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Abstract

The Queen Maud Gulf Migratory Bird Sanctuary in Nunavut, in the central Canadian Arctic, is an important breeding area for a variety of species of waterfowl and other wildlife. An assessment of the types and spatial extent of land cover, with a particular emphasis upon wildlife habitat capability, has not been available for this sanctuary, preventing an adequate environmental assessment of proposed changes to the sanctuary's boundaries and limiting attempts to evaluate population trends and the distribution of wildlife species within the sanctuary.

LANDSAT Thematic Mapper satellite imagery and digital image processing technology were used to prepare a land cover map for this large and remote area. Data from an examination of a variety of possible image enhancements, three field seasons of ground and aerial inspections of land cover types, and image classification were used to generate a thematic map of land cover types. An accuracy assessment of the classification provided an estimate of the reliability of the land cover map.

Thirteen land cover types were identified and mapped, including three turbidity classes of water bodies and 10 terrestrial land cover types. An image enhancement, using power stretches of Bands 4 and 5 and a linear stretch of Band 2, proved to be an excellent means of visually interpreting land cover types and was used to generate colour map plots for field inspections. During the three field seasons, 75 detailed ground visits and 2606 low-level aerial inspections of land cover sites were undertaken.

Overall accuracy of the classification of water body turbidity was 84%, with no confusion between turbid and clear lakes. Overall classification accuracy for terrestrial land cover types was 89%, with most of the individual cover types having an estimated accuracy of >80%.

The land cover map will provide an effective means of assessing proposed boundary changes when used in conjunction with wildlife data and professional judgment. It will also provide a basis for effective design and evaluation of current and future surveys to monitor wildlife populations within the sanctuary. Similar land cover mapping of other migratory bird sanctuaries using satellite image analysis may be an effective means of evaluating the wildlife habitat of these other important areas.

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J. Hudson of the Fraser Herbarium, University of Saskatchewan, Saskatoon, identified species of plants collected during our fieldwork. Turbidity measurements of water samples were provided by the National Hydrology Research Institute, Environment Canada, Saskatoon.

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Contents

Digital maps

Digital land cover maps of the Queen Maud Gulf Migratory Bird Sanctuary are included in various formats on the accompanying CD-ROM. Please consult the readme file on the CD-ROM for complete details.

1. Introduction

The Queen Maud Gulf Migratory Bird Sanctuary (MBS) was established in 1961. It encompasses 63 655 km^2 of the central Canadian Arctic and is the largest bird sanctuary in the country (Fig. 1). Since the discovery of the nesting grounds of Ross' Goose *Chen rossii* near the Perry River in 1938 (Gavin 1947), the MBS has been the focus of frequent biological investigations. Early work focused on an inventory of the physical and biological resources of the Perry River area (Hanson et al. 1956) and research on the nesting biology and distribution of Ross' Geese (Ryder 1967, 1969, 1972). During the 1960s, Ryder (1971) also collected information on the distribution and breeding biology of Snow Geese *Chen caerulescens* in the MBS.

Since these early investigations, there has been accelerated research on and monitoring of goose populations in the MBS. Photographic inventories at Ross' and Snow goose nesting colonies, which have been rapidly increasing in size, are conducted at intervals (Kerbes et al. 1983; Kerbes 1994). A variety of nesting and brood ecology research has been, and continues to be, conducted in the MBS (McLandress 1983; Slattery 1994). Recent investigations focus upon the development of population estimates for Ross' Geese, Snow Geese, Greater White-fronted Geese *Anser albifrons*, and several populations of Cackling Geese *Branta hutchinsii* using aerial surveys (R. Alisauskas, pers. commun.) and marking programs to evaluate fall and winter distributions, population affiliation, annual survival, and population size (R. Kerbes, pers. commun.). These initiatives were sponsored in part by the Arctic Goose Joint Venture of the North American Waterfowl Management Plan.

The MBS contains many other wildlife species, some on a seasonal basis. There are large numbers of muskox *Ovibos moschatus* on the alluvial plains of the MBS, and some of the Bathurst barren-ground caribou *Rangifer tarandus groenlandicus* herd calve and summer in the eastern portion of the MBS (Heard 1989). Grizzly bears *Ursus arctos*, Sandhill Cranes *Grus canadensis*, Tundra Swans *Cygnus columbianus*, and a variety of waterfowl breed within the MBS.

