort required and uncertain appropriate time intervals of re-assessment. Clear establishment of a detailed programme is a pre-requisite. Even with such possibilities, this finest-scale analysis is still highly limited spatially.

4.1.2 Applicability to Reindeer

The reindeer diet follows seasonal trends in terms of vegetation preferred as forage (species based) and vegetation types selected for grazing areas (spatially based). The community description and composition assessment provided at this most detailed level allow examination of both of these diet perspectives. Areas containing appropriate forage species or suitable for grazing habitat could be readily identified based on the data analyses. If considering potential climate or other change, shifts in these characteristics and patterns as they relate to reindeer should be discernable. Thus, the botanical assessment has particular value in marrying the reindeer and climate change perspectives, providing satisfactory data for each alone and also in combination.

Disadvantages include the possibility of too much detail: non-essential data can obscure clarity of results or ease of overall assessment. As was discovered when talking to the reindeer herders, they rarely identify plants to an exact species (or other unique) name and talk about preferred reindeer forage plants in a more general sense (as mentioned in Chapter 3, Section 3.3). Even critical species such as lichen are not generally singled out to the species level although some, such as *Cetraria islandica,* may be. However, the availability of data, to the most detailed level possible, ensures that analysis potential is not constrained and that future assessment can be as specific as desired and there will be no limitations. Assessments can be generalised as needed although the labour intensive data collection and analysis aspects remain.

4.1.3 Applicability to Climate Change

This in-depth level of analysis allows vegetation change to be examined and registered (assuming the repetition of field protocol) on a level far more specific than any detailed spatial (mapping) regional analysis. Changes in individual species can only be observed here, at least given current satellite sensor technology and viability. Species-specific changes would be most relevant for indicator species known to colonise in cases of community shifts or believed to be associated with vegetation shifts due to a changing climate (*e.g.,* grasses, shrubs), in assessing species declines (*e.g.,* lichens), or other species already on the margin of their existence. Rare species or those of conservation importance would hold particular interest. A particular benefit of this botanical analysis is its flexibility: it provides a spectrum of data, informing about overall community level trends as well as the most detailed individual species identification. Furthermore, the supplied location (GPS) data would allow analysis on gradients from south to north, for example, were enough similar comparable sites assessed.

A serious disadvantage in climate change assessment of the fine-scale botanical analysis approach is its lack of spatial perspective and coverage due to the focus on detail. The ability to see at a glance spatial trends and shifts is of certain advantage in understanding climate changes. A related disadvantage is the difficulty of presenting so much data in a way that can at once be understood and trends perceived: the bigger picture can be lost. Overall though, given the unique species detail, this level has application in discerning specific species or detailed community effects of climate change where detail is desired or necessary. As potential global and climate change become better understood, it is possible that the provision of detail may become even more useful.

4.2 Detailed Vegetation Mapping

The Landsat-based vegetation map provided an intermediate level of landscape assessment, covering the Vyucheiskii Kolkhoz and approximately 30 000 km^2 (including water bodies)- significantly greater than the botanical analysis area but still substantially smaller than the multi-national BALANCE region model. The twenty-six vegetation communities in the supervised classification discussed here are distinguished by species composition and sometimes secondarily by aspects of growth structure or form (*e.g.,* firstly hummocks or tussucks; dwarf shrub).

4.2.1 Methodology Assessment

Key advantages of detailed satellite vegetation mapping are 1) the ease in creating initial and therefore updated maps (or expanded coverage), 2) the consequent ability to monitor change, and 3) flexibility in method. This flexibility in method allows valuable freedom and multiple needs to be met, from quickly producible, free of field data unsupervised, to more time-consuming labour-intensive supervised classifications. Overall, repetition of map classification according to defined methodology and protocol should not present a significant problem, providing that data are available. In a potential monitoring situation, a shift in personnel is unlikely to introduce variability, as long as the methodological protocol is clear. Thus comparison over time is possible and without likely complication (changing satellite data sources excepted). A clear advantage of this level of assessment, since it lies between the greatest detail and the greatest coverage, is that relatively detailed coverage can be expanded, in contrast to coarser one-kilometre resolution satellites for example. If map classification is kept simple *i.e.* unsupervised or with limited supervision, and providing other scenes are available, an extensive region could be covered without significant cost or effort. With additional effort and requisite field data, substantial detail can also be maintained, allowing a range of vegetation community divisions depending on scope.

Primary disadvantages of this scale of analysis are 1) potential data availability constraints, 2) cost of data, and 3) the necessary loss of some level of detail. Data availability may be the biggest obstacle to successful monitoring or additional map development: suitable (*i.e.* cloud-free, appropriate seasonal timing, etc.) scenes for the area in question must be available, and appropriate sensors must be in operation. If considering this project specifically, the Landsat sensor system, as discussed in Chapter 4, has been in continuous operation for over thirty years, since 1972. It faces an uncertain future, however, with Landsat 7's lifespan predicted to come to an already overdue end around 2008. For the first time, data may not be continuous even if a new sensor is deployed (http://erg.usgs.gov/isb/pubs/factsheets/fs02303.html). An obvious disadvantage of the unsupervised classifications is the greater uncertainty in the map output versus that of a supervised classification. However, the latter requires input of ground truthing data, adding time (for field work and data processing), expense and logistical complication. All of these factors lessen the ease of updating the data. While collection of ground control points is relatively straightforward and quick, few or no transport options (in the case of this study region), logistics and costs would be the limiting factors. Of notable benefit, however, is that current ground truthing data are linked to GPS locations: the same sites could be re-visited, allowing a more repetitive, controlled analysis of change. In addition, any changes in the vegetation would be immediately observable and more easily compared since a photo archive of ground truthing sites was created at the same time as data collection. Regardless of classification method, all data inputs can with relative ease (compared to detailed botanical analysis) be updated, thereby making change detection more viable on this vegetation community based level. Cost is a potential concern, particularly with increasing detail and detail in scale in satellite imagery. However, data are increasingly available for free, thereby limiting this problem.

In chapter 3, data are exact and results are based on known information: even generalisations are based on botanical divisions, and membership is exactly known. In a mapping analysis, vegetation community separation is into groups based on a range of spectral signatures, and resolution necessitates species and community blending and generalisation. This generalisation is an inherent quality of current satellite image classification technology in intermediate-scale, community-based analysis. It is acceptable if the map's accuracy can be tested and supported and required detail is not lost. The map developed in this study contains sufficient detail to understand vegetation on a complex community level and to probably be able to assess important changes. Therefore, from a spatial point of view, individual botanical species knowledge is not required and this level of detail would meet most research requirements.

4.2.2 Applicability to Reindeer

Perhaps the most immediate advantage of this level of analysis is the spatial overview that it allows: a glimpse shows simple vegetation community boundaries and patterns, and a closer look reveals vegetation community trends and relationships with topographical features and other landscape characteristics. This sort of information is essential in order to assess processes of ecology and change, for example climate, and is also of value for reindeer habitat or pasture understanding.

In regard to reindeer habitat, this intermediate level of assessment is particularly useful, not only because of the spatial dimension, but also its resolution. While reindeer may select for individual preferred species (*e.g.,* types of mushroom, willow shrub, or specific lichens), these species are found in larger community associations rather than scattered randomly throughout the tundra (as shown in statistical analyses in Chapter 3). If these associations are known, community level detail can suffice, especially with the thirty-metre resolution and broad number of communities (26) distinguished in this map development. Of note is the success with which lichens are distinguished. It is known that lichens have distinctive reflectance values (Käyhkö & Pellikka 1994, Théau & Duguay 2001, Nordberg & Allard 2002, Rees et al. 2004) and have been successfully distinguished previously, particularly by Landsat data (Nordberg & Allard 2002, Tømmervik et al. 2003, Stow et al. 2004, Théau & Duguay 2004, Tømmervik et al. 2004, Théau et al. 2005) but it is reassuring to repeat the success. Shrubs were also distinguishable, not only as a type of 'shrub tundra' but also as stands of shrub. As mentioned previously (Chapter 3), this is of benefit given both the positive forage and negative transport and movement qualities of shrub vegetation. Even the separation of the heaths provides valuable seasonal grazing information; *e.g.,* dry ericaceous heaths are useful in autumn for berries but of less value in other seasons, whereas dry lichen heaths are of greatest value in winter but not in other seasons. Similar, relevant distinctions can be made with the moist heath categories. Without these divisions, far less insight could be gained from the classification and it would become significantly less useful than the detailed botanical analysis.

Lending further support to this level of detail for applicability to reindeer, reindeer grazing lands in the kolkhoz are divided into six types of seasonal pasture, as shown in Figure 5.7, and the detail in the satellite map is more than sufficient to allow a sound quantitative assessment of pasture-vegetation relationships. This would be true in other pasture regions in addition: a thirty-metre resolution provides plenty of detail in comparison to pasture division resolutions as can be seen in the map below. It is not enough, however, to resolve only spatially (*i.e.* ensure a satisfactory number of Landsat units per seasonal pasture area), the level of spectral detail (*i.e.* vegetation type divisions) within the spatial units must be sufficient to resolve the pasture territories. Again, Landsat data are sufficient. Spectrally, other satellite data may be insufficient even though they are spatially adequate or they may be neither spatially nor spectrally sufficient (*e.g.*, AVHRR). More specific details in regard to scale will be discussed later in the chapter. Given the spectral and spatial suitability of this scale of analysis, an assessment was conducted with the pasture map of the region.

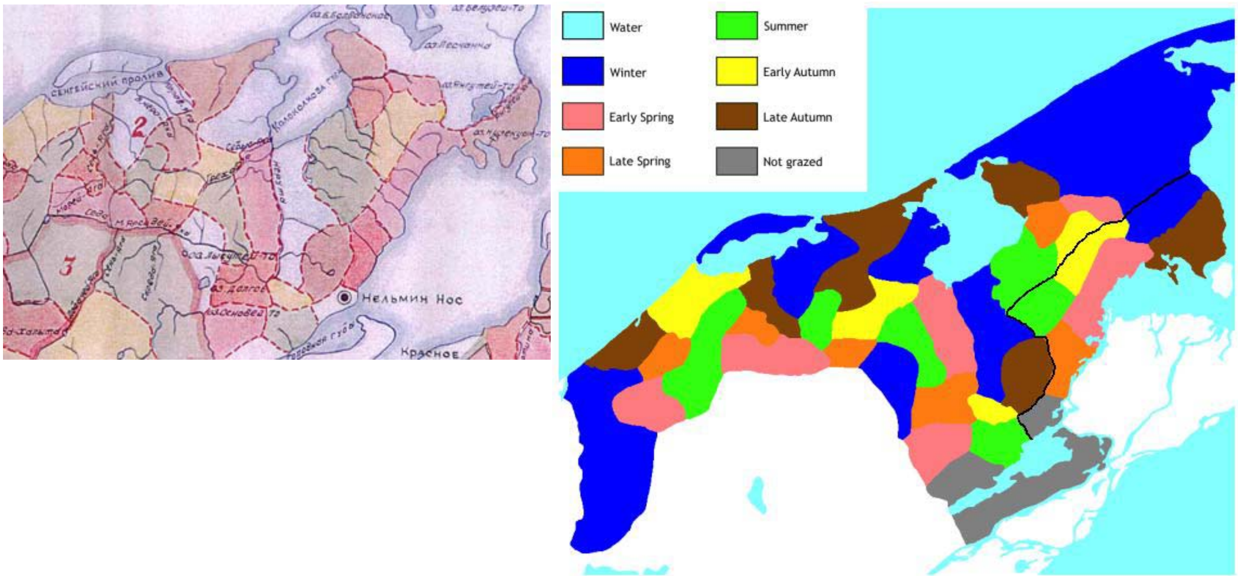


Figure 5.7. Vyucheiskii Kolkhoz reindeer administration pasture maps, showing the six season division, the original hand-drawn version on the left and the digitised, geo-referenced electronic version on the right (transformation by G. Rees) (black line on the digitised version signifies the Fifth Brigade territory boundary).

4.2.2.1 Pasture Map Analysis

The pasture map that exists for the Vyucheiskii Kolkhoz is typical of Russian pasture maps originating in Soviet times, with six different seasonal pasture types: summer, early autumn, late autumn, winter, early spring and late spring. Seasonal variation in use follows forage and diet shifts. The map shown here was developed (by digitising and geo-referencing other maps) into an electronic version (by G. Rees) from the original paper version that was without projection or graticule data. There was no citation although the map was probably developed in the 1970's or 1980's by the Vyucheiskii Kolkhoz's reindeer herding administration. Consequently, accuracy is not high: the error is estimated to be about two kilometres. Although the map was developed some time ago, the pasture divisions still hold, and the map is still generally followed by the Kolkhoz administration and the reindeer herding brigades. Small changes may occur or may have occurred but generally changes are to do with use of a type or an area within a type and not switching of seasonal pasture types assigned to a given area.

By overlaying the vegetation map data with these pasture divisions and analysing the statistical relations, it was possible to identify trends in vegetation community composition of seasonal pasture types. This is shown in the correspondence analysis in Figure 5.8 generated by G. Rees as part of our joint work but analysed explicitly here by the author in terms of detailed relevance to seasonal reindeer habitat and vegetation requirements and use. This figure looks at the correspondence of each of the vegetation types to each of the six seasonal pasture types, i.e. the closer a vegetation type is to a seasonal pasture type on the figure, the more related the two variables are or the greater the presence of this vegetation type is in this particular seasonal pasture type. It should be noted that classes as developed in the vegetation map in Chapter 4 have been condensed into eighteen classes in this analysis (as described in the figure legend).

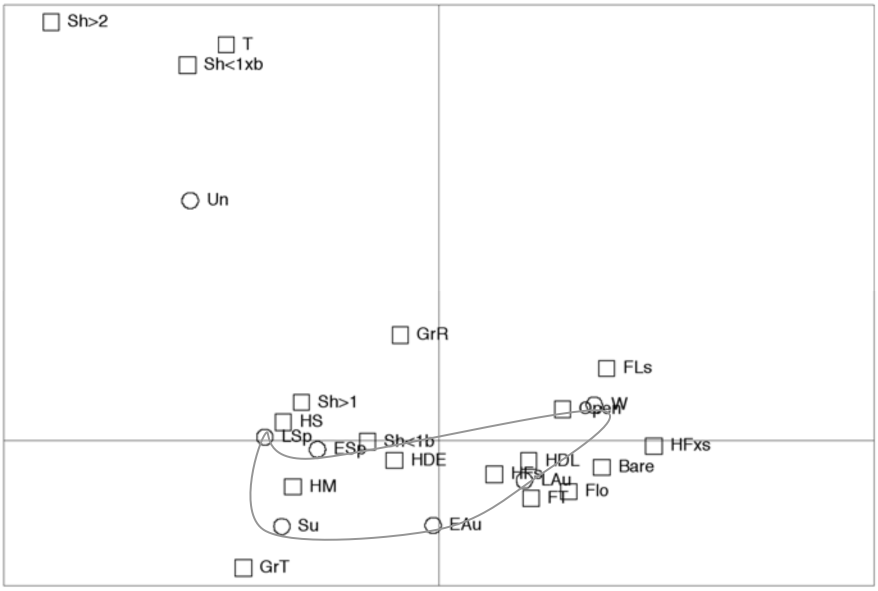


Figure 5.8. Correspondence analysis for seasonal pasture divisions and the Landsat ETM+ sensor satellite based vegetation map classes. ☐s represent vegetation classes and ○s the 6 seasonal pasture divisions (connected by the grey line). Explanation of all abbreviations is as follows: Bare- bare ground and unvegetated; HS- herb slope; GrT- Grassland, tundra; GrR- Grassland, riparian; FLs- Mire, low sphagnum bog; Flo- Mire, low other moss; FT- mire, tall; HFxs- Heath Mire, without shrubs; HFs- Heath Mire with shrubs; HDL- Dry lichen heath; HDE- Dry ericaceous heath; HM- Moist heaths; T- Trees; Sh>2- Tall shrubs; Sh>1- Medium shrubs; Sh<1xb- Low shrubs, *Salix* dominated; Sh<1b- Low shrubs, birch dominated; Open- Scrub.

The seasonal pasture divisions can be followed by time of year in a counter-clockwise roughly elliptical shape, shown in grey on the figure. From Winter in the 1st quadrant to Early spring and Late spring in the 2nd , and then to Summer in the 3rd with Early autumn on the border with the 4th and, finally, Late autumn in the 4th. The vegetation communities that follow this trend can be examined. In winter, pasture association is with open scrub and low sphagnum bogs, and also dry lichen heaths and mire-heaths without shrubs. These associations make sense on multiple fronts. First, based on time spent in winter pasture: shrub presence was more limited than in summer pasture and shrubs were generally lower and less dense; dry lichen heaths were common, as were mires, with the two types often in close association (and topography obviously varying on a micro-topographic level); bare sand patches were also quite typical. As an additional note, in winter (and autumn once the ground is frozen) mires do not present an obstacle to transport as in summer or spring. Second, based on known reindeer seasonal forage trends: lichen is typical in winter diet and is generally found in heath-mire complexes, on the elevated heath, and as a major component of lichen heath.

Early spring pasture is associated with low birch-dominated and willow-dominated shrub, dry ericaceous heath and moist heath. Field experience in this pasture type was not substantial enough to merit comment on vegetation communities observed. However, young shrubs are preferred as forage in spring and often shrubs are one of the first species to green up, typically being above the snow level earliest. Moist heath also provides young shrubs and other young plants for forage as does dry heath similarly. Late spring has similar associations but is more closely linked to low shrub vegetation than dry ericaceous heath.

Summer pasture has the strongest associations with moist heath and (tundra) grassland. Moist heath was certainly the dominant vegetation type in summer pastures visited during fieldwork, and grassland, while a far less common community, was only observed in summer habitat and not in winter or other regions seen en route to planned summer or winter pasture. In terms of grazing, grasses provide rich nutritional forage in summer once green-up has occurred throughout the tundra. Moist heaths support a variety of plant species including low *Salix* and *Betula* shrubs (which would still be young and preferred), graminoids in tussocky and mixed patches, and berries as summer progresses.

Early autumn has fewer immediate associations than the other seasonal pasture divisions but is associated with dry ericaceous heath, heath-mire complexes with shrubs and, perhaps somewhat surprisingly, tall mires. As with spring pastures, it is not possible to substantiate findings based on field visits. However, in autumn, reindeer forage is typically composed of berries (most common in dry ericaceous heath and in the heath components of heath-mire complexes) and remaining vegetation such as graminoids and shrubs that has not yet senesced (both present in heath-mire (with shrub) complexes. In addition reindeer actively seek mushrooms. Mushrooms are found in moist vegetation communities but not wet: mixed heath-mire complexes are ideal. The tall mires may provide an association but it could be due to the fact that in late autumn the ground is frozen and there is likely to be some snow cover so the reindeer can more easily navigate this community. It is also possible that tall mire vegetation would remain above any snow and therefore provide some forage at a difficult time of year. These two ideas are speculative, however.

