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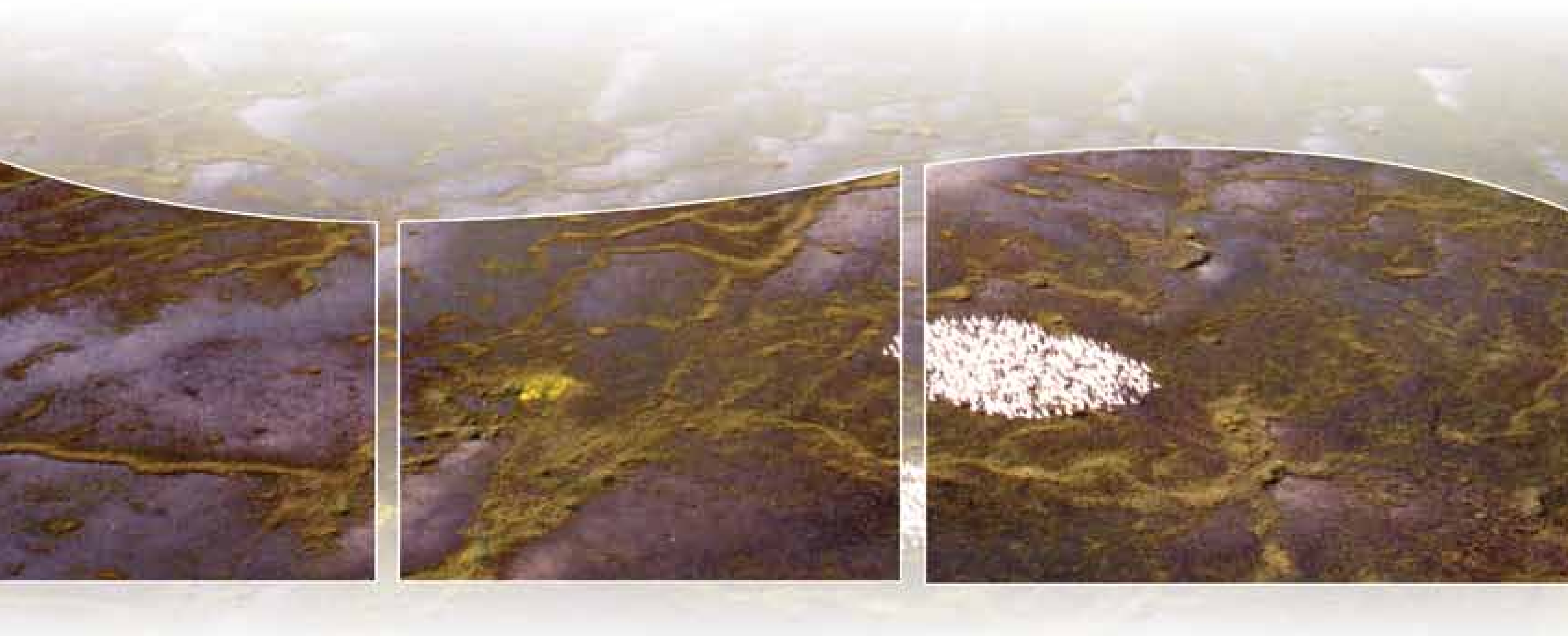
# Detection and Classification of Land Cover Classes of Southampton Island, Nunavut, Using Landsat ETM+ Data

**Occasional Paper**
**Number 119**
**Canadian Wildlife Service**
**Prairie and Northern Region**

**Alain J. Fontaine**
**Mark L. Mallory**



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# Detection and Classification of Land Cover Classes of Southampton Island, Nunavut, Using Landsat ETM+ Data

**Alain J. Fontaine[1] and Mark L. Mallory[2]**

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Détection et classification des catégories de couvertures terrestres de l'île Southampton, au Nunavut, à l'aide des données du Landsat ETM+

[1] Eastern Arctic Habitat Program
Canadian Wildlife Service
Environment Canada
Qimugjuk Building 969
P.O. Box 1714
Iqaluit NU X0A 0H0

[2] Eastern Arctic Seabird Program
Canadian Wildlife Service
Environment Canada
Qimugjuk Building 969
P.O. Box 1714
Iqaluit NU X0A 0H0
Email: mark.mallory@ec.gc.ca

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Cover photo: Flock of moulting Lesser Snow Geese (*Chen caerulescens*) with broods in brood-rearing lowland habitat, Harry Gibbons Migratory Bird Sanctuary, Southampton Island, Nunavut



Aussi disponible en français

Abstract

Coastal habitats and lowlands generally support the highest terrestrial wildlife and vegetation biodiversity in the Arctic. In some areas, the condition and quality of these habitats are being threatened or damaged by overabundant Lesser Snow Goose (*Chen caerulescens*) and Ross's Goose (*Chen rossii*) populations overgrazing the graminoid cover. This may be contributing to the decrease observed in the population of other Arctic breeding migratory birds, especially shorebirds. As well, in recent years, interest in natural resource development (e.g., base and precious metals, gems, oil and gas) has increased significantly across the Canadian Arctic. Such projects must be carefully monitored to minimize project footprints on habitats and wildlife.

Southampton Island supports large populations of birds, many of which are located in the relative fat, wet and fragmented landscape of the southern part of the island. The island includes two important goose nesting areas: the East Bay and Harry Gibbons Migratory Bird Sanctuaries (MBSs). These sanctuaries, like all other MBSs, are also important breeding areas for other migratory birds besides waterfowl (especially shorebirds and waterbirds) and for other wildlife.

To prepare a land cover map of Southampton Island, we used a variety of digital image processing tools to enhance LANDSAT 7 Enhanced Thematic Mapping (ETM+) satellite imagery. Selected scenes were captured in late July and early August 2000, a time judged adequate with regard to plant phenology given that most plants have reached their growth peak but are not yet senescent. Various enhancements and band combinations were initially evaluated. We selected an enhancement using transformations of bands 4, 5 and 2 in a red, green and blue configuration, as it provided the best overall images, allowing us to visually identify distinct habitats across the landscape.

Ground-truthing of enhanced images was performed in the field across the whole island south of 64°31'N of latitude in late July of 2001 and 2002. We conducted detailed ground evaluations of habitats at 74 sites, and rapid low-level aerial assessments at 1425 sites. We then used a variety of classification techniques to classify each image and generate a land cover map of Southampton Island.

We identified two water classes, two variable coastal classes in the inter-tidal zone, one snow and ice class (which includes sea ice), and 18 terrestrial land cover classes. The land cover classes identified in this study were those that could be easily distinguished from low-altitude aerial inspections outside of transition zones between classes. These showed distinctive differences in substrate, vegetation community, topographic position, and moisture regime, and could be easily distinguished visually by observers. Due to their characteristic composition, these were also the habitats that had the highest potential to have distinct wildlife communities or assemblages. The overall accuracy of our classification was 96%. This figure is elevated because of the contribution of numerous high reflectance and absorption land cover classes that

were easily identified and classified and for which we obtained high producer and user accuracies.

This project generated a baseline geo-referenced habitat map of the current habitat condition of Southampton Island, against which future changes to this arctic ecosystem can be assessed. Despite the complexity of the landscape, we were able to develop an accurate land cover map of the island, which will allow wildlife and habitat practitioners to define or refine habitat maps for many wildlife species, thereby assisting in future management of their populations and in the design and implementation of effective wildlife surveys.

# Résumé

Les habitats côtiers et les basses terres abritent généralement les espèces sauvages terrestres et une biodiversité de la végétation parmi les plus riches de l’Arctique. Dans certaines régions, la condition et la qualité de ces habitats sont menacées ou endommagées par les populations surabondantes de Petites Oies des neiges (*Chen caerulescens*) et des Oies de Ross (*Chen rossii*), qui broutent excessivement la couverture graminoïde. Cela peut contribuer à la diminution de la population que l'on constate chez d'autres oiseaux migrateurs qui nichent dans l'Arctique, en particulier les oiseaux de rivage. Par ailleurs, au cours des dernières années, l'intérêt pour l'exploitation des ressources naturelles (p. ex. les métaux communs et précieux, les gemmes, le pétrole et le gaz) a augmenté de façon considérable dans l’Arctique canadien. De tels projets doivent être rigoureusement surveillés afin de réduire au minimum leur empreinte sur les habitats et les espèces sauvages.

L'île Southampton abrite de nombreuses populations d’oiseaux, dont bon nombre sont situées dans le paysage relativement plat, humide et morcellé de la partie sud de l'île. Il existe deux importantes aires de nidification des oies sur l'île : le Refuge d'oiseaux migrateurs de la baie Est et le Refuge d'oiseaux migrateurs de Harry Gibbons. Ces refuges, comme tous les autres refuges d’oiseaux migrateurs, représentent également des aires de reproduction importantes pour les oiseaux migrateurs autres que la sauvagine (en particulier les oiseaux de rivage et les oiseaux aquatiques) et pour d'autres espèces sauvages.

Pour préparer la carte de la couverture terrestre de l’île Southampton, nous avons utilisé des outils de traitement d’images numériques pour améliorer l'imagerie satellitaire obtenue avec l'appareil de cartographie thématique amélioré plus (ETM+) du LANDSAT-7. Les scènes sélectionnées ont été capturées à la fin du mois de juillet et au début du mois d’août 2000, une période jugée adéquate en ce qui concerne la phénologie des plantes, étant donné que la plupart des plantes ont atteint le sommet de leur croissance, mais ne sont pas encore sénescentes. Diverses améliorations et combinaisons de bandes ont d'abord été évaluées. Nous avons sélectionné une amélioration en transformant les bandes 4, 5 et 2 selon une configuration rouge, verte et bleue, car elles représentaient les meilleures images d'ensemble, nous permettant de déterminer les habitats distincts à travers le paysage.

La vérification au sol des images améliorées a été effectuée sur le terrain sur toute la partie de l'île au sud de la latitude 64°31’N, vers la fin du mois de juillet de 2001 et 2002. Nous avons mené des évaluations au sol approfondies sur les habitats de 74 sites et réalisé des évaluations rapides à basse altitude de 1 425 sites. Nous avons ensuite utilisé une variété de techniques afin de classer chaque image et de produire une carte de la couverture terrestre de l’île Southampton.

Nous avons déterminé deux catégories d’eau, deux catégories côtières variables dans les zones intertidales, une catégorie de neige et de glace (qui comprend les glaces de mer) et 18 catégories de couvertures terrestres. Les catégories de couvertures terrestres déterminées dans cette étude

sont celles qui peuvent être aisément distinguées des inspections à basse altitude à l’extérieur des zones de transition entre les catégories. Ces dernières ont affiché des différences distinctes au niveau du substrat, de la communauté végétale, du régime d'humidité et de la position topographique, ce qu'un observateur peut remarquer facilement à l'œil nu. En raison de leur composition caractéristique, ce sont également les habitats qui présentaient le plus grand potentiel d'avoir des communautés ou des assemblages d'espèces sauvages distincts. L'exactitude générale de notre classification était de 96 %. Ce chiffre est élevé grâce à la contribution de nombreuses catégories de couvertures terrestres à l'absorption et à la réflectance élevées qui ont été facilement déterminées et classées et pour lesquelles nous avons obtenu une très bonne précision du producteur et de l'utilisateur.

Ce projet a permis la création d'une carte de l'habitat géoréférencé de base des conditions actuelles de l'habitat de l'île Southampton et grâce à laquelle les changements futurs de cet écosystème arctique pourront être évalués. Malgré la complexité du paysage, nous avons été en mesure de dessiner une carte exacte de la couverture terrestre de l’île, ce qui permettra aux spécialistes de la faune et de l’habitat de définir ou de préciser les cartes de l'habitat pour de nombreuses espèces sauvages, facilitant ainsi la gestion future de leurs populations et la conception et la mise en œuvre de relevés efficaces sur les espèces sauvages.

# Acknowledgements

This manuscript follows in large part the format and text of the Queen Maud Gulf (QMG) Migratory Bird Sanctuary land cover mapping project, published as Canadian Wildlife Service Occasional Paper No. 111 by Andrew B. Didiuk and Robert S. Ferguson. The land cover mapping of QMG is the first in a series of occasional papers presenting habitat maps of migratory bird sanctuaries important to snow geese. The following land cover mapping occasional papers are forthcoming: Dewey Soper Migratory Bird Sanctuary (western Baffin Island), Banks Island, and McConnell River Migratory Bird Sanctuary (western Hudson Bay). We followed the format of the QMG occasional paper to maintain consistency between these documents, and are grateful to Andrew and Robert for providing us with a model to follow.

We offer our special thanks to Rachel Bryant, Anna Hargreaves, Kerrith McKay, Paul Smith and Iain Stenhouse for their assistance and support in the field. And thank you to Dan Kennedy of Custom Helicopters for his excellent piloting skills and assistance.

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# 1 Introduction

## 1.1 General

Research in various parts of the Canadian Arctic has demonstrated that some lowland habitats are currently threatened with degradation as a result of foraging by overabundant goose populations (Kerbes 1994; Kotanen and Jefferies 1997; Giroux et al. 1998; Jano et al. 1998; Gauthier et al. 2004; Didiuk and Ferguson 2005). For example, vegetation changes in damaged coastal wetlands along western Hudson Bay have altered the long-term productivity of breeding and staging habitat for Lesser Snow Geese (*Chen caerulescens*) and Ross's Geese (*Chen rossii*), both hereafter referred to as "white geese," and other wildlife species (Kerbes et al. 1990; Ganter et al. 1996; Strivastava and Jefferies 1996; Bazely and Jefferies 1997; Kotanen and Jefferies 1997; Jefferies et al. 2006). Habitat assessment and monitoring are important to determine the magnitude of habitat damage to date, the extent and amount of intact vegetation remaining, effects on other wildlife (Rockwell et al. 2003), and to monitor changes in vegetation over the long-term in response to the anticipated declines in white geese resulting from population control harvest programs in southern Canada and the United States (Arctic Goose Joint Venture 1998; Béchet et al. 2003).

In addition to this threat, other factors of anthropogenic or natural origin may also have deleterious effects on Arctic ecosystems. Climate models suggest that the Arctic will experience increases in temperature and precipitation in the future (Balling 1997; Nadelhoffer et al. 1997; Balling et al. 1998; Hansell et al. 1998; Walsh et al. 2000). Coastlines throughout the Hudson Bay region are rising due to glacio-isostatic rebound, which affects the moisture regime of coastal lowlands and puts these habitats under further stress (Hunter 1970; Andrews and Peltier 1976). Coastal habitats are typically the most diverse and productive terrestrial habitats in the Arctic region, and changes in moisture availability and growing seasons could affect them significantly (Arft et al. 1999). In recent years, interest in natural resource development (e.g. base and precious metals, gems, oil and gas) has increased drastically across the Canadian Arctic, as shown by the increase in number of prospecting claims, exploration licences and project certificates issued in recent years. Such projects must be carefully monitored to minimize project footprints on habitats and wildlife.

The development of habitat maps addresses the need for an assessment of baseline habitat condition, aids in the establishment of intensive vegetation monitoring stations to gauge ecosystem recovery, and provides a framework for future wildlife population surveys (Arctic Goose Joint Venture 1998). Furthermore, knowledge of the distribution, abundance and diversity of habitats in Migratory Bird Sanctuaries (MBSs) across the Canadian Arctic is required to verify that current protected areas adequately protect wildlife for local communities and for hunters and wildlife enthusiasts elsewhere in the species range. It also allows habitat managers to monitor habitat change in the current protected areas, in order to assess whether those areas continue to support the wildlife usage that was the initial ecological reason for their protection.

In Nunavut, five MBSs were created to protect areas considered significant for breeding Lesser Snow Geese and Ross's Geese (i.e. protecting > 75% and 95%, respectively, of the eastern and central Arctic populations; Kerbes et al. 2006). Habitat classification and assessment has been completed for one of these sanctuaries, the Queen Maud Gulf MBS (Didiuk and Ferguson 2005), and is currently in progress for the Dewey Soper MBS (western Baffin Island) and McConnell River MBS (western Hudson Bay; Didiuk, unpublished data). Habitat change, and the need for habitat mapping, is particularly important for the two remaining important goose nesting areas, East Bay and Harry Gibbons MBSs, Southampton Island. These two sanctuaries, like all other MBSs, are also important breeding areas for other migratory birds besides waterfowl, especially shorebirds and waterbirds, as well as for other wildlife.

White goose populations on Southampton Island continue to increase, unlike the goose colonies of western Hudson Bay (La Perouse Bay and McConnell River area) that, since the population high of the mid-1990s, have experienced habitat degradation combined with a decline in Lesser Snow Goose numbers and an increase in Ross's Goose numbers (Canadian Wildlife Service Waterfowl Committee 2004). The condition of lowland habitats in western Hudson Bay may provide an example of what may occur at Southampton Island if white goose populations continue to grow and degrade northern ecosystems unchecked. Waterfowl, notably white geese, and a diversity of wildlife that rely on lowland tundra, comprise an important part of First Nations' and Inuit peoples' diet for the communities around Hudson Bay (Priest and Usher 2004). Clearly, changes in the distribution and abundance of geese and their corresponding impact on habitats and other wildlife populations on Southampton Island should be of concern to the residents of the community of Coral Harbour and residents of other communities along the white goose migration route in Hudson Bay and the Foxe Basin (Bellrose 1980; Mowbray et al. 2000). Thus, mapping habitats on Southampton Island during Snow Goose population increases, and then repeating this in several years, will provide further information on the relationship between goose population growth, grazing and degradation of Arctic coastal ecosystems, as has been shown at some other Arctic locations (Didiuk and Ferguson 2005; Jefferies et al. 2006).

As is true of most Arctic locations, the large areal extent and remoteness of Southampton Island create obstacles to wildlife and habitat managers with regard to mapping habitats found on the island. Therefore, the use of remote sensing technology was necessary to conduct this project. The use of these technologies for habitat mapping and surface geological surveys has become increasingly popular in recent years as the technology evolves and becomes more diverse and accurate in reflecting the needs of its users, as well as more affordable to the general public and research scientists (Ferguson 1991; Joria and Jorgensen 1996; Morrison 1997; Jano et al. 1998; Johnston et al. 2000; Nordberg and Allard 2002; Virtanen et al. 2004). This habitat assessment project involved acquisition and analysis of LANDSAT 7 Enhanced Thematic Mapping (ETM+) imagery combined with ground-truthing operations. The resolution captured by this satellite is adequate for macro-scale habitat mapping of Arctic regions and its land cover types, and the wide range of spectral sensitivity captured by its sensors discriminates well between habitat classes with regard to vegetation type and surface moisture.

## 1.2 Objectives

The purpose of this project was to generate a detailed baseline habitat map of the distribution and abundance of the various land cover types that comprise Southampton Island, similar to the approach used for mapping habitats of the Queen Maud Gulf (Didiuk and Ferguson 2005) and Banks Island No. 1 (Hines et al. 2006) MBSs. Similar work at the McConnell River and Dewey Soper MBSs has been undertaken (Didiuk, unpublished data).

Specific objectives were as follows:

- Summarize factors influencing habitat characteristics and expression on Southampton Island.
- Develop a land cover classification scheme of habitats found on Southampton Island.
- Produce a land cover map of Southampton Island with special attention paid to East Bay and Harry Gibbons MBSs.
- Describe the physical characteristics and plant community of each cover type.
- Provide a summary of the location and extent of each cover type within the sanctuaries and the island as a whole.

# 2 Study area

## 2.1 Geographical location

Early explorers in search of the Northwest Passage (1612 to 1837), and then whalers starting in 1860 (Figure 1), charted portions of the Southampton Island coastline (Bird 1953). However, much of what is known of the geology, fauna and flora of Southampton Island is based on some of the early inland survey expeditions of H. T. Munn (1917-18), T. Mathiassen (1922-23), G. M. Sutton (1929-30), T. H. Manning (1933-41), and J. B. Bird (1950) (Munn 1919; Mathiassen 1931; Sutton 1932; Sutton and Hamilton 1932; Manning 1936; Manning 1942; Bray and Manning 1943; Bird 1953).

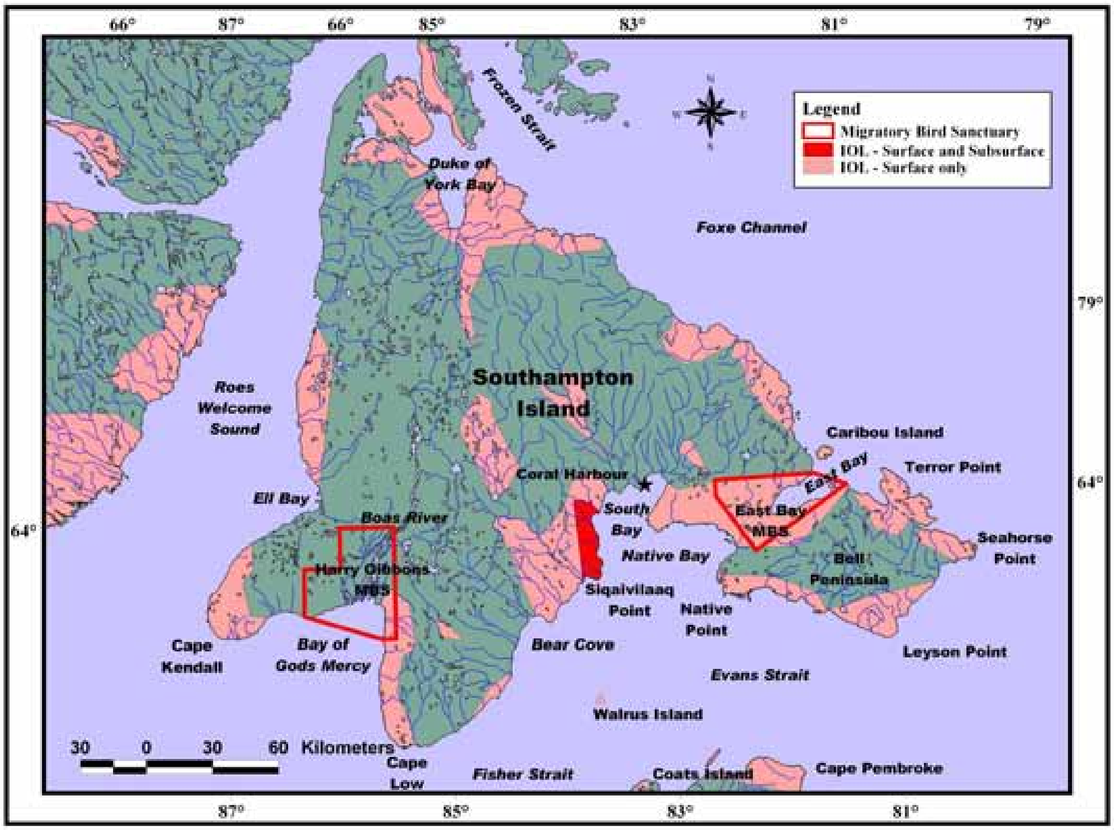
**Figure 1**
Old whaling station on the eastern shore of the Bay of God's Mercy: a) aerial view of the station; b) ground view of one of the dwellings made of shale plates, and whale and walrus bones

**a)**

**b)**

Southampton Island is part of the Kivalliq region of the Nunavut Territory (formerly Keewatin, Northwest Territories). It is located in northern Hudson Bay and is separated from the mainland by Roes Welcome Sound and Frozen Strait (Figure 2). It is the ninth-largest island in Canada, encompassing a surface area of 41 214 km$^2$. The island was named by the English explorer Thomas Button in 1604 to honour the Earl of Southampton, who sponsored Button's search for the Northwest Passage (Bird 1953). The Hudson's Bay Company relocated its trading post from Coats Island to the present site of Coral Harbour in 1924 (Bird 1953). The post attracted Inuit from around Hudson Bay, who began settling in its vicinity. Coral Harbour, located at the head of South Bay, is the only community on the island and has a population of approximately 670, of which 90% are Inuit. The community was named after the fossilized coral found in the harbour and at Fossil Creek. Inuit residents also know the community as Salliq, which means "flat island in front of the mainland."

**Figure 2**
Southampton Island, Nunavut, showing the location of Inuit Owned Lands (IOL) and the East Bay and Harry Gibbons Migratory Bird Sanctuaries




## 2.2 Ecoregion and topography

Exclusive of the highlands in the northeastern portion of the island, Southampton Island (as well as Coats and Mansel Islands) is located in the Southampton Plains Natural Region (Parks Canada 1997). This ecoregion is classified as having a low Arctic eco-climate. The mean annual temperature is approximately -11°C, with a summer mean of 3°C and a winter mean of -24.5°C. The mean annual precipitation ranges from 200-300mm. It is underlain by continuous permafrost with medium ice content.

The largest sections of lowland habitat are located between East Bay and Native Bay on the eastern side of the island, and in the Boas River floodplain on the western side. Large extents of wet moss and sedge meadows, and broad tidal flats broken and interspersed with numerous shallow ponds, raised limestone beaches and small streams, characterize the coastal plains and other lowlands. Most of the lowlands lie less than 60 m above sea level and show very little relief except for exposed raised beaches and Paleozoic limestone deposits (glacio-marine lag).

These deposits underlie much of the lowlands and often erupt through the landscape on higher ground. About 25 km from the coast, the Boas River becomes a braided river of about 5 km in width. During spring melt (mid-June to early July), the river braids and surrounding lowland area are entirely flooded. Similarly, the lowlands between East Bay and Native Bay are often almost entirely covered with sheet water during spring melt. The coastal lowlands often have little or no vegetation, mainly composed of a sparse cover of sedges, grasses and a few forbs over moss carpets. The large extents of sedge meadow that were once found on the island (Abraham, personal communication) are now much reduced, but some can still be found on the western interior lowlands. Graminoid vegetation is also found on slightly higher ground, in addition to willows, heath-related plants, and lichen interspersed with frost heaves. Willows sometimes reach 1–2 m in height along sheltered drainages and in some small, localized lowland areas along the coast between Coral Harbour and Bear Cove.