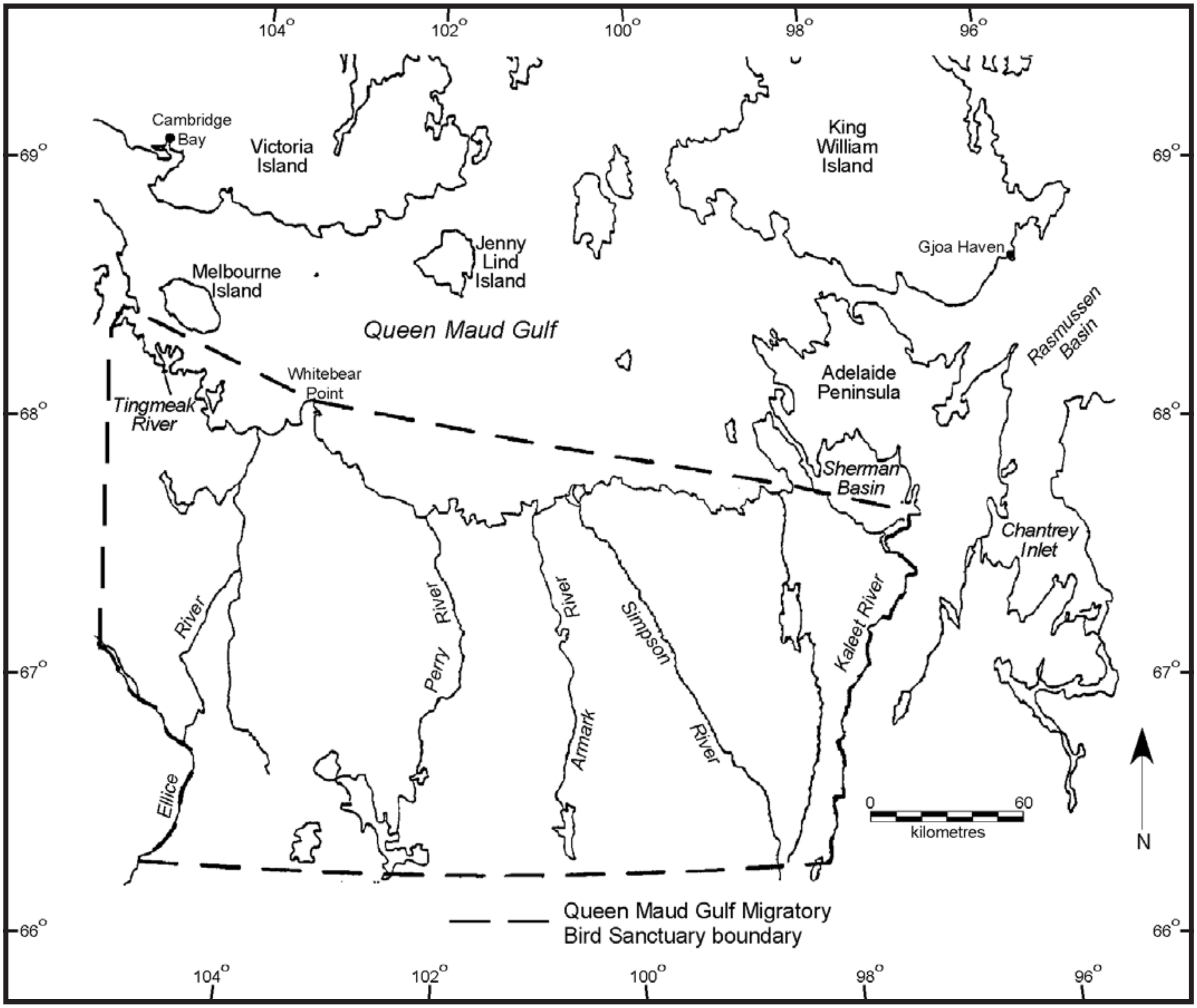
In 1990, the Conservation Advisory Committee on the Northern Mineral Policy reviewed the boundaries of migratory bird sanctuaries in the Northwest Territories that lie north of the 60th parallel (Conservation Advisory Committee 1990). The Committee proposed a reduction in size of the Queen Maud Gulf MBS to approximately 54 000 km^2 but did not recommend where these reductions should occur. The Committee's recommendation was put forward on the condition that any proposed MBS boundary changes should be supported by a thorough field assessment of the migratory bird habitat of the MBS.

The Committee's review demonstrated that current information was inadequate for any alteration of the MBS boundaries. Although recent survey and monitoring efforts have improved understanding of the distribution of some species of waterfowl, much of this information remains focused upon the known nesting colonies of Ross' and Snow geese. Little information is available regarding wildlife habitat within the MBS, and there is no information on the distribution of those habitat features of importance to waterfowl and other species of wildlife.