Finally, late autumn pasture is associated with heath-mire complexes with shrubs and tall mires (as early autumn) and dry lichen heaths, and low moss mires. These communities were observed briefly en route to fieldwork in winter pasture. Based on limited observation, lichen heath and low moss mires were particularly noted. Depending on snow conditions in late winter, reindeer would eat any remaining berries and mushrooms (as found in the heath-mire complexes) and they would begin to feed on lichen (in the dry lichen heaths). Again, the presence of mires is unlikely to play an important role in forage but mires do present transport options impossible in summer months.

As seen from the examination above, the level of detail provided in this mapping component is particularly suited to specific habitat assessment: the community level provides some degree of knowledge about species and other details and also focuses on patterns and distribution at a slightly broader, more useful, level in terms of grazing and land use. Such data are particularly useful if land use pressures exist, as they do in some regions of the mapping area, and as oil and natural gas development increases. Suitable habitat can be assessed and changes detected should preservation become an issue.

A final consideration in assessing this mapping level in terms of suitability for reindeer habitat understanding is to examine how successful the mapping process was at separating out the specific vegetation communities considering their relevance to reindeer habitat (in a general versus statistical sense). Even with training data the mapping process was not without a few problems; arguably, these would be worse without the benefit of field data, however. Water and water-rich types map out clearly and are distinct and present no problem but are also not a consideration in grazing. Mires seem to be distinguishable in tundra regions and even differences in tall and low mires appear to have separated correctly. Since mires provide, if dry enough, good grazing in summer and spring, and suitable migration terrain near winter, this separation is valuable. Grassland division is more problematic. It is a less common community, meaning that fewer GCPs were included, giving less certainty to its classification. There appeared to be difficulty separating out herb slopes and grassland. However, these two communities are similar, both dominated by rich vegetation and graminoid species and so the reduced ability to distinguish between them is less of a concern than were they very different botanically. Both herb slopes and grassland can form important dietary components in spring and summer; to distinguish between them is not of great benefit at this level of pasture assessment. Specifically, riparian grassland is not mapped with as much confidence as the other communities, primarily due to the fact that data collection was from a moving boat and not within the communities as with the other field data. This community has little relevance to reindeer habitat, however. Mire heath complexes did not seem to present any classification problems, nor did moist heaths which clearly dominate the landscape; both are important in grazing. Dry heaths, including lichen heaths, appear to be represented particularly well, based on field observations and topographic assessment. This is of value when assessing applicability to reindeer habitat assessment as lichen and ericaceous heaths provide particularly valuable forage. Finally shrubs and trees, the former being of substantial habitat importance (both positively and negatively as explained previously in Chapter 3), also seemed to be adequately represented in the map, except in riparian areas there may be some error due to potential inaccuracies with riparian grassland affecting surrounding shrub/tree types. These areas are of less relevance to reindeer habitat though as they do not graze in the delta. It can be concluded that the vegetation map and its communities successfully provide relevant grazing and pasture information and that while problems exist, they are not generally of consequence when considering reindeer habitat.

4.2.3 Applicability to Climate Change

With regard to potential climate or other global change, shifts would be easy to identify if up-to-date satellite images could be obtained and new classifications produced, either unsupervised, or ideally, supervised. Again, the spatial component would allow certain changes to be immediately evident. Time scale plays a role: some changes may take longer than others or be less noticeable, while others may be quicker or more immediately obvious, as seems true with current shrub expansion (*e.g.,* Sturm et al. 2001, Fifth Brigade pers. comm.). It may be difficult to determine an appropriate time scale of reassessment overall; for example, shrub presence in the region seems to have changed significantly already (according to herders, Chapter 3, Section 3.3) while other changes may take substantially longer. However, the ease of classification repetition, assuming cost and data availability were not too limiting, means that reassessment can occur at any chosen time scale, and eventually a suitable pattern of repetition could be established.

Shrub changes should be particularly easy to observe since shrubs are one of the vegetation communities that was most successfully mapped (in conjunction with NDVI which can be applied again). Lichen change should likewise be examinable, since the current classification appears able to discern them. Other changes, such as grassification, may take longer or be more difficult to assess if the community is less common in the region or is more difficult to map with certainty.

The mapped coverage (versus ground based data) results in a certain loss of detail, a potential disadvantage with relevance to reindeer habitat (Burkhard et al. 2003). Species identifications are missing and community composition is necessarily generalised. However, with understanding of community structure comes awareness of typical species associations and, if community divisions are sufficiently detailed, as is the case with the vegetation map developed in this project, little data of relevance are lost. The level of detail in the map, while limited to a degree, seems certainly sufficient for change assessment.

Should vegetation communities be further generalised, species associations and the ability to detect specific changes would be lost, however, and the level of assessment would be less suitable.

4.3 Global and Regional Coverages

Comprising the first component of the broadest, third analysis level, are the global (or circumpolar) vegetation maps developed externally to this project but discussed and shown here for their contributions and as a comparison against the second component, the BALANCE vegetation models.

4.3.1 Global Vegetation Maps

4.3.1.1 General Assessment

Specific aspects of methodology will not be thoroughly detailed for the two global and one circumpolar map included in this multi-scale assessment; however, pertinent observations are noted.

Advantages to global coverages include 1) the extent of area covered, and 2) the ability to see and assess regional or national patterns and trends that would otherwise have remained hidden. Current global vegetation maps are heavily based on satellite data. Without recent satellite data availability and development and the ease of expanded coverage this technology allows, global coverages with the same spatial resolution or level of detail that now exist would not be possible. Data limitations, time and monetary constraints, and difficulty in transferability of different regional methods of mapping have prevented the advanced development of global maps in the past. Despite any problems therefore in global coverages, their existence is nonetheless valuable and, in time, technological advancements should allow further improvement in accuracy and level of detail.

Major weaknesses of these coverages are 1) the loss of detail with increased coverage, 2) the impossibility of thoroughly ground testing a map with such a large coverage area, and 3) the potential error and inaccuracy that result. Substantial loss of detail has occurred in the global coverages- no species associations exist and many community associations have also been lost. Collecting adequate field data to improve map accuracy is virtually impossible for the entire coverage region. Furthermore, of particular detriment to Arctic regions, is that typically, more populated, southern regions receive greater attention in global maps and consequently may be more accurately mapped. An advantage of the CAVM as compared to the Olson and JRC maps, therefore, is that it focuses solely on Arctic vegetation and thus is more limited in scope, potentially limiting confusion and increasing accuracy. CAVM masks out both forest and regions south of the Arctic, simplifying the potential range of vegetation included. Shrubs will be Arctic specific in CAVM, whereas in the global classifications, shrubs will include worldwide varieties, necessarily very different in growth form, size and species to Arctic-specific shrub species. The same holds for other vegetation species groups in the global classifications. The Olson map, for example, while containing about three times as many classes in the region of interest (the Landsat mapping area), is in fact less correct and contains substantial error, as explained below, while the CAVM is more accurate although lacks detail.

Supplementary data or other techniques can substitute for or serve in addition to field data to improve results: all three maps may benefit from this, particularly the Olson and JRC maps. As technology improves, computing power will grow and satellite data are likely to be more refined, broadened in scope and more easily accessible; opportunities for improved, more detailed regional maps should therefore exist in future. This is a necessary requirement before these maps can be of substantial use for more than generalised assessment.

Olson Classification

The Olson map (Figure 5.2) appears to be the poorest map for this study region. Most of the area is claimed, incorrectly, to be wooded tundra. While shrubs are prevalent they do not cover the entire tundra region. All the heterogeneity (discussed in Chapter 3) is gone and critical levels of detail lost. No shrub expanses, grassland, mires, exposed areas, etc. appear in the tundra region, although mire and exposed types, even some grassland patches should occur in large enough expanses to be detected. In the case of shrub patches and some grassland, the Olson map's low spatial resolution does not allow this level of detail. In the northern peninsula, the area north of Korovinskaya Bay, small amounts of cold grassland show up, but not mires and lichen heaths, two known communities. Shrubs are missing in the Pechora River delta also: it is mapped as further wooded tundra, which is clearly inaccurate. Increasing shrub (and tree) presence and height with southward movement are altogether absent. Mires, a key delta component (of both the Pechora and Neruta Rivers), are entirely absent. In general the Olson classification is much too uniform to be of value in this highly varied, heterogeneous region. The class and spatial resolutions are not the problems: more than enough potential exists for a far improved map with the number of class divisions and pixel size or map resolution. The Olson classification simply does not produce an accurate, acceptable map for this region.

JRC Map

The JRC map (Figure 5.3) looks entirely different from the Olson map and shows more promise with greater diversity of vegetation classes represented within the study region and in a more correct heterogeneous distribution. The inland tundra region is listed as sedge and shrub tundra, with some prostrate shrub tundra on the western side of the ridgeline where smaller shrubs were generally observed. Some grassland was present, and towards the southern part of the map, shrubs and trees begin to appear. Mires appear in very small amounts in the northern area and in the delta. These are both supported claims based on fieldwork. Riparian vegetation dominates the river deltas (Pechora and Neruta), which are somewhat reasonably mapped with the addition of some mire vegetation as well. Significant problems do exist in this classification, however: the entire northern section of land appears as water and within the Pechora delta there is an excess of water; shrubs are underrepresented, not appearing in the inland tundra region at all. Bare land also does not appear although substantial patches exist in the region. This error may be attributable to resolution, however.

CAVM

Finally, on quick inspection the third map, the CAVM (Figure 5.4), bears almost no resemblance to the previous two on account of its limited five classes and substantially coarser resolution. However, it does not necessarily produce inferior classification results, if generalisation reduces error. The amount of the region mapped as water is relatively good compared to other sources, although lakes are slightly large in the northern area. The Pechora delta is predominantly wetland, with a random, inexplicable section of erect dwarf shrub tundra in the northwestern delta region. The inland region is divided into low shrub tundra and erect shrub tundra, on or near the ridgeline, a fair categorization for such a coarsely delineated product. As with the Olson map, all the variety is in fact absent, however, and significant, potentially important heterogeneous detail is lost. Wetlands are found in the Pechora delta (low shrub wetland) and in the northern area (sedge moss dwarf shrub wetland) - again an acceptable assessment - but they are missing from the Neruta delta. Shrubs and trees as separate types are conspicuously absent given the coarse resolution. An isolated odd patch of non-tussock sedge tundra shows up strangely in the north near the coastal region. On the whole, however, despite the major generalisation of CAVM, it produces credible results that can be partially substantiated.

The observation that each map showed entirely different patterns of vegetation does not lend support for universal credibility among them. Some trends should at least be consistent among all three maps but each map seems to have its major weaknesses, but in the case of the JRC and CAVM, certain strengths.

4.3.1.2 Applicability to Reindeer

The global (and circumpolar) vegetation maps assessed contain spurious data, significant errors and/or are too generalised to be of use and applicability in examination of reindeer pasture or habitat. The majority of species-level information was effectively lost. Some could still be inferred from the JRC map classification divisions but not from the Olson as it was so poor at characterising the region, and the CAVM was simply too generalised. Assessment of habitat requires sufficient community detail to distinguish between seasonal characteristics, but this relevant community information was also lost in many cases. Detail may be greater in these global maps than in the BALANCE model, which will be detailed below, but this detail is of no value if results are erroneous.

Shrub vegetation was particularly poorly mapped, typically absent from the tundra and river delta areas. Only in the JRC map did it show any inclination to increase with decreasing latitude. In the CAVM, resolution was simply too broad to allow detail to be distinguished. Shrubs are important in assessing reindeer habitat, for their positive quality as valuable forage and for their negative value as a deterrent to movement and herding ability. Separation between moist and dry heath tundra was almost non-existent in the three maps. This is an important distinction for seasonal reindeer vegetation use in terms of lichen, dwarf shrubs and other species such as berry-producing ericaceous shrubs. Lichens, one of the vegetation types of greatest interest and value in habitat, were entirely absent from these regional maps. It may not be possible to generate lichen maps on a regional level given their patchy distribution, and in general, smaller area of coverage. The more detailed MODIS and Landsat sensor satellite data, for example, did show promise in this regard, particularly if combined with phenology.

4.3.1.3 Applicability to Climate Change

While the resolution of the Olson and JRC maps is sufficient to allow potential climate change effects on vegetation to be observed, should the maps be updated in the future, the degree of error and inaccuracy is generally so high that value is limited. The Olson map could conceivably show shifts in deciduous shrubs or grasslands, however, as it does distinguish these from general tundra, but the accuracy of their position and overall relative presence is so low that results would be of little to no value, merely indicative of potential change. The same can be said for grassland. Due to the already present inaccuracies, changes shown could not be trusted unless substantiated by other means.

The JRC map does distinguish between sedge and two types of shrub tundra. If shrub presence changes enough, shifts in the distribution of these three tundra classes may be observed. Mapping of shrub and tree classes was not accurate, but relative shifts may be seen. The inaccuracy remains an issue, however. The situation with grassland is the same: while it appears on the map and might increase with potential climate change, its presence is improperly shown and so little value lies in the data.

The CAVM, excerpted to cover only a small region relative to its design purpose and overall mapping area, is of limited use in assessing climate change at this scale. However, the map in its entirety would probably show evidence of trends and shifts in vegetation community distribution on a broader, regional basis, and given its more substantiated (although less detailed) results, this would be of value though not for the purposes desired here.

As mentioned above, lichen distribution is absent from all of these maps and any changes would not be depicted in updates of these classifications. This is a critical oversight given present and expected changes in lichen distribution. While shrub coverage does show up in some of the maps, the detail is limited or erroneous and, consequently, observed changes would be of less value than those seen in more detailed, accurate coverages with more specific shrub categories. Future global maps should ideally better distinguish shrub and lichen representative, and other, vegetation types in order to be of use in observing climate change effects.

4.3.2 BALANCE Vegetation Modelling

The second component of the third analysis level is the vegetation model series developed as part of the BALANCE Project, incorporating feedbacks and displaying predicted results alongside current (1990) results.

4.3.2.1 Methodology Assessment

The main advantage of the BALANCE models lies in their incorporation of climate change model data and other feedback mechanisms in order to more accurately model the vegetation given current and predicted scenarios. The current (1990) derived map was checked against actual data to ensure model acceptability before progressing with the three future scenarios (2020, 2050 and 2080) that required continued, similar modelled and feedback input. As climate and climate-related research models are developed, refinements will be made and results improved. There is confidence in the BALANCE models given current abilities and acceptance of the coarse resolution; in time, however, more advanced models will surpass them as computing abilities continue to improve. The BALANCE models are innovative and allow new assessments of climate change impacts previously not possible and therefore they have some value.

The two unavoidable downsides of the BALANCE models, developed with so much data input for such a large region, however, are 1) the coarse resolution (half a degree), and 2) the resultant limitation of this resolution in detailing the distribution of the eleven vegetation types included in the model. These weaknesses limit the potential application and value of the models. Project and technical limitations such as computing time and power and human research effort prevented further development or refinement of resolution or vegetation differentiation. Given the scale, the vegetation models present even less detail than the global vegetation maps discussed previously; however, the models do have greater, more varied inputs and predictive abilities.

This regional coverage is more limited than global or even circumpolar coverages, and therefore somewhat specific in its broadness. It provides a substantial overview of the Barents region, and therefore distinctions among countries or among districts within or across the national boundaries. This may be of particular relevance to reindeer pasture divisions should detail prove adequate for pasture assessment. Furthermore, regional differences exist, whether in temperature, moisture, precipitation or other environmental and climatic factors, and an analysis on a scale such as this allows these regional effects to be taken into account in the vegetation outputs. This lends credibility to the outputs, even if they are coarse.

If the models are examined individually and the changes by 2080 noted, certain trends are evident. On the overall BALANCE level, general trends show a decrease in shrubs and broad leaf trees in general, but particularly along the Scandinavian coastal areas and in the east of the region. Needle leaf trees consequently increase over time. Tundra grassland while not very prevalent in the first instance doesn’t show as much change, but there is an increasing decrease to the west and a slight northern shift. Trends noted in examining the study area of interest in this research are difficult to discern given the coarse resolution. However, currently present is some tundra grassland, shrub vegetation and trees. In time the models predict that broad leaf vegetation will be replaced by needle leaf and that shrub cover will increase in the area. The very limited application of such a coarse level of detail to this particular study area is evident. If this level is broadened slightly to include the general NAO region, similar trends are seen: shrubs increase and needle leaf trees dominate over broad leaf or tundra species.

Of note is that shrub cover, except in the NAO and the region of interest in this study, does not appear to increase in the overall BALANCE region as might be expected. However, on closer examination and discussion with the model development team (A. Wolf & T. Callaghan pers. comm.), it appears that shrub cover shifts may be lost in the model time frame and shrubs may have come and gone in the 80 year model development, being replaced by needle leaf trees. One drawback therefore of the models is that they miss potentially important trends. Although not relevant to our study area, it is worth examining the position of the treeline: the model seems to over-represent trees not only in the future but also the present.

Additional drawbacks considering vegetation detail are a result of the extremely coarse resolution and vegetation cover divisions: it is simply impossible for lichen and many other vegetation communities to be represented adequately or at all. In the case of lichen and moss, an additional deficiency is the fact that the model, as developed, is incapable of representing either vegetation type.

4.3.2.2 Applicability to Reindeer

At this extremely coarse, half a degree level, little or no information of value remains for reindeer if considering habitat patterns. Species-level data are effectively removed and many community-based associations are no longer applicable at this resolution and level of detail. Overall trends have some value from a regional perspective but this value is limited if shifts such as shrub cover change are masked or lichen coverage is inaccurate.

Reindeer pasture can be divided seasonally on a relatively coarse level: spring and summer grazing is dominated by graminoid vegetation and young shrubs, autumn by heath and possibly some graminoids, winter by lichen and dry heath. However, the resolution of this BALANCE model does not even allow effective assessment on this overly simplified basis. Information relevant and critical to reindeer and reindeer habitat are effectively lost in the downsizing of the data and resolution.

4.3.2.3 Applicability to Climate Change

Climate change is not predicted to be universal in its effects and some areas may face increased heat, others increased cooling, others still a drier than normal moisture regime and others a wetter future. Current regional differences also exist. These differences will have effects on the response of the landscape, which will in turn not be uniform. A major advantage of this broad level analysis is that it covers sufficient area to show such potential trends. However, when considering the Vyucheiskii Kolkhoz, our specific study area, the application is highly limited: data are too coarse.

A further disadvantage results from the limited detail in the vegetation types included: many finer, important community details are lost, and certain vegetation particularly susceptible to climate change, is simply not included in the models or lost within the model development, *e.g.,* lichens and shrubs. This further reduces the utility of the vegetation model on both a regional and more specific level.