Isostatic lift following the retreat of the glaciers can be observed by the numerous raised beaches that generally run parallel to the coast (Lee 1968). Land rebound, although slowing, still raises the coastline around Hudson Bay and James Bay at a rate varying between 1 and 2 m per century depending on the location (Hunter 1970; Andrews and Peltier 1976). Land rebound is especially evident in the Cape Low area (Figure 3). Oceans flooded most of this region after the retreat of the glaciers, and wave-reworking eliminated most glacial landforms except for a few scattered eskers. The large extents of frost-shattered limestone found as extensive deposits throughout much of the island are truly barren and only support small mats, or sometimes nets, of heath vegetation—largely Mountain Avens (*Dryas integrifolia*).

**Figure 3**
Isostatic lift shown by raised beaches running parallel to the coastline near Cape Low, Southampton Island, Nunavut

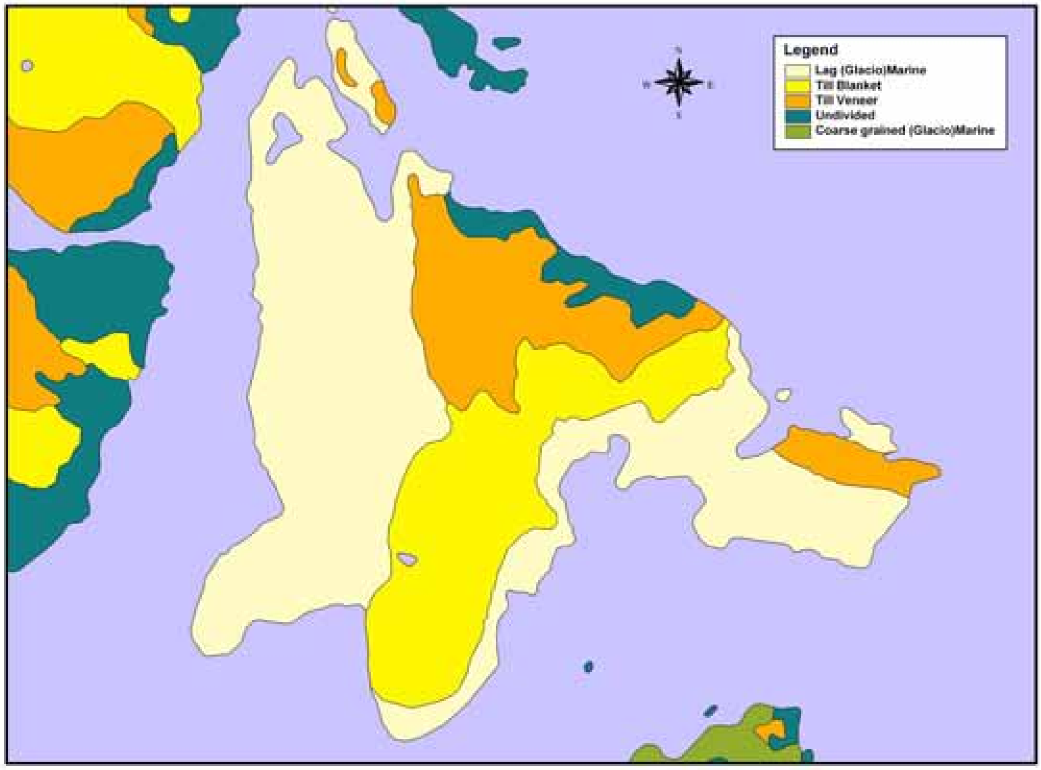
The highlands of Southampton Island fall in the Central Tundra Natural Region and are strikingly different in terms of topography and vegetation from the rest of the island (Parks Canada 1997). On Southampton Island this region is mainly composed of large boulder ridges interspersed with lichen-heath tundra. Boulder ridges give way to bedrock along the coast, but some bedrock outcrops also occur throughout the highlands. Topography is irregular, featuring high relief and scored by numerous small stream valleys and low areas breaking the landscape. The highest point on the island is north of South Bay in the central highlands, rising to slightly over 600 m above sea level. Vegetation diversity in this region is much higher than in the coastal lowlands and includes a diversity of grasses, sedges and shrubby species, such as Dwarf Labrador Tea (*Ledum decumbens*), willows, numerous shrubs of the *Vaccinium* genus, and other heath type and perennial plants. Lichens and mosses of dry environments are also quite diverse. Numerous deep lakes are scattered along the northern coast, mainly in the portion covered with bedrock outcrops.

## 2.3 Geology

### *2.3.1 Surficial expression*

The dominant surface deposits are glacio-marine lag (Figure 4) (Lee 1968; Whitmore and Liberty 1968; Heywood and Sanford 1976; Geological Survey of Canada 2001). These areas are covered with materials ranging from sand (or finer materials) to gravel and cobble-size materials, all of glacial origin developed during marine submergence. They cover nearly the whole western third of the island along Roes Welcome Sound, much of the peninsula north of Cape Low between the Boas River and South Bay, all the lowlands between East Bay and Native Bay, and over half of the southern portion of the Bell Peninsula. Some deposits of finer-grain marine sediments formed broad coastal plains in Native Bay, Bear Cove and the Boas River Delta. Unsorted and generally non-stratified glacial sediments, known as till, cover most of the remaining surface area. The upper part of glacio-marine lag and till exposures has often been mixed with fine-grained marine sediments by periglacial processes and wave reworking during isostatic rebound. The map from the Geological Survey of Canada shows that a thick and continuous till blanket covers the peninsula north from Cape Low between the Boas River and South Bay, and extends east through the lower portion of the highlands northwest of East Bay (Figure 4). Subsequent to our work, we revised the coverage of the area covered in a till blanket south of a line level with Siqaivilaaq Point and south toward Cape Low. Although there are some pockets of till, much of the surficial geology of that area is glacio-marine lag, as was evident from our land cover mapping work. A thin and discontinuous till veneer with extensive areas of rock outcrop (bedrock and boulder ridges) covers the remaining highlands and the northern Bell Peninsula. Undivided bedrock follows the northern coast between Duke of York Bay and East Bay and along the northern edge of the Bell Peninsula. Since rebound and emergence, the dominant soils that formed on the island are static and turbic cryosols, which developed mainly over the lowland marine deposits (Tarnocai 1999).

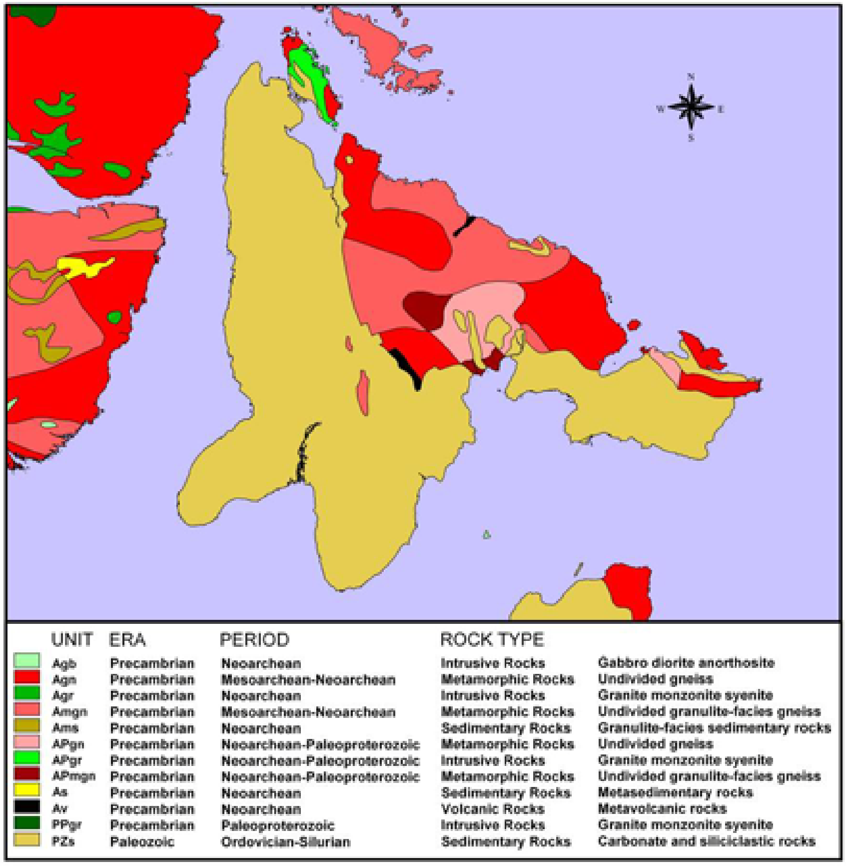
**Figure 4**
Surficial geology of Southampton Island, Nunavut




## *2.3.2 Origin*

The island's geology can be broadly divided into the Paleozoic carbonate strata of the island's western half and southern Bell Peninsula, and the Precambrian basement of the northeastern section (Figure 5) (Lee 1968; Whitmore and Liberty 1968; Heywood and Sanford 1976; Geological Survey of Canada 1999). Nearly all of the area covered in glacio-marine lag and till blanket is composed of limestones and sandstones from the Ordovician, Silurian and Devonian periods of the Paleozoic era (Heywood and Sanford 1976; Dewing and Copper 1991). Small pockets of Paleozoic rocks occur in the highlands, but most of this region is covered in undivided metamorphic rocks of Precambrian origin. Pockets from various periods (Neoarchean, Mesoarchean, Paleoproterozoic) and slightly different composition (gneiss, granulite-facies gneiss) are intermingled throughout the highlands and the northern Bell Peninsula. A small outcrop of undivided volcanic rocks can be found in the southern reaches of the highlands west of South Bay.

**Figure 5**
Geological origin of Southampton Island, Nunavut




## 2.4 Protected areas

The Harry Gibbons and East Bay MBSs were established by the federal government on Southampton Island in 1959, in what was then part of the Northwest Territories (now Nunavut), to protect the large numbers of Lesser Snow Geese and many other migratory bird species during the nesting, brood-rearing and moulting periods (Figure 6). The primary purpose of MBSs is conservation of migratory birds, and, incidentally, other wildlife. As such, only land claim beneficiaries can enter and conduct any activity within a sanctuary in Nunavut when migratory birds are present, unless authorized by authority of a permit issued by the Canadian Wildlife Service. However, sanctuary regulations apply only when migratory birds are present and do not protect the habitat per se. Both the East Bay / Native Bay area and the Boas River lowlands are listed as Important Bird Areas by BirdLife International and their Canadian partners Bird Studies Canada, and by the Canadian Nature Federation (Bird Studies Canada 2004).

**Figure 6**
Common birds of Southampton Island, Nunavut: a) Lesser Snow Geese; b) King Eider (*Somateria spectabilis*) hen incubating her eggs

**a)** **b)**

East Bay MBS is located on the eastern side of Southampton Island, encompassing the marine waters of East Bay and most of the lowland terrestrial area west of the Bell Peninsula between East Bay and Native Bay (Figure 2). The sanctuary is 60 km east of the hamlet of Coral Harbour and occupies a surface area of approximately 1165 $km^2$.

Harry Gibbons MBS is located on the southwestern portion of the island, north of the Bay of God's Mercy (Figure 2). It occupies the southern portion of the Boas River, including the delta, adjacent tidal flats and surrounding lowland areas. The sanctuary is 135 km southwest of Coral Harbour and occupies a surface area of approximately 1490 $km^2$.

Exact sanctuary boundary definitions can be found in the *Migratory Bird Sanctuary Regulations* (Government of Canada 1997).

Inuit of Coral Harbour and Nunavut Tunngavik Incorporated selected all lands within East Bay MBS and a small portion of land on the southeastern corner of Harry Gibbons MBS as Inuit Owned Lands (IOL), as part of the Nunavut Land Claims Agreement (Figure 2) (INAC 1993). This does not alter the status of the sanctuaries. Article 17 of the Agreement states that IOL are expected to include areas of value for renewable resources such as wildlife harvesting areas, areas of significant biological productivity, and areas of value for conservation purposes as well as areas of value for the development of non-renewable resources and of commercial value such as mineral deposits (INAC 1993). IOL offer a certain level of protection for wildlife given that access to these lands requires a permit from the relevant regional Inuit association.

Federal and territorial government agencies have expressed interest in creating other protected areas in this region. For example, Parks Canada does not yet have a National Park in this natural region as per their National Park System Plan (Parks Canada 1997). However, at this time we are unaware of other initiatives under way. This document should assist in any such efforts.

## 2.5 Wildlife

A photographic inventory of nesting geese conducted in 1997 found 721 200 nesting Lesser Snow Geese on Southampton Island (Kerbes et al. 2006). When Southampton Island was first surveyed in 1973, 155 800 nesting birds were found (Kerbes, unpublished data) and the area occupied by the nesting colonies was much smaller than in the late 1990s. The nesting colonies of Southampton Island support approximately 12% of the Canadian breeding population of Lesser Snow Geese, and are the second-largest nesting site in the eastern Arctic after the Great Plains of the Koukdjuak on Baffin Island and the third-largest nesting site in the Canadian Arctic after the Queen Maud Gulf MBS (Canadian Wildlife Service Waterfowl Committee 2004). Ross's Goose numbers have also substantially increased on the island as they have at other white goose nesting locations across their range.

Moulting Atlantic Brant (*Branta bernicla hrota*) are numerous in mid-July and early August in coastal areas, especially along Native Bay and Native Point. However, it is unclear at this point whether these birds actually attempted breeding on Southampton Island in recent years or if they are failed breeders from elsewhere. Between 2001 and 2004, only two broods of Atlantic Brant were observed on the island (both in 2001, in East Bay) in the course of this project and goose banding operations as well as during more than 200 hours of helicopter flight time throughout the island for this project (Fontaine and Leafloor, personal observation). In contrast, during systematic searches of plots around East Bay and the Boas River in 1979 and 1980, large numbers of Brant nests were recorded each year (455 and 358, respectively), and significant numbers of goslings were banded (Abraham and Ankney 1986). Many nests were also observed at the Boas River in 1983 (Gaston, personal observation).

The lowlands, particularly within the sanctuaries and surrounding areas as well as the Bear Cove area, support large numbers of other breeding and moulting waterfowl, such as Canada Goose (*Branta canadensis*), Tundra Swan (*Cygnus columbianus*), Northern Pintail (*Anas acuta*) and Oldsquaw (*Clangula hyemalis*). The lowlands also support high densities of shorebirds and songbirds, the predominant species being the Red Phalarope (*Phalaropus fulicarius*), Ruddy Turnstone (*Arenaria interpres*), White-rumped Sandpiper (*Calidris fuscicollis*), Lapland Longspur (*Calcarius lapponicus*) and Snow Bunting (*Plectrophenax nivalis*), although numerous other species of shorebirds and some songbirds also occupy these areas (Smith and Johnston, unpublished data). Peregrine Falcons (*Falco peregrinus*), Rough-legged Hawks (*Buteo lagopus*) and Ravens (*Corvus corax*) can be found nesting in the highlands, especially along the rugged northern coastline (Riewe 1992). Gyrfalcons (*Falco rusticolus*) are not known to nest on the island but occur in migration and as winter residents (Riewe 1992).

The coastal ponds, beach ridges and nearshore ocean zone are especially important to sea ducks, such as the Common Eider (*Somateria mollissima*) and King Eider (*Somateria spectabilis*), and numerous seabirds and water birds such as Glaucous Gull (*Larus hyperboreus*), Herring Gull (*Larus argentatus*), Iceland Gull (*Larus glaucoides*), Sabine's Gull (*Xema sabini*), Arctic Tern (*Sterna paradisaea*), jaegers (*Stercorarius* spp.), Sandhill Crane (*Grus canadensis*), Pacific Loon (*Gavia pacifica*) and Red-throated Loon (*Gavia stellata*). Pacific and Red-throated Loons are notably abundant in the coastal ponds of the Native Point area. Common Loons (*Gavia immer*) were also observed in the highlands in 2002 (Fontaine, personal observation).

Mammal species whose range includes Southampton Island are those typical of the Canadian Arctic, i.e., the Arctic Hare (*Lepus arcticus*), Northern Collared Lemming (*Dicrostonyx groenlandicus*), Caribou (*Rangifer tarandus*), Ermine (*Mustela erminea*), Arctic Fox (*Alopex lagopus*) and Polar Bear (*Ursus maritimus*) (Sutton and Hamilton 1932; Riewe 1992). Caribou and Gray Wolves (*Canis lupus*) were hunted to extinction on Southampton Island in the late 1950s. Caribou were reintroduced with stock from Coats Island in 1967 and their numbers have since increased sufficiently to support a small commercial harvest (Figure 7) (Riewe 1992). A Wolverine (*Gulo gulo*) was observed at the Boas River in Harry Gibbons MBS in 2002

(Hargreaves and McKay, personal observation.). We suspect that Wolverines and Gray Wolves probably cross over on the ice from the mainland infrequently. The coastal lowlands of Harry Gibbons and East Bay MBSs, Bear Cove and Native Bay are especially important to Polar Bears during the summer months after pack ice retreats from the waters surrounding Southampton Island.

**Figure 7**
Yearling caribou in the highlands of the Bell Peninsula, Southampton Island, Nunavut

Aside from Ringed Seal (*Phoca hispida*) and Bearded Seal (*Erignathus barbatus*), which are commonly found in the marine waters around Southampton Island, large Walrus (*Odobenus rosmarus*) herds haul out at the mouth of East Bay and at nearby Walrus Island and Cape Pembroke on Coats Island (Riewe 1992; Mallory and Fontaine 2004). The waters of East Bay harbour an estimated 350-400 Beluga Whales (*Delphinapterus leucas*) during the summer months (Mallory and Fontaine 2004).

# 3 Methods

## 3.1 Image data

The Geographical Information System (GIS) terminology used in this document is derived from ArcView GIS (ESRI 1996), ER Mapper (Earth Resource Mapping 2003), PCI Geomatica (PCI Geomatics 2003), and general GIS studies (e.g., Congalton 1991; Tso and Mather 2001). Please refer to these texts for more details.

Land cover mapping of Southampton Island was performed using LANDSAT 7 ETM+ satellite scenes. LANDSAT 7, launched in 1999, is a sun-synchronous satellite with a repeat cycle coverage of 16 days in a circular orbit (path) at an altitude of 705 km. As opposed to active satellites that have sensors that supply their own energy source, LANDSAT 7 is a passive satellite that captures reflected solar energy. Clouds and fog therefore prevent it from capturing ground data effectively.

Indexing of the continuous interval data stream captured by the sensors is framed into individual scenes by their orbits (referred to as paths) and by scene centres (called rows), comprising 233 paths and 248 rows following the Worldwide Reference System. Southampton Island falls within paths 25 to 30 and rows 14 to 16 of this system. A standard scene is approximately 185 km wide and 180 km long.

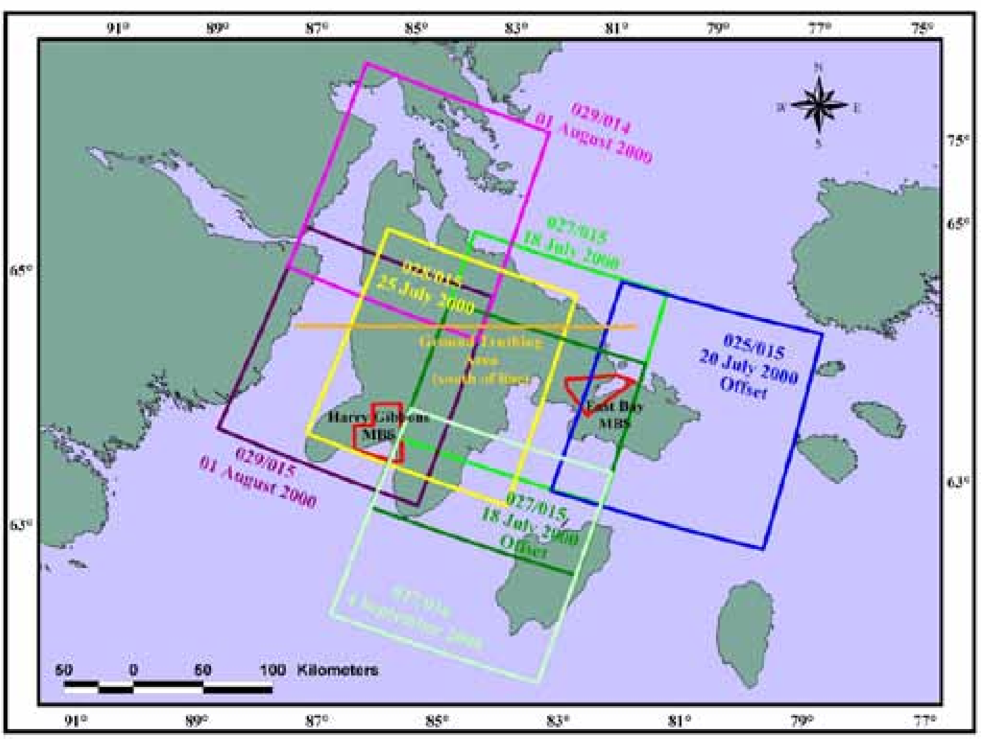
We were fortunate to have good availability of nearly cloud- and fog-free scenes at an appropriate time of the year for moisture regime (water, ice, snow) and vegetation development. A total of five scenes provided nearly complete cloud-free coverage of Southampton Island (Table 1, Figure 8). All of the five main LANDSAT scenes were captured between July 18 and August 1, 2000, the year prior to the first ground-truthing field season. These dates encompass the peak of vegetation growth in this region of the Canadian Arctic and coincide with the midpoint of the goose brood-rearing period. Two additional scenes were acquired to complete the land cover map (Table 1, Figure 8). Small portions of the first, 028/015, were used to replace two small cloud-obscured regions on 029/015 (both northeast of Ell Bay); the second, 027/016, was used to insert a small missing section of landmass at Cape Low. In the case of the latter, only a small portion measuring approximately 100 by 200 pixels was required, and was used to complete the landmass at Cape Low. More information regarding scene capture date, location and cloud cover is provided in Table 1.

**Table 1**
Image dates, path/row identifiers and cloud cover of LANDSAT 7 ETM+ scenes used in the land cover classification of Southampton Island, Nunavut

| Satellite | Image Date | Path | Row | Cloud Cover (%)[a] | Offset |
|---|---|---|---|---|---|
| LANDSAT 7[b] | 20 July 2000 | 025 | 015 | < 1 | Offset in row 16 to 63°44'N, 80°23'W |
| LANDSAT 7 | 18 July 2000 | 027 | 015 | < 1 | None |
| LANDSAT 7[b] | 18 July 2000 | 027 | 015 | < 15 | Offset in row 16 to 63°41'N, 83°31'W |
| LANDSAT 7 | 4 Sept. 2000 | 027 | 016 | < 10 | None |
| LANDSAT 7[b] | 25 July 2000 | 028 | 015 | < 20 | None |
| LANDSAT 7 | 1 August 2000 | 029 | 014 | < 5 | None |
| LANDSAT 7 | 1 August 2000 | 029 | 015 | < 1 | None |

[a] Cloud cover over the entire scene.
[b] Purchased commercially. All other scenes were obtained from Natural Resources Canada.

**Figure 8**
Map of Southampton Island, Nunavut, showing the approximate coverage of each Landsat 7 ETM+ scene



## 3.2 Datasets and geo-referencing

LANDSAT 7 is equipped with a wide array of sensors. Thermal infrared sensors capture reflected wavelengths in the 10.4–12.5 μm spectrum at a 60-m pixel resolution (band 6), and a panchromatic sensor captures reflected wavelengths between 0.50 and 0.90 μm at a 15-m pixel resolution (band 8). Of use for this project was the sensor array, which captured reflected wavelengths at a 30-m pixel resolution in the range of 0.45–2.35 μm of the visible light to reflective infrared of the electromagnetic spectrum in six different bands (1–5 and 7). Bands 1–5 and 7 can be used in combinations of three layers displayed in red, green and blue in GIS software, to display or emphasize desired surface characteristics. As different surfaces each reflect wavelengths with their own specific variations, these variations can be used to establish spectral signatures specific to each reflecting surface.

All initial image processing was performed using ER Mapper 6.3 software (Earth Resource Mapping 2003). Bands 1–5 and 7 of each scene were joined into integrated datasets, so that all bands would be available for use during image processing. An added benefit of creating datasets is that all data-altering procedures applied to the datasets would be applied to all bands at once (e.g., geo-referencing).

All scenes except for two, 27/15 offset in row 16 and 28/15 (Table 1), were acquired through a data sharing agreement between Natural Resources Canada (NRCan) and Environment Canada. These scenes were already accurately geo-referenced to the Universal Transverse Mercator (UTM) map projection in the 1983 North American Datum (NAD83). All were projected in zone 17 except for 29/15, which was projected in zone 16. To allow the scenes to be mosaiced, this scene was re-projected in zone 17. Scenes 28/15 and 27/15 (offset) were obtained commercially and required geo-referencing. To geo-reference these scenes, we used image-to-image geo-referencing procedures using the scenes acquired from NRCan as base geo-reference material. We selected 50 points located at easily identifiable landscape features spread homogeneously throughout the scene, and kept the root mean square for each selected point under 0.10.

## 3.3 Image enhancements

We prepared the satellite scenes for ground-truthing by following the methodology described in Didiuk and Ferguson (2005). Prior to the field season, LANDSAT 7 scenes were enhanced by creating colour composites displayed in red, green, and blue of bands 4 (0.75 to 0.90 μm, near infrared), 5 (1.55 to 1.75 μm, short-wave infrared), and 2 (0.525 to 0.605 μm, green light), respectively. Discrimination between cover types was further increased by applying an auto-clip transformation to band 4, and a linear transformation to bands 5 and 2 as well as a water spike reduction to band 2. Didiuk and Ferguson (2005) found these enhancements adequate to discriminate between upland and lowland cover types.

Enhanced satellite scenes were used to create map books of the island for use during ground-truthing work. Each scene was plotted at a scale of 1:250 000 and subdivided into nine areas plotted at a scale of 1:50 000. Sub-area maps were then assigned a unique identifier and assembled into map books as appropriate for ground-truthing. Due to the localized nature and large surface coverage of some of the land cover types (e.g., glacio-marine sedimentary lag), sub-area maps did not necessarily cover the whole range of spectral values found within the satellite scene.