Creation of a land cover map applicable for the assessment of wildlife habitat capability will assist in a variety of current and future wildlife inventories and research programs. Habitat inventory data will allow the detection and mapping of specific areas within the MBS that are particularly important to waterfowl and other species and will complement long-term ecological studies of geese and other wildlife. Habitat maps will greatly enhance future aerial surveys of wildlife species by allowing stratification of survey effort. Integration of habitat maps, derived from satellite imagery, with other wildlife data in a geographic information system (GIS) can enhance the evaluation of relationships between habitat and wildlife presence or use (Butler et al. 1995).

The extremely large area and remoteness of the MBS provide a challenge to those contemplating the creation of a habitat map, and the use of remote sensing technology was necessary to overcome these obstacles. There has been increasing use of various sources of satellite imagery and processing technologies to conduct terrain and wildlife habitat mapping in northern regions (Thompson et al. 1980; Harvie et al. 1982; Shasby and Carneggie 1986; Petersen 1987; Dickson et al. 1989; Wakelyn 1990; Ferguson 1991; Markon and Derksen 1994). LANDSAT Thematic Mapper (TM) imagery was chosen for the creation of a digital thematic map of the MBS. The ground resolution of this sensor was appropriate for the macroscale mapping to be conducted, and the high spectral sensitivity of the sensor was useful for detecting differences in surface moisture and vegetation. This imagery, when referenced to a map projection, can be integrated with other digital databases and maps.

Figure 1
Queen Maud Gulf Migratory Bird Sanctuary, Nunavut



The primary goal of the project was to create a macroscale inventory of land cover types within the Queen Maud Gulf MBS, with particular emphasis upon land cover types that may be important as waterfowl habitat. Specific objectives were:

- to develop a classification scheme for land cover types;
- to produce a thematic map (classified map) of the MBS showing the distribution of cover types;
- to describe the physical and biological characteristics of each cover type; and
- to provide a tabular summary of the areal extent of each cover type within the MBS.

The products derived from this project will be used to prepare recommendations regarding any proposed changes to the MBS boundaries following integration with population data on waterfowl and other wildlife.

2. Methods

2.1 Image data

Due to frequent cloud cover and fog along the coastline of Queen Maud Gulf, there were few LANDSAT images available for processing. A total of four full scenes and three quadrats were required for complete cloud-free coverage of the MBS. Image dates ranged from mid-July to early August from 1986 to 1992. More information regarding image date and location is provided in Appendix 1. Image processing was performed on ARIES III systems (Applied Resource Image Exploitation System; DIPIX 1987) at the Manitoba Remote Sensing Centre in Winnipeg, Manitoba, and at the Saskatchewan Research Council in Saskatoon, Saskatchewan.

2.2 Image enhancements

A variety of enhancements were created, including linear and power stretches, histogram equalizations, and principal component transformations (Short 1982; Showengerdt 1983; DIPIX 1987). A colour composite of near-infrared (Band 4), shortwave infrared (Band 5), and green (Band 2) spectral bands, displayed in red, green, and blue, respectively, was deemed to provide excellent discrimination of lowland and upland cover types. Ease of interpretation was enhanced further by applying a power contrast stretch to Bands 4 and 5 (power = 2.0) and a linear contrast stretch to Band 2.

This composite was used to create colour map plots. All images were plotted at a scale of 1:250 000, and these were used to select 11 subareas within the images, ranging from 2250 to 4200 km², which appeared to contain the full range of spectral values (and, presumably, land cover types) of the images. Colour map plots at a scale of 1:50 000 were created for these 11 subareas and used in the field to select and determine land cover types.

2.3 Field studies

Helicopter-assisted fieldwork was conducted from 10 to 17 July 1991, from 7 to 20 July 1992, and from 5 to 14 July 1993 to determine land cover types associated with homogeneous areas on the 1:50 000 colour map plots. In 1991, a reconnaissance of the entire MBS and detailed ground checks at selected sites resulted in the determination of 13 land cover types (including three types of water turbidity). These were distinctive, important for wildlife habitat assessments, and considered to be suitable for classification with minimum classification confusion. Preliminary image classifications used information from this reconnaissance and the detailed ground checks. In 1992 and 1993, additional inspections of selected sites, primarily low-level aerial inspections, were made throughout the MBS, and these were used for the final image classifications. During the three field seasons, 75 detailed ground visits and 2606 low-level aerial inspections of land cover sites were undertaken (Table 1).