5. DISCUSSION AND COMPARISON AMONG SCALES

5.1 Spatial component

A key difference between the most detailed botany analysis and the rest of the assessments was the spatial component present in all but the botanical analysis. Spatially projected data have a clear advantage in terms of viewing trends in vegetation (or forage) distribution, observing changes, climatic or other, or in noting patterns and relationships, *e.g.,* with seasonal reindeer pasture divisions. The botanical analysis has spatial data associated (GPS coordinates) which are valuable in examining for change or shifts, as overall patterns can be derived; however, the lack of immediate spatial understanding can be seen as a drawback. On the other hand, while satellite-based classifications are useful in examination of distribution of more broadly defined vegetation classes, they have limitations (Holmgren & Thuresson 1998, Achard et al. 2001) and for more detailed information, such as precise community structure, field-based vegetation analysis is superior or necessary.

With the aid of appropriate resolution satellite imagery (or aerial photographs), which can distinguish detailed vegetation communities, localised mapping based on the detailed botany could be developed, as was done in Zackenberg, northeast Greenland (Bay 1998). However, the practicality is limited: such an effort would be time- and labour-intensive, require the acquisition of appropriate image data, probably expensive high resolution satellite imagery, and spatial coverage would still be limited.

5.2 Maps versus Models

A distinction should be made between time-evolved maps and dynamic (*i.e.* evolving over time) maps, termed here models (such as the BALANCE vegetation model). All of the spatial approaches examined were built on time-evolved map development and not dynamic map development with the exception of the BALANCE regional vegetation model. A time-evolved map is static, based on the data being depicted, and portrays real data. A model or dynamic map has mechanisms for inclusion of data shifts and can be predictive, as in the case of the BALANCE future scenario models, rather than merely presenting current data. It can produce new outputs simply by inputting new data, simplifying the process producing additional results. Advantages and disadvantages exist for both. A model can be of less value because it abstracts somewhat reality. On the other hand, predictions are immensely useful, increasingly so now, as we face unknown global changes and must be prepared to understand and respond. The BALANCE vegetation model can in some sense therefore be considered both superior and inferior to the other, more simply derived time-evolved maps. As outlined previously, despite the model's strengths in ecological assessment, weaknesses in resolution and detail are not without consequence.

Future developments in technology, computing ability and ecological understanding are likely to improve the potential of dynamic maps by increasing their utility, application, coverage, if appropriate, and level of detail in both resolution and model components. Certain developments are necessary before models such as BALANCE can be reliably used for detailed analysis.

5.3 Monitoring

Any vegetation analysis is of superior value if it can readily repeat assessments with new data simply and efficiently. The botanical analysis approach is the most difficult to repeat with its time- and labour-intensity, potential costs and logistical requirements. Although duplication of analyses and a monitoring programme are possible and would be of significant value, the disadvantage is in the difficulty and intensity required. The detailed vegetation mapping and the global (or circumpolar) maps, however, can easily be repeated, either using the same techniques or, if preferred, different (possibly improved) methodology. The only obstacles to repetition are cost if there is cost associated with obtaining new data or images (as in the case of Landsat data, for example), and availability of suitable data for the periods required. The issue with these current spatial satellite-based maps is not one of ease of repetition generally, but of the spatial resolution and level of detail provided and lost. However, recent and future technological developments may help solve this issue: 1) MODIS data, for example, contains significant spectral data with about 30 bands, creating the possibility of increased detail, and 2) the possibility exists in the future for hyper-spectral data, *i.e.* data in which different spectral values can be given within the same pixel, increasing the detail available with a certain spatial resolution.

5.4 Scale, Detail and Spectral Confusion

5.4.1 Scale

Details of the variation in resolution and coverage of the multi-scale vegetation assessments included in this chapter allowed a clear perception of the substantial differences in scale: from less than 1 Landsat pixel through to 200 Landsat scenes, each containing over 34 million pixels. Restrictions became obvious: for example, the logistical infeasibility of increasing coverage of botanical analysis to a sizeable area when less than one Landsat pixel required two seasons of fieldwork and substantial processing effort. Another restriction was the inadequate ecological detail in global coverages for reindeer habitat examination when resolution was a matter of kilometres and vegetation communities are commonly measured in metres. Benefits also are clear, however: the compromise between scale, detail and coverage of a Landsat-based vegetation map allows assessment of both habitat and climate change effects in a spatially valuable region.

Purposes of the various assessments differed: from providing the most detailed species-level information (fine scale) to highly generalised global trends in vegetation (coarse scale), with applications necessarily differing as well. Every level is subject to technical limitations: expanding coverage in one direction versus generally increasing detail and spatial and spectral resolution in the other.

5.4.2 Detail

In the assessments included in this analysis, detail was correlated to spatial resolution with the resolution determining the level of detail. That is each pixel (spatial resolution) contained one value (detail), *e.g.,* vegetation community type. In future, it may be possible, as mentioned in Section 5.3, to have hyperspectral data, thus giving more than one value of a variable per pixel and increasing detail without affecting spatial resolution. The distinction between spatial resolution and entrained detail is an important one, particularly with regard to habitat as detailed below.

5.4.3 Spectral Confusion

Loss of detail and therefore precision was increased among the multi-scale assessments, typically with increasing coarseness of scale and generalisation. Error and inaccuracy, however, do not necessarily result; for example the CAVM was more correct than the global coverages, particularly the Olson. Error, as spectral confusion, therefore, seems to become a problem under two circumstances: 1) oversimplification and increased generalisation not of scale but of detail, *i.e.* the global maps have much more diverse vegetation to fit into the classes provided than more specific coverages do, and possibly 2) a lack of training data; *i.e.* CAVM had specific training sites within the Arctic but the global coverages did not have the same region-specific data input and were poorer.

5.4.4 Reindeer Habitat Considerations

Reindeer habitat assessment requires consideration of not only forage availability in terms of species or community detail within a pixel but also the spatial distribution of this information, which relates to foraging distance, *i.e.* the distance able to be covered by reindeer on a daily basis in the search for food.

Detail within a pixel has been discussed already in terms of species or vegetation community information provided. The botanical analysis and detailed vegetation mapping level provide adequate information and resolve the detail. The global maps and BALANCE model do not. However, a scale more coarse than the 30 m Landsat map could still be sufficient depending on the detail provided. A one-kilometre resolution image, if it provided proportions of different vegetation communities present within each pixel could provide suitable forage availability detail. If, however, it only provided a generalised value, it is insufficient for resolving the detail, *e.g.,* AVHRR data. Increased spectral resolution improves the situation but, as demonstrated in Chapter 4, the heterogeneity in the landscape can be high and relevant data would still be lost. The spectral resolution of and distinctions made within each pixel are therefore important. For example, if pixels were given one value according to the dominant vegetation and one contained 55% suitable and 45% unsuitable forage and a neighbouring pixel contained 45% suitable and 55% unsuitable forage, only one of the pixels would be considered suitable, when in effect they both have similar suitability, and neither one of them would be as valuable as a pixel that contained 90% good forage, another distinction that would be lost.

An estimated daily foraging range for reindeer might be something of the order of 10-20 km, or potentially more during migration. In considering foraging distance, the pixel sizes should be smaller than the foraging range; if they are not, habitat value in terms of actual potential cannot be examined beyond a single pixel, reducing the assessment to a theoretical one. So anything below 1 km is sufficient from this perspective. A 55 km pixel, such as the BALANCE level, clearly does not reveal necessary habitat information. A reindeer's position within a 55 km pixel could not be determined for example.

The interplay of (class) detail within a pixel and spatial resolution is critical. A 30 m resolution image, such as the Landsat ETM+ sensor based classification, has enough detail and spatial division to be suitable. A 55 km resolution image, such as the BALANCE model, contains neither enough detail nor adequate spatial resolution to allow habitat assessment on a practical level. A 1 km resolution image contains sufficient spatial resolution for foraging distance but may or may not contain enough vegetation detail within it to be of use, as described above. Spectral confusion is an additional consideration. Therefore in evaluation of habitat and determination of appropriate levels of scale, multiple factors need to be considered: detail is set by foraging needs in terms of content, and scale by factors such as foraging distance.

5.4.5 Climate Considerations

Consideration of climate is simpler when it comes to issues of scale and detail than reindeer habitat. Climate can be assessed on a number of scales, from the detailed botanical analysis level through to the BALANCE coarse regional level. Different information is extracted from different analysis levels, each serving a purpose depending on what information is required. The level of detail in the examination sets the scales.

5.5 Losses and Gains of Multi-scaled Approaches

The detailed botanical assessment contains as much detail as is possible to derive from the landscape and nothing is lost. However, coverage is highly limited and would have to be increased to be of spatial relevance. As described previously, given the intensity of effort, substantial expansion is not possible and this is a significant limitation. Suitable analyses and evaluation can combat the potential problem of lack of clarity in the data resulting from excess detail and resultant clouding of trends or shifts. This method of assessment of landscape vegetation shows the value in traditional, non-technical field data; in fact satellite or other technological applications would be unable to duplicate all the information provided, at least currently. In addition, all of the data is real and therefore this level of analysis is the most reliable; nothing is generalised or modelled, reducing error and inaccuracy. This most detailed level allows a clear examination of just what detail does potentially exist and allows the loss of detail associated with decreasing resolution to be assessed more easily.

Given the heterogeneity and variety in the data observed in the botanical analysis assessment, it is evident that even the detailed vegetation mapping suffers from a loss of detail. While species presence within a community can be virtually known in some cases and supposed with clear foundation in others, in still others it would be absolutely uncertain. However, at the relatively high thirty-metre resolution of this map, significant, valuable details are also preserved: community divisions can be highly detailed, certain specific species-community associations are still present, and relationships between communities or between communities and topography and other environmental characteristics can still be ascertained. Furthermore, there is flexibility for increased or decreased detail depending on methodological effort. This level of assessment is the most universally useful, with its balance of data preservation and loss and its flexibility in up- or down-scaling in both detail and coverage as compared to the other methods.

The global and circumpolar maps are commendable for their ambition in covering vast, highly varied areas. Certain coarse-scale regional trends could not be observed otherwise and would be entirely hidden in more fine-scale developments. However, much potentially valuable detail is also necessarily lost in these generalised maps. They may appear heterogeneous on a level known not to be correct (based on the other more detailed analyses and field visits and photos). Their primary utility lies only in these broad assessments as they lose all relevance to detailed applications. Furthermore they contain significant errors in classification. Loss of detail is a universal problem at coarse analyses levels, one potentially exacerbated by increased extent of area included. For example, existing global vegetation maps do not provide superior information even with their more refined resolutions because their vegetation category divisions are even more generalised to cover a wider range of global vegetation types. So, as the extent of area being mapped diminishes, accuracy generally improves; for example, the CAVM (Walker et al. 2002, CAVM Team 2003) is superior in this regard to the global maps. While still over-generalised, it manages to pick out established trends.

The BALANCE vegetation model has the same drawbacks as the global maps, although it has other specific benefits as mentioned above in section 5.2. While substantial detail is absent from the models and increased error is present as a result, broader variation is modelled and it has an advanced, innovative approach of incorporating feedbacks from various environmental systems (climate, hydrology, etc.). It is a valuable start to this sort of assessment, the frequency and utility of which are likely to improve in the future.

5.5.1 Specific Vegetation Considerations

Of particular interest in these multi-scale assessments are the detail and reliability of certain, specific vegetation types. There may be relevance to one or both reindeer habitat or potential climate/global change.

Shrub distribution is of critical importance in reindeer habitat assessment, for its positive and negative effects (as detailed in Chapter 3), and also in monitoring vegetation and climate change, particularly since changes have already been noted (*e.g.*, Sturm et al. 2001). Therefore a suitable scale of assessment is required that shows enough detail in shrub cover and that has sufficient accuracy and lack of error. The detailed vegetation map level seems most appropriate. Current global and circumpolar maps do not contain suitable vegetation type categories, are not produced at a fine enough resolution or contain too many errors to be of value. The detailed botanical analysis is useful to a degree, easily showing species shifts, but not easily spatial changes in distribution.

A similar assessment can be made if considering lichens, also critical both for reindeer pasture and climate change assessments. Critical in this case is an analysis of resolution detailed enough to be able to display lichens with their typically small and scattered patches, as well as the ability of the analysis to discern lichens in the first place. The BALANCE model and global coverages have virtually no utility in lichen assessment as they fail on one or both counts. The botanical analysis level certainly provides important detail but, again, compromises spatial display as a result. The detailed vegetation map successfully distinguishes lichens and is therefore of definite value.

5.6 Challenges and Developments

The vegetation of the circumpolar Arctic is not known in uniform detail: some regions are clearly understudied. Maps like the CAVM are of particular benefit in providing an overview of Arctic vegetation at a level that can be adequately detailed with verifiable accuracy. However, greater detail is needed and gaps in circumpolar vegetation knowledge need filling. With the advent of more advanced satellite mapping and computer technology and processing ability, detailed documenting of the vegetation of the Arctic will become a viable possibility. There are current limits in resources and computing power, although improvements to date in computer power and greater availability and selection of satellite data have already enabled development of more detailed classifications over increasingly large areas (Homer et al. 1997, Cihlar 2000, Ma et al. 2001, Franklin & Wulder 2002, Rees et al. 2002) and future developments should continue this process. The recent potential for more detailed regional and global datasets is partially enabled with the advent of 1 km resolution satellite sensors such as AVHRR (Hansen et al 2000, Loveland et al 2000, Franklin & Wulder 2002, Bartalev et al 2003). But even this improved resolution is too coarse to model vegetation or assess ecological processes in sufficient detail or with sufficient spectral resolution due to the heterogeneity and patchiness of Arctic vegetation (*e.g.*, Woodcock et al. 1997, Stow et al. 1998, Virtanen at al. 1998, Rees et al, 2002). Given current technological limitations in producing finer resolution regional and global coverages, more detailed scale classifications of smaller regions that can identify ecosystem processes are still superior in providing data for examining potential change and analysing current situations in sufficient detail (Hansen et al 2000, Loveland et al. 2000, Franklin & Wulder 2002, Bartalev et al. 2003, Virtanen et al. 2004). In terms of habitat studies, required resolution depends on the species considered and on their ranges and use of the land. For example, the habitat of more sedentary populations such as muskoxen, which also rely heavily on microscale landscape characteristics (Danks & Klein 2002), could not be sufficiently mapped on this current global level and instead require detail similar to Landsat level resolution. Reindeer and caribou, on the other hand, cover significant territory and general aspects of their ecology and habitat use (such as overall trends in seasonal vegetation community use) might be evident through coarse assessments. However, more detailed, useful habitat assessment including specific community use and characteristics is not possible. If considering potential climate change the problem remains. General trends may be evident across coarser resolutions but small-scale changes will not be observed, and these changes may occur for some time before larger scale changes are noticed. Transition zones (*e.g.,* of vegetation), are areas of particular interest and are difficult to define currently (Hansen & Reed 2000). Consideration of the potential for climate-related vegetation shifts, for example, in treeline or shrub advancement, adds an additional complication. Resolving needs of scale and coverage will be increasingly important.

For the time being, currently operational satellite data sources of potential value in mapping global Arctic vegetation in sufficient detail and with potential for assessing any changes include MODIS (Terra and Aqua satellites) and MERIS (Envisat satellite). Derived products, such as MODIS's land cover product, may be useful with further development. Resolution for MODIS is 250, 500 or 1000 metres and for MERIS, 300 metres. Coverage is frequent. While Landsat provides suitable data for detailed assessment, its utility in global mapping is currently limited due to potential data costs (not all images are free) and availability. In addition, the satellite is scheduled to have run its course by 2008. This is a serious drawback to potential monitoring and derivation of vegetation shifts using consistent data and methodology.

Lichen mapping is considerably more challenging due to its more heterogeneous distribution and generally smaller patch size as well as its association with other vegetation. Resolution of MODIS and MERIS data for example is likely to overlook much lichen coverage, particularly at the 500 and 1000 metre resolutions. Some success at mapping lichens has been achieved (Nordberg & Allard 2002, Tømmervik et al. 2003, Stow et al. 2004, Théau & Duguay 2004, Tømmervik et al. 2004, Théau et al. 2005); however none of these attempts have utilised data coarser than thirty metres in resolution. This is a somewhat impractical approach to circumpolar coverage, at least currently. With increases in data availability, decreases in cost, and increases in computing power, the future generation of more detailed coverages from finer scale data is increasingly likely although still far off. It would be of significant value to develop techniques for mapping lichen at currently available resolutions.

5.7 Reindeer Habitat Summary

Both the most detailed botanical analysis and the detailed vegetation mapping undertaken in this research are of relevance and application to understanding reindeer habitat. Each level plays different roles. The botanical analysis's strength lies in specific species understanding and assessment. The map's strengths lie in community association and the relationship between pasture lands which seem to be ecologically derived, rather than by terrain or topographical distinction which is limited in the Vyucheiskii Kolkhoz.

At the regional BALANCE model level and beyond, *i.e.* the circumpolar and global coverages, virtually all relevance and application to reindeer habitat is lost with the elimination of detailed and important communities and species associations, which are important considerations in habitat. Should the global maps with the higher resolution and most vegetation divisions be more accurate, however, they would be of some general value. Currently they are spurious and contain errors and are therefore generally unsuitable.

5.8 Climate Change Summary

Climate change can be assessed on a wider variety of scales, unlike reindeer habitat, which requires a certain amount of detail. Consequently all of the multi-scale vegetation analyses have some relevance and applicability. The botanical analysis is useful in determining species changes (with potential relevance therefore for conservation) and detailed community composition shifts. The detailed vegetation map contains enough detail on a community level to include likely discernable species-community relationships. It is therefore useful both in terms of species and community detail and in terms of community changes and shifts in distribution. Again the spatial component is of particular utility. The global level maps and the CAVM even though it is of coarser resolution, have application in showing broad trends across regional or national boundaries. These trends are probably influenced by other ecological factors such as land characteristics, topography, weather patterns, etc. The advantage of the BALANCE model with its incorporation of other, sometimes location-specific environmental criteria is demonstrated in this regard: its value is increased over the static, simpler maps. While these broad maps and models are still valid in assessing potential climate change effects, they only allow broad-scale assessment. The potential for loss of critical information on this level should be considered.

6. CONCLUSION

The provision and creation of not just one type but multiple types of data for a region for which very little detailed or up to date information existed previously is of particular benefit, particularly with the range of purposes and applications that exists.

Through the comparison of these multiple scales of vegetation analysis various distinct differences, benefits, and drawbacks are found, depending on perspective and application. New data, regardless of its detail and coverage, are justified and have at least specific if not broad ranging application. Mid-range assessments have the broadest application base while the most focussed and most generalised analyses necessarily are limited in diversity of application (particularly the broad-scale analyses) but have increased specialised benefit.

Whether detail is considered lost or unnecessary depends on the application. In considering regional shifts and potential climate change effects, generalised information is valid. If climate change needs to be examined in detail and for specific effects, the highest level of detail is preferred. Climate change needs are wide-ranging, depending on specific requirements, and an array of analyses levels can be suitable. On the other hand, habitat considerations, in this case for reindeer, require a certain level of detail. Regional and global coverages have lost too much information to be of serious value; detailed mapping is highly suitable in terms of spatial analysis and community understanding; and botanical analysis is suitable for more specific species and pasture analyses.