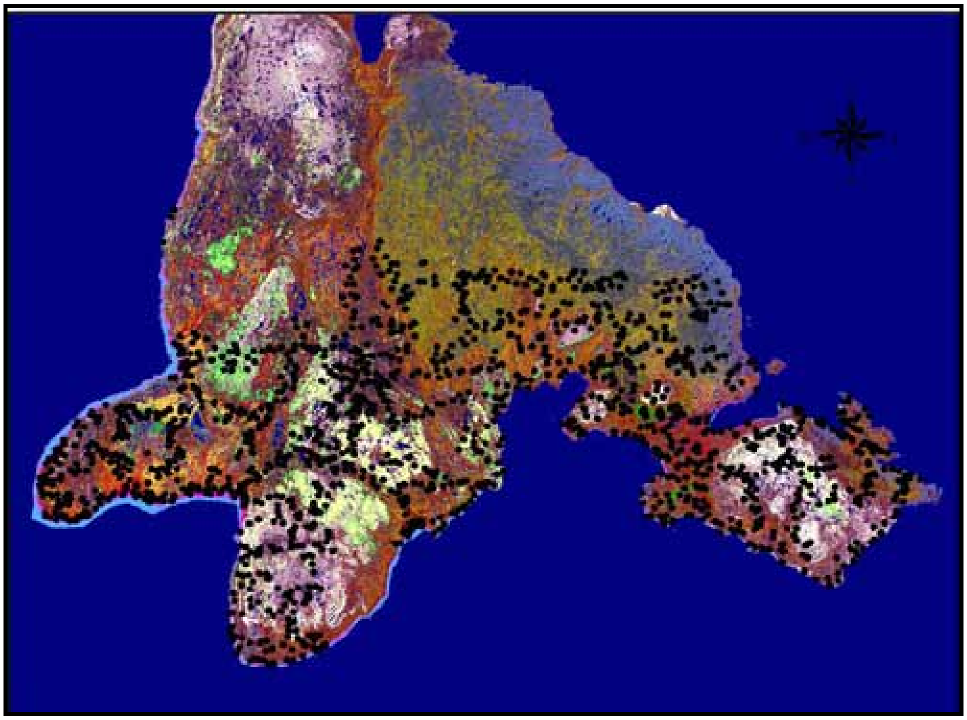
Samples of distinct ground-truthing targets were pre-identified before going to the field, but most plots were selected once a few reconnaissance flights had been flown to confirm that the distinct colours on the field maps could be related to distinct land covers or to differing land covers based on distinct topographical location. Ideal ground-truthing targets are areas on the enhanced images where a number of neighbouring pixels all bear the same spectral signature (i.e., all having the same colour). We selected plots that were located in areas with a minimum of 5 x 5 pixels bearing the same signature; on average, most were much larger. These areas were usually easy to identify from the air. In turn, they make ideal training regions that are then used to classify the satellite imagery during the classification process. Training regions are polygons drawn onto the raster image (i.e., the LANDSAT scene), which serves to calculate a variety of spectral statistics for each band within these regions (e.g., area, minimum, maximum, mean, median) or to identify the pixels in an image that have similar spectral signatures and are therefore likely to have a similar surface cover (i.e., classification). Normally, many training regions well-dispersed throughout an image are required for each of the individual classes to properly "train" the classification process. We avoided selecting training regions with mixed cover classes and with patches of other cover types, where discernible.

## 3.4 Field studies

Ground-truthing fieldwork, to assess land cover types associated with specific spectral signatures on the enhanced satellite scenes, was carried out with helicopter support on the eastern half of the island in 2001 and on the western half in 2002. Field studies' timelines were selected to coincide with the capture dates of the main LANDSAT 7 scenes. The eastern side of the island, covered between July 20 and 30, 2001, encompassed an area ranging from north of Bear Cove to the area north of Coral Harbour, and east toward Native Bay and East Bay as well as the Bell Peninsula. The summer of 2002 was used to cover the western side of the island and any land cover types that may have been sampled inadequately during our ground-truthing efforts of 2001. Covered between July 18 and 23, this area included regions south of Bear Cove to Cape Low, going west through the Boas River lowlands to Cape Kendall and the western shore along Roes Welcome Sound.

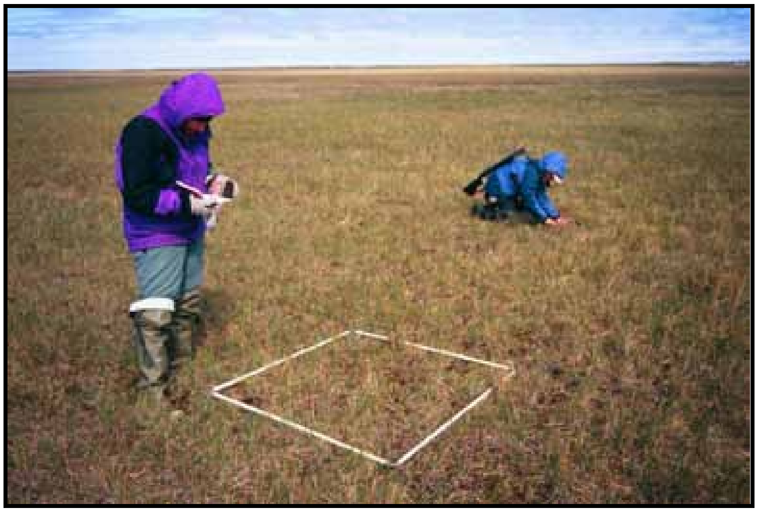
Travel routes were generally planned in advance to maximize efficiency and data collection efforts, but were kept flexible because of local weather patterns, fuel cache locations, and helicopter range limitations. In all, 41 and 33 ground-truthing landings were completed in terrestrial land cover types in 2001 and 2002, respectively. These were judged by crew consensus to be land cover classes that could be easily and accurately distinguished from one another based on their spectral signatures and terrain characteristics. We landed and collected data in at least two target areas for each land cover type. Ground-truthing landings could not be carried out in the low-centre polygons land cover class on the western side of the island in 2002. Nearly all of the area covered by this class was too deeply flooded. Once we were familiar with the cover types present on the island, we identified over 700 training regions in each year from the air by mapping their boundaries on the images (Figure 9).

**Figure 9**
Distribution of ground-truthing and rapid inspection sites, Southampton Island, Nunavut



A general assessment of site characteristics was recorded upon landing at each ground check location. These are summarized in Table 2. The coordinates in latitude and longitude of the sampling areas, a topsoil profile to permafrost level or 30 cm, as well as wildlife observed at the site were also recorded. After this initial assessment of site characteristics, ground cover details were recorded using a 100-m linear transect established in a random direction. Every 10 m, a square 1 $m^2$ quadrat was dropped on the ground and percent coverage of each detailed ground cover type (Table 2; Figure 10) was estimated visually. Ten measurements of the height and width of all microfeature types (tussocks, hummocks, mud boils and sorted circles), if found at a site, were also recorded every 10 m along the transect.

**Figure 10**
Illustration of ground-truthing detail recording and plant collection techniques



A thorough collection of all vascular plant and moss species was collected at each site. Specimens of vascular plants were identified using Porsild and Cody (1980) and Aiken et al. (2003). Susan Aiken of the Canadian Museum of Nature identified some specimens collected in 2001 (mostly sedges). Nomenclature of vascular plants primarily follows Aiken et al. (2003). Linda Ley identified all bryophyte specimens, and nomenclature follows Stotler and Crandall-Stotler (1977), Anderson (1990) and Anderson et al. (1990). Lichens were also collected as part of this sampling, though collections were not exhaustive. Most crustose species were not collected and some others were likely overlooked. Only the dominant specimens were identified to species and others were identified to genus following Brodo et al. (2001). Voucher collections of all specimens are kept on file at the Environment Canada office in Iqaluit.

Colour photographs were obtained at each site using a 35 mm SLR camera. Shots were taken from the ground looking directly at the ground and at the horizon. Pictures were also taken in the air from the helicopter looking down at the site prior to or just after the collection of ground-truthing information, at an average height of 75-100 m.

Turbidity and ice cover of numerous water bodies was assessed visually from the air and each was assigned a depth (ice-covered, deep, mid-depth, shallow, drained bed) and turbidity (no turbidity, low turbidity, turbid, mud/sediments) class. No other specific measurements were recorded at water bodies.

**Table 2**
Data recorded during visual assessment of ground-truthing sites on Southampton Island, Nunavut, 2001-2002

| | |
|---|---|
| General ground cover type | Coastal flat, wet sedge meadow, wet moss meadow, hummock graminoid tundra, tussock graminoid tundra, low shrub tundra, closed shrub thicket, open shrub thicket, moss-lichen upland, lichen-heath upland, gravel/till deposit, rock outcrop, boulders, exposed lake bottom, cobble and sand, other |
| Landform | Moraine, chevron, esker, bedrock outcrop, beach ridge, boulder ridge, unsorted lag deposits, sorted lag deposits, lowlands, lowland depression, coastal flat, high-centre polygons, low-centre polygons, frost boils, sorted circles, tussocks with sorted circles, river shoreline, small drainage shoreline, lake shoreline, pond shoreline, thermal karst shoreline, gravel ridge, till deposits, other |
| Slope | - Upper, middle, lower<br>- Gentle, moderate, steep, flat |
| Surficial expression | Level, undulating, hummocky, tussocky, broken/eroded, other |
| Substrate | Measured to either permafrost or to a depth of 30 cm: bedrock, glacio-marine lag, glacial till, sand, cobbles, gravel, boulders, clay/silt/alluvium, sedge peat, moss peat, heath peat, other |
| Moisture regime | Xeric, mesic, hygric, hydric |
| Ground cover detail (%) | Bedrock, boulders, gravel, sand, silt/clay, wet peat, dry peat, water, seashells, mosses, lichens, graminoids, forbs, shrubs, glacio-marine lag |

## 3.5 Image classification

Prior to selecting training regions on the digital data, an unsupervised classification of the satellite scenes using the full dataset (bands 1 to 5 and 7) was performed, thereby allowing us to verify the validity of our ground-truthing efforts through an approach unbiased by our knowledge of the site. An unsupervised classification automatically allocates all pixels with similar spectral signatures to the same class based on parameters set by the user, or to default values. On the other hand, a supervised classification process uses the class means of the spectral information, found in each band defined by the training regions of a scene, to find all other pixels with similar spectral signatures and classify them correspondingly.

Classification decisions made by the software were based on parameters set prior to running the unsupervised classification. The maximum number of classes was set to 100 because of the large extent of high absorption or reflectance ground cover on the island, the number of iterations (i.e., the number of classification attempts by the software) were not limited (default of 99 999), the classification percentage to remain unchanged was set to 99.9%, minimum class size was set to 0.025% of the total image, the sampling row interval was set at 1 (samples every row of the image), minimum distance between class means was set to 3.2, and the maximum standard deviation was set to 4.5. The last two parameters are typical default parameters for unsupervised classifications, and the other parameters were set to refine accuracy.

The unsupervised classification of each scene was then interpreted based on the enhanced scenes and the ground-truthing data. These classified scenes (i.e., unsupervised) were used in conjunction with the enhanced scenes used for ground-truthing in order to select more accurate training regions for each scene. Isolated pixels or small pixel-groupings that were inconsistent with the ground-truthing areas were not included in the training regions, to minimize variability. The size and number of training areas used for each class was variable and was a reflection of the distribution and frequency of each class on each scene. Generally, land classes with large uniform cover (e.g., deep water, ice, glacio-marine sedimentary lag) had larger training areas and a larger total number of training area pixels.

Once all training regions were selected, a supervised classification was then performed on each scene, again using the full dataset for each scene (bands 1 to 5 and 7), which allowed the software to use the full range of spectral signatures within all bands. A 20% filter was applied to the supervised classification process, to remove 10% of outliers at the tail ends of the distribution of spectral signature for each class within the scenes.

Unfortunately, efforts to complete satisfactory supervised classifications were unsuccessful. The results from the initial supervised classifications of the main scenes were obviously different from what we had observed on the ground throughout the island. Except for a few high absorption and reflectance classes, few classes were consistent with our ground-truthing data. A number of tests yielded similar results.

We decided to go back to the unsupervised classifications of each scene and to visually compare each class to our ground-truthing data and assign a class name to each. This procedure produced much better classified images. All like classes in each scene were grouped into a single class, because most land cover classes, especially high reflectance or absorption surfaces, were often split into numerous classes by the unsupervised classification process (e.g., out of the 100 classes on an individual scene, many could have been classified as “deep to mid-depth clear water bodies” and these were all grouped into one class labelled with the same name). We used the Post Classification Analysis Aggregation tool of the PCI Geomatica 9.1 software for this grouping procedure (PCI Geomatics 2003). All additional processing of digital images was done using PCI Geomatica 9.1, as numerous software problems and constraints were encountered with ER Mapper 6.3.

### 3.6 Image mosaic

Of the five main mapping scenes, only one scene, 029/014, was completely free of cloud cover over the Southampton Island landmass (Table 1, Figure 8). Nevertheless, all of the scenes were free of cloud cover over the MBSs. Scene 025/015 had a small cloud and cloud shadow area northwest of East Bay (64°18’45”N, 81°55’55”W) and scene 027/015 had one small cloud and cloud shadow area halfway between Ell Bay and South Bay (64°07’50”N, 84°36’49”W). In both cases, the neighbouring scenes were free of clouds in those regions and were used to produce the land cover map.

Two small areas on scene 025/015 were covered in a very thin fog or haze rolling inland from the sea ice over the eastern tip of the Bell Peninsula. The first covered the eastern third of Seahorse Point (63°45’43”N, 80°12’59”W), an area composed of greater than 90% bedrock and water. The second covered a small area halfway between Seahorse Point and Leyson Point (63°40’26”N, 80°45’26”W), an area composed of greater than 90% heath mats and nets, glacio-marine lag deposits, and water. We did not obtain imagery to correct the land cover classification in these areas, given that both were considered to be in marginal habitats for waterfowl and shorebirds and that the classification was not substantially altered by the thin haze.

Scene 029/015 presented two small cloud cover and shadow areas northeast of Ell Bay (64°30’10”N, 85°16’30”W and 64°22’25”N, 85°50’30”W) and another along the coast north of Ell Bay (64°35’10”N, 86°23’50”W). The latter was not corrected, as it was small and located over nearshore ocean waters, tidal flats and beach ridges. It is displayed in gray on the land cover map. Scene 028/015 (Table 1, Figure 8) was purchased to fix the former two small cloud cover areas. The scene was processed and treated using the same methodology as other scenes, and the appropriate portions of scene 028/015 were cropped and used to replace cloud-covered portions of scene 029/015 using the PCI Geomatica EASI modeller.

All scenes were combined into a seamless mosaic to create a land cover map of Southampton Island. As we did not conduct any ground-truthing north of latitude 64°31'N**,** we present the classification north of this latitude as being tentative. However, the lead author flew over this area on July 1 and 2, 2002, and we feel that the classification is valid for the most part, with some reservations regarding low-lying areas at the southern end of Duke of York Bay due to classification errors associated with lowland classes. Vector regions were created for each scene delineating the areas to be used to produce the image mosaic. The classification accuracy in the selected regions seemed to be more consistent with our ground-truthing data when compared to other overlapping scenes. The scenes were mosaiced using PCI Geomatica's OrthoEngine. To preserve classification values, no feathering or blending was used while creating the mosaic.

Vector regions were defined on the land cover map to reclassify some groups of pixels to other classes. These masks were used to:

- Reclassify sea and lake ice to the deep to mid-depth clear water bodies class;
- Split remaining ice and snow ridges into a separate class from coastal foreshore and backshore flats based on topography (found in highlands only);
- Split active deposits and drained water bodies into classes separate from the coastal foreshore and backshore flats based on topography;
- Reclassify, to the bedrock class, areas covered in shadows in deep valleys and other high-relief zones along the northeastern coast that were incorrectly classified as shallow or deep water.

Once all these modifications were applied to the mosaic, a smoothing function was applied to reclassify isolated single or double pixels to the dominant neighbouring habitat class. After a number of filtering tests, we selected the SIEVE filter in PCI Geomatica with a threshold size of three pixels because it produced the best results by effectively removing isolated pixels while still preserving linear features. The SIEVE filter merged pixels within a group smaller than user-specified filters (e.g., 3 x 3, 5 x 5) that tended to obliterate image details. This procedure minimized the speckling effect caused by these numerous pixels that are, in any event, likely incorrectly classified due to pixel averaging. However, we found that the spectral signature of water is quite specific and different from that of other cover types (with the exception of dark shadows in deep valleys), resulting in high classification accuracy for pixels in the water classes. Additionally, they provide good geo-referencing and navigation targets while flying over an area. Therefore, we removed the effect of the filtering process to preserve the water pixels, by creating and saving, as a separate file, a copy of all pixels in the water classes prior to applying the filter and then adding the water pixel layer back on post-filter.

Given that the scene pixels are 30 x 30 m (no resampling was ever done on the scenes), all surface area measurements were calculated by adding the total number of pixels assigned to each class in the specified area of interest (all of Southampton Island, East Bay MBS and Harry Gibbons MBS) and multiplying by 900 $m^2$ (0.0009 $km^2$). Measurement areas were defined using vector regions.

## 3.7 Accuracy assessment

The accuracy of the classification can be determined by comparing points or regions assigned to set land cover classes during field studies to the same points or regions on the land cover map. We evaluated the accuracy of our land cover map by following the descriptive technique for accuracy assessment procedures described by Story and Congalton (1986) and reviewed by Congalton (1991).

To maximize the number of pixels used in the accuracy assessment, we intended to use a region approach based on the training regions that had been defined on the ground-truthing field maps. However, software constraints required the use of a point approach. A total of 1499 independent sample points from the 23 land cover classes (27 to 110 points per class, most with ~ 50 points) were selected and evaluated to verify classification accuracy (i.e., how well each pixel was allocated to each land cover class). Figure 9 shows the distribution of the sample points.

The simplest descriptive statistic derived from an accuracy assessment is the overall accuracy of the classification, which is obtained by dividing the total number of correct classifications (the sum of the major diagonal) by the total number of pixels in the error matrix.

Similarly, accuracies on each individual land cover class can also be calculated. However, the producer has the choice to divide the number of correct pixels in that class by the total number of pixels in the corresponding column (reference data) or row (classified data) (Congalton 1991). In the former case, this is a measure of exclusion (omission) error and is referred to as producer's accuracy, because it indicates the probability that an area on the ground will be classified correctly. Producers are generally more interested in how well a specific area on the ground can be mapped. In the latter case, this is a measure of inclusion (commission) error and is referred to as user's accuracy, as it indicates the probability that a pixel from a classified map actually represents that land cover class on the ground. Users of classified maps are generally more interested in how well the map corresponds to what can be found at the site.

Producers of land cover classification maps often fail to acknowledge that even if an accuracy assessment is performed, this assessment is only as good as the selection (or independence) of data points or regions that are used for its production. While performing this selection, there is an inherent bias by producers to use points/regions in which they are the most confident, and these are points/regions that are usually accurately classified.

# 4 Results and discussion

## 4.1 Land cover classes

We identified two water classes, two variable coastal classes in the zone affected by rising and falling tides, one snow and ice class (includes sea ice), and 18 terrestrial land cover classes for the classification of the satellite scenes and creation of the land cover map of Southampton Island and its MBSs (Tables 3 and 4). These were in large part based on adaptation and expansion of the land cover classes described by Didiuk and Ferguson (2005), and Parker (1975). The surface area and relative cover covered by each class can be found in Table 3. General features of each class, and ground cover details, can be found in Tables 4 and 5, respectively. Ground and aerial pictures of each land cover class as well as descriptions of their colour on the enhanced scenes, topographic position, surficial expression, substrate, moisture regime, and brief vegetation descriptions can be found in Appendix 1. Colour names follow the Stanley Gibbons colour key (Stanley Gibbons 1979).

Other classes were also observed and sampled during fieldwork, but for various reasons (e.g., small scattered patches, spectral signature similar to other classes) we could not distinguish them as distinct classes during the classification process. General features for some of these classes can be found in Table 6, and more details and pictures can be found in Appendix 2.

We found 90 species of vascular plants on Southampton Island, of which 26 were graminoids, 51 were forbs, 6 were ericaceous shrubs and 7 were shrubs. We also collected 66 species of moss, 5 hepatics, and 14 lichens. Worthy of note were the two fertile specimens of *Bryum marratti* (collected at the same location) that were the first confirmed specimens found in North America. Both were independently verified by two specialists (Spence and Ley). Details on the vascular plants, mosses and lichens recorded in each class can be found in Appendix 3.

The land cover classes identified in this study are those that could be easily distinguished from low-altitude aerial inspections outside of transition zones between classes. These showed marked differences in substrate, vegetation community, topographic position and moisture regime, and could be easily distinguished visually by observers (Didiuk and Ferguson 2005). Based on these characteristics, we also deemed that they had the best potential to be easily and accurately distinguished using satellite image processing and classification. More detailed ground-truthing efforts could potentially identify a number of sub-classes for some land covers, especially in the lowlands and uplands with mesic to hygric moisture regimes as well as in transition zones. Due to their marked composition, these were also the habitats that had the highest potential to have distinct wildlife communities or assemblages.

Lowlands cover a considerable portion of both MBSs, slightly over 37% and 39% for East Bay and Harry Gibbons, respectively (Table 3). Lowlands and their surrounding habitats shelter some of the richest abundance and diversity of terrestrial fauna and flora in the Arctic (CAFF

2001). Since they comprise the backbone of good-quality wildlife habitats, their protection is essential to meet the conservation goals of the sanctuaries. However, we believe that the structure of the lowlands on Southampton Island has changed drastically since the creation of the sanctuaries. We suggest that overabundant white geese, and possibly caribou, have caused heavy damage to the vegetation community over large extents of graminoid meadows, both in the interior and along the coast. As has been shown at other breeding colonies and staging areas in Hudson Bay, under intensive grazing pressure, the feeding methods of white geese (grubbing and shoot pulling) cause a replacement of the graminoid cover by mosses and some salt-tolerant forbs (Handa et al. 2002; Jefferies et al. 2006). In extreme cases, even mosses disappear, leaving behind exposed peat and sediments often covered with a saline crust. Conversations with other researchers who have worked on Southampton Island intermittently over the last 20 years (e.g., Abraham, personal communication and unpublished data) reinforce our opinion that current habitat conditions in much of the lowlands represent a low-quality successional replacement of the original graminoid meadow community. A separate study of vegetational change by multi-temporal analysis of satellite imagery, focusing on lowland habitats of East Bay and the Boas River, is currently under way (Fontaine and Mallory, unpublished data).

Less than 7% of East Bay MBS was covered by graminoid meadows or low-centre polygons, most of which was showing signs of heavy grazing by geese. The remaining portions of the lowlands (over 31% of the surface area of the sanctuary) were covered with poorly vegetated moss carpets, exposed peat, exposed marine clays and silts, and salt crusts. Harry Gibbons MBS had 15–18% of its area under cover of graminoid meadows that were in reasonably good condition. These meadows can mainly be found away from the coast. Along the coast, habitat conditions were similar to that of East Bay, with much of the lowlands showing signs of having been drastically degraded. Over 21% of the sanctuary was covered in moss carpets and exposed sediments.

Since ground-truthing landings could not be carried out in the low-centre polygons land cover class on the western side of the island in 2002 due to high water levels, we could not evaluate the habitat quality of this class in that region as we did on the eastern side of the island in 2001. Between East Bay and Native Bay, most of the low-lying centres showed obvious signs of intensive goose grazing and had a meagre cover of vascular plants (Figure 11). As for other lowland classes, the dominant ground cover was mosses (often coated with dried algae). Frost ridges were usually well-vegetated with heath type plants, forbs and some graminoids, but showed evidence of grazing on the most palatable plants (Gauthier 1993; Handa et al. 2002). From what we could observe in 2002 from the air, and on the ground from the fringe of these habitats, low-centre polygons appeared to have a better vegetation cover on the western side of the island than on the eastern side.

**Figure 11.**
Low-lying area of low-centre polygons in the interior lowlands southeast of East Bay, Southampton Island, Nunavut. The dominant ground cover is moss coated in dried algae (black in colour) and the remaining vegetation is poor and usually in raised clumps.