Table 1
Number of detailed ground visits and aerial inspections of land cover types of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

Cover type	Ground visit	Aerial inspection
Water		
Clear	5	287
Moderately turbid	5	279
Turbid	5	271
Wet sedge meadow	8	454
Hummock graminoid tundra	9	116
Tussock graminoid tundra	10	151
Low shrub tundra	11	190
Shrub thicket	3	60
Moss-lichen tundra	5	78
Lichen-heath tundra	3	383
Bedrock and boulder field	3	162
Active deposits	1	53
Exposed peat	2	42
Coastal graminoid turf	5	80
Total	75	2606

During detailed ground checks, we recorded the following information when walking linear transects across representative areas: landform (upland — bedrock, esker, ridge, ridge slope, terrace; lowland — depression, shoreline, wetland); topography (level, undulating, hummocky, broken/eroded, slope); microtopography (hummocks, polygons, sorting and striping); substrate (bedrock, boulders, gravel, till, clay/silt, peat); surface moisture (xeric, mesic, hygric, hydric), and vegetation type and extent. Vegetation descriptions included dominant growth form (lichens, mosses, non-woody forbs, grasses/sedges, woody shrubs and forbs), percent vegetation cover (visually estimated), average height, and species composition. The percent cover of lichens and mosses was recorded for each site, but species were not identified.

During aerial inspections of a selected site, a lead observer delineated a homogeneous area on the 1:50 000 colour map. The helicopter approached, hovered within 25 m above the ground, and, in many cases, landed briefly within the area. Both observers achieved a consensus of land cover type. Close approach to the ground was necessary to obtain adequate assessment of shrub cover.

Colour photographs were obtained on the ground and from the air during all ground and many aerial inspections. Vegetation samples were collected and identified by J. Hudson using reference materials at the Fraser Herbarium, University of Saskatchewan, Saskatoon. Nomenclature of vascular plants primarily follows Porsild and Cody (1980).

Turbidity of water of lakes, ponds, rivers, and streams was inspected from the air, and each sample was assigned a turbidity category (clear, moderately turbid, or turbid). Measurements of suspended solids (mg/L) and Secchi disk readings (m) were obtained at five lakes for each of the three turbidity categories to assist in the selection of spectral signatures for classification.

2.4 Classification of water and ice

Digital image classification of the three water types was performed using unsupervised classification techniques. Unsupervised classification uses the inherent spectral variability of a scene to define "natural groupings" based on the spectral reflectance of the multispectral image. Pixels of the scene with similar spectral characteristics were assigned to one of these groupings. This technique proved to be efficient in determining the spectral classes for the wide range of spectral values associated with water of lakes and streams and offshore ice cover.

Spectral signatures were obtained from unsupervised classifications of each image for a range of water turbidity conditions. These were grouped into three water turbidity classes — clear water, moderately turbid water, and turbid water — using reference data from aerial inspections of a large number of lakes and streams. These water class signatures were used in the final image classification for each scene.

Spectral signatures were obtained from the unsupervised classifications of each image for the wide range of ice conditions for inland lakes and rivers and offshore ice. Spectral signatures for these ice cover types were grouped to classify ice as one ice cover type, and these were used in the final image classification for each scene. Specific areas of ice were manually assigned to the water turbidity class evident from open water between the ice and the adjacent shorelines. Offshore ice of Queen Maud Gulf was manually assigned to the moderately turbid water class.

2.5 Classification of terrestrial land cover types

Supervised classification was used to classify the 10 terrestrial land cover types. This procedure assigned pixels of the image to specific image classes by comparing the reflectance values for each pixel with the reflectance values of "training areas" — areas of land cover type known from the field investigations. The number of training areas for each class ranged from 20 to 100, and the number of pixels within each training area varied from 12 to 1111. Training areas were delineated on the 1:50 000 colour maps for field inspections, and care was taken to omit patches of other cover types where apparent. Additional editing of training areas was conducted during digital delineation of training areas. A 20% filter (removal of outliers in 10% of each end of reflectance distribution) was applied to obtain the final signature files for each land cover type for the final image classification for each scene.

2.6 Geo-referencing and combining of images

Images were digitally transformed to conform to the Universal Transverse Mercator (UTM) map projection. A smoothing function, to delete areas of one or two pixels in size, was applied to the classification. This minimized the "speckling" effect caused by these small areas and eliminated some small areas likely misclassified due to pixel averaging. This smoothing was not applied to water, active deposit, or exposed peat cover types. A mosaic was created using selected portions of the images to create a cloud-free image of the entire MBS. Two thematic maps were created, one with a UTM zone 13 projection (portion of MBS west of longitude 102 degrees) and one with a UTM zone 14 projection (portion of MBS east of longitude 102 degrees). The total area of the MBS represented by each land cover type was calculated by totalling the pixels assigned to each of the 13 land cover types.