Tradeoffs exist and it is impossible given current data restrictions for one analysis scale to provide both highly detailed information (particularly, in this case, in an area of extreme heterogeneity) while still allowing ‘the bigger picture’ to be seen. The detailed vegetation mapping level assumes the best balance, lying at the transition points of adequate detail provision on one side and regional overview capability on the other.

Future Arctic research is important for two reasons: first in considering the potential for monitoring and, second, the potential for advancements in data processing abilities and computing power. The former is of considerable importance as the Arctic environment is undergoing uncertain global and climate change. Data processes that can support future assessment are therefore of particular value. The latter can critically advance our abilities in analysis and particularly in modelling: coverage extent can be increased without compromise of spatial resolution or categorical division detail, and vice versa. The likely beneficial results of more valuable and accurate analyses and data are an improved understanding of vegetation dynamics, what changes have occurred and a more sound perspective on what changes may lie ahead.

Results from this chapter on multi-scale landscape analysis have provided knowledge of assessment scales, details of their techniques and their potential application. All of this information can be used in improving future vegetation analysis studies, choosing appropriate levels of scale and detail and being able to better determine future needs.

CHAPTER 6 - HABITAT ASSESSMENT

“They were travelling steadily along, a great mass of dark-brown figures; …all bathed in the golden light of this Arctic night. The quiet unmoving landscape I had scanned so carefully from the ridge before dinner had come alive- alive in a way I am not competent to describe. The rightful owners had returned. … The total effect of sound, movement, the sight of those thousands of animals, the clear golden western sky, the last sunlight on the mountain slope, gave one a feeling of being a privileged onlooker at a rare performance- a performance in nature’s own way, in the setting of countless ages, ages before man. … Every kind and every variety was here; something in some valley west of here, had brought them together into this sixteen-hundred-strong herd of talking, grunting pilgrims- they travelled as though they had a goal and knew the way and were not stopping. … Here was the living, moving, warm-blooded life of the Arctic with the wisdom of the ages, moving always, not depleting their food supply, needing all these valleys and mountains in which to live.”

Margaret Murie, *Two in the Far North*

1. INTRODUCTION

1.1 Overview and Rationale

So far this thesis has addressed landscape in terms of vegetation only, from individual botanical species to a detailed map and through to regional and global model and map coverages. If considering reindeer habitat and ecology, and potential climate change effects, however, inclusion of other environmental variables and landscape characteristics is necessary. While vegetation is critical for reindeer and may be subject to climatic shifts with habitat implications, there remain other significant factors in the determination of reindeer habitat suitability.

This final chapter seeks to move beyond discussion limited to vegetation and introduce a broader reindeer habitat perspective. Factors affecting habitat are outlined, details of a recent habitat modelling assessment undertaken as part of the BALANCE Project are presented, and recommended future improvements are discussed.

Most habitat research to date has examined current situations, based on existing data. Lundqvist (submitted) provides a highly complex and detailed multi-factor characterisation of Swedish reindeer habitat supported by substantial data and after a detailed review of factors affecting reindeer husbandry (Lundqvist 2003). Rettie and Messier (2000) examine woodland caribou habitat on a fine-scale (daily) and coarse-scale (seasonal) basis but primarily examine vegetation and vegetation related aspects. Some studies have examined other landscape characteristics such as terrain ruggedness (Nellemann & Thomsen 1994, Nellemann & Fry 1995) or other land uses (Sandström et al. 2003) and their roles in habitat, and much has been studied about reindeer, vegetation and foraging (*e.g.*, Edenius et al. 2003, Mårell & Edenius 2006), in particular using remote sensing data (Käyhkö & Pellikka 1994, Colpaert et al. 1995, Kumpula et al. 1997). Kumpula's work in particular has increasingly focused on application of more detailed remote sensing data, from Landsat to SPOT, TERRA, ASTER and Quickbird, on reindeer pasture (*e.g.*, Kumpula et al. 1999, Kumpula 2003, 2004, 2006). Few studies provide a comprehensive Geographical Information Systems (GIS) or remote sensing based analysis which combines multiple data types as has been done by Lundqvist (submitted) for example, or with other Arctic ungulates (*e.g.,* Danks & Klein 2000). Development of predicted habitat models that incorporate climate and other relevant feedback data for reindeer, as presented here, appears to be a new approach (Rees et al. in press).

That the earth's climate is changing and will change is increasingly difficult to deny, as detailed previously, although precisely what changes will occur and when, and what the ramifications will be are not known. Given the seeming inevitability of change, attempting to cautiously develop and examine possible scenarios based on available knowledge and advancing predictive abilities is an important first step. Science is under growing pressure from the research community, government and even the public to provide information. Specifically, attempting to understand how reindeer might be affected is of particular importance given their prevalence in tundra regions, role in creating livelihood for many people in the Barents Sea region, and as of yet still not fully understood role in shifting vegetation and ecosystem dynamics.

This chapter takes a necessary step in ecological understanding beyond the development or assessment of basic data: it introduces added dimensions in terms of data, feedbacks and temporal perspective and presents novel research ideas in a way that has not been done before, allowing beginning perspectives on preparing for future shifts. The value and applicability of a regional quantitative approach in assessing potential climate change impacts on reindeer habitat is compared with the potential that exists in more detailed assessments. With current limitations of computing power restricting detail there is value in assessing tradeoffs between detail and generalisation, and detail and expansive coverage.

The identified weaknesses, strengths and recommendations for future studies and expanded analysis could not be made on the knowledge of the habitat studies alone, but are also derived from the basis of knowledge gained from the outcomes of Chapters 3 and 4 that focussed on ecosystem detail. Thus, this chapter further synthesizes the components of the thesis, through additional examination of effects of scale, this time as they relate to other habitat criteria.

Overall benefits of the BALANCE approach include an improved awareness of predicted climate change impacts on the Barents region's reindeer populations and insight into how changes and effects might differ across the area; a greater awareness of complex feedback-analyses; and better understanding of improvements necessary for application of future habitat studies.

1.2 Objectives

The initial objective of this chapter is to introduce environmental and landscape characteristics beyond vegetation that are critical to reindeer habitat suitability and that can or should be brought into habitat analyses. The second objective is to assess results from a novel, regional habitat assessment developed in conjunction with this thesis research and the third to determine whether there are any data gaps and weaknesses that should be filled and how assessments might be improved.

Actual development of a habitat model is beyond the scope of this thesis given the state of suitable, current data available at project inception and limits of time, but recommendations useful for such development will be made in terms of factors that are important and issues of scale.

2. BACKGROUND HABITAT INFORMATION

Vegetation is undoubtedly a - or even the - key factor in understanding landscape, particularly as it relates to reindeer, dominant herbivores in the Arctic environment. However, a number of other landscape characteristics must be considered, playing their own role in the ecosystem dynamic and in particular in influencing reindeer and reindeer habitat. They may be immune or subject to environmental and climate change but nonetheless are important in the determination of reindeer habitat suitability, *e.g.* hydrology (in the form of water, snow and ice), wind, topography and terrain characteristics, faunal diversity, and land and resource use.

2.1 Factors Affecting Reindeer Habitat

2.1.1 Vegetation

Vegetation's critical role in reindeer habitat, the characteristics of which change over the seasons, has been assessed and discussed in significant detail in the three previous chapters and thus will not be expanded upon again. Vegetation is mentioned, however, in the context of the BALANCE habitat assessment.

2.1.2 Hydrology

Hydrological characteristics influence reindeer habitat in various ways: indirectly through influence on vegetation species and distribution, and directly as discussed below throughout the seasons as water, snow and ice.

2.1.2.1 Snow and Ice

While vegetation is often the focus of habitat discussions, effects of other factors and of climate change on other factors, notably snow and ice cover may be as important. Reindeer are resilient and can adapt to a variety of conditions and pasture vegetation, *e.g.* high Arctic tundra, boreal forest environments, more lush Arctic zones such as the Seward Peninsula, Alaska, or even the vegetation of South Georgia. However, they are limited by snow and ice conditions and an unfavourable event can endanger entire populations. Snow and ice cover is a particularly important factor in determining suitability of reindeer habitat in winter months and in affecting survival (Putkonen & Roe 2003, Kohler & Aanes 2004, Schiermeier 2006). Ambient temperature, particular shifts in temperature near (above and below) freezing (0 C), and snow depth, are all important considerations. Stable temperatures present little problem, certainly if they are consistently below freezing.

Fluctuating temperatures, in particular above and below freezing, present significant problems as they allow the development of ice layers within the snow pack. These hard layers are impenetrable by reindeer hooves in the animals' search for lichen and other winter forage. They can also limit the reindeer's ability to smell lichens under the snow, potentially affecting quality of forage obtained. Previous study has shown that caribou required twice as much energy to obtain their food from a dense snowpack with a hard crust than in snow conditions without a crust (Fancy & White 1985). In cases of extreme, widespread icing events severe population crashes occur. For example in 1993/94 a Svalbard population suffered an 80% reduction in numbers (Chan et al. 2005) and according to Fifth Brigade herders in 1972, entire herds were virtually wiped out (Rees et al. in press, Fifth Brigade pers. comm.). The animals perish without access to critical food resources. In cases of localised icing events, reindeer can find other forage patches that remain suitable because of the landscape heterogeneity which leads to variation rather than uniform effects, or be led to suitable areas by herders and these small-scale events are less of a problem. Icing events are potentially worse early in winter than late as layers may not melt if temperatures remain cold. In spring, warming temperatures can mean icing events are shorter in duration or less severe.

Snow depth presents a further problem. Reindeer are adept at digging through and walking on snow with the large surface area of their hooves (Pielou 1994); however, snow that is too deep limits access to important forage and increases energy spent in movement at a time when reserves are low. Additional climate factors relevant to snow and ice cover that can contribute to icing in snow are humidity, snow density (dense snow can cause compaction), albedo (particularly coupled with temperature), wind speed and direction, aspect and slope (related to albedo and wind etc.) and size of snow grains.

In some regions, *e.g.*, Finland, supplemental feed is given to reindeer, lessening the impact of snow and ice effects. In this discussion, however, the practice of herding entirely based on pasture consumption is the focus. Potential effects of climate change on patterns and characteristics of snow and ice cover increase its relevance: detrimental possible changes pose one of the greatest threats to reindeer.

Consideration of climate change effects is often incorrectly limited to warmer months with temperatures above freezing, but effects in colder months on winter temperatures and patterns are at least as important. If temperatures are well below freezing effects may be minor or insignificant, at least in regard to reindeer. If however, temperatures hover just below freezing or fluctuate around 0 degrees, potential for affecting reindeer is great. Snow and ice characteristics subject to change in these conditions include distribution, depth and hardness, ice crust formation and freeze and thaw events, all of which are important in habitat suitability.

Inclusion of snow and ice characteristics requires availability of preferably detailed climate data and modelling in order to develop coverage information for the landscape versus point location data. An approach used with coarser and fewer data is detailed later in this chapter (Rees et al. in press). Lundqvist (submitted), working on reindeer husbandry in Sweden, in contrast, has access to significantly more detailed spatial and temporal data, and can analyse variables more precisely. He has developed specific parameters for ice crust formation, for example: temperature fluctuations just above and then below freezing over a few day period; a defined (*e.g.*, 10 degrees) maximum-minimum range with minimum temperatures below freezing and maximum above; a defined minimum precipitation with above freezing maximum and below freezing minimum temperatures.

2.1.2.2 Water

In winter months during sufficiently sustained, cold temperatures water bodies are frozen and in fact improve movement through habitat, providing that snow depth is manageable. In summer months water can impede movement if regions are dominated by lakes and surrounding wet, impassable marshy ground: while reindeer are proficient swimmers they get trapped in muddy, soft ground (Fifth Brigade pers. comm.). Quantifying this would be more difficult: 1) not all lakes are surrounded by wet boggy ground and 2) not all boggy ground is impassable. If satellite data were available of sufficient spatial and spectral resolution (particularly in mid-infrared), the possibility of specific remote sensing vegetation analysis might exist, particularly in combination with other ancillary data. Alternately radar data (RADARSAT) has proven utility due to its sensitivity in distinguishing wetlands (*e.g.*, van der Sanden & Ross 2001, Taft et al. 2003, Li & Chen 2005). However, generally terrain is varied enough to not present a problem given the micro-variability present, particularly in this study region (Chapter 3, Section 3.7). Conversely, reindeer, and herders require water for survival and so presence of lakes or rivers and streams is important. Herders say that lakes and rivers are drying up though (Images in Chapter 3, Section 3.7.6) which will affect migration routes and summer camps with potential habitat consequences for their animals (Fifth Brigade pers. comm.).

It is assumed that water as a factor is less critical than other potential habitat factors since frozen water is taken into account as snow cover and water bodies do not present a problem on the whole, at least given current climate conditions, relative to other critical factors. Its exclusion from assessments is unlikely to have a large impact unless the situation of water availability changes significantly.

2.1.3 Temperature

Both summer and winter temperature can be considered in assessment of relevant habitat factors. Reindeer are highly adapted to harsh Arctic environments and can survive in extreme cold and the lower limits in winter are less critical than the upper which affect snow cover as previously discussed and also snow softness. Reindeer movement is obstructed by soft snow and they expend valuable energy when they sink deeply into snow rather than walking near the surface of the snow layer.

Winter or near-winter temperatures that fluctuate above and below freezing complicate herders' plans and ability to manage their herds. Firstly, herd movement is costly and difficult in the resultant soft, unfavourable snow conditions. Secondly, changing temperatures affect the freeze and thaw of lakes and rivers, essential transport corridors during migration. Herders may be without the ability of critical route planning or find themselves delayed or even stuck in certain pasture areas if conditions have led to unexpected early thaw, for example. Consequences of such conditions would be of particular concern at critical calving time when reindeer must be in their habitual areas before calving begins. Finally, temperature patterns that are stable but that have changed due to climate shifts, such as predicted warmer winters and colder springs, could result in similar unfavourable snow and ice conditions.

As with winter temperature, the lower summer ranges are not likely to be particularly important although they many be beneficial in limiting insect populations and harassment. Upper summer temperatures are, however, a concern due to 1) increased insect harassment and resultant energy loss and potential decrease in health, 2) heat stress effects and 3) effects of high, dry temperatures on reducing forage quality and therefore animal condition.

2.1.4 Wind

Wind is important in summer primarily due to its effects on insects: wind keeps mosquitoes and other insect pests away from reindeer and significantly reduces harassment, allowing the animals to conserve critical energy resources (Anderson et al. 1994, Mörschel & Klein 1997, Mörschel 1999). It also reduces potential summer heat stress. In winter shifting wind causes snow cover distribution to be non-uniform, potentially a benefit in foraging if cover is less deep. In extremely cold temperatures, however, added wind is negative (more so for herders). Inclusion of wind effects in habitat assessment requires sufficient coverage and detail in climate data, potentially a difficult challenge if climate data stations are few and far apart. Mörschel (1999) and Weladji et al. (2003) have developed indices of insect harassment, relating to both temperature and wind. In the Weladji et al. study, the threshold of declining insect harassment was set at wind speeds of 6m/s and greater. Mörschel's method is recently applied in Lundqvist's examination of Swedish reindeer pasture characterisation using kriging to expand climate station wind data (submitted). Topography affects wind characteristics as well and ideally the two should be considered together in areas where topographical variation is present, particularly if wind data are difficult to obtain or develop.

2.1.5 Insects

Insect harassment by mosquitoes, nose bots and warble flies is a particularly serious problem that affects all herd members although calves may be particularly susceptible to mosquitoes when very young or weak. Harassment disturbs typical behaviour patterns and reduces valuable reindeer energy reserves: reindeer may be forced to stay on the move to deter insects when they would otherwise be resting or foraging, or they may seek exposed zones where insects presence is lower, but so is forage value. As mentioned above, insect activity is correlated to wind and also to temperature (Mörschel 1999, Weladji et al. 2003). Warmer temperatures, particularly in spring and summer, encourage insect harassment. Seasonal trends in moisture or precipitation also influence the degree to which reindeer can suffer attacks by insects, with a dry spring discouraging larval growth and abundance and a wet one having the opposite affect. Severity of winter is irrelevant to mosquito harassment as most of the insects in a season develop that year. However, extended winters or increased snowfall may have an effect by encouraging moist spring conditions in which mosquitoes, in particular, thrive.

2.1.6 Predators

While predation is not a significant factor affecting habitat of herded reindeer in our study region because the herd is carefully watched twenty-four hours a day by the herders, and predator populations seem low even though habitat seems optimal (field observation of signs, Fifth Brigade pers. comm.), predation is a significant factor affecting habitat and reindeer herds in other regions with wild reindeer or loosely herded domestic animals. As mentioned in Chapter 2, common predators include brown bears and wolves, and to a lesser extent wolverines and raptors, for example. Calves and weak animals are most at risk. Predator effects can be incorporated into assessments providing knowledge is known about their habitats or territories and populations. Radio collar or GPS data are particularly valuable in providing accurate spatial definition; den site data is also useful; however, habitat or home range territories and population data also give relevant though less specific information.

2.1.7 Land Use Conflicts

Other land uses within reindeer pasture or migration zones can be a factor affecting habitat suitability, as is the case with forest resources in Scandinavia, or oil and mineral development in Alaska (*e.g.*, Cameron 1994, Nellemann & Cameron 1996, Nellemann & Cameron 1998) and Russian regions including the NAO and Yamal Peninsula, for example (*e.g.*, Stammler 2005). Within the Vyucheiskii Kolkhoz study region, however, there is little other land use in reindeer pasture areas (see Section 3.7.7 and Figure 3.4). Substantial conflict and differences of opinion exist regarding compatibility of reindeer (including caribou) with other land uses and effects of infrastructure and other disturbances on the animals (Nellemann & Cameron 1996, Nellemann & Cameron 1998, Vistnes & Nellemann 2001, Vistnes et al. 2001) and no consensus has been, or is likely to be, reached. Land use conflicts are a critical issue in other Arctic regions of reindeer presence and would merit substantial, in depth assessment if relevant.

To assess impacts of oil exploration or other land use activities, shown in studies (above) to have increasing effects with decreasing distance, buffered areas around potential disturbances could be created as a means of incorporating disturbance effects. Previous studies' findings and methodologies could be consulted to develop acceptable values, exact definitions of which would vary depending on the specific region, size of the area and specific type of disturbance as well as on the season if particularly sensitive calving season and grounds might be particularly affected.