**Table 3**
Area ($km^2$) and percent cover (%) of land cover classes found on Southampton Island (SHI) and East Bay and Harry Gibbons Migratory Bird Sanctuaries (MBSs), Nunavut

| Land Cover Class | SHI | | East Bay MBS[a] | | Harry Gibbons MBS | |
|---|---|---|---|---|---|---|
| | Area ($km^2$) | % | Area | % | Area | % |
| 1. Water Bodies[b] | | | | | | |
| 1.1 Deep to mid-depth clear water bodies | 2357.62 | 5.39 | 335.64 | 29.36 | 78.00 | 5.42 |
| 1.2 Shallow and/or turbid water bodies | 1674.25 | 3.83 | 102.61 | 8.98 | 177.09 | 12.31 |
| 1.3 Ice and snow ridges | 149.85 | 0.34 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2. Exposed Sediments | | | | | | |
| 2.1 Drained water bodies (thaw lakes) | 16.21 | 0.04 | 0.00 | 0.00 | 4.24 | 0.29 |
| 2.2 Coastal foreshore flats | 113.12 | 0.26 | 2.85 | 0.25 | 6.70 | 0.47 |
| 2.3 Coastal backshore flats | 356.35 | 0.81 | 16.12 | 1.41 | 70.06 | 4.87 |
| 2.4 Active deposits | 281.69 | 0.64 | 2.30 | 0.20 | 17.01 | 1.18 |
| 3. Highlands | | | | | | |
| 3.1 Bedrock outcrops | 3312.05 | 7.57 | 16.68 | 1.46 | 0.07 | 0.00 |
| 3.2 Boulder ridges | 3064.82 | 7.01 | 1.27 | 0.11 | 0.01 | 0.00 |
| 3.3 Lichen-heath tundra | 4286.43 | 9.80 | 23.20 | 2.03 | 121.79 | 8.47 |
| 3.4 Mix of lichen-heath and boulder ridges | 2809.06 | 6.42 | 10.98 | 0.96 | 27.73 | 1.93 |
| 4. Uplands: Bare Glacio-marine Lag Deposits | | | | | | |
| 4.1 Hand-size or larger fragments deposits | 1393.93 | 3.19 | 23.19 | 2.03 | 24.70 | 1.72 |
| 4.2 Gravel-size fragments deposits | 2049.13 | 4.68 | 15.25 | 1.33 | 5.33 | 0.37 |
| 4.3 Algae-covered lag | 1458.62 | 3.33 | 3.54 | 0.31 | 9.81 | 0.68 |
| 5. Uplands: Patterned Ground | | | | | | |
| 5.1 Heath mats | 4660.62 | 10.65 | 17.07 | 1.49 | 16.65 | 1.16 |
| 5.2 Heath nets | 3976.89 | 9.09 | 19.83 | 1.73 | 25.02 | 1.74 |
| 5.3 Heavy heath-shrub nets | 2195.01 | 5.02 | 8.86 | 0.77 | 72.12 | 5.01 |
| 5.4 Mixed tundra (heath/graminoid/shrub) | 3237.65 | 7.40 | 111.24 | 9.73 | 215.23 | 14.97 |
| 6. Lowlands | | | | | | |
| 6.1 Exposed peat and sediments | 1914.69 | 4.38 | 67.05 | 5.86 | 169.03 | 11.75 |
| 6.2 Hydric moss and peat carpet | 2017.92 | 4.61 | 241.18 | 21.10 | 98.98 | 6.88 |
| 6.3 Hygric moss carpet | 569.14 | 1.30 | 48.79 | 4.27 | 36.54 | 2.54 |
| 6.4 Graminoid meadows | 1442.19 | 3.30 | 24.49 | 2.14 | 225.63 | 15.69 |
| 6.5 Low-centre polygons | 389.05 | 0.89 | 51.13 | 4.47 | 36.36 | 2.53 |
| 7. Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8. Clouds[c] | 17.87 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 43 744.16 | 100.00 | 1143.27 | 100.00 | 1438.10 | 100.00 |

[a] Figures include Mitiq Island (64°1’46”N, 81°47’18”W) within the East Bay MBS.
[b] Figures include portions of ocean waters for East Bay and Harry Gibbons MBS, as they are part of the sanctuaries; however, figures for Southampton Island do not include any portions of ocean waters.
[c] Figures for cloud cover include portions located over ocean waters.

**Table 4**

General summary of features recorded for land cover classes identified using LANDSAT 7 ETM+ satellite imagery, Southampton Island, Nunavut. Refer to Appendix 1 for more details.

| Land Cover Class | Bands 4,5,2 Enhancements[a] | Topographic Position | Surficial Expression | Substrate | Moisture Regime | Dominant Vegetation |
|---|---|---|---|---|---|---|
| 1. Water Bodies | | | | | | |
| 1.1 Deep to mid-depth clear water bodies | Black to blue-black | Offshore ocean waters and ponds on higher ground | Bottom usually not visible | n/a | n/a | None |
| 1.2 Shallow and/or turbid water bodies | Bluish violet to bright violet | Nearshore tidal waters, coastal ponds and small streams | Bottom evident or water turbid | n/a | n/a | Few emergent graminoids |
| 1.3 Ice and snow ridges[b] | Bright magenta | Ocean ice; lake ice and snow drifts in highlands | Ocean ice in large expanses; snow drifts usually long and narrow | n/a | n/a | None |
| 2. Exposed Sediments | | | | | | |
| 2.1 Drained water bodies[b] | Rose-pink to brown rose | Thaw lakes in lowlands | Flat drained ponds, most unvegetated | Silt, clay and organic matter | Mesic to hydric | None when recently drained; mosses and graminoids where vegetation has had time to colonize |
| 2.2 Coastal foreshore flats | Rose-pink to dull rose | Long narrow strip above backshore flats | Unvegetated level mud flats | Marine silts and clays | Hygric to hydric | Unsampled; mostly algae |
| 2.3 Coastal backshore flats | Bright magenta | Wide band of tidal flats | Unvegetated level mud flats | Marine silts and clays | Hygric | Unsampled; mostly algae |
| 2.4 Active deposits[b] | Bright rose to rose-pink | Eroding stream banks; alluvial deposits and fans | Narrow strips along streams and wide deposits at river mouths | Rounded cobble, gravel and sand | Xeric at surface | Forbs |
| 3. Highlands | | | | | | |
| 3.1 Bedrock outcrops | Deep green | Wide band along northern coastline | Broken with abrupt changes in slope and aspect | Undivided metamorphic rocks | Xeric | Unsampled; similar to boulder ridges but sparse cover |
| 3.2 Boulder ridges | Yellow-green | Covers most of the highlands | Broken with abrupt changes in slope and aspect | Large rounded or angular metamorphic rock boulders | Xeric | Mosses with similar amounts of lichens, forbs, graminoids and shrubs |
| 3.3 Lichen-heath tundra | Yellow-orange to dull orange | Small to medium patches in highlands | Middle and upper slopes in highlands, uneven surface | Boulders, large rocks, cobble and sparse till | Xeric to mesic | Lichens and forbs |
| 3.4 Mix of lichen-heath and boulder ridges | Ochre to brown-ochre | Nearly all in highlands, often on large surface area with exposed till | On level ground and as a transition zone between boulder ridges and lichen-heath tundra | Till, cobble and large rocks | Mesic | Mosses, forbs and shrubs |
| 4. Uplands: Bare Glacio-marine Lag Deposits | | | | | | |
| 4.1 Hand-size or larger fragments deposits | White to light yellow | With 4.2, constitutes most of the uplands on southern 2/3 of the island | As extensive bare deposits with level to undulating surface | Broken lag (limestone and sandstone) | Xeric | Nearly bare except for occasional small mats of forbs |
| 4.2 Gravel-size fragments deposits | Light to bright yellow | With 4.1, constitutes most of the uplands on southern 2/3 of the island | As extensive bare deposits with level to undulating surface | Broken lag (limestone and sandstone) | Xeric | Nearly bare except for occasional small mats of forbs |
| 4.3 Algae-covered lag | Bright lime green | Depressions with ephemeral water levels | Easily identifiable by black colouration due to algal crust | Lag and mixed till | Variable | Variable |

| Land Cover Class | Bands 4,5,2 Enhancements[a] | Topographic Position | Surficial Expression | Substrate | Moisture Regime | Dominant Vegetation |
|---|---|---|---|---|---|---|
| | | over lag and till deposits | | | | |
| 5. Uplands: Patterned Ground | | | | | | |
| 5.1 Heath mats | Pink to "flesh" (pink-beige) | Uplands over mixed-till blankets and gravel-size lag | Large expanses with level to undulating ground; mats well separated | Mixed-till blankets and lag deposits | Xeric to mesic | Forbs |
| 5.2 Heath nets | "Flesh" (pink-beige) to cinnamon/sage green | Uplands over fine-grained till blankets | Large expanses with level to undulating ground; clear vegetation nets | Clay/silt and fine-grained till blankets and lag deposits | Mesic | Forbs and shrubs |
| 5.3 Heavy heath-shrub nets | Sage green to dull yellow-green | Shallow drainages of uplands over fine-grained till blankets | Usually linear formations along shallower upland areas surrounded by expanses of heath nets | Clay/silt and fine-grained till blankets and lag deposits | Mesic | Shrubs, forbs and graminoids |
| 5.4 Mixed tundra (heath/graminoid/shrub; patterned ground) | Dull yellow-green to yellow-orange | Throughout uplands and on higher ground in lowlands | Variable; melting pot of other classes heavily influenced by frost action (mud boils and other patterns caused by frost heave) | Variable; generally fine-grained tills | Mesic to hygric | Variable mosses, shrubs, graminoids and forbs with few lichens |
| 6. Lowlands | | | | | | |
| 6.1 Exposed peat and sediments | Rosine to carmine-red | Hygric and hydric lowlands | Level ground in extensive expanses of exposed peat; drainages inland and along the coast | Peat over marine silts and clays | Hydric to hygric; often with surface water | Mosses |
| 6.2 Hydric moss and peat carpet | Scarlet to red-orange | Hydric to hygric lowlands and drainages; usually along coast | Level ground in extensive expanses of bare moss and peat; mosses are often dead | Peat over marine silts and clays | Hydric to hygric; often with surface water | Mosses with variable graminoid cover |
| 6.3 Hygric moss carpet | Bright orange to orange-yellow | Hygric lowlands; along coast and inland | Level ground in extensive expanses of live bare moss | Peat over marine silts and clays | Hygric; sometimes with surface water | Mosses with variable graminoid cover |
| 6.4 Graminoid meadows | Orange-yellow to greenish-yellow | Throughout lowlands; now mostly found inland | Large expanses on level ground with well-developed vegetation community | Peat over marine silts and clays | Hygric; sometimes with surface water | Graminoids and mosses |
| 6.5 Low-centre polygons | Bright yellow-green to green | Interior lowlands | Large expanses easily identifiable from the air by checkered pattern | Peat over marine silts and clays | Hydric to hygric; centres covered with sheet water in wet years | Mosses and graminoids |
| 7. Unclassified | Various | n/a | n/a | n/a | n/a | n/a |
| 8. Clouds | Rose-pink to bright rose for clouds and black to brownish black for cloud shadows | n/a | n/a | n/a | n/a | n/a |

[a] Colour names follow Stanley Gibbons (1979).

[b] Although these classes could not be teased apart from the coastal foreshore and backshore flats classes based on their spectral signatures, their topographic location and/or regular shapes allowed them to be easily identified and separated during the classification process.

**Table 5**
Ground cover detail (%) of land cover classes of Southampton Island, Nunavut

| Land Cover Class[a] | Ground Cover Detail Class (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bedrock | Boulder | Gravel | Sand | Clay/Silt | Wet Peat | Dry Peat | Water | Seashells | Mosses | Lichens | Graminoids | Forbs | Shrubs | Lag |
| 2.1[b] | | | | | 85-95 | 0-10 | | | | 0-10 | | < 5 | | | |
| 2.2[b] | | | | | 5-95 | | | | | | | | | | |
| 2.3[b] | | | | | 5-95 | | | | | | | | | | |
| 2.4[b] | | 5-10[c] | 80-95[c] | 0-15[c] | 0-15[c] | | | | | | | | < 5 | | 80-95[c] |
| 3.1[b] | 85-95 | 5-15 | | | | | | | | < 5 | < 5 | < 5 | < 5 | | |
| 3.2 | < 5 | 75-85 | | | | | < 5 | | | 5-10 | < 5 | < 5 | < 5 | < 5 | |
| 3.3 | < 5 | < 5 | 5-15 | 5-15 | | < 5 | 5-10 | | | 5-10 | 20-60 | 5-15 | 25-60 | < 5 | |
| 3.4 | | 15-30 | | | | | 5-10 | | | 10-40 | 5-10 | 5-15 | 5-25 | < 5 | |
| 4.1 | | | | | | | | | | | | | < 5 | | 95-100 |
| 4.2 | | | | | | | | | | | | | < 5 | | 95-100 |
| 4.3[d] | | | | | | | | | | | | | < 5 | | 95-100 |
| 5.1 | | | | | 5-40 | | | | | | < 5 | < 5 | 5-15 | < 5 | 40-90 |
| 5.2 | | | | | 15-40 | | 5-10 | | | 5-10 | 5-10 | 5-10 | 5-15 | 5-20 | 30-45 |
| 5.3 | | | 5-10 | | 10-45 | 5-10 | < 5 | | | 0-10 | | 5-20 | 5-20 | 10-20 | 10-20 |
| 5.4 | | < 5 | 0-10 | < 5 | < 5 | 5-20 | 5-20 | | < 5 | 5-20 | 5-10 | 10-30 | 20-45 | 5-25 | 0-10 |
| 6.1 | | | | | 5-10 | 60-95 | | 0-10 | | 5-15 | | 0-15 | < 5 | < 5 | < 5 |
| 6.2 | | | | | 5-10 | 5-20 | | 0-10 | | 60-95 | < 5 | 5-20 | < 5 | | < 5 |
| 6.3 | | | | | | | | | | 60-95 | < 5 | 5-40 | < 5 | | < 5 |
| 6.4 | | | | | | 0-25 | < 5 | < 5 | | 5-50 | < 5 | 35-75 | 5-10 | < 5 | |
| 6.5 | | | | | | 0-10 | 0-10 | | | 40-95 | < 5 | 5-35 | < 5 | < 5 | |

[a] Land Cover Class: 2.1 = Drained water bodies (thaw lakes), 2.2 = Coastal foreshore flats, 2.3 = Coastal backshore flats, 2.4 = Active deposits, 3.1 = Bedrock outcrops, 3.2 = Boulder ridges, 3.3 = Lichen-heath tundra, 3.4 = Mix of lichen-heath and boulder ridges, 4.1 = Hand-size or larger fragments deposits, 4.2 = Gravel-size fragments deposits, 4.3 = Algae-covered lag, 5.1 = Heath mats, 5.2 = Heath nets, 5.3 = Heavy heath-shrub nets, 5.4 = Mixed tundra (heath/graminoid/shrub), 6.1 = Exposed peat, 6.2 = Hydric moss and peat carpet, 6.3 = Hygric moss carpet, 6.4 = Graminoid meadows, 6.5 = Low-centre polygons.

[b] 2.1 to 3.1 – not measured, figures are estimates only.

[c] 2.4 – figures depend on whether the deposits are located within or in the vicinity of till (boulder, gravel, sand, clay/silt) or glacio-marine lag (clay/silt, lag) deposits.

[d] 4.3 – the ground cover of this class is highly variable along large drainages such as the Boas River, and may include clay/silt, graminoids, forbs and shrubs; however, when found within large expanses of glacio-marine lags, the ground cover is identical to that surrounding it except for a coating of dried algae.

**Table 6**
General summary of features recorded for land cover classes indiscernible from other classes using LANDSAT 7 ETM+ satellite imagery, Southampton Island, Nunavut. Refer to Appendix 2 for more details.

| Land Cover Class | Bands 4,5,2 Enhancements[a] | Topographic Position | Surficial Expression | Substrate | Moisture Regime | Dominant Vegetation |
|---|---|---|---|---|---|---|
| 1. Shrub Thicket | Orange-vermillion to orange-red | Sheltered drainages on higher ground and as small patches on the west coast of South Bay south to Siqaivilaaq Point | Long narrow bands on upper part of drainage slopes or as small isolated thickets | Peat over mixed loose till | Hygric to mesic | Shrubs and forbs |
| 2. Coastal Turfs | Orange-yellow (but often mixed colours) | Exclusively along coastline of lowlands in zone often inundated by high tides | Level ground in broken patches interspersed with exposed marine sediments and brackish pools | Marine silts and clays | Hygric to hydric | Mosses |
| 3. Wet Sedge Meadow (Drainages) | Crimson to carmine | Drainages and depressions in uplands | Small localized pockets on level to gentle slopes with poor drainage; well-diversified plant community | Top horizon of deep peat over layer of silt and clay, the bottom portion of which is often mixed with till | Hygric to hydric | Graminoids, mosses and shrubs |
| 4. Hummock / Tussock Graminoid Tundra | Orange-brown and olive-sepia to reddish brown | Interior lowlands and lower uplands usually associated with lake shorelines | Gently undulating with broken surface due to troughs of exposed peat between hummocks and tussocks | Peat over thin layer of marine silts and clays, followed by broken lag or till | Mesic to hygric | Forbs and graminoids |
| 5. Shrub / Shale (Lag) Tundra | Ochre and brown-ochre | Isolated small patches in interior lowlands, often on the edge of upland lag deposits | Patterned ground; level surface broken by shrub-covered tussocks/hummocks and sorted shale (lag) flakes | Peat over mixed marine silts and large lag flakes | Mesic to hygric | Shrubs and graminoids |

[a] Colour names follow Stanley Gibbons (1979).

## 4.2 Visual interpretation of enhancements

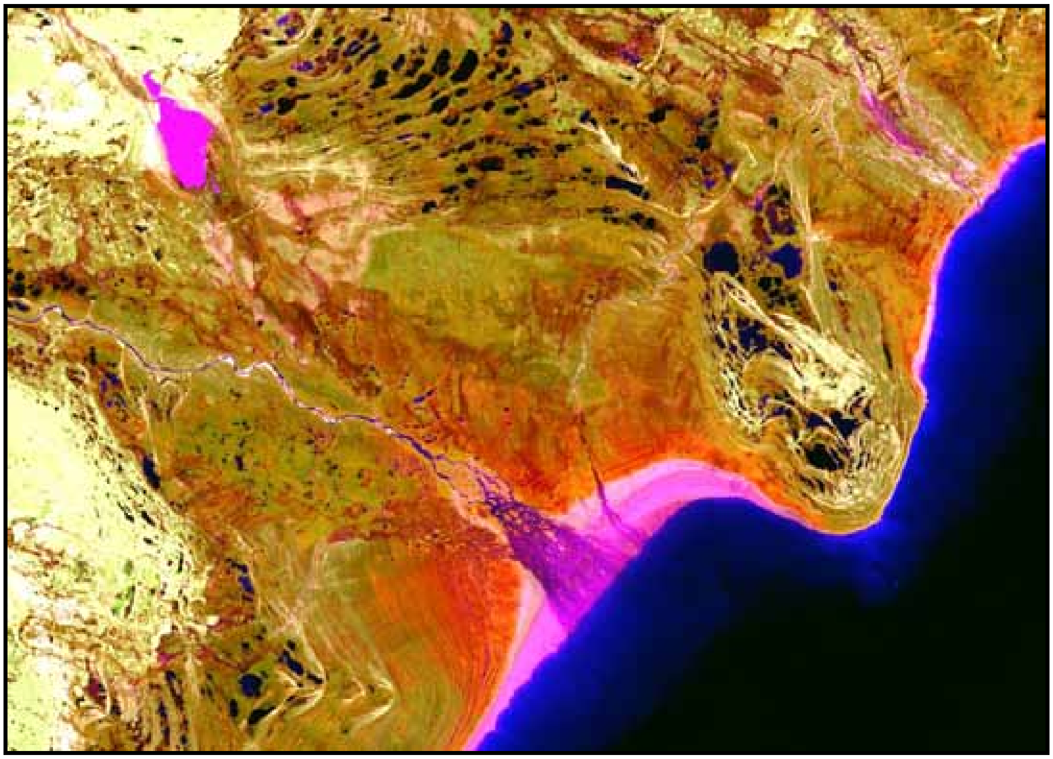
The enhancements using bands 4, 5 and 2 (displayed in red, green and blue, respectively) provided adequate overall separation of land cover classes (Figure 12). An additional benefit of this enhancement was that it provided images in a "natural" warm colour scheme that is easy to intuitively link to habitats on the ground. Targets with high reflectance or absorption were the most easily distinguished using the field maps. However, we observed an overlap of colours for land cover classes that were strikingly different in the field (e.g., lowland and upland tundra habitats were both displayed as shades of orange). This led to some confusion initially while conducting the field studies, and subsequently when examining the field maps and data. Appendix 1 lists the range of colours and shades associated with each land cover class using the enhancement of bands 4, 5 and 2.

We believe that the effectiveness and accuracy of field studies for Southampton Island could have been greatly improved and simplified using a different approach. Although more effort-intensive, the use of field maps created from either unsupervised classification procedures prior to field studies or from a combination of multiple enhancements specific to the three main regions of the island (highlands, till and lag uplands, and lowlands) would have alleviated this problem. Later tests revealed that enhancements specific to broad zones permitted a much greater level of class segregation.

Water bodies were easily distinguished by their clear margins and unique spectral signatures, ranging from black for deep and clear water bodies to shades of violet for shallow or turbid water bodies.

Exposed sediments, snow and ice were easily distinguished from all other land cover classes because of their high reflectance, clear margins and topographic positions. However, within this broad group, the spectral signatures of sea ice, snow ridges, coastal foreshore and backshore flats, active deposits, and the exposed bottom of drained water bodies all showed large portions of overlap and were consequently difficult to distinguish from one another based on colour, which were all in shades of bright magenta to rose-pink. Nonetheless, their distinct topographic positions or shapes were useful in separating these classes. All snow ridges, displayed in shades of bright magenta, were in long and narrow strips two to four pixels wide on the sheltered side of depressions or slopes in the highlands. Ice was also displayed in bright magenta, but was readily identified because it was located at sea in Hudson Bay and some isolated deep lakes in the highlands. Coastal backshore flats also were displayed for the most part in bright magenta, but due to their position along the coast were easy to distinguish. The exposed bottoms of drained water bodies were easily identified, as they were all inland and had the clear margins typical of water bodies, but they shared a large portion of their spectral signature with coastal foreshore flats, both displaying in shades of rose-pink to dull rose. However, coastal foreshore flats often had a light hint of turquoise green, yet were hard to distinguish from backshore flats because of the long transition zones between the two classes and because foreshore flats were usually narrow. Active deposits of rounded cobble, gravel and sand were displayed in colours similar to drained water bodies (bright rose to rose-pink), but were located in the elbows of streams and other drainages throughout the island and in alluvial fans where streams met the ocean in areas of moderate slope.

**Figure 12**
An example of an image enhancement of a LANDSAT 7 ETM+ satellite scene using an auto-clip transformation to band 4, and a linear transformation to bands 5 and 2 as well as a water spike reduction to band 2, displayed in red, green and blue, respectively.



High reflectance glacio-marine lag deposits made of hand-size fragments were white with a gradual transition to bright yellow as the size of the fragments decreased to the size of small gravel. In zones of ephemeral water levels, these deposits were often covered with black algae, which displayed in shades of bright lime green to apple green. The margins of lag and till deposits were generally well-defined. Lag and till deposits vegetated with heath mats or nets, usually composed of a high percentage of Mountain Aven and willows, were also easily distinguished. Those vegetated with mats or thin and broken vegetation crusts were in light shades of pink to pink-beige and, as the percentage of vegetation cover increased into heath nets, colours shifted to darker shades of pink-beige to light brown-rose turning to cinnamon and sage green where nets became very dense. The unsupervised classification easily identified all lag and till deposits and confirmed our ground-truthing efforts.

Moss carpets, graminoid meadows and various tundra cover classes proved difficult to separate initially because their spectral signatures were all displayed in overlapping shades of orange on the enhancements. We quickly learned to distinguish between them in the field based on their topographic position, although shade differences were also helpful. The unsupervised classification easily identified the core of these land cover classes, but it had problems with transition or mixed zones. All these land cover classes often had wide transition zones from one to the other throughout the uplands and lowlands, due to the low slope.

Exposed peat composed mostly of dead or dying moss was displayed in rosine to scarlet red along the coast, and darker reds in shades of crimson to carmine-red in interior lowlands. Somewhat less damaged hydric moss carpets were displayed in scarlet to red-orange, and colours changed progressively to bright orange and yellow-orange as moisture regime conditions became more hygric. Although more common along coastlines, hygric moss carpets could be found throughout the lowlands on level to low ground. As surface vegetation increased and lowlands turned to graminoid meadows, usually well away from the coast, displayed colours became darker so that the orange-yellow to greenish-yellow of graminoid meadows gave way to the bright yellow-green to green of low-centre polygons.

The colours displayed by well-vegetated uplands and highlands overlapped with graminoid meadows, although they tended to have more of an olive or ochre wash. Mixed tundra was in shades of dull yellow-green to yellow-orange, and was generally found as extensive cover on level or low-slope ground just below the highlands and in areas of higher ground in the lowlands. Lichen-heath tundra was found most commonly in the highlands intermingled with boulder ridges, and was in shades of yellow-orange to dull orange. Its transition zone with boulder ridges was in shades of ochre to brown-ochre.

We found that it was difficult to visually distinguish the yellow-green shades of boulder ridges and the deep green shades of bedrock on the enhanced images. The unsupervised classification showed some overlap between these two classes but easily identified their core. Topographic position again played a large role while ground-truthing. Boulder ridges and bedrock outcrops were found nearly exclusively in the northern highlands and northern Bell Peninsula, with bedrock in a strip along the coast changing into boulder ridges toward the interior. However, small bedrock outcrops also surfaced throughout the highlands, northeast of Coral Harbour, around the periphery of the Bell Peninsula, and in a “spit”-like formation in the centre of the island.

## 4.3 Classification of land cover classes

Extensive collections of ground-truthing information proved effective in creating a land cover map of Southampton Island. The pictures taken at each ground-truthing plot were a valuable tool in the course of digital processing work and we stress their importance for future studies. The land cover classes selected as part of our ground-truthing efforts provided an appropriate level of landscape detail and addressed future needs for wildlife surveys and habitat assessments. Importantly, we successfully identified areas with extensive damage from white goose overgrazing.

Sometimes, clear margins existed between different cover classes, especially in the highlands and lag/till deposits (Figure 13). More frequently, a gradual and irregular transition zone separated land covers where the spectral signature of one blended into that of another (Figure 14). These transition zones and their frequency, especially in the lowlands, rendered the selection of uniform or “pure” ground-truthing plots difficult. Allocation of these transition zone pixels to the land cover class with the closest spectral signature introduced error and affected the accuracy of the classification.

We were successful in effectively separating only one class of transition zone, that between boulder ridges and lichen-heath uplands. This was possible only because of the low number of classes found in the highlands, their different spectral signatures, and their large extent.

The land cover classification of Southampton Island was made more difficult by the heterogeneity of covers and variability of moisture regimes over covers that had similar surficial expressions. The landscape on Southampton Island is quite different from that of the Queen Maud Gulf and Dewey Soper MBSs, where large tracks of homogeneous terrain can be found, allowing land cover mapping efforts at these sites to achieve fine levels of segregation within the lowland classes. In contrast, Southampton Island has few unbroken expanses of uniform vegetative cover with a constant moisture regime, especially in the eastern lowlands. Changes in ground cover and moisture regime were high in frequency and were chaotic, making it difficult to refine the classification to better than broad, complex terrain types. Much of the lowlands of Southampton Island are so damaged that their spectral signatures are greatly influenced by a variety of surface features, such as water content of the moss and peat, small and often ephemeral ponds and sheet water, highly broken tracts of moss, peat and sediments, saline crusts, and intermittent small strips or pockets of slightly raised ground and old beach ridges partially vegetated with heath and willows.

It was also evident during our work that classification of Arctic tundra and lowlands is in large part driven by surface moisture regime and exposed substrates. Habitat classes that often looked nearly identical in the field (e.g., hydric and hygric moss carpet) had different spectral signatures due to their varying moisture regime, whereas habitat classes with distinct vegetation communities and surficial expression but with similar moisture regimes (e.g., inland graminoid meadows and mixed tundra) proved difficult to separate.

**Figure 13**
Illustration of the distinct boundaries between two land cover classes, in this case gravel-size glacio-marine lag adjacent to heath mats: a) aerial photograph from 100-m altitude; b) enhancement of bands 4, 5 and 2 of a LANDSAT 7 ETM+ satellite scene of the same site displayed in red, green and blue

**a)**

**b)**

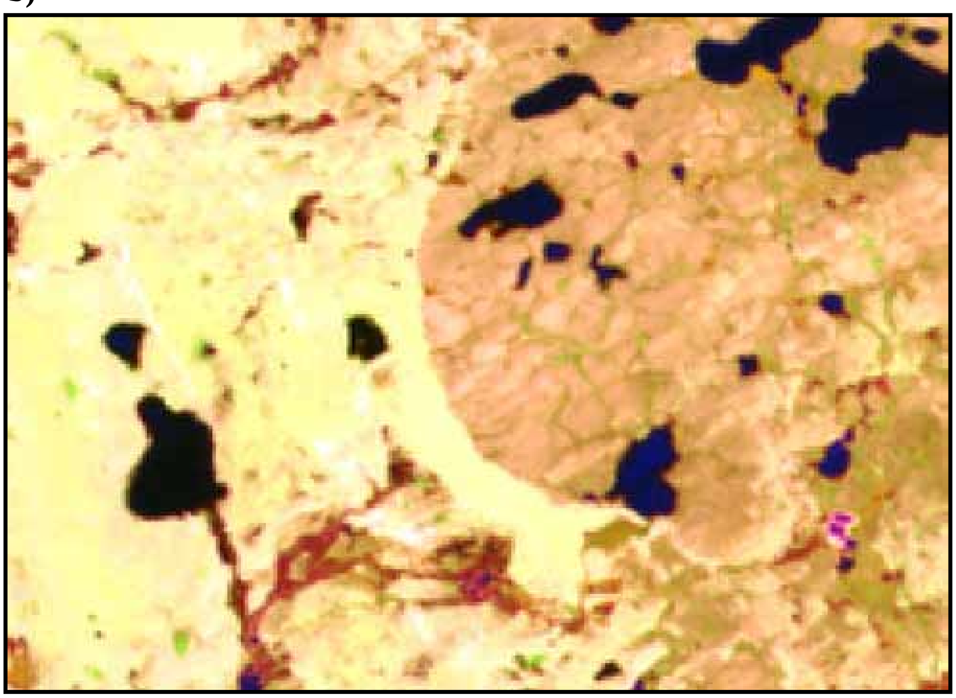
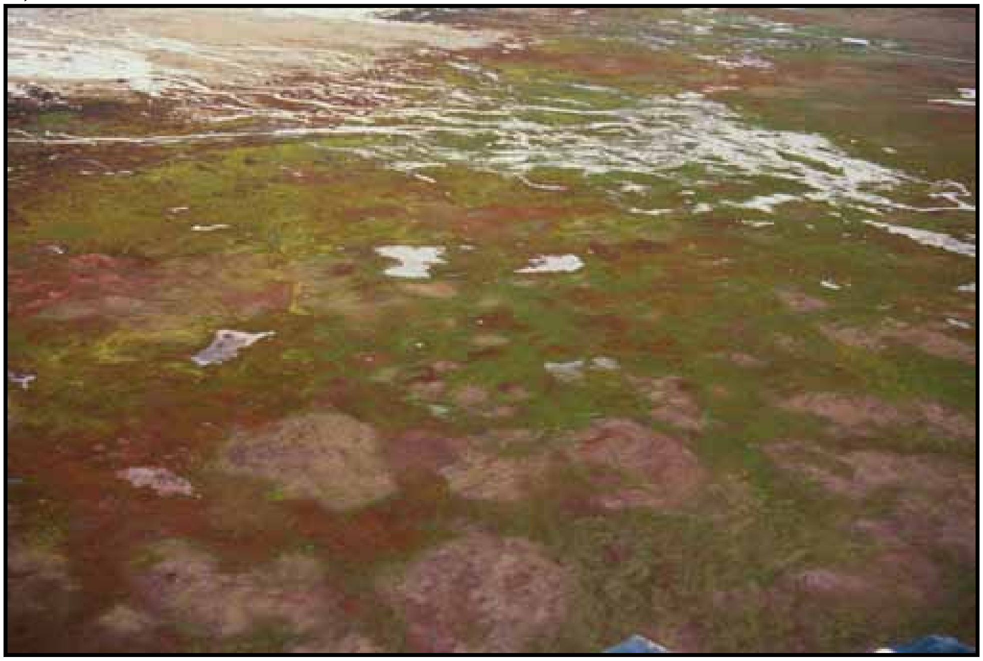


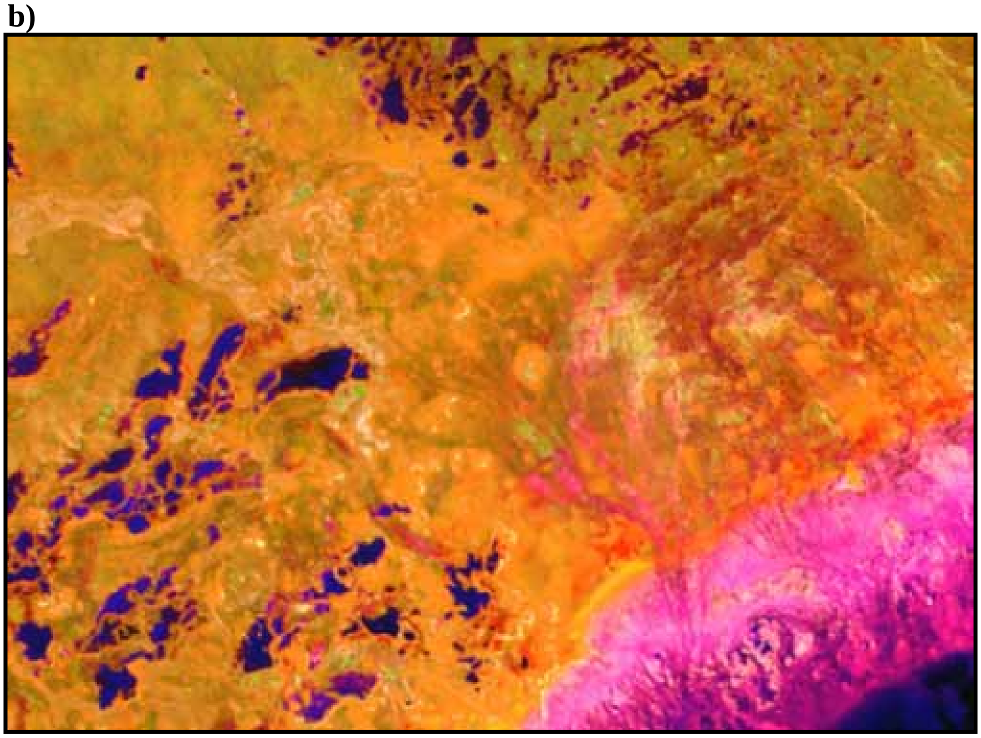
**Figure 14**

Illustration of land cover heterogeneity, in this case coastal lowlands showing foreshore flats, small braided pockets of shallow and turbid water, graminoid meadows, exposed sediment and peat, and hydric and hygric moss carpets: a) aerial photograph from 100-m altitude; b) enhancement of bands 4, 5 and 2 of a LANDSAT 7 ETM+ satellite scene of the same site displayed in red, green and blue

**a)**



**b)**



Differences in tide levels between some scenes (because some scenes were captured at different periods in the tide cycle) affected the surface area of land cover classes found in coastal areas, especially shallow ponds along the coast at East Bay and areas of coastal foreshore, backshore flats (tidal mud flats) and breakwater tidal bars. It also created some distinct “breaks” in the classification of coastal flats and waters where scenes captured at different tide levels merged.

Some portions of the lowlands in scene 027/015 (Figure 8) were classified as mixed tundra when they are in fact graminoid meadows; this is especially true in areas adjacent to low-centre polygons between Native Bay and East Bay as well as in the lowlands of Bear Cove and the coves on either side of Siqaivilaaq Point. This could have been caused in part by the drier conditions of these sites due to a steeper slope or raised ground, which in turn affected their vegetation composition (i.e., a lower proportion of water-absorbing mosses and a greater proportion of forbs and heath-related plants).

The classification accuracy in the area west of Caribou Island and north of East Bay is affected by a highly heterogeneous combination of vegetated drainages, boulder ridges, a thin vegetation cover over till veneers, exposed till veneers, and shallow water. In our classification, large portions were classified as shallow water, but, depending on moisture conditions in any given year, some of these areas may be better classified as a mix of lichen-heath and boulders.

Low-lying areas along the Boas River are subject to heavy flooding in some years. When receding, flood waters often leave behind a deposit of sediments (silt and clay), peat, dead vegetation and other flotsam, and shallow water conditions lead to algal growth over all substrates (e.g., vegetation, rocks, lag, etc), which results in poor classification accuracy in this zone. The inherent variability of land cover classes, their covering deposits and the water regime makes it difficult to predict what classes were attributed to any specific ground cover in any specific location during the classification process.

## 4.4 Accuracy of the classification

Collectively, we believe the overall accuracy of 96% to be reasonable, but perhaps biased slightly high (Table 7). The highest errors were associated with habitat classes with variable moisture regimes (e.g., lowlands) and the lowest errors were for classes with xeric moisture regimes (e.g., glacio-marine lag). Four main factors contributed to increasing the overall accuracy of the classification: software constraints, the use of a filter, avoidance of transition zones, and the large number of classes with high spectral absorption or reflectance. We discuss each factor below.

As stated in the methods, the boundaries of training regions (groups of pixels) were drawn on the field maps during ground-truthing work. Due to software constraints, we had to use a point approach (single pixels) instead of a region approach (groups of pixels) to produce the accuracy assessment. One of the problems with this approach is that there is an inherent bias by the producer to place the point within the training region where he/she is most confident that the classification is accurate, thereby increasing accuracy values.

The land cover map was refined by using a smoothing SIEVE filter function that was applied post-classification to remove single and double pixels isolated within larger blocks of a uniform land cover class (PCI Geomatics 2003). These isolated pixels often are incorrectly classified as a result of pixel averaging, and hence performing the accuracy assessment on the “filtered” land cover map likely increased classification accuracy values by reducing the odds of placing a point on such pixels.

Users must acknowledge the presence of transition zones between classes and that the producer had to make a decision to allocate such pixels to the class with the nearest spectral signature. For example, this was the case for glacio-marine lags, because beds of fragments that were larger than gravel but smaller than cobble (hand-size) were also present on the island. Few such transition (or mixed) zones were assessed during ground-truthing, which decreased errors, although they are an integral part of the Southampton Island landscape.

Due to their unique spectral signatures, we easily identified land cover classes with high absorption or reflectance. Furthermore, these classes often covered large surface areas, and had regular shapes, sharp boundary edges, xeric moisture regimes, little vegetation or a combination of any of these factors, which further enhanced our ability to classify them accurately. Many such classes were identified and their large number contributed to increase the overall accuracy of the classification.

The classification accuracy for the two water classes was 100% for both users' and producers' accuracies (Table 7). We expected high classification accuracy values for the water classes because of their high spectral absorption, regular shapes of water bodies, and often-predictable topographical locations. Deep, clear lakes were most common in areas favourable to stable shorelines, such as the uplands and highlands. Shallow ponds were common throughout the inland and coastal lowlands. Furthermore, with the exception of watercourses (streams, rivers, small drainages, alluvial plains), we observed very few turbid water bodies while ground-truthing the images, which decreased classification errors.

The high reflectance of coastal backshore and foreshore flats, ice (lake and ocean), and snow ridges resulted in very high classification accuracies (100% for all), and so these regions were easily classified. Their well-defined or identifiable topographic location also contributed to high classification accuracy.

The overall classification accuracy of terrestrial land cover classes was high: 74–100% for producers' accuracy and 82–100% for users' accuracy, demonstrating that most land cover classes were suitably classified. The highest accuracies were obtained for classes found over large areas of uniform cover with either xeric moisture regimes, high reflectance, or little vegetation (or all three), such as bare glacio-marine lag deposits and heath mats.

The classification of mesic upland and lowland (hydric and hygric) classes was driven by their ground cover composition and moisture regime. Changes in the proportion of exposed ground, mosses, graminoids, shrubs and forbs (especially ericaceous plants) influenced the classification results. This produced errors of commission when a land cover class was assigned to another with an overlapping spectral signature. Such errors were likely due to the variability in ground cover within classes (e.g., graminoid meadows with slightly drier conditions and with a higher proportion of forbs and shrubs being incorrectly classified as mixed tundra). Nevertheless, classification accuracy of vegetated upland and lowland classes remained high (74–100% producers' and 82–100% users' accuracy).

In summary, we believe the 96% average accuracy of the mapping realistically depicts the overall ability of a user to take our map and assess the type of ground cover across most of Southampton Island, based on the proportional contribution of different land covers to the entire area of the island (Table 7). However, if we were to restrict such an assessment to key wildlife habitats, we caution that accuracy in some of those areas will be somewhat lower.

**Table 7**

Producers' and users' accuracies of classification of land cover classes of Southampton Island, Nunavut

| | Reference data (number of sites sampled)[a] | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Classified Data[a] | 1.1 | 1.2 | 1.3 | 2.1 | 2.2 | 2.3 | 2.4 | 3.1 | 3.2 | 3.3 | 3.4 | 4.1 | 4.2 | 4.3 | 5.1 | 5.2 | 5.3 | 5.4 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | Row total | Users' accuracy (% correct) |
| 1.1 | **56** | | | | | | | | | | | | | | | | | | | | | | | 56 | 100 |
| 1.2 | | **72** | | | | | | | | | | | | | | | | | | | | | | 72 | 100 |
| 1.3 | | | **44** | | | | | | | | | | | | | | | | | | | | | 44 | 100 |
| 2.1 | | | | **27** | | | | | | | | | | | | | | | | | | | | 27 | 100 |
| 2.2 | | | | | **49** | | | | | | | | | | | | | | | | | | | 49 | 100 |
| 2.3 | | | | | | **50** | | | | | | | | | | | | | | | | | | 50 | 100 |
| 2.4 | | | | | | | **73** | | | | | | | | | | | | | | | | | 73 | 100 |
| 3.1 | | | | | | | 1 | **65** | 1 | | | | | | | | | | | | | | | 67 | 97 |
| 3.2 | | | | | | | | | **50** | | | | | | | | | | | | | | | 50 | 100 |
| 3.3 | | | | | | | | 1 | | **43** | | | | | | | 2 | 3 | | | | | 1 | 50 | 86 |
| 3.4 | | | | | | | | | | 1 | **70** | | | | | | | | | | | | | 71 | 99 |
| 4.1 | | | | | | | | | | | | **78** | | | | | | | | | | | | 78 | 100 |
| 4.2 | | | | | | | | | | | | | **86** | | | | | | | | | | | 86 | 100 |
| 4.3 | | | | | | | | | | | | | 2 | **55** | 4 | | | | | | | | | 61 | 90 |
| 5.1 | | | | | | | 1 | | | | | | | | **106** | | | | | | | | | 107 | 99 |
| 5.2 | | | | | | | 1 | | | | | | | | | **102** | | | | | | | | 103 | 99 |
| 5.3 | | | | | | | | | | | | | | | | | **51** | | | | 1 | | | 52 | 98 |
| 5.4 | | | | | | | | | | 1 | | | | | | | | **100** | | | 6 | 11 | 2 | 120 | 83 |
| 6.1 | | | | | | | | | | | | | | | | | | | **57** | | | | | 57 | 100 |
| 6.2 | | | | | | | | | | | | | | | | | | | | **71** | | 3 | | 74 | 96 |
| 6.3 | | | | | | | | | | | | | | | | | | | | | **43** | 2 | | 45 | 96 |
| 6.4 | | | | | | | | | | | | | | | | | | | | | | **45** | 10 | 55 | 82 |
| 6.5 | | | | | | | | | | | | | | | | | | | 2 | | | | **50** | 52 | 96 |
| Column total | 56 | 72 | 44 | 27 | 49 | 50 | 76 | 66 | 51 | 45 | 70 | 78 | 88 | 55 | 110 | 102 | 53 | 103 | 59 | 71 | 50 | 61 | 63 | **1499** | |
| Producers' accuracy (% correct) | 100 | 100 | 100 | 100 | 100 | 100 | 96 | 98 | 98 | 96 | 100 | 100 | 98 | 100 | 96 | 100 | 96 | 97 | 97 | 100 | 86 | 74 | 79 | | |
| Overall accuracy = 96% | | | | | | | | | | | | | | | | | | | | | | | | | |

[a] Land cover class reference numbers for classified and reference data: 1.1 = Deep to mid-depth clear water bodies, 1.2 = Shallow and/or turbid water bodies, 1.3 = Ice and snow ridges, 2.1 = Drained water bodies (thaw lakes), 2.2 = Coastal foreshore flats, 2.3 = Coastal backshore flats, 2.4 = Active deposits, 3.1 = Bedrock outcrops, 3.2 = Boulder ridges, 3.3 = Lichen-heath tundra, 3.4 = Mix of lichen-heath and boulder ridges, 4.1 = Hand-size or larger fragments deposits, 4.2 = Gravel-size fragments deposits, 4.3 = Algae-covered lag, 5.1 = Heath mats, 5.2 = Heath nets, 5.3 = Heavy heath-shrub nets, 5.4 = Mixed tundra (heath/graminoid/shrub), 6.1 = Exposed peat, 6.2 = Hydric moss and peat carpet, 6.3 = Hygric moss carpet, 6.4 = Graminoid meadows, 6.5 = Low-centre polygons

# 5 Management and research opportunities

## 5.1 Research suitability

The mapping scale requirement of any given project is a leading factor in assessing the suitability of LANDSAT satellite imagery. For instance, LANDSAT scenes provide users working at the landscape level with an effective means of generating detailed base maps of land cover classes. However, at the pixel level, pixel size and pixel-averaging causes individual pixels located over the margin of land cover classes or in transition zones to bear a spectral signature that is an amalgam of these classes. During the classification process, these pixels may be assigned to a class that is quite different from the “parent” classes.

The suitability of a land cover classification map is often dictated by the timing of satellite image acquisition, the type of research being conducted, and the biology of the species studied. As an example, for this project we used images that were captured by the satellite from mid-July to early August. The vegetation phenology of images captured at that time was suitable to assess habitats used by brood-rearing and moulting geese. However, these image acquisition dates are too late for Arctic shorebird projects, which require a depiction of habitats earlier in the season. Such projects are initiated in mid-June when normally secretive shorebirds are easier to detect through song as well as courtship and territorial displays. Images acquired at that time of year, although suitable for shorebird nesting and habitat studies, would produce a much different land cover map. Large areas throughout the island would still be covered in snow, large portions of the lowlands would be flooded, many lakes would still be covered in ice, and plant phenology would be in an early growth stage, producing a different vegetation classification.

Although the cost of this technology is still relatively high, prices have steadily been decreasing. To assist the classification process and increase accuracy of the land cover maps, field studies must be conducted to ground-truth the imagery. In remote locations, expenses associated with such ground-truthing efforts and their planning and logistics are significant. In the Canadian Arctic, these field studies require helicopter support, which entails early planning and expenses for the purchase of fuel and placement of fuel caches.

Since costs associated with producing habitat maps with satellite imagery are high, efforts should be made to increase communication between and within government departments for projects requiring the use of this technology. Collaborative research projects should be implemented to minimize overlap and decrease overall costs, both in terms of program financial allocation and the amount of time required to process the imagery (which can be considerable).

Production of such habitat base maps offers numerous advantages in that they are easily processed to suit the needs of the user whether they remain in the original raster (pixel) format or are converted to vector format. Since they are a geo-referenced digital product, map scale can be automatically adjusted and other digital or paper map products can be easily produced. File format can be changed easily to allow files to be imported into standard GIS software such as ArcView (ESRI 1996) or graphic software. Various spatial analyses of the full habitat map or subsets can be performed, such as analyses of surface area and fragmentation as well as patch size calculations.

## 5.2 Wildlife habitat and environmental assessment

Production of the land cover classification of Southampton Island, including detailed physical characteristics of each class, fulfills the primary objectives of this study. This habitat map will prove to be a valuable tool for a variety of wildlife and habitat research and monitoring programs. Given the growth in exploration for natural resources in the territory, this project provides baseline data that will be helpful for environmental impact assessment studies. Baseline habitat mapping may also have long-term applications for wildlife management, as it relates to climate change.

These habitat maps can be integrated with waterfowl and other wildlife surveys into a GIS to enhance the evaluation of wildlife-habitat relationships. One main use will be to identify sections of the island that are either ecologically critical for migratory bird species, namely white geese for which past and current population survey data are available (Kerbes 1975; Abraham and Ankney, unpublished data, 1979-80; Reed et al. 1980; Reed et al. 1987; Bazin et al., unpublished data, 1993-95; Kerbes et al. 2006), or that otherwise simply contain habitat recognized to be important based on general habitat preferences of the species examined. This is especially important in light of the dramatic increase in white goose populations (Canadian Wildlife Service Waterfowl Committee 2004) and decrease of many species of shorebirds across the Canadian Arctic over the past 20 years (Gratto-Trevor et al. 1998; Donaldson et al. 2000; Morrison et al. 2001a, 2001b). Monitoring programs are in place for both of these groups of migratory birds, the North American Waterfowl Management Plan and the Canadian Shorebird Conservation Plan (Donaldson et al. 2000; North American Waterfowl Management Plan Committee 2004), and land cover maps will greatly enhance monitoring by allowing stratification of survey efforts. Furthermore, suitable habitats can be readily identified, and plots can be selected and mapped prior to fieldwork without going through the logistical and financial expense of making extensive reconnaissance flights.

This land cover map also provides a baseline for comparison with past and future imagery to examine the extent of spatio-temporal changes in land covers, notably the extent and rate of increase of habitat degradation caused by grazing of over-abundant white geese. We found clear evidence of damage to graminoid meadows and other hydric to mesic lowland habitats throughout Southampton Island, especially in the prime brood-rearing habitats located in both MBSs (Figures 15 and 16). We suggest that much of each area is undergoing a conversion to exposed bare peat and moss with little or no other vegetation, as a result of white goose feeding habits involving grubbing and shoot-pulling—which effectively kills the plant (Handa et al. 2002). This damage, especially in the East Bay MBS, appears to be similar to that which has been found on the western coast of Hudson Bay (Kerbes et al. 1990; Ganter et al. 1996; Strivastava and Jefferies 1996; Bazely and Jefferies 1997; Kotanen and Jefferies 1997; Giroux et al. 1998). This type of habitat degradation has also been documented at other Arctic white goose breeding locations (Kerbes 1994; Didiuk and Ferguson 2005; Gauthier et al. 2004). Western Hudson Bay serves as a breeding area for white geese and a staging area for geese on their way north to Southampton Island and western Baffin Island (Bellrose 1980). This means that nearly all of the 3 million birds from the Lesser Snow Goose eastern Arctic colonies move through that area in migration, and compound any effects on habitats (Kerbes et al. 2006). Therefore, it is logical that Southampton Island, the next stopover on the migration route north for eastern Artic white geese (Bellrose 1980), should show signs of extensive damage.

**Figure 15**
Heavily damaged coastal lowlands adjacent to coastal foreshores near the Boas River delta, Harry Gibbons Migratory Bird Sanctuary, Southampton Island, Nunavut

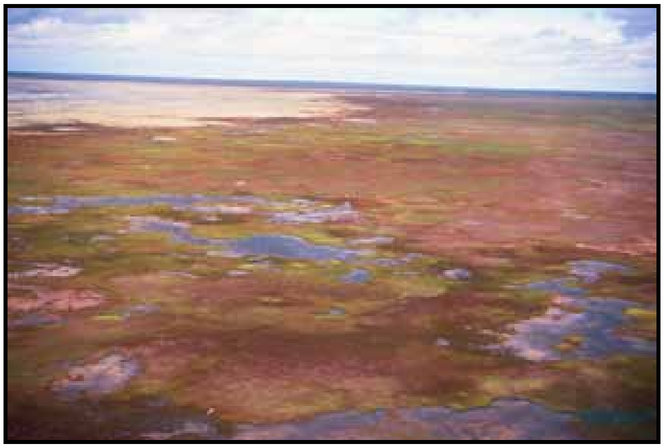


**Figure 16**
Salt crusts between East Bay and Native Bay, East Bay Migratory Bird Sanctuary, Southampton Island, Nunavut (taken from a height of approximately 75 m)

# Literature Cited


Abraham, K.F.; Ankney, C.D. 1986. Summer birds of East Bay, Southampton Island, Northwest Territories. Can. Field-Nat. 100: 180-185.

Aiken, S.G.; Dallwitz, M.J.; Consaul, L.L.; McJannet, C.L.; Gillespie, L.J.; Boles, R.L.; Argus, G.W.; Gillett, J.M.; Scott, P.J.; Elven, R.; LeBlanc, M.C.; Brysting, A.K.; Solstad, H. 2003. Flora of the Canadian Arctic Archipelago: Descriptions, Illustrations, Identification, and Information Retrieval. http://www.mun.ca/biology/delta/arcticf.

Anderson, L.E. 1990. A checklist of *Sphagnum* in North America north of Mexico. Bryologist 93: 500-501.