2.1.8 Accessibility and Infrastructure

Accessibility is generally only an issue in regard to landscape infrastructure. Expanses of natural landscape do not present an impediment except in rare cases of overly wet ground as mentioned above. Infrastructure can disrupt reindeer and limit accessibility to pasture regions. Roads are a problem: reindeer are attracted to the ease of movement roads enable but face death and injury by vehicles, and roads can simply disturb movement. Problems with roads and other infrastructure such as powerlines or even fences are a particular problem in regions of Scandinavia (Vistnes & Nellemann 2001, Vistnes et al. 2001) but in our study region virtually no roads or infrastructure exist and habitat assessments are therefore simplified. Infrastructure, however, can also have positive aspects. Roads increase access for herders to market, potentially expanding areas of potential habitat. Fences while limiting accessibility and movement are purpose-built in regions of reindeer herding in Scandinavia to allow separation of herds and territories, or prevention of access to dangerous roads.

Infrastructure is a potentially complicated habitat factor. If considering habitat suitability from a reindeer perspective alone, influences are generally negative with movements obstructed and changes in typical behavioural patterns possible. However, if considering overall herding suitability, *i.e.* involving the herders, the same influences can be positive, making herding in the region in fact viable. For example roads allowing better market access and fences making herding easier. When analysing accessibility and infrastructure variables this distinction between habitat and herding suitability should be clear.

3. BALANCE HABITAT ASSESSMENT

The habitat assessment that formed part of the BALANCE Project research incorporates climate change predictions and vegetation, hydrology and other environmental feedbacks. It represents an initial attempt at modelling future habitat so that potential changes can be considered. The work was completed through substantial multi- and inter-disciplinary collaboration with various data contributed by project partners and the SPRI group (author's association). A summary of the data contributions and the assessment parameters and results is provided in this section. Full details can be found in Rees et al. (in press).

3.1 BALANCE Data

Data from the relevant BALANCE partners included: 1) Reindeer population and density data (SPRI Team); 2) Vegetation data, as presented in Chapter 5 (A. Wolf, Royal Swedish Academy of Sciences); 3) Snow and ice hydrology model data (R. Dankers, University of Utrecht); and 4) Climate models (various researchers, Hamburg University), as inputs into the vegetation, snow cover and wind models. Figure 6.1, an expanded, more explicit version of Figure 2.2, presents an overview of the modelled components that yielded the habitat assessment. Data were modelled and optimum and pessimum values based on habitat criteria knowledge derived for use in a tolerable windows method (Petschel-Held et al. 1999), which follows the approach that the degree to which an environmental factor positively or negatively affects reindeer is assumed to be a monotonic function of the amount of exposure. The optimum represents the ideal habitat characteristic and the pessimum the least tolerable. If the value of the variable in question (*e.g.*, summer temperature or snow depth) is between the defined optimum and pessimum values there is a sliding scale of suitability. A value beyond the optimum value simply takes the optimum and a value beyond the pessimum is an entirely unsuitable habitat condition. Optimum and pessimum values are defined for each habitat factor and all of the values are combined using a weighted average approach (Rees et al. in press). Various runs with different weighted average values were developed in the habitat assessment and are presented in Section 3.2.

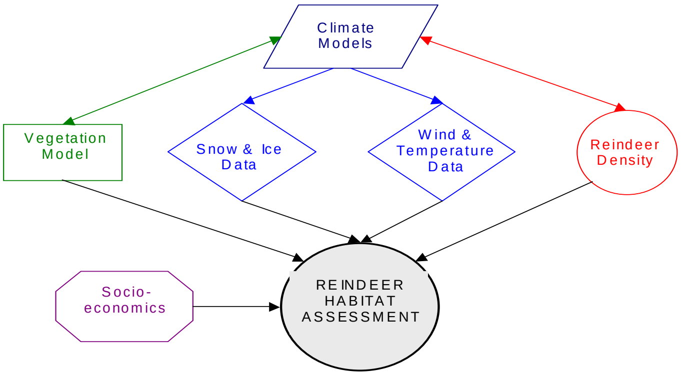


Figure 6.1. Schematic diagram of data inputs with feedbacks (double arrows) and model or other outputs.

3.1.1 Reindeer Data

Reindeer data are required in order to determine the effect of environmental data variation on the reindeer population. The SPRI group developed current data on reindeer density and numbers in the BALANCE region for contribution to the assessment (see Figure 1.1). Data were gathered and aggregated for as much of the Barents region as possible (primarily by G. Rees) and projected to the BALANCE-wide REMO grid (plate carrée projection, 0.5 degree resolution). Data are missing in small pockets in northern Finnmark, generally where overlap exists between summer and winter pastures, and pasture is used by separate herds in different seasons, thereby rendering density calculations impossible.

3.1.2 Vegetation Data

The vegetation data were described previously in Chapter 5 and will not be presented again here, however, some modifications were made, with increased detail in parts of the region. The same PFTs were used and biomass data for each was incorporated (as kilograms per square metre, above and below ground). Dependence of reindeer density on biomass was modelled as a simple linear function and a regression analysis completed. A regionalised version (versus BALANCE wide) of the model yielded superior results, explaining 53% of the variance.

3.1.3 Temperature Data

The climate model which was coupled with the vegetation model provided monthly temperature data over the period January 1990 to December 1999 (present) and January 2070 to December 2079 (future). The winter optimum and the pessimum for the present were –16 C and –2 C, above which snow melts increasing freezing events and difficulty in movement, and below which heat loss could be a factor. The equivalent summer values for the same period are 12 C and 26 C, above which heat stress is more likely to be an issue.

Temperature data were also used to rather crudely model freeze-up in the case of large rivers, the thawing of which might make migration impossible. The frozen period was a function of the number of sub-zero temperature recordings in each of the two (present and future) data scenarios. Flow accumulation data were obtained and calibrated. Cases where rivers crossed rather than ran alongside territories were noted.

3.1.4 Wind data

A lower threshold wind speed of 5 m/s was set, above which wind speed in summer was considered beneficial in cooling and reducing insect harassment and in winter detrimental due to heat loss (negating potential benefits of uneven snow distribution). This is similar to the 6 m/s value assumed by Mörschel (1999). Wind data were derived from the climate data and the resulting model forecasted windier winters and calmer summers overall.

3.1.5 Snow and Ice Data

Snow and ice cover data incorporate the BALANCE modelled climate data in their modelled outputs. Depth, estimated from Snow Water Equivalents (SWE) and refreezing data were developed by R. Dankers within the TANASnow model (2002), again on a monthly resolution. Depth and frequency of deep snow events were included and both showed decreases from the present to future dates, in line with reported trends (Brown 2000). A refreezing index, indicative of conditions leading to icing events, was estimated from the amount of water infiltrating the snow and then freezing, and while the data are not refined to a fully satisfactory extent or able to be calibrated (R. Dankers pers. comm.), they suggest a realistic pattern. The optimum and pessimum were the lower and upper limits of the refreezing index scale.

3.2 Habitat Assessment Results and Discussion

Simplified results showed that, in general, environmental changes were negative or neutral on reindeer in the BALANCE herding region. Positive exceptions are frequency of snow depth (throughout the region), summer wind (northern Norway), winter wind (northern Norway and also Sweden and Kola Peninsula, Russia), the October refreezing index (primarily Russia) and vegetation (most of European Russia). Factors were combined in four weighted average models (Figure 6.2): A assigns equal weight to all factors; B weights winter re-freezing more heavily than the other factors; C includes only factors that show an increased suitability; and D none of the factors in C. Models A and B are simplest and make the fewest assumptions while C and D serve as estimates of the extremes of habitat shifts. Results of all factors combined suggest that effects will be negative generally in Sweden and northernmost Norway and Finland and the northeastern NAO. Other regions in Russia yield a tendency to positive trend in reindeer habitat. Overall there is an increasing positive habitat trend from western Scandinavia into the eastern NAO and Ural Mountain region. Not all variables were equal in their roles. Vegetation, not surprisingly, was more highly correlated with reindeer habitat than any of the others. If assessing only this factor, similar trends were derived, with Russia being the only part of the BALANCE region showing a positive result (+10%) for reindeer herding, and an overall decrease across the BALANCE region of 25% (Rees et al. in press).

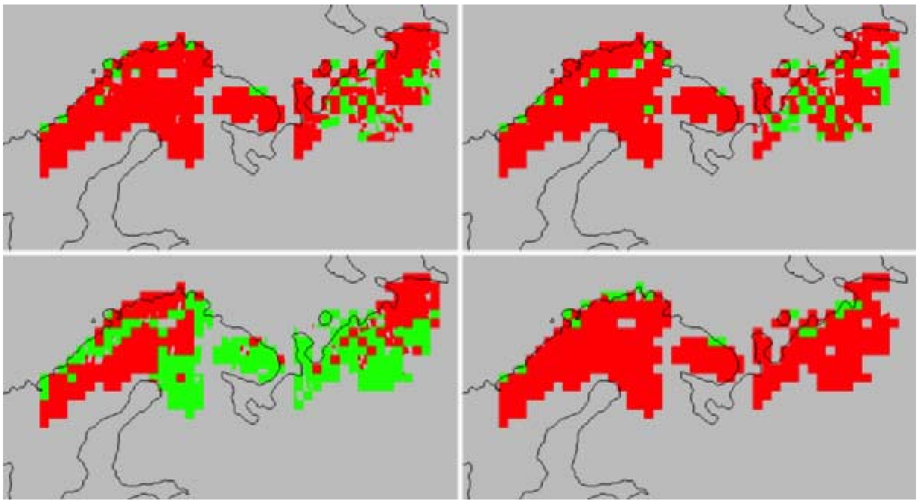


Figure 6.2. Results of the four weighted average habitat assessment models that combined all habitat factors to show potential impact on habitat between present (1990) and 2080. Green signifies increase (more favourable), medium grey no change and red a decrease (less favourable). (clockwise from top left: models A through D)

The approach which incorporates modelled complex feedbacks is novel and valuable in its attempts to relate multiple habitat factors in a predictive way that incorporates multiple feedbacks. Techniques were innovative and results interesting from a broad perspective. However, as discussed in Chapter 5, at coarse scales, information relevant and critical to reindeer habitat is generally lost. While the results of this habitat assessment may show some overall trends, details cannot be elucidated or determined at such a coarse scale of analysis and with the roles of micro-topographic effects and influences of vegetation heterogeneity on habitat, this is necessary for a thorough assessment. As climate related shifts are likely to develop, understanding of habitat uses and needs will become even more important in the survival and long-term viability of reindeer herding.

Specific problems with the vegetation component include the fact that lichen modelled accuracy was low and that changes in shrubs over the ninety-year model period were effectively obscured by shifts in tree species. The exclusion of lichens from known areas (such as our study area) is probably a consequence of two factors, scale and the eco-modelling approach used by A. Wolf: lichens are difficult to include in a coarse model given their patchy and limited distribution in the landscape; and the modelling approach methodology was not lichen-specific and lichen is thus hidden by other vegetation that prefers similar environmental growth conditions. The hidden transformation of tundra to shrubs and then trees is particularly relevant to both reindeer habitat and climate change, and to assume the colonisation was by trees only would be a grave error in understanding vegetation shift dynamics. The fact that the shift to trees occurs so quickly could be an indication of the potential for climate related change in the Arctic due to ecological conditions being met. However, biological mechanisms and conditions such as dispersal and growth must also be considered (Sveinbjörnsson et al. 2002). In terms of other habitat factors, the coarse scale is also an issue for snow and ice data and modelled refreezing events, given the microclimate influences on these landscape characteristics and the habitat suitability implications.

While the BALANCE habitat model is a valuable first examination of what changes the Barents region may face, data are coarse and inaccurate and probably not entirely reliable. However, with this start, the potential for continued advancement and development that will improve upon this initial attempt should be great and in time with better data access and computing power, more sophisticated assessments will be possible. Benefits of this research include the innovative incorporation of feedback mechanisms and the dynamic nature of the models, allowing re-development and improvement in accuracy and scale.

4. FUTURE DEVELOPMENT OF HABITAT ASSESSMENTS

Much potential exists for development of high quality, thorough habitat assessments with an understanding of key habitat factors and the appropriate data. As demonstrated by Lundqvist (submitted), complex, multi-factor analysis of habitat characterisation is possible already in certain regions, primarily Scandinavia. At this stage, given the potential for technical and other data advancement and the limited complete habitat assessments that have been developed and thus the gaps in understanding, value is not limited to future-based models only. Current in-depth models would be of equal worth. Various types of models would be valid, in particular habitat suitability types that can incorporate and weigh a wide variety of factors in user-defined ways would be ideal.

Potentially the single-most important factor to address in habitat assessment is scale. When considering reindeer habitat, relatively fine-scale assessment is highly valuable (as discussed in Chapter 5), and in consideration of certain factors such as detailed forage, required. Thresholds of utility exist. For example, AVHRR data at one-kilometre resolution do not provide adequate vegetation community detail to yield a detailed seasonal understanding of habitat use, but may still be useful for a very generalised assessment, particularly given reindeer's large, seasonal movements. A coverage like CAVM is of little use even for broad seasonal assessment given the lack of detail and coarser resolution or scale.

A variety of improvements are necessary in developing a satisfactory, dependable habitat assessment. Capacity exists for high quality, detailed vegetation data with potential for considerable coverage in addition with the advent and increasing availability of high resolution satellite sensors. Climate data in particular, however, need significant improvement. Temperature data should ideally be frequent, daily at least with maxima and minima and preferably measured at surface and in the air, (relevant for both snow and ice cover and vegetation). Winter temperature primarily relates to snow cover while summer is related to insect harassment, vegetation and reindeer condition. Snow cover data are also critical. Depth and hardness measurements would ideally be available and an index related to fluctuating temperature applied in addition (*e.g.*, Lundqvist submitted). Snow modelling is perhaps the most difficult of habitat factors to quantify in detail and with confidence but efforts are being made in this field, particularly in regard to blowing snow models (Pomeroy et al. 1997, Pomeroy & Li 2000, Liston & Sturm 2002). While key habitat factors have been outlined here, potential exists for including others of course, for example, terrain ruggedness (Nellemann & Thomsen 1994, Nellemann & Fry 1995) and associated topographic data such as slope, aspect and basic elevation data. An in-depth examination of specific habitat needs would be a valuable exercise as a precursor to habitat model development.

Significant regional discrepancy in the state of data exists in the circumpolar north, limiting current potential for detailed expansive and regional efforts at this time. It is imperative to begin to try to fill in existing basic data gaps. In Scandinavia, high quality environmental data are generally available throughout the region. Detailed topographic maps and vegetation maps, even reindeer-specific vegetation maps (County Administration Boards, 2000) exist and such data are kept current; *e.g.*, vegetation mapping in Norway is currently being re-examined and updated (Johansen & Karlsen pers. comm.). Climate data are available, broad in both selection of data types and in sampling locations. This level of detail makes innovative, complex analysis attempts possible, such as those involving small-scale temperature shifts or changes in ice cover characteristics (Lundqvist, submitted). Similar efforts are impossible currently for Russia where substantial data gaps exist still: basic data are out of date, not readily accessible or lacking altogether and detailed data are even more sparse. Research efforts from this project have improved the situation for a region of the NAO at least and a habitat assessment could now be developed for this region on a level previously not possible.

Habitat characteristics of other fauna may allow development of sufficient habitat suitability models in Arctic Russia, even currently. For example, mapping muskox habitat following methodology developed for Alaskan populations (Danks & Klein 2002) would in fact now be possible with the existence of a Landsat-based vegetation map and digital topographic maps that can be modified into elevation and other related topographic characteristic maps. Reindeer, however, with their incompletely understood, complex environmental and ecological interactions present a more difficult case particularly if data are limited. Certain data do exist or would be possible to create. As shown in Chapter 4, vegetation map development is possible and a classification now exists for a small portion of reindeer herding territory in the NAO. Some effort, however, would be required to expand this but it is not infeasible. In addition, digital topographic maps are available for Russia. From these maps it is possible to develop Digital Elevation Models (DEMs) and from DEMs other topographic data such as slope, aspect or ruggedness values (Nicholson et al. 1997) as applicable.

Other data currently remain more difficult to develop or are unavailable, in particular detailed climate data falls into this category and remains a problem. While in Scandinavian regions, operational climate stations are plentiful and resultant data abounds, in Russia climate stations are infrequent. Many have been decommissioned since Soviet times. Type and frequency of data collection are also more limited. Snow and ice have been described as critical factors in winter habitat suitability: where climate stations are plentiful statistical techniques such as kriging can be employed to develop relatively accurate climate values for an entire region, again as developed by Lundqvist (submitted). Where stations are sparse, techniques such as this are impossible as error would simply be too high. Models can be developed alternately, as employed in the BALANCE assessment; however, scale, accuracy and level of detail are an issue. Given the wide range of climate factors and snow properties that influence snow and ice layer characteristics and firnification, the processes are complicated for large or coarse scale assessments. Current limited climate data availability significantly hampers development of detailed, reliable habitat assessments. Satellite remote sensing is, however, an option for providing widely applicable climate data. More specifically, AVHRR has been shown to derive approximations of conditions (Goward et al. 1994), thermal sensors detailed temperature information (Lo et al. 1997) and microwave and radar data potential for snow depth and other characteristics (*e.g.*, Bruland et al. 2001, Mote et al. 2003). On a global scale, however, microwave satellite observations are not sufficiently refined for more than qualitative application due to limitations of coarse resolution (Cordisco et al. 2006).

An ideal reindeer habitat assessment would be produced on a detailed scale, even more detailed or similar to that of the Landsat-based vegetation map produced in Chapter 4, although currently such assessment would necessarily be limited in coverage due to time and cost restraints and current data availability. To begin, coarser assessments are more realistic, on the order of one kilometre resolution, particularly if covering a substantial area such as all or part of the Barents region. Essential data to be included are vegetation, snow and ice cover characteristics, climate data such as wind effects, temperature details and precipitation (as it affects snow and ice).

Computing power is increasing all the time and providing data gaps are filled, and data technology advances, the future will bring the advent of more detailed and improved studies across broad circumpolar regions. The BALANCE computer model could not process data in any more detail than 0.5 degree although 1/6 of a degree was the hope. In time, even more detailed resolutions than 1/6 of a degree will be possible, allowing analysis of the effects of and responses to climate change. Another consideration of the future, aside from the increasing availability of data is the sophistication of it and the invention of new data types, particularly in remote sensing. The lack of climate data may be solvable not by traditional meteorological data but by improved satellite sensors. MODIS and AVHRR data have transformed our abilities in recent years for landscape and ecological analysis; there is substantial potential for the equivalent new technology down the road to do just the same. Modern data are likely to play a significant role in assessments of the future given the greater flexibility, possible expansion of territory and coverage of large areas with little additional effort compared to traditional field-based, time-intensive data. Traditional data will still have their role, however: aspects of them cannot be replaced.

There are clear advantages in being able to examine habitat and models across a broad region so dominated by reindeer but with widely varying characteristics. However, substantial detail is lost and given the complexities of both habitat determination and climate change effects, overall value is decreased in such a broad examination. Ideally a model on a more detailed level should be developed. However, the attempt made as part of the BALANCE project was a start and a novel examination. Subsequent research can focus on increasing detail and therefore accuracy and utility. As mentioned previously in Chapter 5, the BALANCE level of analysis has the advantage of covering nations and regions with substantially different reindeer herding regimes and habitat qualities that may be differently affected by climate change.