Anderson, L.E.; Crum, H.A.; Buck, W.R. 1990. List of the mosses of North America north of Mexico. Bryologist 93: 448-499.

Andrews, J.T.; Peltier, W.R. 1976. Collapse of the Hudson Bay ice center and glacio-isostatic rebound. Geology 4: 73-75.

Arft, A.M.; Walker, M.D.; Gurevitch, J.; Alatalo, J.M.; Bret-Harte, M.S.; Dale, M.; Diemer, M.; Gugerli, F.; Henry, G.H.R.; Jones, M.H.; Hollister, R.; Jónsdóttir, I.S.; Laine, K.; Lévesque, E.; Marion, G.M.; Molau, U.; Mølgaard, P.; Nordenhäll, U.; Raszhivin, V.; Robinson, C.H.; Starr, G.; Stenström, A.; Stenström, M.; Totland, Ø.; Turner, L.; Walker, L.; Webber, P.; Welker, J.M.; Wookey, P.A. 1999. Response patterns of tundra plant species to experimental warming: a meta-analysis of the International Tundra Experiment. Ecol. Monogr. 69: 491-511**.**

Arctic Goose Joint Venture. 1998. Science needs for the management of increasing snow goose populations. Canadian Wildlife Service, Ottawa, ON.

Balling, R.C., Jr. 1997. Analysis of daily and monthly spatial variance components in historical temperature records. Phys. Geogr. 18: 544-552.

Balling, R.C., Jr.; Michaels, P.J.; Knappenberger, P.C. 1998. Analysis of winter and summer warming rates in gridded temperature time series. Clim. Res. 9:175-181.

Bazely, D.R.; Jefferies, R.L. 1997. Trophic interactions in Arctic ecosystems and the occurrence of a terrestrial trophic cascade. Pages 183-207 in S.J Woodin and M. Marquiss (eds.), Ecology of Arctic Environments. Special Publication Number 13 of the British Ecological Society. Blackwell Science, Oxford, UK.

Béchet, A.; Giroux, J.-F.; Gauthier, G.; Nichols, J.D.; Hines, J.E. 2003. Spring hunting changes the regional movements of migrating Greater Snow Geese. J. Appl. Ecol. 40: 553-564.

Bellrose, F.C. 1980. Ducks, geese and swans of North America, third edition. Stackpole Books, Harrisburg, PA. 540 pp.

Bird, J.B. 1953. Southampton Island. Canada Department of Mines and Technical Surveys, Ottawa, ON. Geographical Branch Memoir 1. 84 pp.

Bird Studies Canada. 2004. Important Bird Areas of Canada, online directory. Bird Studies Canada, Port Rowan, ON. http://www.bsc-eoc.org/iba/IBAsites.html.

Bray, R.; Manning, T.H. 1943. Notes on the birds of Southampton Island, Baffin Island and Melville Peninsula. Auk 60: 504-536.

Brodo, I.M.; Duran Sharnoff, S.; Sharnoff, S. 2001. Lichens of North America. Yale University Press, New Haven, CT. 828 pp.

CAFF. 2001. Arctic flora and fauna: status and conservation. Conservation of Arctic Fauna and Flora, Edita, Helsinki, FIN. 272 pp.

Canadian Wildlife Service Waterfowl Committee. 2004. Population status of migratory game birds in Canada: November 2004. CWS Migr. Birds Regul. Rep. No. 13. Environment Canada, Ottawa, ON. 94 pp.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ. 37: 35-46.

Dewing, K.; Copper, P. 1991. Upper Ordovician stratigraphy of Southampton Island, Northwest Territories. Can. J. Earth Sci. 28: 283-291.

Didiuk, A.B.; Ferguson, R.S. 2005. Land cover mapping of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut. Can. Wildl. Serv. Occas. Pap. No. 111. Environment Canada, Ottawa, ON. 32 pp.

Donaldson, G.M.; Hyslop, C.; Morrison, R.I.G.; Dickson, H.L.; Davidson, I. 2000. Canadian Shorebird Conservation Plan. Canadian Wildlife Service, Environment Canada, Ottawa, ON. 27 pp.

Earth Resource Mapping. 2003. ER Mapper 6.4: User guide. Earth Resource Mapping Pty Ltd., San Diego, CA. 922 pp.

ESRI. 1996. ArcView GIS: the geographic information system for everyone. Environmental Systems Research Institute, Inc., Redlands, CA. 340 pp.

Ferguson, R.S. 1991. Detection and classification of muskox habitat on Banks Island, Northwest Territories, Canada, using Landsat Thematic Mapper data. Arctic 44: 66-74.

Ganter, B.; Cooke, F.; Mineau, P. 1996. Long-term vegetation changes in a snow goose nesting habitat. Can. J. Zool. 74: 965-969.

Gauthier, G. 1993. Feeding ecology of nesting greater snow geese. J. Wildl. Manage. 57: 216-223.

Gauthier, G.; Bêty, J.; Giroux, J.-F.; Rochefort, L. 2004. Trophic interactions in a high Arctic snow goose colony. Integr. Comp. Biol. 44: 119-129.

Geological Survey of Canada. 1999. Nunavut bedrock geology and faults. In Canada-Nunavut Geoscience Office, Nunavut Geoscience Sampler, October 2002: CD-ROM. Canada-Nunavut Geoscience Office, Iqaluit, NU.

Geological Survey of Canada. 2001. Nunavut surficial geology. In Canada-Nunavut Geoscience Office, Nunavut Geoscience Sampler, October 2002: CD-ROM. Canada-Nunavut Geoscience Office, Iqaluit, NU.

Giroux, J.-F.; Gauthier, G.; Costanzo, G.; Reed, A. 1998. Impact of geese on natural habitats. Pages 32-57 in B.D.J. Batt (ed.), The Greater Snow Goose: report of the Arctic Goose Habitat Working Group. Arctic Goose Joint Venture Special Publication. U.S. Fish and Wildlife Service, Washington, D.C. and Canadian Wildlife Service, Ottawa, ON.

Gratto-Trevor, C.L.; Johnston, V.H.; Pepper, S.T. 1998. Changes in shorebird and eider abundance in the Rasmussen Lowlands, NWT. Wilson Bull. 110: 316-325.

Government of Canada. 1997. Migratory Birds Sanctuary Regulations, C.R.C. c. 1036. Minister of Supply and Services Canada, Ottawa, ON.

Handa, I.T.; Harmsen, R.; Jefferies, R.L. 2002. Patterns of vegetation change and the recovery potential of degraded areas in a coastal marsh system of the Hudson Bay lowlands. J. Ecol. 90: 86-99.

Hansell, R.I.C.; Malcolm, J.R.; Welch, H.; Jefferies, R.L.; Scott, P.A. 1998. Atmospheric change and biodiversity in the Arctic. Environ. Monit. Assess. 49: 303-325.

Heywood, W.W.; Sanford, B.V. 1976. Geology of Southampton, Coats, and Mansel Islands, District of Keewatin, Northwest Territories. Energy, Mines and Resources Canada, Geological Survey of Canada, Memoir 382. 35 pp.

Hines, J.E.; Latour, P.B.; Squires-Taylor, C.; Moore, S. 2006. Survey and mapping of lowland habitat conditions in Banks Island Sanctuary Number 1, 1999-2001. Canadian Wildlife Service Unpublished Report, Yellowknife, NWT. 47 pp.

Hunter, G.T. 1970. Postglacial uplift at Fort Albany, James Bay. Can. J. Earth Sci. 7: 547-548.

INAC. 1993. Agreement between the Inuit of the Nunavut Settlement Area and Her Majesty the Queen in Right of Canada. Tungavik Inc. and Indian and Northern Affairs Canada, Ottawa, ON. 282 pp.

Jano, A.P.; Jefferies, R.L.; Rockwell, R.F. 1998. The detection of vegetational change by multitemporal analysis of LANDSAT data: the effects of goose foraging. J. Ecol. 86: 93-99.

Jefferies, R.L.; Jano, A.P.; Abraham, K.A. 2006. A biotic agent promotes large-scale catastrophic change in the coastal marshes of Hudson Bay. J. Ecol. 94: 234-242.

Johnston, V.H.; Gratto-Trevor, C.L.; Pepper, S.T. 2000. Assessment of bird populations in the Rasmussen Lowlands, Nunavut. Can. Wildl. Serv. Occas. Pap. No. 101. Environment Canada, Ottawa, ON. 56 pp.

Joria, P.E.; Jorgenson, J.C. 1996. Comparison of three methods for mapping tundra with Landsat digital data. Photogram. Eng. Remote Sens. 62: 163-169.

Kerbes, R.H. 1975. Lesser snow geese in the eastern Canadian Arctic. Can. Wildl. Serv. Rep. Ser. No. 35. Environment Canada, Ottawa, ON. 47pp.

Kerbes, R.H. 1994. Colonies and numbers of Ross's geese and lesser snow geese in the Queen Maud Gulf Migratory Bird Sanctuary. Can. Wildl. Serv. Occas. Pap. No. 81. Environment Canada, Ottawa, ON. 47 pp.

Kerbes, R.H.; Kotanen, P.M.; Jefferies, R.L. 1990. Destruction of wetland habitats by lesser snow geese: a keystone species on the west coast of Hudson Bay. J. Appl. Ecol. 27: 242-258.

Kerbes, R.H.; Meeres, K.M.; Alisauskas, R.T.; Caswell, F.D.; Abraham, K.F.; Ross, R.K. 2006. Surveys of nesting mid-continent lesser snow geese and Ross's geese in eastern and central Arctic Canada, 1997-98. Can. Wildl. Serv. Tech. Rep. Ser. No. 447. Environment Canada, Prairie and Northern Region, Saskatoon, SK. 54pp.

Kotanen, P.; Jefferies, R.L. 1997. Long-term destruction of sub-arctic wetland vegetation by lesser snow geese. Écoscience 4: 179-182.

Lee, H.A. 1968. Chapter 9, Part 1, Quaternary Geology. Pages 503-543 in C.S. Beals (ed.), Science, History and Hudson Bay, Volume 2. Department of Energy, Mines and Resources, Ottawa, ON. 1058 pp.

Mallory, M.L.; Fontaine, A.J. 2004. Key marine habitat sites for migratory birds in Nunavut and the Northwest Territories. Can. Wildl. Serv. Occas. Pap. No. 109. Environment Canada, Ottawa, ON. 92 pp.

Manning, T.H. 1936. Some notes on Southampton Island. Geogr. J. 88: 232-242.

Manning, T.H. 1942. Remarks on the physiography, Eskimo and mammals of Southampton Island. Can. Geogr. J. 24: 16-33.

Mathiassen, T. 1931. Contributions to the physiography of Southampton Island. Report of the fifth Thule expedition 1921-24, Vol. 1, No. 2. Gyldendalske Boghandel, Nordisk Forlag, Copenhagen, DNK. 30 pp.

Morrison, R.I.G. 1997. The use of remote sensing to evaluate shorebird habitats and populations on Prince Charles Island, Foxe Basin, Canada. Arctic 50: 55-75.

Morrison, R.I.G.; Aubry, Y.; Butler, R.W.; Beyersbergen, G.W.; Donaldson, G.M.; Gratto-Trevor, C.L.; Hicklin, P.W.; Johnston, V.H.; Ross, R.K. 2001a. Declines in North American shorebird populations. Wader Study Group Bull. 94: 34-38.

Morrison, R.I.G.; Gill, R.E.; Harrington, B.A.; Skagen, S.; Page, G.W.; Gratto-Trevor, C.L.; Haig, S.M. 2001b. Estimates of shorebird populations in North America. Can. Wildl. Serv. Occas. Pap. No. 104. Environment Canada, Ottawa, ON. 64 pp.

Mowbray, T.B.; Cooke, F.; Ganter, B. 2000. Snow goose (*Chen caerulescens*). No. 514 in A. Poole and F. Gill (eds.). The Birds of North America. The Birds of North America Inc., Philadelphia, PA.

Munn, H.T. 1919. Southampton Island. Geogr. J. 54: 52-55.

Nadelhoffer, K.J.; Shaver, G.R.; Giblin, A.; Rastetter, E.B. 1997. Potential impacts of climate changes on nutrient cycling, decomposition, and productivity in arctic ecosystems. Pages 349-364 in W. Oechel, T. Callaghan, T. Gilmanov, J.I. Holten, B. Maxwell, U. Molau and B. Sveinbjörnsson (eds.), Global change and Arctic terrestrial ecosystems. Ecological Studies, Vol. 124. Springer, Berlin, DEU.

Nordberg, M.-L.; Allard, A. 2002. A remote sensing methodology for monitoring lichen cover. Can. J. Remote Sens. 28: 262-274.

North American Waterfowl Management Plan Committee. 2004. North American Waterfowl Management Plan 2004. Strategic Guidance: Strengthening the Biological Foundation. Canadian Wildlife Service, U.S. Fish and Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales. 22 pp.

Parker, G.R. 1975. An investigation of caribou range on Southampton Island, NWT. Can. Wildl. Serv. Rep. Ser. No. 33. Environment Canada, Ottawa, ON. 81 pp.

Parks Canada. 1997. National Park System Plan. Canadian Heritage, Parks Canada, Ottawa, ON. 106 pp.

PCI Geomatics. 2003. Geomatica 9, software solutions. PCI Geomatics, Richmond Hill, ON. 330 pp.

Porsild, A.E.; Cody, W.J. 1980. Vascular plants of continental Northwest Territories, Canada. National Museum of Natural Sciences, National Museums of Canada, Ottawa, ON. 667 pp.

Priest, H.; Usher, P.J. 2004. The Nunavut Wildlife Harvest Study, August 2004. Nunavut Wildlife Management Board, Iqaluit, NU. 822 pp.

Reed, A.; Dupuis, P.; Fisher, K.; Moser, J. 1980. An aerial survey of breeding geese and other wildlife in Foxe Basin and northern Baffin Island, Northwest Territories, July 1979. Can. Wildl. Serv. Prog. Notes No. 114. Environment Canada, Ottawa, ON. 21 pp.

Reed, A.; Dupuis, P.; Smith, G.E.J. 1987. A survey of lesser snow geese on Southampton and Baffin Islands, NWT, 1979. Can. Wildl. Serv. Occas. Pap. No. 61. Environment Canada, Ottawa, ON. 24 pp.

Riewe, R. (ed.). 1992. Nunavut Atlas. Tungavik Federation of Nunavut and Canadian Circumpolar Institute, Edmonton, AB. 259 pp.

Rockwell, R.F.; Witte, C.R.; Jefferies, R.L.; Weatherhead, P.J. 2003. Response of nesting savannah sparrows to 25 years of habitat change in a snow goose colony. Écoscience 10: 33-37.

Stanley Gibbons. 1979. Stanley Gibbons stamp colour key. Stanley Gibbons Publications Ltd., London, UK.

Story, M.; Congalton, R.G. 1986. Accuracy assessment: a user's perspective. Photogram. Eng. Remote Sens. 52: 397-399.

Stotler, R.; Crandall-Stotler, B. 1977. A checklist of the liverworts and hornworts of North America. Bryologist 80: 405-428.

Strivastava, D.S.; Jefferies, R.L. 1996. A positive feedback: herbivory, plant growth, salinity, and the desertification of an Arctic salt-marsh. J. Ecol. 84: 31-42.

Sutton, G.M. 1932. The birds of Southampton Island. The Exploration of Southampton Island, Hudson Bay. Mem. Carnegie Mus. Vol. 12, Pt. 2 Zoology, Sec. 2. 275 pp.

Sutton, G.M.; Hamilton, W.J., Jr. 1932. The mammals of Southampton Island. The Exploration of Southampton Island, Hudson Bay. Mem. Carnegie Mus. Vol. 12, Pt. 2 Zoology, Sec. 1. 111 pp.

Tarnocai, C. 1999. The effect of climate warming on the carbon balance of cryosols in Canada. Permafrost Periglac. Process. 10: 251-263.

Tso, B.; Mather, P.M. 2001. Classification methods for remotely sensed data. Taylor and Francis, New York, NY. 332 pp.

Virtanen, T.; Mikkola, K.; Nikula, A. 2004. Satellite image based vegetation classification of a large area using limited ground reference data: a case study in the Usa Basin, north-east European Russia. Polar Res. 23: 51-66.

Walsh, J.E.; Chapin, F.S.; Osterkamp, T.; Dyurgerov, M.; Romanovsky, V.; Oechel, W.C.; Morison, J.; Zhang, T.; Barry, R.G. 2000. Observational evidence of recent change in the northern high-latitude environment. Clim. Change 46: 159-207.

Whitmore, D.R.E.; Liberty, B.A. 1968. Chapter 9, Part 2, Bedrock geology and mineral deposits. Pages 543-557 in C.S. Beals (ed.), Science, History and Hudson Bay, Volume 2. Department of Energy, Mines and Resources, Ottawa, ON. 1058 pp.

# Appendices

## Appendix 1

## Land cover classes of Southampton Island, Nunavut

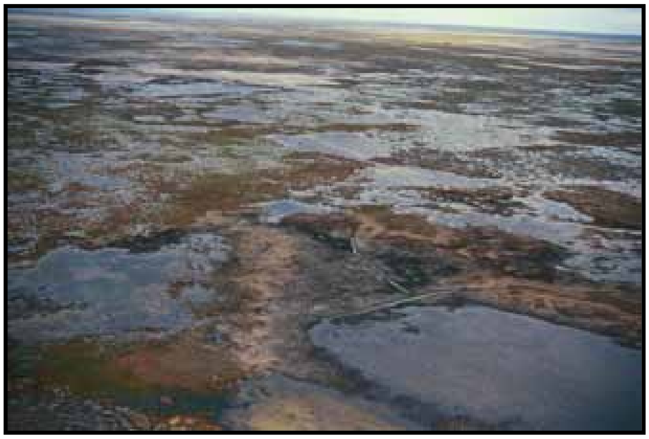
## 1. WATER BODIES

**1.1 DEEP TO MID-DEPTH CLEAR WATER BODIES**

**Bands 4, 5, 2 Enhancement:**
Black, blue-black to deep violet.

**Topographic position:** Offshore ocean waters. All lakes and ponds found in boulder and bedrock highlands, and most of those located in lag or till beds and heath tundra uplands. Some deeper lowland and coastal ponds. Inland water bodies, usually with stable shorelines.

**Surficial Expression:** Water appeared greenish when bottom was visible.



## 1.2 SHALLOW AND/OR TURBID WATER BODIES

**Bands 4, 5, 2 Enhancement:** Bluish violet to bright violet.

**Topographic position:** Nearshore tidal waters, deltas, tidal and coastal ponds, and small streams. Nearly always found in lowlands for inland ponds, and often associated with peat covered with sheet water, drainages, and small streams. Shorelines are unstable because they are mostly located in tidal zones and areas with level or low slopes.

**Surficial Expression:** Bottom evident and water depth noticeably shallow with very little colour in the case of clear water bodies. Nearshore tidal waters along lowland coastal areas often obviously turbid.

### 1.3 ICE AND SNOW RIDGES

**Bands 4, 5, 2 Enhancement:** Bright magenta.

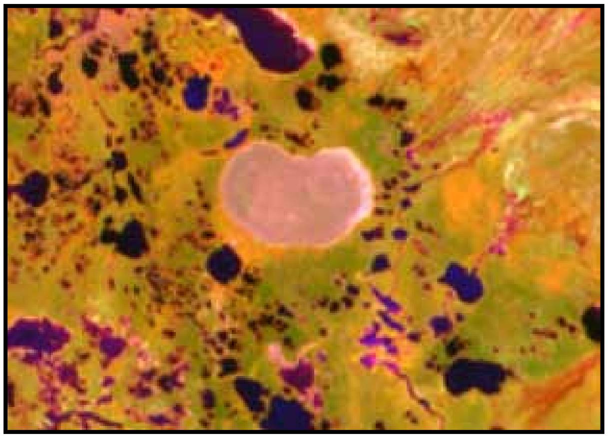
**Topographic position:** Landfast ice and drifting pack ice on ocean waters along the northern coast and some lake ice in the highlands near the northern coast. Snow drifts nearly all located along sheltered valleys and ridges in the highlands and ridges on steep to moderate upper slopes.

**Surficial Expression:** Large expanses of floating ice, portions covered by melt water. Snow drifts usually long and narrow and often covered in part by an accumulation of sediments from snow melt.

*Lake and ocean ice was reclassified to the Deep to Mid-Depth Clear Water Bodies class in the final classification.*

# 2. EXPOSED SEDIMENTS

**NO PICTURES AVAILABLE**



## 2.1 DRAINED WATER BODIES

**Bands 4, 5, 2 Enhancement:** Rose-pink, dull rose, brown rose.

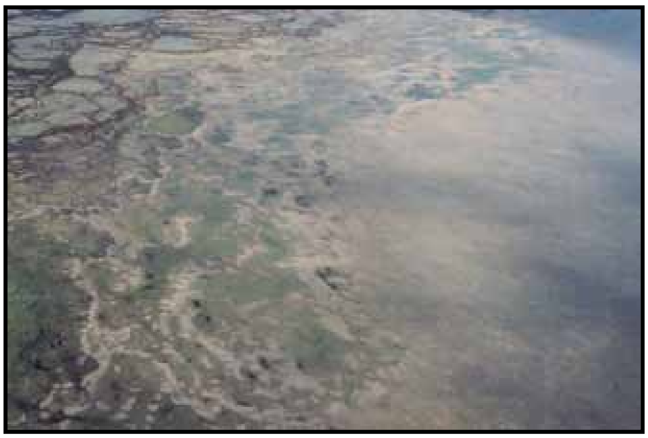
**Topographic position:** Uncommon, mostly thaw lakes. All were located in lowlands or lag/till deposits.

**Surficial Expression:** Flat drained pond or lake beds easily identifiable by their clear margins. Older thaw lakes often partially revegetated, whereas more recent drained bodies had muddy beds with variable amounts of water puddles or small drainages. Those found in lag/till deposits were unvegetated and usually had bisecting drainages and deposits of finer sediments.

**Substrate:** Variable. Lag and till deposits in uplands. Silt, clay and organic matter in lowland thaw lakes.

**Moisture Regime:** Variable depending on location and topography; mostly mesic to hydric.

**Vegetation:** Unsampled. Variable depending on substrate and topography. None when recently drained and mostly mosses and graminoids in older drained water bodies.



## 2.2 COASTAL FORESHORE FLATS

**Bands 4, 5, 2 Enhancement:** Rose-pink to dull rose. In areas adjacent to lowlands, will often have hints of light turquoise-green along coastal turfs.

**Topographic position:** In long narrow strip immediately above tidal flats (backshore flats) of coastal lowlands and small pockets of variable shape in the vicinity of river mouths. Rare small pockets in protected coves and bays of bedrock or till-controlled coastal shorelines. Inundated by high tides on a daily basis except for strip adjacent to coastal turfs. Also includes some coastal beach ridges.

**Surficial Expression:** Always on level ground. Unvegetated mud flats and shallow brackish to saline pools and channels. Some beach ridges.

**Substrate:** Marine silts and clays along foreshore flats and fine sediments of mixed origin at river mouths.

**Moisture Regime:** Hydric.

**Vegetation:** None.

## 2.3 COASTAL BACKSHORE FLATS

**Bands 4, 5, 2 Enhancement:** Bright magenta.

**Topographic position:** Wide band of tidal flats along lowland coastal areas. Sometimes also as small patches in small sheltered coves and bays associated with tidal ponds.

**Surficial Expression:** Large flats of marine silts and clays on near-level slope broken by shallow saline pools and channels and scattered boulders. Variable in width depending on topography and tidal conditions at the time of satellite scene capture.

**Substrate:** Marine silts and clays with pockets of mixed substrate.

**Moisture Regime:** Hydric.

**Vegetation:** None.

## 2.4 ACTIVE DEPOSITS

**Bands 4, 5, 2 Enhancement:** Bright rose to rose-pink.

**Topographic position:** Eroding banks, cut banks, and elbows of streams and other drainages throughout the island as well as alluvial fans where streams meet the ocean in areas of moderate slope.

**Surficial Expression:** Usually in narrow eroding banks or deposits along streams and wide fans at river deltas.

**Substrate:** Variable but usually rounded cobble, gravel and sand from glacial till deposits. Rarely finer sediments.

**Moisture Regime:** Variable but usually xeric at the surface layer.

**Vegetation:** Variable, depending on substrate and topography. Some common vascular plants include *Carex scirpoidea*, *Cochlearia officinallis*, *Oxyria digyna*, *Salix arctica* and *Smilax herbacea*. Some common mosses include *Polytrichum piliferum* and *Rhacomitrium canescens*.

# 3. HIGHLANDS

## 3.1 BEDROCK OUTCROPS

**Bands 4, 5, 2 Enhancement:** Deep green.

**Topographic position:** Mostly in a wide band in the highlands along the northern coast as well as scattered outcrops throughout the highlands.

**Surficial Expression:** Broken, frequent and abrupt changes in slope and aspect. Few vegetated pockets but covered with numerous shallow ponds on northwestern section of East Bay. Upper or middle slopes.

**Substrate:** Undivided metamorphic rocks of Precambrian origin. Pockets from various periods (Neoarchean, Mesoarchean, Paleoproterozoic) and slightly different composition (gneiss, granulite-facies gneis) are intermingled throughout the highlands and the northern Bell Peninsula. A small outcrop of undivided volcanic rocks can be found in the southern reaches of the highlands west of South Bay.

**Moisture Regime:** Xeric.

**Vegetation:** Not sampled but appeared mostly bare of vascular plants, though with crustose lichens in abundance. Vegetation present must be similar to that of boulder ridges and lichen-heath tundra.

### 3.2 BOULDER RIDGES

**Bands 4, 5, 2 Enhancement:** Yellow-green.

**Topographic position:** Covered most of the highlands in large expanses, giving way to bedrock nearing the coast.

**Surficial Expression:** Broken, frequent and abrupt changes in slope and aspect. Generally found on upper or middle slopes, though sometimes on level ground. Small portions (< 25%) covered with lichen-heath tundra or heath tundra carpets and small-vegetated depressions.

**Substrate:** Large rounded boulders or angular boulders of metamorphic rocks of Precambrian origin (see bedrock outcrops).

**Moisture Regime:** Xeric; localized mesic sites in depressions.

**Vegetation:** Sparse flora but similar to lichen-heath tundra. Common vascular plants include *Cassiope tetragona*, *Hierochloe alpine*, *Ledum decumbens* and *Luzula confusa*. Common mosses include *Dicranum elongatum* and *Rhacomitrium lanuginosum*. Most exposed rock surfaces are covered with crustose lichens. Other common lichens include *Alectoria ochroleuca*, *Bryoria nitidula*, *Cetraria cucullata*, *Cetraria nivalis*, *Thamnolia vermicularis* and *Umbelicaria* sp.

## 3.3 LICHEN-HEATH TUNDRA

**Bands 4, 5, 2 Enhancement:** Yellow-orange to dull orange.

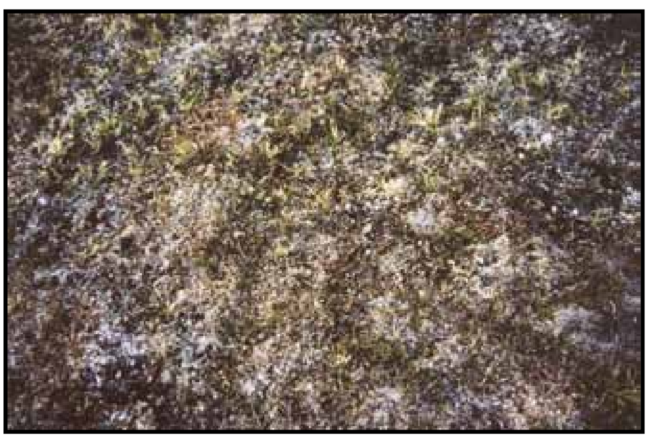
**Topographic position:** Nearly all found as small to medium patches in the northern highlands. Also, scattered patches in other well-drained upland areas with coarse-till veneers.

**Surficial Expression:** Depressions or level to moderate portions of middle slopes in highlands, but with rough uneven surface due to the presence of underlying boulders and large rocks. Boulders and other rock substrates often break the surface but cover less than 25% of surface area.

**Substrate:** Mostly boulders, and large rocks and cobble, sometimes mixed with sparse till but with thick blanket of heath/moss peat.

**Moisture Regime:** Xeric to mesic.

**Vegetation:** Very diverse vascular plant, moss and lichen communities. Heath-related plants are typical of this cover class. Common species include *Astragalus alpinus*, *Carex fuliginosa*, *Carex scirpoidea*, *Cassiope tetragona*, *Dryas integrifolia*, *Epilobium latifolium*, *Hierochloe alpine*, *Ledum decumbens*, *Luzula confusa*, *Lycopodium selago*, *Oxyria digyna*, *Oxytropis Maydelliana*, *Pedicularis lanata*, *Rhododendron lapponicumm*, *Salix arctica*, *Salix herbacea*, *Salix reticulata*, *Saxifraga oppositifolia*, *Silene acaulis*, *Vaccinium uliginosum* and *Vaccinium vitis-idaea*. Common mosses include *Dicranum elongatum* and *Rhacomitrium lanuginosum*. Very diverse lichen community; most exposed rock surfaces are covered with crustose lichens. Other common lichens include *Alectoria ochroleuca*, *Bryoria nitidula*, *Cetraria cucullata*, *Cetraria nivalis*, *Thamnolia vermicularis*, and *Umbelicaria* sp.



## 3.4 MIX OF LICHEN-HEATH / BOULDER RIDGES

**Bands 4, 5, 2 Enhancement:** Ochre to brown-ochre.

**Topographic position:** Nearly all found as medium to large expanses in the northern highlands. Also, scattered patches in uplands just below the highlands. Usually found over coarse-till veneers. This can be a transition zone between these two classes, or a distinct class in its own right due to the large uniform surface area it often covers.

**Surficial Expression:** Intermingled mix of lichen-heath tundra and boulder ridges, sometimes undivided bedrock outcrops. Mostly on level ground with uneven or undulating surface due to the presence of protruding boulders and other large rocks as well as underlying substrate.

**Substrate:** Mostly large rocks and cobble mixed by frost-heave action with coarse but finer till material and peat of heath and moss origins. Till substrate is thicker and more uniform than for lichen-heath tundra but the peat layer is much thinner.

**Moisture Regime:** Mostly mesic, sometimes xeric.

**Vegetation:** Flora typical of lichen-heath tundra but thin and stunted over xeric till deposits. Heath-related plants are typical of this cover class. Common species include *Cassiope tetragona*, *Dryas integrifolia*, *Hierochloe alpine*, *Ledum decumbens*, *Salix arctica*, *Salix reticulata*, *Saxifraga oppositifolia*, *Silene acaulis* and *Vaccinium vitis-idaea*. Sparse moss cover over tills; important elsewhere but little diversity. Diverse lichen community; most exposed rock surfaces are covered with crustose lichens. Common lichens include *Alectoria ochroleuca, Bryoria nitidula, Cetraria cucullata, Cetraria nivalis, Thamnolia vermicularis* and *Umbelicaria* sp.

# 4. UPLANDS

## BARE GLACIO-MARINE SEDIMENTARY LAG DEPOSITS

### 4.1 HAND-SIZE OR LARGER FRAGMENTS DEPOSITS

**Bands 4, 5, 2 Enhancement:** White to light yellow.

**Topographic position:** Lag deposits constitute most of the upland land cover in the southern two thirds of the island (Figure 4). Pockets of lag broken in hand-size fragments, scales or plates are located within larger expanses of gravel-size beds on the centre of the island, and as large pure beds on the Bell Peninsula and along the coast northwest of Cape Low and southeast of the Boas River Delta.

**Surficial Expression:** Extensive expanses of bare deposits with a level to undulating surface. Interspersed with numerous deep to moderately deep clear water bodies. Often oriented and sorted vertically by frost-heave action within deposits where fragments are shattered in thin flakes.

**Substrate:** By definition, lag broken in hand-size fragments or wide thin flakes.

**Moisture Regime:** Xeric.

**Vegetation:** Nearly bare of vegetation due to poor growing conditions except for occasional isolated plants of *Draba corymbosa*.

## 4.2 GRAVEL-SIZE FRAGMENTS DEPOSITS

**Bands 4, 5, 2 Enhancement:** Light to bright yellow.

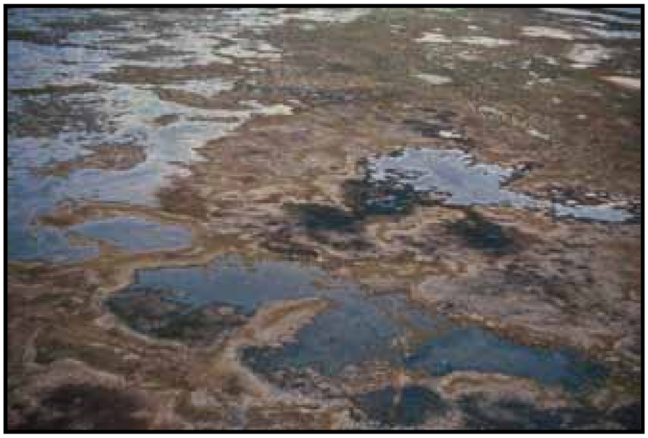
**Topographic position:** Glacio-marine sedimentary lag deposits constitute most of the upland land cover in the southern two thirds of the island (Figure 4). Large expanses of gravel-size beds can be found on the centre of the island and as pockets within beds of larger fragment beds on the Bell Peninsula.

**Surficial Expression:** Extensive expanses of bare deposits with a level to undulating surface. Interspersed with numerous deep to moderately deep clear water bodies.

**Substrate:** By definition, lag broken into gravel-size fragments.

**Moisture Regime:** Xeric.

**Vegetation:** Nearly bare of vegetation due to poor growing conditions, except for occasional isolated plants or small mats of *Draba corymbosa*, *Papaver radicatum* and *Saxifraga oppositifolia*.



## 4.3 ALGAE-COVERED LAG

**Bands 4, 5, 2 Enhancement:** Bright lime green to apple green.

**Topographic position:** Depressions with ephemeral water levels over coarse lag and till deposits throughout the uplands. Common around the edge of upland water bodies and along shallow ephemeral drainages.

**Surficial Expression:** Easily identifiable by the black colouration of the lag and till deposits due to their coating of dead, encrusted algae. When found over large areas, this class can also be deposits of gravel-size fragments from very dark limestone or sandstone origin.

**Substrate:** Lag and mixed till with moderate drainage.

**Moisture Regime:** Variable by definition, as this class is revealed when water levels drop. Xeric at drawdown but often mesic to hygric.

**Vegetation:** Unsampled. Variable. Usually bare of vegetation except for unidentified coating of algae and occasional small mats of *Draba corymbosa*, *Saxifraga oppositifolia*, *Dryas integrifolia* and willows.

# 5. UPLANDS

## PATTERNED GROUND

### 5.1 HEATH MATS

**Bands 4, 5, 2 Enhancement:** Light shades of pink to "flesh" (pink-beige).

**Topographic position:** Found throughout the uplands over mixed-till blankets and over gravel-size lag deposits, especially near the coast. Often found in areas of sorted materials from frost-heave action. Raised beaches and eskers.

**Surficial Expression:** In large expanses with level to gently undulating ground. Typically, vegetation mats are sparse and well separated. Sometimes in large expanses of sparse vegetation crusts, especially on the large peninsula north of Cape Low.

**Substrate:** Mixed-till blankets and lag beds made of small fragments.

**Moisture Regime:** Xeric to mesic.

**Vegetation:** Typical flora forms small circular mats; common species include *Draba corymbosa*, *Dryas integrifolia*, *Salix arctica*, *Saxifraga oppositifolia*, with some sparse sedges such as *Carex fuliginosa* and *Carex rupestris*. Sparse moss community, mostly *Bryum* species and *Ditrichum flexicaule*. Common lichens include *Cetraria cucullata*, *Cetraria nivalis* and *Thamnolia vermicularis*.

**OVER FINE-GRAINED MATERIALS**

## 5.2 HEATH NETS

**Bands 4, 5, 2 Enhancement:** Dark shades of “flesh” (pink-beige) and light brown-rose (often with a hint of yellow-olive) to cinnamon and sage green.

**Topographic position:** Found throughout the uplands over fine-grained till and lag blankets, especially in areas where silt makes up a large portion of the deposits. Usually in areas of intensive frost heaving with little coarse material larger than small gravel.

**Surficial Expression:** In large expanses over level to gently undulating ground. Narrow to broad veined vegetation nets in areas of fine-grained materials with intensive frost heaving. In large expanses of dry vegetation crusts in areas of unsorted coarse-grained materials (mixed till and lag), especially on the large peninsula north of Cape Low.

**Substrate:** Till blankets and lag or marine deposits composed of finer materials, mainly silt and clay.

**Moisture Regime:** Mesic, sometimes hygric. May be water saturated seasonally in areas of fine-grained materials.

**Vegetation:** Good vascular plant community, typical flora forms dense mats or vegetation veins; common species include *Arctagrostis latifolia*, *Carex aquatilis*, *Carex rupestris*, *Carex scirpoidea*, *Draba corymbosa*, *Dryas integrifolia*, *Eriophorum* sp., *Hulteniella integrifolia*, *Pedicularis lanata*, *Salix alaxensis*, *S. arctica*, *Saxifraga aizoides* and *Saxifraga oppositifolia*. Common mosses include *Bryum pseudotriquetrum*, *Bryum wrightii*, *Ditrichum flexicaule* and *Hypnum* sp. Few lichens, mostly crustose and squamulose species; common lichens include *Cetraria nivalis*, *Parmelia* sp. and *Stereocaulon* sp.

## 5.3 HEAVY HEATH-SHRUB NETS

**Bands 4, 5, 2 Enhancement:** Light shades of sage green to dull yellow-green (often with hints of brown-rose).

**Topographic position:** Similar to heath nets but usually found within large expanses of heath nets in the shallower areas and drainages with higher moisture levels. Found throughout the uplands over fine-grained till and lag blankets, especially in areas where silt makes up a large portion of the deposits. Usually in areas of intensive frost heaving with little material coarser than small gravel.

**Surficial Expression:** Similar to heath nets but interspersed with small pockets of graminoids, denser vegetation and a greater proportion of shrubs. Usually in large linear strips within shallower upland areas surrounded by expanses of heath nets.

**Substrate:** Till blankets and lag or marine deposits composed of finer materials, mainly silt and clay.

**Moisture Regime:** Mesic, sometimes hygric. May be water saturated seasonally.

**Vegetation:** Good vascular plant community. Typical flora forms dense vegetation veins or large mats; common species include *Arctagrostis latifolia*, *Braya glabella*, *Carex rupestris*, *Carex scirpoidea*, *Draba corymbosa*, *Dryas integrifolia*, *Eriophorum* sp., *Hulteniella integrifolia*, *Pedicularis lanata*, *Salix arctica*, *Salix reticulata*, *Saxifraga aizoides* and *Salix oppositifolia*. Common mosses include *Bryum pseudotriquetrum*, *Bryum wrightii*, *Ditrichum flexicaule* and *Hypnum* sp. Few lichens, mostly crustose and squamulose species such as *Parmelia* sp. and *Stereocaulon* sp.

## 5.4 MIXED TUNDRA (HEATH/GRAMINOID/SHRUB)

**Bands 4, 5, 2 Enhancement:** Dull yellow-green to yellow-orange.

**Topographic position:** Scattered in small to medium patches throughout the uplands and on higher ground in the lowlands. Usually associated with hummock/tussock graminoid tundra.

**Surficial Expression:** Highly variable land cover class. Generally on level to gently sloping ground. Melting pot of heath nets, heath tundra carpet, and hummock/tussock graminoid tundra with variable shrub cover. Usually heavily broken by frost heaves. Sometimes with sorted circles with fine tills in centre of mud boils and lag plates oriented vertically on the edges interspersed with willow nets.

**Substrate:** Generally sedge peat overlying mixed tills, most often silty tills, sometimes lag or highly frost-shattered broken metamorphic rocks.

**Moisture Regime:** Variable, but generally mesic to hygric.

**Vegetation:** Flora is a melting pot of other land cover classes and varies based on water regime. Most often falls between flora typical of lichen-heath tundra and heath nets. Common species include *Alopercus borealis*, *Arctagrostis latifolia*, *Carex aquatilis*, *Carex fuliginosa*, *Carex membranacea*, *Carex scirpoidea*, *Cassiope tetragona*, *Draba* sp., *Dryas integrifolia*, *Equisetum scirpoides*, *Eriophorum* sp., *Pedicularis* sp., *Salix arctica*, *Salix reticulata*, *Saxifraga hirculus*, *Saxifraga oppositifolia* and *Silene* species. Diverse moss community in areas with hygric moisture regime. Common mosses include *Aulacomnium acuminatum*, *Brachythecium turgidum*, *Campylium stellatum*, *Hypnum* sp., *Rhacomitrium lanuginosum* and *Tomenthypnum nitens*. Diverse lichen community that is often similar to that of lichen-heath tundra, but squamulose species more important. Common lichens include *Alectoria ochroleuca*, *Cetraria cucullata*, *Cetraria nivalis*, *Cladonia* sp., *Parmelia* sp., *Stereocaulon* sp. and *Thamnolia vermicularis*.

# 6. LOWLANDS

## COASTAL LOWLANDS

## 6.1 EXPOSED PEAT

**Bands 4, 5, 2 Enhancement:** Rosine to scarlet red along the coast and darker reds in shades of crimson to carmine-red in interior lowlands.

**Topographic position:** Mostly in hydric portions of lowlands of what used to be wet sedge meadows. Some also found in depressions of upland habitats.

**Surficial Expression:** Level ground. In wide expanses of bare peat with little to no living vegetation. Patches of thin algal or saline crusts as well as pockets of bare sediments are often present.

**Substrate:** Top horizon of peat of variable depth, mostly composed of bryophytes and sometimes of sedge and other graminoids overlying silts and clays of marine origin. Lag or till sometimes present under the marine clays (likely always present but too deep to confirm).

**Moisture Regime:** Always hydric along the coast, hydric to hygric inland. Often with standing surface water.

**Vegetation:** Poor floral communities, especially along coastlines. More species present inland, usually located on raised clumps of ground. Individual plants, often isolated. Most commonly observed vascular plants were *Arctagrostis latifolia*, *Arctophila fulva*, *Carex* sp., *Eriophorum* sp., *Hippuris vulgaris*, *Pedicularis sudetica*, *Salix arctica* and *Saxifraga hirculus*. Mosses formed the dominant cover and were mostly composed of *Bryum* species, typically *Bryum pseudotriquetrum*. We did not record any lichens in this cover class.

## 6.1 EXPOSED PEAT (CONTINUED)



## 6.2 HYDRIC MOSS AND PEAT CARPET

**Bands 4, 5, 2 Enhancement:** Scarlet to red-orange.

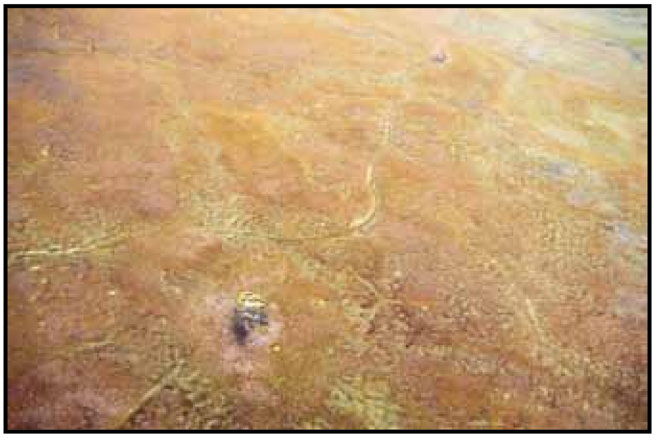
**Topographic position:** Hydric to hygric lowlands and drainages of what used to be sedge meadows. Usually along coast but also inland. Some also found in depressions of upland habitats.

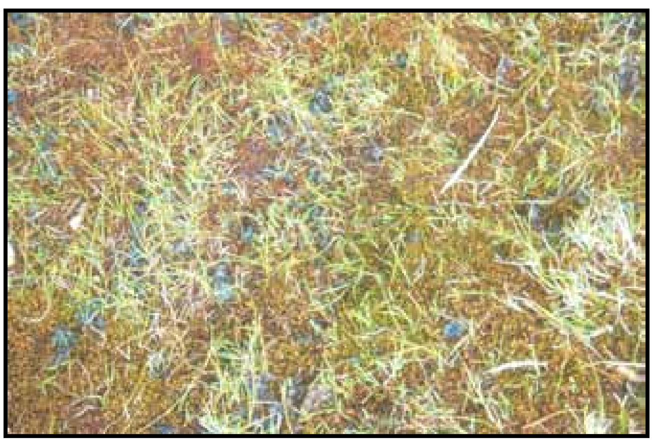
**Surficial Expression:** Level ground in extensive expanses of bare moss and peat carpets. Bryophyte community, usually dying, few vascular plants present (if any). Often with small crusts of green algae when water-logged.

**Substrate:** Top horizon of peat of variable depth, mostly composed of bryophytes and sometimes of sedge and other graminoids overlying silts and clays of marine origin. Lag or till sometimes present under the marine clays (likely always present, but too deep to confirm).

**Moisture Regime:** Hydric to hygric, but usually water-logged. Often with standing surface water.

**Vegetation:** Poor vascular plant community, plants sparsely distributed. Most common identifiable vascular plant was, by far, *Saxifraga hirculus*. Graminoids were difficult to identify due to plant damage and few flowering heads. Common plants included *Arctagrostis latifolia*, *Carex* sp., *Chrysosplenium tetrandrum*, *Eriophorum* sp., *Hippuris vulgaris*, *Kobresia simpliciuscula*, *Pedicularis sudetica* and *Salix arctica*. Mosses formed the dominant cover and were mostly composed of *Bryum* species, typically *Bryum pseudotriquetrum*. Other common moss species included *Campylium stellatum*, *Cinclidium latifolium*, *Drepanocladus brevifolius*, *Limprichtia revolvens* and *Scorpidium scorpioides*. Few lichens, but *Cetraria nivalis* and *Thamnolia vermicularis* were recorded at a few sites.





## 6.3 HYGRIC MOSS CARPET

**Bands 4, 5, 2 Enhancement:** Bright orange to orange-yellow.

**Topographic position:** Mostly in interior hygric lowlands of what used to be sedge meadows; also along coastal lowland areas. Some also found in depressions of upland habitats.

**Surficial Expression:** Similar to hydric moss carpets but with good bryophyte community. Usually some small graminoid shoots and other vascular plants present. In wide expanses on level ground.

**Substrate:** Top horizon of peat of variable depth, mostly composed of bryophytes and sometimes of sedge and other graminoids overlying silts and clays of marine origin. Lag or till sometimes present under the marine clays (likely always present but too deep to confirm).

**Moisture Regime:** Hygric, usually not as wet as hydric moss carpets and exposed peat. Sometimes with standing surface water.

**Vegetation:** Poor vascular plant community with individual plants sparsely distributed. Graminoids were difficult to identify due to plant damage and few flowering heads, but most common species appeared to be *Carex subspathacea*. Common plants included *Arctophila fulva*, *Carex* sp., *Chrysosplenium tetrandrum*, *Cochlearia officinallis*, *Hippuris vulgaris*, *Kobresia simpliciuscula*, *Salix arctica* and *Saxifraga hirculus*. Mosses formed the dominant cover and were mostly composed of *Bryum* species. Other common moss species included *Campylium stellatum*, *Limprichtia revolvens* and *Scorpidium scorpioides*. Few lichens.

## 6.4 GRAMINOID MEADOWS

**Bands 4, 5, 2 Enhancement: O**range-yellow to greenish-yellow.

**Topographic position:** Mostly in lowlands, usually along coastal lowland areas but sometimes further inland. Often adjacent to lakes and ponds or on wet middle slopes below snowdrifts.

**Surficial Expression:** In large expanses on level to gentle slopes with moderately damaged to undamaged well-diversified vascular plant community. However, large expanses have been altered to moss carpets and exposed peat.

**Substrate:** Top horizon of peat of variable depth, mostly composed of bryophytes and sedges overlying silts and clays of marine origin. Lag or till usually mixed in bottom portion of marine sediments.

**Moisture Regime:** Hygric to hydric. Often with standing surface water.

**Vegetation:** Diverse floral communities. Good diversity of vascular plants, graminoids being predominant. Common species included *Arctagrostis latifolia*, *Cardamine pratensis*, *Carex aquatilis*, *Carex membranacea*, *Cerastium alpinum*, *Draba* sp., *Dupontia Fisheri*, *Eriophorum angustifolium*, *Minuartia Rossii*, *Pedicularis sudetica*, *Salix arctica*, *Salix reticulata*, *Saxifraga hirculus* and *Silene uralensis*. Well-developed and diverse moss community, most commonly *Campylium stellatum*, *Ceratodon purpureus*, *Dicranum elongatum*, *Drepanocladus brevifolius*, *Hypnum bambergeri*, *Pohlia obtusifolia*, *Pseudocalligeron turgescens* and *Tomenthypnum nitens*. Some lichens, most commonly *Cetraria nivalis*, and species of *Cladonia*, *Parmelia* and *Stereocaulon*.

## DRY CONDITIONS

## 6.5 LOW-CENTRE POLYGONS

**Bands 4, 5, 2 Enhancement:** Bright yellow-green to green.

**Topographic position:** Interior lowlands and depressions in highlands.

**Surficial Expression:** In very large expanses with moderately damaged and poorly diverse vascular plant community. Overall area on level ground, but centre of polygons lower than the rims. Sometimes mixed with other lowland classes. Easily identifiable by the characteristic checkered “polygon” separations and the dark (almost black) colour of the bryophyte community. Polygon breaks variable in width, from 30 cm to 2 m, sometimes containing standing or gently flowing water.

**Substrate:** Top horizon of peat of variable depth, mostly composed of bryophytes and sedges overlying silts and clays of marine origin. Lag or till usually mixed in bottom portion of marine sediments.

**Moisture Regime:** Hygric to hydric. Poorly drained, usually with sheet water when on inland lowlands.

**Vegetation:** Vascular plant community showing obvious signs of damage by grazing geese, and is being replaced by moss. Diversity is low in many areas. Common species included *Carex aquatilis*, *Carex bicolor*, *Carex fuliginosa*, *Carex subspathacea*, *Chrysosplenium tetrandrum*, *Hierochloe pauciflora*, *Minuartia rossii*, *Salix arctica* and *Saxifraga hirculus*. Well-developed and diverse moss community, most commonly *Bryum* sp., *Ditrichum flexicaule*, *Drepanocladus brevifolius*, *Pseudocalligeron turgescens* and *Scorpidium scorpioides*. Few lichens, most commonly *Cetraria nivalis* and *Thamnolia vermicularis*.

**WET CONDITIONS**

## 6.5 LOW-CENTRE POLYGONS (CONTINUED)

# Appendix 2

## Observed land cover classes indiscernible from other classes, Southampton Island, Nunavut

**1. SHRUB THICKET**

**Bands 4, 5, 2 Enhancement:** Orange-vermillion to orange-red.

**Constraints:** Generally in narrow strips (< 30-m width) with inconsistent edges associated with moist sediments, wet mosses, surface water and other land cover classes causing incorrect classification due to pixel averaging.

**Topographic position:** Rare. Generally found in sheltered drainages and middle slopes below snowdrifts throughout the uplands and highlands. Some patches are found as isolated exposed thickets growing to nearly 2 m in height but only on the western coast of South Bay south to Siqaivilaaq Point.

**Surficial Expression:** Usually bottom or middle slopes in drainages of sheltered hills or valleys, but variable. Thickets usually narrow and often broken by wet sedge meadows.