5. CONCLUSIONS

The habitat assessment presented here provides an interesting new approach to the examination of reindeer habitat, particularly with the incorporation of climate change effects on the environment and multiple feedbacks. In addition to the positive qualities, it outlines existing shortcomings and develops more detailed, appropriate suggestions for future research improvements. New approaches, despite weaknesses or faults, are beneficial, at the least in providing a platform from which to improve. The BALANCE habitat assessment contribution is one such example. Future studies can be more refined and results more useful. A relevant scale must be chosen and applicable data developed or incorporated. Reindeer ecology is particularly complex and adequate habitat assessments will reflect this.

Reindeer habitat studies require input of a variety of critical environmental factors, such as vegetation, snow and ice cover, wind and other climatic variables, making analysis complex. Addition of feedback mechanisms adds utility but also complexity and challenges. Current data gaps and extremely limited availability of fine-scale data prevent adequate habitat assessments and models in Russia, for example. Data availability in Scandinavia, however, is vastly improved and detailed habitat assessments in this Barents region show promise.

Of additional concern in regions of reindeer herding is the political and socio-economic situation. Included in the BALANCE habitat assessment was also a social science component. The results of both the natural and social science components in fact suggested that socio-economic factors have greater potential for influencing herding, at least in the short term. Climate change effects will necessarily take time to be of influence but certain government decisions can have an immediate impact. A recent event which has proven this conclusion true is the collapse in summer (2006) of the Vyucheiskii Kolkhoz reindeer administration due to bankruptcy (Chapter 2, Section 3.1.2.1), ironically a few months after the SPRI team had drawn these conclusions. The future of the Kolkhoz is uncertain and what will happen to all of the herders and their deer is not known. Just as climate change is unpredictable, so can be other more ‘definable’ factors.

CHAPTER 7 - CONCLUSION

> "The truth is that we have never conquered the world, never understood it; we only think we have control. We do not even know why we respond in a certain way to other organisms, and need them in diverse ways so deeply."
>
> Edward O. Wilson, *Biophilia*

1. SYNOPSIS

This research focuses on the Vyucheiskii Kolkhoz in the NAO, an under-studied region of northern European Russia but also addresses topics of relevance to the entire Barents region and indeed the circumpolar Arctic: reindeer habitat and the potential effects of climate change. A multi-scale approach to landscape assessment in the study area is adopted, with development of relevant data at three scales 1) fine-scale traditional field-based botanical analysis, 2) intermediate-scale moderately high-resolution satellite-based vegetation classification, and 3) coarse-scale data in the form of global or circumpolar landcover maps and a Barents Region vegetation model.

A detailed descriptive assessment of the study area was initially completed (Chapter 3), based on fieldwork and development of observational knowledge of the landscape and local environment, their influences on vegetation, and the vegetation communities themselves. It is supplemented by photographs illustrating more clearly the characteristics of the local landscape. This assessment is of substantial use for improved understanding of the botanical and vegetation classification data developed subsequently.

The fine-scale botanical analysis data illustrate the statistical relationships between vegetation classes, and quantitatively define key vegetation species or species groups responsible for differentiating vegetation community types (Chapter 3). In addition, the role of environmental characteristics in establishing vegetation community separation can be determined. Further and future botanical analyses may allow potential effects due to grazing influences or possible climate change to be observed.

The intermediate-scale vegetation classification developed from thirty-metre Landsat ETM+ satellite sensor imagery provides spatial representation of the community data defined in the botanical analysis (Chapter 4). The accuracy could not be determined in a traditional way using additional field data due to data collection limitations. Therefore, a number of other unsupervised, supervised and hybrid classifications are developed which yield similar patterns of vegetation in the landscape.

Relevant coarse-scale vegetation data (existing maps and a model developed coincident with this thesis research) are included and an examination of the three primary scales of landscape assessment is presented (Chapter 5). The focus is on general benefits and weaknesses of the various levels of data scale and, more particularly, on relevance and utility to reindeer habitat assessment and climate change. Key factors to consider are appropriateness of scale, level of detail, coverage and effects of error or spectral confusion in the data.

In the final chapter, the focus turns more specifically to reindeer habitat and potential consequences of climate change (Chapter 6). The landscape assessment theme is expanded to address not only vegetation but also other critical reindeer habitat factors. A recent habitat model developed coincident with this thesis involving a team of scientists including the author is presented and assessed. Results from this habitat assessment are not definitive but this avenue of modelling research is likely to become increasingly important as effects of change are felt, awareness of the likelihood of change grows and computing potential continues its rapid improvement.

2. SUMMARY OF DEVELOPMENTS

This thesis develops and brings together for comparison multi-scale ecological landscape assessments, including detailed botanical and spatial vegetation community distribution data. Focus is on reindeer habitat and climate change. It eventually broadens the focus, considering a range of relevant reindeer habitat factors. Through this research approach, key questions set out in the introduction (Chapter 1 Section 3) are answered.

2.1 Landscape Characteristics

Landscape characteristics of the study region are detailed and defined using qualitative and quantitative methodologies. Regional patterns of vegetation distribution in the Vyucheiskii Kolkhoz region are heavily influenced by its surrounding landscape and associated influences. These include: the vast delta of the Pechora River and the smaller but not insignificant delta of the Neruta River; the defined Nenets Bank ridgeline (about 100 metres in elevation) located between the two river plains; surrounding low relief tundra; and, in the north, a heavily mosaiced pattern of lakes and vegetation patches, some subject to coastal, marine influences. Wet, rich vegetation types are generally found in low lying, poorly drained areas, and drier types in elevated better-drained areas. Upon closer examination, it is determined that micro-scale topographic and environmental influences heavily influence vegetation patterns on a finer scale. Heterogeneity is pronounced and vegetation communities are heavily mixed within the landscape. Patch size is as small as a few metres but can extend to more than 500 metres in diameter in rare cases.

Heath vegetation dominates the tundra zone and is the most diverse with various, distinct moist and dry types. Lichen and shrubs, key species in quantitative community separation, and in examinations of climate change and reindeer habitat may or may not be present in heath communities. Shrub stands (and trees found further south) form their own communities, and other primary vegetation types are mires, herb slopes, grassland, exposed vegetation and mixed complexes. In quantitative botanical assessment, deciduous shrubs, lichen, forbs, graminoids and grasses were important in community separation. Environmental influences such as moisture and conditions of exposure also differentiate vegetation communities. Vegetation community distribution in this region appears particularly heterogeneous compared to other regions of Arctic tundra and is certainly different from much of the North American landscape. The species composition of the communities, however, appears typical of Arctic regions and the species richness is as expected given botanical studies in other regions of Russia.

Another key influence on the region is reindeer. Grazing by reindeer has influenced the landscape in noticeable ways. Large corral areas (greater than 100 metres in diameter) are devoid of vegetation and the surrounding landscape is heavily affected, dominated by grass species. Differences in lichen presence and absence in the tundra are noticeable in unused and used pastures. Research so far has not assessed the effect that grazing might have on shrub vegetation. Climate change is also believed to impact vegetation, but no assessment has been made yet in the study region. With the development of baseline data for the Vyucheiskii Kolkhoz this now becomes possible. It is interesting to note that shrubs, lichen and grass are important in statistical community analysis. These vegetation types play critical roles also in habitat determination and assessment of climate change effects. Additional quantitative analysis may detail changes or interesting trends.

The detailed botanical species determinations and community descriptions represent entirely new data. While the methodology or technology are already established, this research provides a unique contribution, not only because it was conducted in a location that is difficult to access and in which limited study has been previously undertaken, but also because of the foundation it provides for the application of new scientific and research techniques. Technology is becoming more accessible; the likelihood of using spaceborne data is increasing; and the types of data utilized and questions that can be answered by satellite imaging likewise increasing. The value of ground data is therefore paramount, particularly when assessing initial attempts at new remotely sensed data.

2.2 Assessments of Scale

Scale was compared on three primary levels: fine-scale detailed botanical analysis, intermediate-scale (in this case Landsat-based) vegetation classification, and coarse-scale regional and global vegetation coverages.

The multi-scale assessment of landscape data provides valuable information, highlighting advantages and disadvantages of various scales of analysis and demonstrating that landscape can be assessed on wide-ranging levels, from species-specific (about 300 m^2) with highly limited spatial coverage to global or broad regional levels with generalised detail in expansive coverage. Scale suitability depends on the research focus and the specific information required. Fine-scale analysis will provide the most detail, resolving at the smallest unit possible in the landscape. This level of understanding can inform about specific species presence or shifts in the landscape. Important downsides, however, include the lack of spatial coverage and difficulty in expansion of data. If spatial understanding is required, technical satellite or other remote sensing data are most suitable. The tradeoff is the loss of detail, which may or may not be relevant to the purpose at hand. The coarsest scale assessment data, while lacking detail, often reveal regional trends that otherwise remain hidden in assessments covering smaller areas. In general, selection of assessment scale is highly purpose-specific.

If considering climate change, the three primary scales of assessment are useful, each providing different information. The botanical analysis level allows examination of rare plants and other specific species absence or presence determination. The intermediate level of landscape assessment achieves a compromise between detail and coverage and allows specific community information to be known in a spatial distribution. It is only at broad, regional scales that certain general patterns might be observed. Regional differences lack substantial detail, however and have limited, specific purpose, showing only generalised trends in potential climate changes for example.

When assessing reindeer habitat, suitability criteria for scale are far more rigorous: habitat is closely tied to specific and seasonal vegetation types. Sufficient vegetation community information must be contained within the spatial assessment for it to be of value. The most detailed botanical analysis level is useful in terms of providing appropriate species information; however, the lack of spatial transformation of the data weakens its usefulness. The intermediate- level detailed Landsat vegetation map appears to be the most suitable for habitat assessment. Sufficient detail is present at a scale that is meaningful in habitat selection, and a broad region is included adequately covering habitat areas. Broad global or other coverages are significantly less valuable due to insufficient spatial- and spectral-resolution, loss of important detail and potential spectral confusion if classification is too generalised over a wide variety of vegetation types. The broad level assessments are of use in assessing regional environmental trends that may impact reindeer but they do not allow analysis of reindeer habitat specifically.

The Landsat ETM+ satellite sensor imagery based, 30-metre resolution vegetation classification ultimately mapped twenty-six separate vegetation or landcover types. Importantly, the classification includes coverage of shrubs and lichens – vegetation types of established importance in the assessment of climate change and reindeer habitat suitability. It is concluded that the classification was appropriate for these research purposes. There is room for modification and application of refinement techniques to the classification should it be required for specific purposes. The impossibility of collecting enough data for a traditional accuracy assessment necessitated comparison with other classification methodologies instead. Results were similar amongst all efforts, lending credibility to the detailed classification.

Overall, the Landsat-based level of assessment developed as part of this research appears to be the most flexible and provides widely suitable data for the purposes of both habitat assessment and potential climate change detection. Its value flows from its compromise between detail, scale and coverage, ease of potential further development and ability to assess both detailed species- or community-specific habitat needs and more general potential effects due to climate change. The fine-scale botanical data are relevant to both reindeer habitat and climate change analysis if highly specific species-level assessment is desired, but potential utility is limited by lack of a true spatial component and highly restricted coverage, expansion of which is realistically infeasible.

As a consequence of this research, a clearer understanding has been gained of the value and representation of different landscape scales in the region: in this case, primarily the Vyucheiskii Kolkhoz, but ranging from the specific territory of the Fifth Brigade to the larger Barents Region, and with particular focus on the issues of climate change effects and reindeer habitat suitability.

2.3 Habitat Analysis

In addition to vegetation, factors determined to be critical for habitat suitability and assessment include: snow and ice, water, wind, temperature, insects, predators, and other land use and infrastructure, i.e. anthropogenic influences. The role of each factor varies according to region, climate, season and specific regional or national reindeer herding environment. Snow and ice are probably the most critical factors other than vegetation, with the potential for unsuitable conditions to decimate an entire herd.

The value of the BALANCE model assessment lies in the inclusion of climate, vegetation and hydrological feedbacks in a complex model, the resulting multi-temporal future time-slice assessment and its attempt to cover a broad region throughout which such habitat information is highly valuable. However, due to current logistical, technical and computing limitations, data are too coarse for a detailed habitat assessment, although on a broad regional level, predicted trends have value in suggesting potential future scenarios worth considering.

Habitat analysis is complex, requires in-depth analysis of detailed and varied data, and is complicated by changing seasonal requirements and environmental characteristics. In addition, ecological interactions and bi-directional relationships of reindeer with their environment add additional complication. Teasing apart the role of reindeer in affecting vegetation and the role of vegetation in affecting reindeer is not easy. With potential for climate change effects, the picture becomes more complicated. Limited research has been done in terms of complex multi-data source habitat assessments and there is room for advancement. Progress in terms of understanding the roles of reindeer, climate and natural fluctuations in affecting habitat would be particularly beneficial. An additional valuable advancement would be the development of data or a model that covered a large area while maintaining a fair amount of detail. Currently, data availability and the feasibility of such fine-scale coverage expansion limit this potential. While 1-km resolution data are widely available, and on a spatial scale such data are fine, current restrictions in entrained detail limit the potential applicability to detailed habitat studies.

Detailed habitat assessment is not yet possible for many Arctic regions due to data gaps and limitations although the situation is improving with increased availability and advancing technology (in Fennoscandia for example). Prior to complex assessment, however, basic assessment is critical and still lacking in certain regions. Data provided by this project allow such foundational basic assessment and they provide the opportunity for more advanced future examination in a region for which a lack of data has limited virtually all assessment. Both the botanical data and the mapping data should be of significant applicability to examinations of reindeer habitat, climate change effects and other broad-ranging research topics. With hopefully continued development of data more complex habitat examination will be possible, leading to improved understanding of the important and complex ecological dynamics of reindeer in the Arctic.

3. CONSIDERATIONS FOR THE FUTURE

The issue of reindeer habitat suitability is particularly complex; factoring in potential, unknown effects of climate change on the landscape makes it more so. In turn, the understanding of potential implications of climate change is complicated by the role that reindeer play in altering vegetation and the landscape, not only through grazing but also by manuring and trampling. Teasing apart the ecological components of this dynamic system remains a challenge. Efforts to better understand the components individually and as they interact must continue to ensure stability of the reindeer grazing system in a changing environment.

When considering herded reindeer, an extra, critical dimension must be considered, that of the socio-economic and political environment. The distinction between the relative importance and influence of ecological versus socio-economic and political factors for wild versus semi-domesticated reindeer and the consequences of human influence must be considered. In wild systems, reindeer, while perhaps subject to nature’s laws and whims, govern themselves. However, in herded systems, the government determines pasture use and population numbers by setting laws and regulations, creating a system subject to fluctuations in political climate. Furthermore, the differences between ecological and political or socio-economic timescales are significant. While the precise rate of ecological change is unknown, events will occur on an extended, multi-decade timescale. The political or socio-economic environment, however, can shift rapidly with significant changes occurring over a few years or even months, with immediate effects on the reindeer herding system. In a stark illustration of this point, in July 2006 the Vyucheiskii Kolkhoz administration went bankrupt and no longer exists. Herders have been left without the governing body that has provided all the rules and regulations that affect their livelihood and they must now deal with the consequences, finding ways to maintain their herding way and means of subsistence. Any consideration of climate change effects in the future is currently, necessarily, far less relevant from the herders’ perspectives. While the details of the human influenced political and socio-economic systems are beyond the scope of this research, the implications must necessarily be considered if dealing with herded populations.

Improved understanding of the ecological complexity of reindeer systems must still remain a priority, however, with a number of studies already suggesting that reindeer husbandry has the potential to be adversely affected by climate change (Gunn 1995, Gunn & Skogland 1997, Weladji & Holand 2003, ACIA 2005). Now that basic data have been generated by this research additional analyses are possible and advanced understanding of the study region can begin to be developed. Further analytical improvements are possible: additional analyses can be conducted on the botanical data and there is room for beneficial and specific refinement of the satellite vegetation classification. With hopeful future development of data more complex examination will be possible, leading to essential and improved understanding of this complex Arctic ecological system and critical reindeer habitat and climate change components.

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APPENDICES

“Sooner or later, we sit down to a banquet of consequences.”