**Substrate:** Variable, but usually on mixed loose tills with overlying peat horizon of variable depth.

**Moisture Regime:** Hygric below snowdrifts, mostly mesic elsewhere.

**Vegetation:** Floral communities, very diverse on middle slopes below snowdrifts. Mostly willows elsewhere. Common vascular plants included *Alopercus borealis*, *Arctagrostis latifolia*, *Betula glandulosa*, *Carex aquatilis*, *Diapensia lapponica*, *Eriophorum* sp., *Ledum decumbens*, *Luzula confusa*, *Pedicularis* sp., *Salix* sp. and *Stellaria crassifolia*. Common mosses included *Bryum pseudotriquetrum*, *Polytrichastrum alpinum*, *Polytrichum juniperinum*, and *Sphagnum girgensohnii*. Common lichens included *Alectoria ochroleuca*, *Cetraria nivalis* and species of *Parmelia* and *Stereocaulon*.

## 2. COASTAL TURFS

**Bands 4, 5, 2 Enhancement:** Orange-yellow but often mixed colours.

**Constraints:** Variable amalgam in a narrow strip along the coast of mud flats, brackish ponds, saline crusts, turf islands, strips of seaweeds and other flotsam, all with different spectral signatures, causing inconsistent, incorrect classification due to pixel averaging.

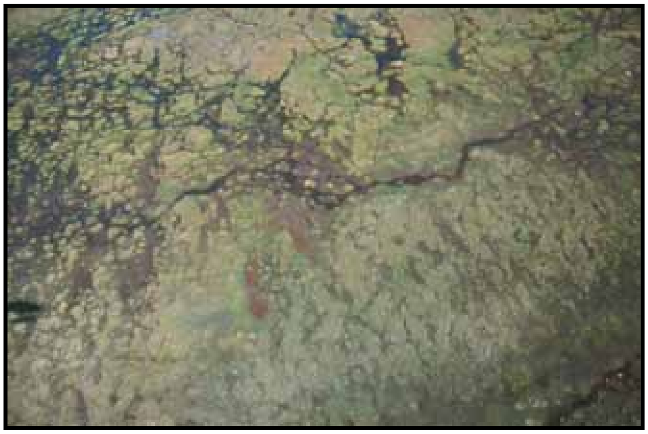
**Topographic position:** Found exclusively in coastal lowlands in long, narrow strips above nearshore and backshore flats. All locations inundated by high tides on a regular but not daily basis.

**Surficial Expression:** Always on level ground. Variable expanses of elevated moss turf islands interspersed with lower unvegetated mud flats and shallow brackish to saline pools and channels.

**Substrate:** Marine silts and clays along foreshore flats and fine sediments of mixed origin at river mouths.

**Moisture Regime:** Hygric to hydric.

**Vegetation:** Vascular plant community similar to hydric and hygric moss carpets. The few graminoids present are difficult to identify because of intensive goose grazing. Most commonly *Carex subspathacea*, *Chrysosplenium tetrandrum*, *Cochlearia officinallis* and *Kobresia simpliciuscula*. Cover is dominated by mosses, mostly *Bryum* and *Campylium* species. No lichens.



**3. WET SEDGE MEADOW (DRAINAGES)**

**Bands 4, 5, 2 Enhancement:** Crimson to carmine.

**Constraints:** Amalgam of surface covers with strongly different spectral signatures, causing incorrect classification due to pixel averaging: exposed wet moss/sedge peat, surface water and graminoid meadow. Usually incorrectly classified as exposed peat.

**Topographic position:** Common in drainages and depressions of upland habitats. Now rare in lowlands, as most wet sedge meadows have been altered to areas of bare peat and sediments. Often adjacent to lakes and ponds or on wet middle slopes below snowdrifts.

**Surficial Expression:** Usually in small localized pockets on level to gentle slopes with moderately damaged to undamaged well-diversified vascular plant community.

**Substrate:** Top organic horizon of deep peat composed of sedges and some bryophytes overlying silts and clays of marine origin. Lag or till usually mixed in bottom portion of marine sediments.

**Moisture Regime:** Hygric to hydric. Often with standing surface water or gently flowing water in drainages.

**Vegetation:** Usually well vegetated but showing signs of goose grazing, especially emergent graminoids. Graminoid cover shows little diversity, with large expanses composed of a few dominant species. Common vascular plants included *Arctagrostis latifolia*, *Carex aquatilis*, *Carex membranacea*, *Eriophorum* sp., *Hierochloe alpina*, *Luzula confusa*, *Pedicularis* sp. and *Salix arctica*. The most common mosses were *Aulacomnium turgidum* and *Sphagnum* species. Common species of lichens included *Alectoria ochroleuca*, *Alectoria ochroleuca* and *Thamnolia vermicularis*.

## 4. HUMMOCK / TUSSOCK GRAMINOID TUNDRA

**Bands 4, 5, 2 Enhancement:** Orange-brown and olive-sepia to reddish brown. Colour blotchy and uneven due to variability of moisture levels and exposed substrates.

**Constraints:** Vegetation community and other surface covers nearly identical to lichen-heath upland and mixed tundra and is therefore classified as such. However, structurally its surface expression in hummocks and tussocks is quite different.

**Topographic position:** Interior lowlands usually associated with shorelines of lakes and large ponds, other times as large plains.

**Surficial Expression:** Gently undulating to level ground with broken appearance due to troughs of exposed peat between hummocks and tussocks.

**Substrate:** Troughs have a top horizon of peat, usually shallow and composed of vascular plant remains and bryophytes overlying thin layer of marine silts and clays, if any. Lag or till usually exposed in troughs or mixed in bottom portion of marine sediments.

**Moisture Regime:** Mesic to hygric; hummocks/tussocks usually mesic and troughs usually hygric.

**Vegetation:** Floral community; a mix of lichen-heath tundra and graminoid meadows. Common vascular plants included *Carex fuliginosa*, *Carex scirpoidea*, *Hulteniella integrifolia*, *Pedicularis* sp., *Salix* sp., *Saxifraga aizoides*, *Saxifraga oppositifolia* and *Silene uralensis*. Few mosses. Common lichens included *Cetraria cucullata*, *Cetraria nivalis*, *Cladonia* sp., *Parmelia* sp., *Stereocaulon* sp. and *Thamnolia vermicularis*.

## 5. SHRUB / SHALE (LAG) TUNDRA

**Bands 4, 5, 2 Enhancement:** Ochre and brown-ochre with bistre, olive-bistre and bistre-yellow mottling or shading. Colour blotchy and uneven due to the variability in the cover of large lag (shale) plates and willows.

**Constraints:** Vegetation characteristics with similarities to mixed tundra and mixed lichen-heath/boulder ridges, and therefore similar colours on the scene enhancements. However, although it had a fairly unique surface expression, it was a rare cover and few patches were observed, which made it impossible to tease apart in the classification.

**Topographic position:** Isolated small patches in interior lowlands, usually on slightly higher and drier ground. Often near upland lag deposits.

**Surficial Expression:** Level ground with surface broken by vegetated (predominantly willows) hummocks and tussocks and frost-heave troughs of sorted shale plates. Patterned ground.

**Substrate:** Hummocks and tussocks composed of peat from moss and vascular plant remains, overlying fine-grained lag and marine clays mixed in with large lag flakes. Troughs composed primarily of large lag flakes at surface over mixed lag and marine clays.

**Moisture Regime:** Mesic to hygric; hummocks/tussocks, usually mesic, and frost-heave limestone troughs—xeric on surface but hygric within substrate.

**Vegetation:** High proportion of the area covered in vegetation; however, the floral community is limited in number of species. Vascular plant cover composed almost entirely of *Dryas integrifolia*, *Kobresia simpliciuscula*, *Salix* sp. and a few *Pedicularis capitata*. Low moss cover, nearly all *Bryum* sp., *Campylium stellatum*, *Ditrichum flexicaule* and *Tomenthypnum nitens*. Few lichens with only trace cover, mostly *Cetraria cucullata*, *Cetraria nivalis* and *Thamnolia vermicularis*.

**Appendix 3**
List of the vascular plants, bryophytes and lichens by land cover class on Southampton Island, Nunavut

| Species | Land Cover Class[a] | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.4 | 3.2 | 3.3 | 3.4 | 4.1 | 4.2 | 5.1 | 5.2 | 5.3 | 5.4 | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | W | D | S |
| **Vascular Plants** | | | | | | | | | | | | | | | | | | |
| *Alopercus borealis* | | | | | | | | | | X | | | | X | | X | | |
| *Arctagrostis latifolia* | | X | X | X | | | | X | X | X | X | X | | X | | X | X | |
| *Arctophila fulva* | | | | | | | | | | | X | | X | | | | | |
| *Arctous alpina* | | | | | | | | | | X | | | | | | | | |
| *Armeria maritima* | | | X | | | | | | | X | | | | | | | | |
| *Astragalus alpinus* | | | X | | | | | | | X | | | | | | | | |
| *Betula glandulosa* | | | | | | | | | | | | | | | | X | X | |
| *Braya glabella* | | | | | | | X | X | X | X | | | | | | | | |
| *Cardamine bellidifolia* | | | | X | | | | | | | | | | | | | | |
| *Cardamine pratensis* | | | | | | | | | | | | | | X | | | | |
| *Carex aquatilis* | | X | X | | | | | X | | X | X | X | X | X | X | X | X | |
| *Carex atrofusca* | | | | | | | | X | X | X | | | | X | X | | | |
| *Carex bicolor* | | | | | | | | | X | | | X | | | X | | | |
| *Carex fuliginosa* | | | X | | | | X | X | X | X | | | | X | X | | X | |
| *Carex glacialis* | | | | | | | | X | | | | | | | | | | |
| *Carex marina* | | | | | | | | | X | X | | X | | | X | | | |
| *Carex membranacea* | | | | X | | | | | | X | | | | X | | | X | |
| *Carex physocarpa* | | | | | | | | | X | | X | | | | | | | |
| *Carex rupestris* | | | X | | | | X | X | X | | | | | | | | | |
| *Carex scirpoidea* | X | | X | | | | X | X | X | X | | | | X | | | | |
| *Carex subspathacea*[b] | | | | X | | | | | | | | | X | X | X | | | |
| Unidentified *Cyperaceae* | | | | | | | X | X | X | X | X | X | X | X | X | | X | |
| *Cassiope tetragona* | | X | X | X | | | | X | | X | | | | | | X | X | |
| *Cerastium alpinum* | | | | | | | X | | | X | | | | X | X | X | | |
| *Cerastium beeringianum* | | | | | | | | | | | | | | X | X | | | |
| *Chrysosplenium tetrandrum* | | | | | | | | | | | | X | X | X | X | | | |
| *Cochlearia officinallis* | X | | | | | | | | | | | | X | X | | | | |
| *Diapensia lapponica* | | | X | | | | | | | | | | | | | X | | |
| *Draba alpina* | | | | | | | | | | X | | | | X | | | | |
| *Draba aurea* | | | | | | | | | | X | | | | | | | | |
| *Draba corymbosa* | | | | | X | X | X | X | X | X | | | | X | | | | |
| *Draba lactea* | | | | | | | | | | | | | | X | | | | |
| *Draba pilosa* | | | | | | | | | | | | | | X | | | | |
| *Draba* sp. | | | | | | | | | | X | X | X | | X | X | | | |
| *Dryas integrifolia* | | | X | X | | | X | X | X | X | X | X | | X | X | | X | X |
| *Dupontia fisheri* | | | | | | | | | | X | | | X | X | | | | |
| *Epilobium latifolium* | | | X | | | | | | | X | | | | | | | | |
| *Equisetum arvense* | | | | | | | | | | X | | | | | | | | |
| *Equisetum scirpoides* | | | | | | | | | X | X | X | X | | X | | | | |
| *Eriophorum angustifolium* | | | | | | | | X | X | X | X | X | | X | | X | | |
| *Eriophorum brachyantherum* | | | | | | | | X | X | | X | | | | | | X | |
| *Eriophorum chamissonis* | | | | X | | | | X | | X | X | X | | X | | | | |
| *Eriophorum scheuchzeri* | | | | | | | | X | | | | | | | | | | |
| Unidentified *Graminae* | | | | | | | | | | | | X | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hierochloe alpina* | | X | X | X | | | | | | | | | | | | X | X | |
| *Hierochloe pauciflora* | | | | | | | | | | | | | | X | X | | | |
| *Hippuris vulgaris* | | | | | | | | | | | X | X | X | | | | | |
| *Hulteniella integrifolia* | | | | | | | X | X | X | X | | | | | | | | |
| *Juncus albescens* | | | | | | | | | X | | | | | | | | | |
| *Kobresia simpliciuscula* | | | | | | | | | | | | X | X | | | | | X |
| *Ledum decumbens* | | X | X | X | | | | | | | | | | | | X | X | |
| *Lesquerella arctica* | | | | | | | X | | | | | | | | | | | |
| *Luzula confusa* | | X | X | | | | | | | | | | | | | X | X | |
| *Lycopodium selago* | | | X | | | | | | | | | | | | | | | |
| *Minuartia rossii* | | | | | | | | | X | | | X | | X | X | | | |
| *Oxyria digyna* | X | | X | | | | | | | X | | | | | | | | |
| *Oxytropis arctobia* | | | | | | | X | | | | | | | | | | | |
| *Oxytropis borealis* | | | | | | | | | | X | | | | | | | | |
| *Oxytropis maydelliana* | | | X | | | | | | | X | | | | | | | | |
| *Papaver radicatum* | | | | | | X | | | | | | | | | | | | |
| *Pedicularis capitata* | | | X | | | | | | X | X | | | | | | X | | X |
| *Pedicularis flammea* | | | | | | | | | | X | | | | X | | | X | |
| *Pedicularis hirsuta* | | | X | | | | | | | | | | | | | X | | |
| *Pedicularis lanata* | | | X | | | | X | X | X | X | | | | | | | | |
| *Pedicularis sudetica* | | | | | | | | X | X | X | X | X | | X | X | | X | |
| *Poa arctica* | | | | X | | | | | | X | | | | X | | | | |
| *Polygonum viviparum* | | | X | | | | X | | | | | | | | | | | |
| *Pucinellia vahliana* | | | | | | | X | | | | | | | | | | | |
| *Pyrola grandiflora* | | | | | | | | | | | | | | | | X | | |
| *Ranunculus hyperboreus* | | | | | | | | | | | X | X | | | | | | |
| *Ranunculus nivalis* | | | | | | | | | | | | | | | | X | | |
| *Rhododendron lapponicum* | | | X | | | | | | | X | | | | | | | X | |
| *Sagina cespitosa* | | | | | | | | | | | | | X | | | | | |
| *Salix alaxensis* | | | | | | | | X | | | | | | | | | | |
| *Salix arctica* | X | | X | X | | | X | X | X | X | X | X | X | X | X | X | X | X |
| *Salix calcicola* | | | | | | | | | | | | | | | | | X | |
| *Salix herbacea* | X | | X | | | | | | | X | | | | | | X | X | |
| *Salix reticulata* | | | X | X | | | X | X | X | X | X | X | | X | X | | X | X |
| *Salix richardsonii* | | | | | | | | | | X | | | | | | | | X |
| *Salix* sp. | | | | | | | | | | | | X | | | | | | |
| *Saxifraga aizoides* | | | X | | | | X | X | X | X | | | | | | | | |
| *Saxifraga foliosa* | | | | | | | | | | X | | | | | | | X | |
| *Saxifraga hirculus* | | | | | | | | X | | X | X | X | X | X | X | | | |
| *Saxifraga nivalis* | | | | | | | | | | X | | | | | | | | |
| *Saxifraga oppositifolia* | | | X | | | X | X | X | X | X | | | | | | | | |
| *Saxifraga tricuspidata* | | | | | | | X | X | | | | | | | | | | |
| *Senecio congestus* | | | | | | | | | | | | | X | | | | | |
| *Silene acaulis* | | | X | X | | | X | | | X | | | | | | | | |
| *Silene uralensis* | | | | | | | X | X | | X | X | | | X | X | | | |
| *Stellaria crassifolia* | | | | | | | | | | | | | | | | X | | |
| *Stellaria longipes* | | | | | | | | | | X | | | | X | | | | |
| *Tofieldia pusilla* | | | X | | | | | | | | | | | | | | | |
| *Vaccinium uliginosum* | | | X | | | | | | | X | | | | | | | X | |
| *Vaccinium vitis-idaea* | | | X | X | | | | | | | | | | | | X | X | |

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| **Mosses** | | | | | | | | | | | | | | | | | |
| *Aulacomnium acuminatum* | | | | | | | | | X | | X | | X | X | | | |
| *Aulacomnium palustre* | | | | | | | | | | | | | X | | | | |
| *Aulacomnium turgidum* | | X | | | | | | | X | | | | X | | | X | |
| *Barbilophozia binsteadii* | | X | | | | | | | | | | | | | | | |
| *Brachythecium groenlandicum* | | | | | | | | | | | | | | | | | |
| *Brachythecium turgidum* | | | | | | | | | X | | X | X | X | X | | | |
| *Bryum algovicum* | | | | | | | | X | X | | | X | | | | | |
| *Bryum arcticum* | | | | | | | | | | X | | | X | | | | |
| *Bryum cyclophyllum* | | | | | | | | | | | X | X | | | | | |
| *Bryum marrati* [c] | | | | | | | | | | X | | | | | | | |
| *Bryum pseudotriquetrum*[d] | | | | | | | X | X | X | X | X | | X | | X | | |
| *Bryum* sp. | | | | | | X | | | X | X | X | X | | X | | | X |
| *Bryum wrightii* | | | | | | X | X | X | X | | | | X | | | | |
| *Campylium chrysophyllum* | | | | | | | | | | | | X | | | | | |
| *Campylium polygamum* | | | | | | | | | | | | | X | | | | |
| *Campylium stellatum* | | | | | | | | | X | X | X | X | X | X | | | X |
| *Catoscopium nigritum* | | | | | | | | | | X | X | | | X | | | |
| *Cephalozia bicuspidate* | | X | | | | | | | | | | | | | | | |
| *Ceratodon purpureus* | | | | | | | | X | X | X | X | | X | | | | |
| *Cinclidium latifolium* | | | | | | | | | | | X | | X | | | | |
| *Dicranum acutifolium* | | | | | | | | | X | | | | | | | | |
| *Dicranum elongatum* | X | X | | | | | | | | | | | X | | | | |
| *Dicranum majus* | | | | | | | | | | | | | | | | X | |
| *Dicranum spadiceum* | | | X | | | | | | | | | | | | | | |
| *Didymodon fallax* | | | | | | | | | | | X | | | | | | |
| *Distichium capillaceum* | | X | | | | | | X | X | X | X | | | | | | |
| *Ditrichum flexicaule* | | | | X | | X | X | X | X | | X | | X | X | | | X |
| *Drepanocladus brevifolius* | | | | | | | | X | X | X | X | | X | X | | | |
| *Fissidens osmundioides* | | | | | | | | | | | | | | X | | | |
| *Hamatocaulis vernicosus* | | | | | | | | | | | X | X | | | | | |
| *Hylocomium splendens* | | | | | | | | | X | | | | | | | X | |
| *Hypnum bambergeri* | | | | | | X | X | X | X | | X | | X | X | | | |
| *Hypnum cupressiforme* | | | | | | | | | X | | | | | | | | |
| *Hypnum procerrimum* | | | | X | | | X | | | | | | | | | | |
| *Hypnum revolutum* | | | | | | | X | | | | | | | | | | |
| *Hypnum* sp. | | | | | | | | | X | | | | | | | | |
| *Hypnum vaucheri* | | | | | | | | X | | | | | | | | | |
| *Limprichtia revolvens* | | | X | | | | | | | | X | X | | X | | | |
| *Meesia triquetra* | | | | | | | | | | | X | | | | | | |
| *Mylia anomala* | | X | | | | | | | | | | | | | | | |
| *Oncophorus virens* | | | | | | | | | X | | | | | | | | |
| *Oncophorus wahlenbergii* | | | | | | | | | X | | X | | X | X | | X | |
| *Orthothecium chryseum* | | | | | | | | | X | | | | | | | | |
| *Orthothecium strictum* | | | | X | | | | | | | | | | | | | |
| *Plagiomnium ellipticum* | | | | | | | | | | | | | X | | | | |
| *Pohlia obtusifolia* | | | | | | | | | | | | | X | | | | |
| *Polytrichastrum alpinum* | | | | | | | | | X | | | | | | X | | |
| *Polytrichum juniperinum* | | X | | | | | | | X | | | | | | X | | |

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| *Polytrichum piliferum* | X | | | | | | | | | | | | | | | | | |
| *Pseudocalligeron turgescens* | | | | | | | | X | | | | X | X | X | X | | | |
| *Ptilidium ciliare* | | | | | | | | | | X | | | | | | | | |
| *Rhacomitrium canescens* | X | | | | | | | | | | | | | | | | | |
| *Rhacomitrium lanuginosum* | | X | X | X | | | | | | X | | | | | | | X | |
| *Rhizomnium* sp. | | | | | | | | | | | | X | | | | | | |
| *Schistidium apocarpum* | | | | | | X | | | | | | | | | | | | |
| *Schistidium rivulare* | | | | | | | X | | | | | | | | | | | |
| *Scorpidium scorpioides* | | | | | | | | | | | | X | X | | X | | | |
| *Sphagnum capillifolium* | | | X | | | | | | | | | | | | | | | |
| *Sphagnum girgensohnii* | | | | | | | | | | | | | | | | X | | |
| *Sphagnum russowii* | | | | | | | | | | | | | | | | | X | |
| *Sphagnum* sp. | | | | | | | | | | | | | | | | | X | |
| *Splachnum vasculosum* | | | | | | | | | | | X | X | | | X | | | |
| *Tetralophozia setiforme* | | X | | | | | | | | | | | | | | | | |
| *Tetraplodon mnioides* | | | | | | | | X | | X | | | | | | | | |
| *Tomenthypnum nitens* | | | X | | | | | | X | X | X | X | X | X | | | | X |
| *Tortella arctica* | | | | | | | X | | | | | | | | | | | |
| *Tortella tortuosa* | | | | | | | | | | | | | | X | | | | |
| *Tritomaria quinquedentata* | | | | | | | | | | | | | | | | X | | |
| *Warnstorfia exannulata* | | | | | | | | | | | | | | | | | X | |
| | | | | | | | | | | | | | | | | | | |
| **Hepatics** | | | | | | | | | | | | | | | | | | |
| *Anastrophyllum minutum* | | | X | | | | | | | X | | | | | | | X | |
| *Aneura pinguis* | | | | | | | | | | | | | | X | X | | | |
| *Odontoschisma macounii* | | | | | | | | | | X | | | | | | | | |
| *Scapania gymnostomophila* | | | X | | | | | | | | | | | | | | | |
| *Scapania irrigua* | | | | | | | | | | | | | | | X | X | | |
| | | | | | | | | | | | | | | | | | | |
| **Lichens** | | | | | | | | | | | | | | | | | | |
| *Alectoria ochroleuca* | | X | X | X | | | X | | | X | | | | | | X | X | |
| *Bryoria nitidula* | | X | X | X | | | | | | X | | | | | | | | |
| *Caloplaca ignea*[e] | | | | | | | | X | | | | | | | | | | |
| *Cetraria cucullata* | | X | X | X | | | X | | | X | | | | X | X | X | | X |
| *Cetraria islandica* | | | X | | | | | | | X | | | | | | | | |
| *Cetraria nivalis* | | X | X | X | | | X | X | | X | | X | X | X | X | X | X | X |
| *Cladina stygia* | | | X | | | | | | | | | | | | | | | |
| *Cladonia coccifera* | | X | | X | | | | | | | | | | | | | | |
| *Cladonia* sp. | | X | X | X | | | | X | X | X | | | | X | | | | |
| *Dactylina arctica* | | | X | X | | | | | | X | | | | X | | | | |
| *Parmelia* sp. | | X | | | | | | X | X | X | | X | | X | | | X | |
| *Sphaerophorus globosus* | | X | X | | | | | | | X | | | | | | | | |
| *Stereocaulon* sp. | | X | X | X | | | X | X | X | X | | | | X | | | X | |
| *Thamnolia vermicularis* | | X | X | X | | | X | | | X | | X | | X | X | X | | X |
| *Umbelicaria* sp. | | X | X | X | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| **Cyanobacteria** | | | | | | | | | | | | | | | | | | |
| *Nostoc* sp. | | | | | | | | | X | X | X | X | X | X | X | | | |
| | | | | | | | | | | | | | | | | | | |
| **Fungus** | | | | | | | | | | | | | | | | | | |

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|---|---|---|---|
| Unidentified sp. | X | X | X |

[a] Land Cover Class: 2.4 = Active deposits, 3.2 = Boulder ridges, 3.3 = Lichen-heath tundra, 3.4 = Mix of lichen-heath and boulder ridges, 4.1 = Hand-size or larger fragments deposits, 4.2 = Gravel-size fragments deposits, 4.3 = Algae-covered lag, 5.1 = Heath mats, 5.2 = Heath nets, 5.3 = Heavy heath-shrub nets, 5.4 = Mixed tundra (heath/graminoid/shrub), 6.1 = Exposed peat, 6.2 = Hydric moss and peat carpet, 6.3 = Hygric moss carpet, 6.4 = Graminoid meadows, 6.5 = Low-centre polygons, W = Willow thickets, D = Drainages or wet sedge meadows, S = Shrub / shale tundra.

[b] *Carex subspathacea*: This species should have been identified in a large number of the samples collected throughout the lowlands, especially along the coast. However, graminoid specimens from these locations were heavily grazed by white geese and often lacked flowering parts, making positive identification to species doubtful. Therefore, such specimens were catalogued as unidentified *Cyperaceae*.

[c] *Bryum marratti*: Two fertile specimens were collected at the same location. These were independently identified by two specialists (Spence and Ley). These are the first confirmed specimens from North America, and were retained by Spence and Ley for their collections.

[d] *Bryum pseudotriquetrum*: This species is unlikely to occur in the Arctic. Numerous *Bryum* specimens were sterile and these cannot be identified with certainty. Specimens originally identified as *Bryum pseudotriquetrum* may possibly be *Bryum arcticum* (Ley, personal communication).

[e] *Caloplaca ignea*: This species was present at most collection sites outside of the lowlands, but adhered firmly to rocks and therefore was not collected.

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