Robert Louis Stevenson

APPENDIX 1

Example of Vegetation Analysis- Data & Information collected at each site (x75)

A) General information and details collected at each analysis site

SITE ID	04-04	04-04
TRANSECT (a / b)	a	b
DATE	2004-07-27	2004-07-27
PLANT COMMUNITY	LOW EMPETRUM BETULA HEATH w CALAMAGROSTIS	LOW EMPETRUM BETULA HEATH w CALAMAGROSTIS
GPS- UTM N	0574823	0574812
GPS- UTM W	7562612	7562627
WAYPOINT	110	110
ASPECT	S	S
TERRAIN (1-3, flat-steep)	1	1
SOIL (1-3, dry - wet)	1	1
AVE. HEIGHT (cm)	10	10
FILM/PHOTO (roll-photo #)	7 - 15	7 - 15
KEY VASCULAR SPECIES	Emp nig. Bet nan. Sal spp. Vac vit. Arc alp. Vac uli.	Emp nig. Bet nan. Sal spp. Vac vit. Arc alp. Vac uli.
OTHER SPECIES	Grass spp. Moss. Equisetum sp. Carex sp.	Grass spp. Moss. Equisetum sp. Carex sp.
NOTES	/	/

All GPS coordinates are in WGS 84 datum, UTM UPS, zone 39W

B) Percent cover data

TRANSECT 1	FRAME					
SPECIES	**1**	**2**	**3**	**4**	**5**	**6**
Arc alp	5	1	0	0	0	0
Emp nig	50	40	10	15	30	40
Vac uli	0	0	0	0	2	3
Vac vit	10	10	3	5	10	5
Bet nan	5	0	10	10	7	25
Sal sp.	0	10	10	2	0	0
Cal lap	13	7	5	2	1	2
Fes ovi	0	1	2	3	1	1
Car big	0	2	2	5	3	3
Equ arv	1	2	1	1	5	5
Ped lap	0	1	0	0	0	0
Pet fri	0	0	1	0	1	1
Pol viv	1	1	1	15	1	1
Ste sp.	0	0	0	0	0	0
Moss spp.	5	15	50	35	35	8
Bare	5	5	2	1	1	1
Litter	5	5	3	6	3	5

TRANSECT 2	FRAME					
SPECIES	**1**	**2**	**3**	**4**	**5**	**6**
Arc alp	0	1	1	1	1	1
Emp nig	10	25	40	45	45	35
Vac uli	0	0	10	0	5	5
Vac vit	5	10	15	10	15	15
Bet nan	1	5	10	5	5	10
Sal sp.	0	3	0	10	7	0
Cal lap	1	3	5	5	7	2
Fes ovi	5	2	1	1	2	2
Car big	2	0	0	5	0	5
Equ arv	10	10	5	5	5	5
Ped lap	0	0	0	0	0	0
Pet fri	0	0	0	0	1	0
Pol viv	5	1	2	1	2	3
Ste sp.	0	0	0	0	1	0
Moss spp.	41	27	5	8	1	13
Bare	15	10	4	2	2	2
Litter	5	3	2	2	1	3

C) Point hit data

Transect 1 (a)					
Frame 1	Emp nig	litter	Vac vit	Arc alp	Cal lap
	Vac vit	Vac vit	Equ arv	moss	moss
	Emp nig	litter	moss	Emp nig	bare
	Vac vit	Emp nig	Emp nig	moss	Emp nig
	Cal lap	Bet nan	litter	Emp nig	Emp nig
Frame 2	Emp nig	Car big	Emp nig	Sal sp.	Sal sp.
	Fes ovi	Car big	moss	Sal sp.	Vac vit
	Emp nig	moss	Car big	Emp nig	Ped lap
	Sal sp.	moss	moss	Vac vit	Car big
	Emp nig	moss	moss	Pol viv	Equ arv
Frame 3	Sal sp.	Bet nan	Emp nig	Emp nig	Fes ovi
	Cal lap	Sal sp.	moss	moss	litter
	moss	Sal sp.	moss	litter	Emp nig
	litter	Fes ovi	Car big	Car big	moss
	moss	moss	Bet nan	Bet nan	Emp nig
Frame 4	Fes ovi	Fes ovi	Cal lap	litter	Bet nan
	Emp nig	Emp nig	Bet nan	Fes ovi	Emp nig
	Sal sp.	moss	moss	moss	moss
	moss	Equ arv	Pol viv	Fes ovi	Litter
	litter	Car big	Emp nig	Pol viv	Car big
Frame 5	Bet nan	Car big	moss	Emp nig	Cet whi
	Emp nig	Bet nan	Vac vit	moss	Vac vit
	Car big	moss	litter	Vac vit	moss
	Equ arv	Pol viv	Pet fri	moss	Equ arv
	Equ arv	moss	moss	Equ arv	litter
Frame 6	Emp nig	Emp nig	Emp nig	Vac vit	Vac vit
	Vac vit	Car big	Bet nan	Bet nan	Bet nan
	Bet nan	Bet nan	Car big	Pet fri	Emp nig
	moss	Cal lap	Bet nan	Equ arv	Emp nig
	bare	Bet nan	Bet nan	moss	Emp nig

Transect 1 (b)					
Frame 1	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig
Frame 2	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig
Frame 3	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig
Frame 4	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig
Frame 5	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig
Frame 6	Emp nig	Pol viv	litter	moss	Fes ovi
	Vac vit	Vac vit	Equ arv	moss	moss
	Fes ovi	moss	Equ arv	bare	moss
	litter	Equ arv	bare	moss	litter
	Emp nig	litter	Fes ovi	Emp nig	Emp nig

D) Species Abbreviations (used in this example)

- All species names were abbreviated to 6 letters, the first 3 from the Genus and the second 3 from the species part of the Latin name.
- In cases where the species is not identified, sp. was used (or spp. in the case of more than a single unidentified species within the same genus).

ABBREVIATION	FULL SPECIES NAME
Arc alp	Arctostaphylos alpina
Emp nig	Empetrum nigrum
Vac uli	Vaccinium uliginosum
Vac vit	Vaccinium vitis-idaea
Bet nan	Betula nana
Sal sp.	Salix species
Cal lap	Calamagrostis lapponica
Fes ovi	Festuca ovina
Car big	Carex bigelowii
Equ arv	Equisetum arvense
Ped lap	Pedicularis lapponica
Pet fri	Petasites frigidus
Pol viv	Polygonum vivipara
Ste sp.	Stellaria sp.

APPENDIX 2

Botanical Analysis Field Site Data

UTM: WGS 84 Zone 39W; D* = disturbed vegetation

SITE ID		DATE	GROUP	PLANT COMMUNITY	UTM	UTM	WAYPT	ASPECT	TERRAIN (1-4[1])	SOIL (1-3[2])	AVE. HT. (cm)	FILM/ PHOTO	KEY VASCULAR SPECIES	OTHER SPECIES
03-01	a	2003-07-18	Heath Moist	EMPETRUM BETULA HEATH w SPHAGNUM	0572103	7558795	14, 15	S	1	2	7	2.4-3	Emp nig. Bet nan. Vac vit. Arc alp. Sal spp. Rub cha	Sphagnum Grass spp.
03-01	b	2003-07-18	Heath Moist		0572090	7558789	14, 15	S	1	2	7	2.4-4,5		
03-02	a	2003-07-18	Heath Moist	BETULA RUBUS HEATH w SPHAGNUM	0572119	7558736	16	S	1	2	12	2.4-6,7	Bet nan. Led pal. Emp nig. Vac vit. Rub cha	Sphagnum Fruticose lichen
03-02	b	2003-07-18	Heath Moist		0572139	7558750	16	S	1	2	9	2.4-8,9		
03-03	a	2003-07-19	Mire	CAREX ERIOPHORUM MOSS MIRE	0571971	7558309	19	/	0	3	15	2.4-15,16	Eri vag. Car sp. Sal sp. Bet nan.	Moss
03-03	b	2003-07-19	Mire		0571967	7558312	19	/	0	3	15	2.4-15,16		
03-04	a	2003-07-19	Heath Moist	BETULA EMPETRUM LICHEN HEATH w SPHAGNUM	0572035	7558335	20	/	0	1	8	2.4-17,18	Bet nan. Emp nig. Vac vit. Rub cha.	Fruticose lichen Car big.
03-04	b	2003-07-19	Heath Moist		0572023	7558338	20	/	2	2	19	2.4-19		
03-05	a	2003-07-19	Heath Dry	EMPETRUM LICHEN HEATH w CAREX (trampled)	0571592	7558592	21	W	1	1	4	2.4-20,21	Emp nig. Led pal. Vac vit. Arc alp. Bet nan. Rub cha.	Car big. Fruticose lichen Moss
03-05	b	2003-07-19	Heath Dry		0571597	7558599	21	W	1	1	4	2.4-20,21		
03-06	a	2003-07-19	Heath Moist	LEDUM EMPETRUM HEATH w HUMMOCKS & CAREX	0571838	7558622	22	/	0	1	6	2.4-22,23	Led pal. Emp nig. Vac vit. Rub cha.	Car big. Fruticose lichen Eri vag.
03-06	b	2003-07-19	Heath Moist		0571837	7558632	22	/	0	1	6	2.4-24		
03-07	a	2003-07-19	Shrub Low	BETULA HEATH w MOSS	0571896	7558575	24	/	0	1	22	2.4-25,26	Bet nan. Vac uli. Arc alp. Rub cha	Moss
03-07	b	2003-07-19	Shrub Low		0571890	7558576	24	/	0	1	25	2.4-27		
03-08	a	2003-07-20	Heath Moist	ERIOPHORUM TUSSOCKS	0572174	7558513	25	S	1	1	10	3.4-1,2,3	Vac vit. Arc alp. Bet nan. Rub cha. Emp nig.	Eri vag. Car sp. Sphagnum
03-08	b	2003-07-20	Heath Moist		0572166	7558518	25	S	1	1	12	3.4-1,2,3		
03-09	a	2003-07-20	Shrub Tall	TALL SALIX SHRUB w GROUND FORBS & EQUISETUM	0572246	7558415	26	S	1	2-3	200	3.4-6,7,8,16*	Salix spp. Com pal. Forbs	Moss Grass spp. Equ sp.
03-09	b	2003-07-20	Shrub Tall		0572203	7558408	26	S	1	2-3	180	3.4-3,4,5		
03-10	a	2003-07-20	Mire	CAREX MIRE w MOSS (trampled)	0572160	7558406	27	/	0	3	28	3.4-10,12-15*	Salis spp. Com pal.	Car spp. Moss Equ sp.
03-10	b	2003-07-20	Mire		0572151	7558410	27	/	0	3	30	3.4-10,12-15*		
03-11	a	2003-07-20	Heath Dry	EMPETRUM DWARF BETULA DRY HEATH	0571869	7558025	28	WNW	1	1	4	3.4-19,20	Emp nig. Bet nan. Vac vit.Sal spp. Vac uli.	Moss Car big. Fruticose lichen
03-11	b	2003-07-20	Heath Dry		0571863	7558020	28	WNW	1	1	4	3.4-19,20		
03-12	a	2003-07-20	Exposed	EXPOSED SAND CRATER w ERICACEOUS SHRUBS & GRASS	0571830	7557881	29	S	2	1	3	3.4-21,22	Emp nig. Sal sp. Bet nan. Vac vit.	Grass sp.
03-12	b	2003-07-20	Exposed		0571838	7557885	29	S	2	1	2	3.4-21,22		
03-13	a	2003-07-20	Heath Moist	EMPETRUM LEDUM VACCINIUM ERIOPHORUM CAREX HEATH w HUMMOCKS AND TUSSOCKS	0571590	7557840	30	S	1	1-2	10	3.4-25,26	Emp nig. Led pal. Bet nan. Vac vit. Rub cha.	Eri vag. Car big. Moss
03-13	b	2003-07-20	Heath Moist		0571633	7557830	30	NE	1	1-2	9	3.4-25,26		
03-14	a	2003-07-20	Heath Moist	ERIOPHORUM TUSSOCKS	0571455	7557996	31	/	1	1-2	10	3.4-29,30	Led pal. Emp nig. Rub cha. Arc alp.	Eri vag. Moss
03-14	b	2003-07-20	Heath Moist		0571448	7558009	31	SW	1	1-2	10	3.4-29,30		
03-15	a	2003-07-20	Heath Moist	LEDUM EMPETRUM VACCINIUM HEATH w HUMMOCKS	0571457	7557945	32	/	1	1-2	6	3.4-31,32,33*	Led pal. Emp nig. Vac vit. Rub cha.	Eri vag.
03-15	b	2003-07-20	Heath Moist		0571469	7557957	32	/	1	1-2	6	3.4-31,32,33*		
03-16	a	2003-07-21	Shrub Scrub	RIPARIAN SALIX SCRUB w CAREX FORBS & MOSS	0572230	7557890	33	/	1	2	30	5.4-5,6,7 & 4.4-12-15	Sal spp. Com pal. Forbs	Car spp. Moss
03-16	b	2003-07-21	Shrub Scrub		0572225	7557881	33	/	1	2	35	5.4-5,6,7 & 4.4-16		
03-17	a	2003-07-21	Heath Moist	VACCINIUM LEDUM EMPETRUM HEATH w LICHEN	0572270	7557785	34	WNW	2	1	3	5.4-8,9,10 & 4.4-17,18	Vac vit. Led pal. Emp nig.	Fruticose lichen Moss

SITE ID		DATE	GROUP	PLANT COMMUNITY	UTM	UTM	WAYPT	ASPECT	TERRAIN (1-4[1])	SOIL (1-3[2])	AVE. HT. (cm)	FILM/ PHOTO	KEY VASCULAR SPECIES	OTHER SPECIES
03-17	b	2003-07-21	Heath Moist		0572244	7557835	34	SE	1	1	3	5.4-8,9,10 & 4.4-19		
03-18	a	2003-07-21	Shrub Tall	TALL SALIX BETULA SHRUB	0572164	7557733	36	E	1	2	125	5.4-12 & 4.4-20	Bet nan. Sal spp. Forbs	Moss Equ sp.
03-18	b	2003-07-21	Shrub Tall		0572145	7557735	36	E	1	2	150	5.4-12 & 4.4-20		
03-19	a	2003-07-21	Mire	ERIOPHORUM CAREX SPHAGNUM BOG	0572146	7557663	37	/	1	3	12	5.4-13,14 & 4.4-21,22	/	Car sp. Eri vag. Sphagnum
03-19	b	2003-07-21	Mire		0572167	7557643	37	/	1	3	15	5.4-13,14 & 4.4-21,22		
03-20	a	2003-07-21	Exposed	SANDY EXPOSED HILLSIDE w ERICACEOUS SHRUBS	0572309	7557490	39	S	3	1	3	4.5-16,17,18 & 4.4-23,24	Emp nig. Vac vit.	Grass sp. Moss Fruticose lichen
03-20	b	2003-07-21	Exposed		0572320	7557512	39	S	3	1	4	4.5-16,17,18 & 4.4-23,24		
03-21	a	2003-07-21	Exposed	SANDY EXPOSED HILLSIDE w ERICACEOUS SHRUBS	0572337	7557479	40	NNW	3	1	4	5.4-19,20 & 4.4 -25	Emp nig. Vac vit. Bet nan. Arc alp.	Grass sp. Moss
03-21	b	2003-07-21	Exposed		0572336	7557444	40	WNW	2	1	3	5.4-19,20 & 4.4 -25		
03-22	a	2003-07-21	Heath Dry	EMPETRUM ARCTOSTAPHYLOUS VACCINIUM BETULA HEATH w CLAY MOUNDS	0572321	7557263	41	E	2	1	5	5.4-23,24,25 & 4.4-26,27	Emp nig. Arc alp. Vac vit. Vac uli. Bet nan. Sal sp.	Moss Grass sp. Fruticose lichen
03-22	b	2003-07-21	Heath Dry		0572329	7557281	41	S	2	1	5	5.4-23,24,25 & 4.4-28		
03-23	a	2003-07-21	Shrub Low-Med	BETULA SALIX SHRUB	0572350	7557364	42	/	2	2	80	5.4 -21,22 & 4.4 -29,30	Bet nan. Sal spp. Forbs Vac vit. Arc alp. Emp nig. Vac uli.	Grass sp. Moss Equ sp.
03-23	b	2003-07-21	Shrub Low-Med		0572345	7557388	42	S	2	2	80	5.4 -21,22 & 4.4 -29,30		
03-24	a	2003-07-22	Mire	CAREX MOSS MIRE	0572161	7558304	43	/	1	3	30	4.4-34,35,36	Com pal. Forbs	Car spp. Moss Equ sp.
03-24	b	2003-07-22	Mire		0572135	7558315	43	/	1	3	30	4.4-34,35,36		
03-25	a	2003-07-22	Mire	CAREX SPHAGNUM BOG	0572253	7557290	44	/	1	3	22	5.4-26,27,28	Com pal.	Car spp. Sphagnum
03-25	b	2003-07-22	Mire		0572242	7557257	44	/	1	3	25	5.4-26,27,28		
03-26	a	2003-07-22	Heath Dry	LICHEN HEATH w EMPETRUM & VACCINIUM	0572203	7557274	45	NW	1	1	2	5.4-29,30,31	Emp nig. Vac vit. Led pal.	Fruticose & Crusticose lichen Moss Grass sp.
03-26	b	2003-07-22	Heath Dry		0572203	7557258	45	NW	1	1	2	5.4-29,30,31		
03-27	a	2003-07-22	Shrub Low	DWARF BETULA SALIX SHRUB w ERICACEOUS SHRUBS & MOSS	0572174	7557135	46	E	2	2	40	5.4-34	Bet nan. Sal sp. Rub cha. Vac vit. Emp nig. Arc alp. Vac uli.	Moss Grass sp.
03-27	b	2003-07-22	Shrub Low		0572175	7557156	46	E	2	2	40	5.4-32,33		
03-28	a	2003-07-22	Heath Dry	SALIX ARCTOSTAPHYLOUS EMPETRUM HEATH w CLAY	0572192	7557066	47	N	1	1	4	5.2-37 & 7.2-1	Arc alp. Vac vit. Emp nig. Bet nan. Sal sp. Vac uli.	Moss Grass sp. Fruticose lichen
03-28	b	2003-07-22	Heath Dry		0572196	7557087	47	N	1	1	4	7.2-2		
03-29	a	2003-07-22	Heath Moist	ERICACEOUS DECIDUOUS HEATH w HUMMOCKS & SPHAGNUM & MOSS	0572051	7556649	49	S	2	2	10	7.2-8,9	Led pa. Emp nig. Vac vit. Rub cha. Bet nan. Sal sp.	sShagnum Moss Grass sp.
03-29	b	2003-07-22	Heath Moist		0572035	7556657	49	S	2	2	9	7.2-8,9		
03-30	a	2003-07-22	Forb	FORB SLOPE w SALIX	0571996	7556815	50	W	4	2	8	7.2-10,11,12	Ran sp. Orc sp. Chr alt. Alc vul. Other forbs. Sal sp. Arc alp.	Moss Equ sp. Grass sp.
03-30	b	2003-07-22	Forb		0572028	7556806	50	W	4	2	8	7.2-13		
03-31	a	2003-07-23	Exposed	EXPOSED SAND CRATER w ERICACEOUS SHRUBS & GRASS	0575275	7563274	51	N	2	1	4	8.2-1	Emp nig. Vac vit. Vac uli. Bet nan.	Moss Grass sp. Equ sp.
03-31	b	2003-07-23	Exposed		0575263	7563279	51	N	2	1	4	8.2-1		
03-32	a	2003-07-23	Shrub Scrub	DWARF BETULA SALIX SHRUB w TUSSOCKS & MOSS	0575345	7563325	52	E	1	2	30	8.2-2	Bet nan. Sal sp. Rub cha.	Car sp. Eri ang. Grass sp. Equ sp. Moss
03-32	b	2003-07-23	Shrub Scrub		057338	7563328	52	E	1	2	30	8.2-2		
03-33	a	2003-07-23	Mire	CAREX MOSS MIRE	0575342	7563267	53	/	1	3	25	8.2-3	Com pal. Sal sp.	Car sp. Moss Equ sp.
03-33	b	2003-07-23	Mire		0575337	7563286	53	/	1	3	25	8.2-3		
03-34	a	2003-07-23	Shrub Low	DWARF SALIX SHRUB w CAREX & MOSS	0575452	7563438	54	S	2	2-3	50	8.2-4	Sal spp. Com pal. Forbs	Car sp. Moss Equ sp.
03-34	b	2003-07-23	Shrub Low		0575450	7563449	54	S	2	2-3	50	8.2-4		

SITE ID		DATE	GROUP	PLANT COMMUNITY	UTM	UTM	WAYPT	ASPECT	TERRAIN (1-4[1])	SOIL (1-3[2])	AVE. HT. (cm)	FILM/ PHOTO	KEY VASCULAR SPECIES	OTHER SPECIES
03-35	a	2003-07-23	Shrub Medium	MEDIUM SALIX SHRUB w MOSS	0575331	7563629	G5	S	2	2	100	8.2-6	Sal spp. Bet nan. Forbs	Moss Grass sp. Equ sp.
03-35	b	2003-07-23	Shrub Medium		0575342	7563612	G5	S	2	2	100	8.2-6		
03-36	a	2003-07-23	Heath Moist	BETULA SALIX EMPETRUM VACCINIUM HEATH w MOSS	0575157	7563606	56	S	1	2	15	8.2-7	Bet nan. Sal spp. Emp nig. Vac vit. Rub cha.	Moss Grass sp. Car sp. Eri sp.
03-36	b	2003-07-23	Heath Moist		0575146	7563611	56	S	1	2	15	8.2-7		
03-37	a	2003-07-23	Mire	CAREX MOSS MIRE w SALIX	0575076	7563715	57	/	1	3	35	8.2-9,10	Sal spp. Com pal. Forbs	Car sp. Grass Moss Equ sp
03-37	b	2003-07-23	Mire		0575037	7563715	57	/	1	3	35	8.2-9,10		
03-38	a	2003-07-23	Heath Moist	EMPETRUM VACCINIUM BETULA RUBUS HEATH w TUSSOCKS & GRASS	0575110	7566364	58	W	1	2	14	8.2-12	Bet nan. Emp nig. Vac vit. Rub cha. Vac uli. Led pal.	Car sp. Eri vag. Moss Grass sp.
03-38	b	2003-07-23	Heath Moist		0575095	7563641	58	W	1	2	14	8.2-12		
03-39	a	2003-07-23	Heath Moist	RUBUS BETULA EMPETRUM VACCINIUM HEATH w MOSS	0574852	7563659	60	SW	1	2	10	8.2-15	Bet nan. Emp nig. Rub cha. Vac vit	Eri vag. Car sp. Moss
03-39	b	2003-07-23	Heath Moist		0574842	7563663	60	SW	1	2	10	8.2-15		
03-40	a	2003-07-23	Shrub Low	DWARF BETULA SALIX SHRUB w CAREX & MOSS	0574304	7564147	61	/	1-2	2	40	8.2-16,17	Bet nan. Sal sp. Rub cha. Com pal.	Car sp. Moss
03-40	b	2003-07-23	Shrub Low		0574280	7564168	61	/	1-2	2	40	8.2-16,17		
03-41	a	2003-07-24	Exposed	CORRAL	0572705	7558519	63	/	1	1	/	10.2-5	/	/
03-41	b	2003-07-24	Exposed		0572695	7558541	63	/	1	1	/	10.2-5		
03-42	a	2003-07-24	Exposed	EXPOSED SAND w EMPETRUM	0572546	7558350	64	S	2	1	3	8.2-25	Emp nig.	Grass spp.
03-42	b	2003-07-24	Exposed		0572546	7558358	64	S	2	1	3	8.2-25		
03-43	a	2003-07-24	Grassland D*	GRASS W BETULA (trampled)	0572503	7558570	65	SE	1-2	1	15	8.2-26	Bet nan. Emp nig. Rub cha. Vac vit. Led pal.	Grass spp. Moss
03-43	b	2003-07-24	Grassland D*		0572490	7558372	65	SE	1-2	1	15	8.2-26		
03-44	a	2003-07-24	Shrub Scrub	MIXED BETULA SALIX SHRUB SCRUB w MOSS & GRASS (trampled)	0572528	7558531	66	SW	2	1	50	8.2-27	Bet nan. Sal spp. Vac uli. Vac vit. Emp nig. Rub cha. Forbs	Gras spp. Moss
03-44	b	2003-07-24	Shrub Scrub		0572509	7558537	66	SW	2	1	100	8.2-27		
03-45	a	2003-07-24	Heath Moist D*	GRASS w MOSS & EMPETRUM SALIX & BETULA (trampled)	0572599	7558545	67	SW	1	1	4	8.2-28	Emp nig. Sal spp. Bet nan. Vac vit.	Grass spp.Moss
03-45	b	2003-07-24	Heath Moist D*		0572593	7558545	67	SW	1	1	4	8.2-28		
03-46	a	2003-07-25	Heath Moist D*	GRASS FORB SALIX BETULA ERICACEOUS SHRUB HEATH w HUMMOCKS (trampled)	0573001	7558313	68	SW	2-3	2	13	8.2-29,30	Sal spp. Bet nan. Forbs Vac vit. Vac uli. Emp nig.	Grass spp. Moss
03-46	b	2003-07-25	Heath Moist D*		0572979	7558289	68	W	2-3	2	10	8.2-31		
03-47	a	2003-07-25	Heath Moist	LEDUM RUBUS EMPETRUM VACCINIUM HEATH w HUMMOCKS & MOSS (trampled)	0573137	7558098	69	/	1	1-2	7	8.2-32,31*	Led pa. Rub cha. Emp nig. Vac vit. Vac uli.	Grass spp. Moss. Eri vag. Crusticose & Fruticose lichen
03-47	b	2003-07-25	Heath Moist		0573112	7558107	69	/	1	1-2	5	8.2-32,31*		
03-48	a	2003-07-25	Forb	FORB SLOPE w SALIX GRASS & MOSS	0573159	7558233	70	E	3	2	10	8.2-33,34	Orc sp. Pol bis. Ran sp. Other forbs Sal spp.	Grass spp. Moss Equ sp.
03-48	b	2003-07-25	Forb		0573206	7558248	70	E	3	1	7	8.2-33,34		
03-49	a	2003-07-25	Shrub Low	DWARF BETULA EMPETRUM VACCINIUM HEATH	0573206	7558297	71	E	1	1	12	8.2-35	Bet nan. Emp nig. Vac vit. Vac uli. Arc alp. Led pal.	Grass sp. Moss
03-49	b	2003-07-25	Shrub Low		0573201	7558311	71	E	1	1	10	8.2-36		
03-50	a	2003-07-25	Grassland D*	GRASS (trampled)	0572696	7558390	72	SE	1	1	6	8.2-37	Emp nig. Pol bis. Orc sp. Alc vul. Other forbs	Grass sp. Moss
03-50	b	2003-07-25	Grassland D*		0572674	7558416	72	S	1	1	6	8.2-37		
03-51	a	2003-07-26	Exposed	CORRAL	0574971	7563009	81	/	1	1	/	7.2-35-38 & 9.2-17	/	/
03-51	b	2003-07-26	Exposed		0574954	7563027	81	/	1	1	/	7.2-35-38 & 9.2-17		
03-52	a	2003-07-26	Shrub Scrub	SALIX SCRUB w FORBS & GRASS	0574798	7562792	73	S	2	2	50	9.2-2	Sal spp. Bet nan. Rub cha. Orc sp. Polem sp. Ran sp. Other forbs	Grass spp. Equ sp. Moss
03-52	b	2003-07-26	Shrub Scrub		0574792	7562799	73	S	2	2	80	9.2-2		
03-53	a	2003-07-26	Heath Moist	DWARF BETULA SALIX SHRUB w HUMMOCKS & TUSSOCKS & ERICACEOUS SHRUBS CAREX & MOSS	0574168	7563149	G31	N	1-2	2	10	9.2-4	Bet nan. Sal spp. Emp nig. Rub cha. Vac vit. Vac uli.	Moss Eri vag. Car sp. Grass spp. Equ sp.

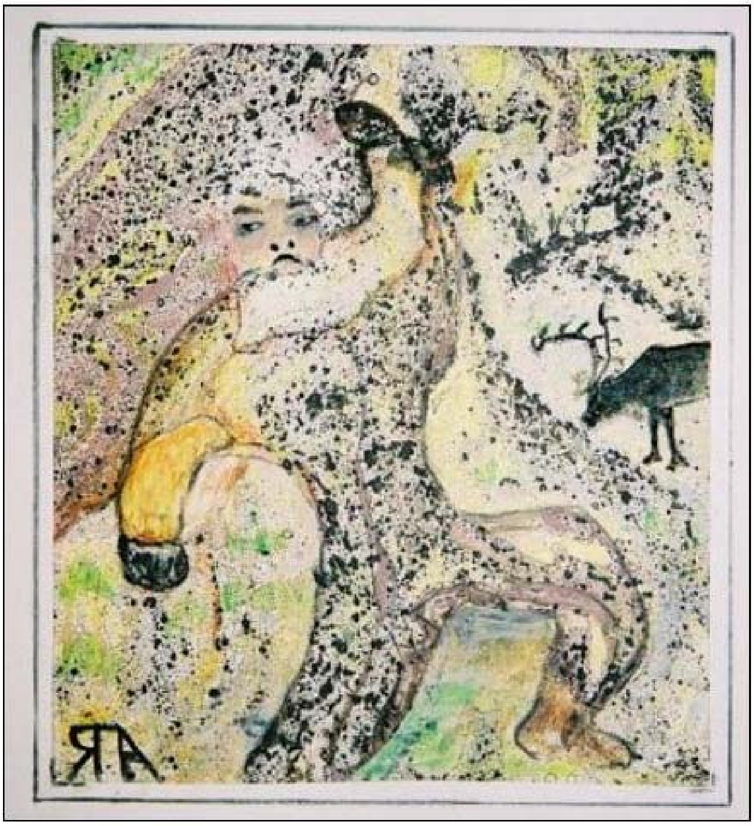
SITE ID		DATE	GROUP	PLANT COMMUNITY	UTM	UTM	WAYPT	ASPECT	TERRAIN (1-4^1)	SOIL (1-3^2)	AVE. HT. (cm)	FILM/ PHOTO	KEY VASCULAR SPECIES	OTHER SPECIES
03-53	b	2003-07-26	Heath Moist		0574155	7563164	G31	N	1-2	2	10	9.2-4		
03-54	a	2003-07-26	Shrub Low	DWARF SHRUB w MOSS FORBS GRASS & EQUISETUM	0574524	7563690	74	WSW	2	2	20	9.2-6,7	Bet nan. Sal spp. Forbs. Emp nig. Vac vit.	Moss Grass spp. Equ sp.
03-54	b	2003-07-26	Shrub Low		0574521	7563696	74	WSW	2	2	40	9.2-6,7		
03-55	a	2003-07-26	Heath Moist	SALIX RETICULATA & MOSS w ERICACEOUS SHRUBS EQUISETUM & GRASS	0574583	7563466	75	S	3	2-3	7	9.2-8,9	Sal ret. Sal spp. Vac uli. Rub cha. Forbs	Moss Equ sp. Grass spp.
03-55	b	2003-07-26	Heath Moist		0574583	7563473	75	S	3	2-3	7	9.2-8,9		
03-56	a	2003-07-26	Mire	CAREX MIRE	0574774	7563205	79	/	1	3	40	9.2-14,15	Com pal.	Car spp. Moss
03-56	b	2003-07-26	Mire		0574776	7563164	79	/	1	3	40	9.2-14,15		
04-01	a	2004-07-20	Heath Dry	LICHEN HEATH w VACCINIUM EMPETRUM & LEDUM	0607083	7513560	29	N	1	1	3	5-12	Vac vit. Vac uli. Emp nig. Led pal. Bet nan.	Cetraria sp. Fruticose & Crusticose lichen
04-01	b	2004-07-20	Heath Dry		0607083	7513560	29	N	1	1	3	5-12		
04-02	a	2004-07-24	Heath Dry	LICHEN HEATH w BETULA EMPETRUM & LOISELEURIA	0570247	7560414	72	NE	1-2	1	2	4-1	Vac vit. Emp nig. Arc alp. Loi pro. Led pal. Bet nan.	Cetraria sp. Fruticose & Crusticose lichen Moss
04-02	b	2004-07-24	Heath Dry		0570247	7560414	72	NE	1-2	1	2	4-1		
04-03	a	2004-07-24	Heath Dry	LICHEN HEATH w EMPETRUM VACCINIUM BETULA ARCTOSTAPHYLOUS & LEDUM	0568601	7561600	T7	/	1	1	3	4-15,16	Emp nig. Vac vit. Bet nan. Arc alp. Led pal. Loi pro. Vac uli.	Cetraria sp. (incl. brown) Fruticose & Crusticose lichen Moss
04-03	b	2004-07-24	Heath Dry		0568601	7561600	T7	/	1	1	3	4-15,16		
04-04	a	2004-07-27	Heath Moist	LOW EMPETRUM BETULA HEATH w CALAMAGROSTIS	0574823	7562612	110	S	1	1	10	7-15	Emp nig. Bet nan. Sal spp. Vac vit. Arc alp. Vac uli.	Grass spp. Moss. Equ sp. Car sp.
04-04	b	2004-07-27	Heath Moist		0574823	7562612	110	S	1	1	10	7-15		
04-05	a	2004-07-27	Heath Moist	LOW EMPETRUM VACCINIUM BETULA HEATH w CALAMAGROSTIS	0575063	7562673	111	SSE	1	1	10	4-15,16	Emp nig. Vac vit. Bet nan. Sal spp. Arc alp. Vac uli. Forbs	Grass spp. Moss
04-05	b	2004-07-27	Heath Moist		0575063	7562673	111	SSE	1	1	10	4-15,16		
04-06	a	2004-07-28	Heath Dry	LICHEN HEATH w EMPETRUM ARCTOSTAPHYLOUS & LEDUM	0566913	7558895	137	S	1	1	3	8-19,30	Emp nig. Vac vit. Arc alp. Led pal. Vac uli.	Cetraria sp. (incl. brown) Fruticose & Crusticose lichen
04-06	b	2004-07-28	Heath Dry		0566913	7558895	137	S	1	1	3	8-19,30		
04-07	a	2004-07-31	Grassland	GRASSLAND w FORBS	0573306	7558002	160	S	2	2	35	10-6	Com pal. Rum sp. Ste sp. Ran sp. Vio sp. Polem sp.	Car big. Grass spp. (Cal lap. Poa pra.) Equ sp.
04-07	b	2004-07-31	Grassland		0573306	7558002	160	S	2	2	35	10-6		
04-08	a	2004-08-04	Shrub Scrub	MEDIUM BETULA SALIX SHRUB SCRUB w CAREX	0602717	7588048	237	/	2	2	40	13-6	Bet nan. Sal spp. Emp nig. Vac vit. Vac uli. Rub cha. And pol. Led pal.	Car rar. Car rot. Equ sp. Moss Sphagnum
04-08	b	2004-08-04	Shrub Scrub		0602717	7588048	237	/	2	2	35	13-6		
04-09	a	2004-08-04	Heath-Mire	BETULA EMPETRUM VACCINIUM RUBUS LICHEN HEATH w HUMMOCKS & CAREX MOSS MIRE DEPRESSIONS	0602340	7587855	236	/	1	2	10	13-5	Emp nig. Bet nan. Vac vit. Vac uli. And pol. Led pal.	Car rar. Car rot. Moss Sphagnum Cetraria (incl. Brown) Fruticose lichen
04-09	b	2004-08-04	Heath-Mire		0602340	7587855	236	/	1	2	15	13-5		
04-10	a	2004-08-04	Mire	CAREX ERIOPHORUM MOSS MIRE	0603389	7588130	238	/	1	3	30	13-7	/	Car rar. Car rot. Car aqu. Eri ang. Eri sch. Moss
04-10	b	2004-08-04	Mire		0603389	7588130	238	/	1	3	30	13-7		
04-11	a	2004-08-04	Heath-Mire	BETULA EMPETRUM VACCINIUM LEDUM RUBUS LICHEN HEATH w HUMMOCKS & CAREX MOSS MIRE DEPRESSIONS	0603814	7588900	239	/	2-3	1-2	5	13-9	Bet nan. Emp nig. Vac vit. Vac uli. Rub cha. Led pal. And pol.	Car rar. Car rot. Moss Sphagnum Cetraria (incl. Brown) Fruticose lichen
04-11	b	2004-08-04	Heath-Mire		0603814	7588900	239	/	2-3	1-2	5	13-9		
04-12	a	2004-08-04	Mire	TALL CAREX MIRE	0604233	7588974	240	/	1	3	100	13-10	Com pal.	Car aqu.
04-12	b	2004-08-04	Mire		0604233	7588974	240	/	1	3	100	13-10		
04-13	a	2004-08-04	Mire	CAREX SPHAGNUM BOG	0604665	7589067	241	/	1	3	10	13-13,14	And pol. Vac vit.	Car rot. Car rar. Sphagnum
04-13	b	2004-08-04	Mire		0604665	7589067	241	/	1	3	10	13-13,14		
04-14	a	2004-08-05	Exposed	EXPOSED SAND CRATER w GRASSES	0601576	7588312	246	S	1	1	2	13-15	Rum ace. Arm sca. Polem sp.	Grass spp. (Koe sp, Agr sp. Fes rup. Luz con.) Jun tri. Crusticose lichen
04-14	b	2004-08-05	Exposed		0601576	7588312	246	S	1	1	2	13-15		
04-15	a	2004-08-05	Exposed	EXPOSED SAND CRATER	0601505	7588473	247	S	1	1	2	13-16	Arm sca. Polem sp. Rum sp.	Grass spp. (Fes sp. Koe sp.

SITE ID		DATE	GROUP	PLANT COMMUNITY	UTM	UTM	WAYPT	ASPECT	TERRAIN (1-4[1])	SOIL (1-3[2])	AVE. HT. (cm)	FILM/ PHOTO	KEY VASCULAR SPECIES	OTHER SPECIES
														Luz con. Poa sp.) Crusticose lichen
04-15	b	2004-08-05	Exposed		0601505	7588473	247	S	1	1	2	13-16		
04-16	a	2004-08-05	Heath Dry	LOW LICHEN HEATH w EMPETRUM ARCTOSTAPHYLOUS LEDUM & BETULA	0601470	7588645	248	W	1	1	3	13-17	Emp nig. Arc alp. Vac vit. Led pal. Vac uli. Bet nan. Rub cha.	Cetraria sp. (incl. brown) Fruticose & Crusticose lichen Grass spp. Car big.
04-16	b	2004-08-05	Heath Dry		0601470	7588645	248	W	1	1	3	13-17		
04-17	a	2004-08-05	Shrub Medium	MEDIUM SALIX w MOSS	0601609	7587863	249	NE	2	2	120	13-18	Sal spp. (incl. hybrids) Bet nan. Com pal.	Moss Car sp.
04-17	b	2004-08-05	Shrub Medium		0601609	7587863	249	NE	2	2	120	13-18		
04-18	a	2004-08-05	Shrub Medium	MEDIUM SALIX w BETULA SHRUB	0601554	7587732	250	/	2	2	100	13-19	Sal spp. (incl. hybrids) Bet nan. Rub cha. Vac uli	Sphagnum Moss Grass sp.
04-18	b	2004-08-05	Shrub Medium		0601554	7587732	250	/	2	2	100	13-19		
04-19	a	2004-08-05	Heath Dry	LOW LICHEN HEATH w LEDUM EMPETRUM VACCINIUM	0601680	587715	251	SE	1	1	3	13-20	Led pal. Emp nig. Vac vit. Arc alp. Vac uli. Bet nan. Loi pro.	Cetraria sp. (incl. brown) Fruticose & Crusticose lichen Moss Grass spp.
04-19	b	2004-08-05	Heath Dry		0601680	587715	251	SE	1	1	3	13-20		

[1] increasing steepness [2] increasing wetness

“What would the world be, once bereft
Of wet and wildness? Let them be left,
O let them be left, wildness and wet,
Long live the weeds and the wildness yet.”

Gerard Manley Hopkins, *Inversnaid*



"Those who contemplate the beauty of the earth find reserves of
strength that will endure as long as life lasts."

Rachel Carson