2.7 Accuracy assessment

Accuracy assessment of the classification followed Story and Congalton (1986). A total of 621 independent samples of the 10 terrestrial land cover types and 721 independent samples of the three categories of water turbidity were evaluated to determine how well each land cover type was classified. Classification accuracy based on an individual pixel basis was not possible due to the difficulties of determining the precise locations of individual pixels on the ground.

3. Results and discussion

3.1 Land cover types

Three types of water cover based upon turbidity and 10 terrestrial land cover types were identified and used for the classification of the satellite imagery and the creation of the land cover map of the MBS:

- Water bodies:
  - *Water — clear*: Clear water, usually in bedrock-controlled basins; submerged features visible except at depth; suspended solids average 4.5 mg/L; Secchi disk average 2.8 m.
  - *Water — moderately turbid*: Water somewhat darkened, occasionally aquamarine in hue; substrate and submerged objects visible in shallow depths only; usually some of basin not bedrock-controlled; most common on periphery of bedrock regions; suspended solids average 15.8 mg/L; Secchi disk average 0.9 m.
  - *Water — turbid*: Water very darkened, often appearance of “chocolate milk”; substrate and submerged objects not visible; usually in alluvial areas with little bedrock; suspended solids average 323 mg/L; Secchi disk average 0.2 m.

- Lowlands:
  - *Wet sedge meadow*: Depressions, downslope of snow beds, and shorelines of portions of some drainages and lakes; mosaic of clear standing or slow-moving water and graminoid vegetation; *Carex aquatilis* (*stans*), *Eriophorum angustifolium*, and *Dupontia fisheri* are the dominant species.
  - *Hummock graminoid tundra*: Level to gently sloping plains most often adjacent to shorelines of drainages and lakes; irregularly shaped hummocks with intervening troughs have a distinctive “pillow” appearance from the air; *Carex aquatilis* (*stans*), *Festuca brachyphylla*, and *Arctagrostis latifolia* are the dominant species; low prostrate shrub cover is usually less than 10%.
  - *Tussock graminoid tundra*: Level to gently sloping plains, often beyond hummock graminoid tundra, adjacent to drainages and lakes; frequent in small patches in depressions on the crests of upland ridges; tussocks have a distinctive “pebbly” appearance from the air; *Eriophorum vaginatum* is the dominant species; low prostrate shrub cover is less than 25%.
  - *Low shrub tundra*: Most common along drainages; mixture of tussocks of *Eriophorum vaginatum*, hummocks, and low prostrate or low erect shrubs; *Eriophorum vaginatum*, *Betula glandulosa*, and *Salix planifolia* are the dominant species; shrub cover varies from 25% to 75%.
  - *Shrub thicket*: Most abundant along the immediate shorelines of drainages and lakes and in protected depressions along valley slopes; similar to low shrub tundra, except low shrubs are the dominant vegetation cover, varying from 75% to 100%.

- Uplands:
  - *Moss-lichen tundra*: Sand and sand/gravel deposits on lower slopes and some crests of eskers and ridges, terraces, and major drainages; extensive moss and lichen cover, patches of heath, scattered small boulders, and areas of exposed gravel or sand.
  - *Lichen-heath tundra*: Middle to upper slopes and crests of ridges and eskers, shallow depressions in boulder fields and bedrock outcrops; lichen, mosses, and ericaceous plants are the dominant species; exposed substrate <25%.
  - *Bedrock and boulder field*: Ridges of consolidated bedrock outcrop or broken boulder fields; small ponds or patches of tussock graminoid tundra may occur in small depressions; moss and lichen growth in crevices and small depressions; crustose lichens on many rock outcrops and boulders; exposed substrate >75%.

- Uplands and lowlands:
  - *Active deposits*: Exposed coastal sediments of coastline, often deltas; exposed lake bottoms; cutbanks along drainages with active erosion of glacio-lacustrine deposits or marine sediments; vegetation cover <5% or none.
  - *Exposed peat*: Hygric to hydric, dark brown, exposed peat bottoms of ponds in wet sedge meadows occur during natural drawdown of water levels; mesic, light to dark brown peat is exposed in and near goose nesting colonies by destruction of vegetation cover, including shredding of *Eriophorum vaginatum*

tussocks, when geese build nests and forage during the nesting period; vegetation cover is minimal and residual.

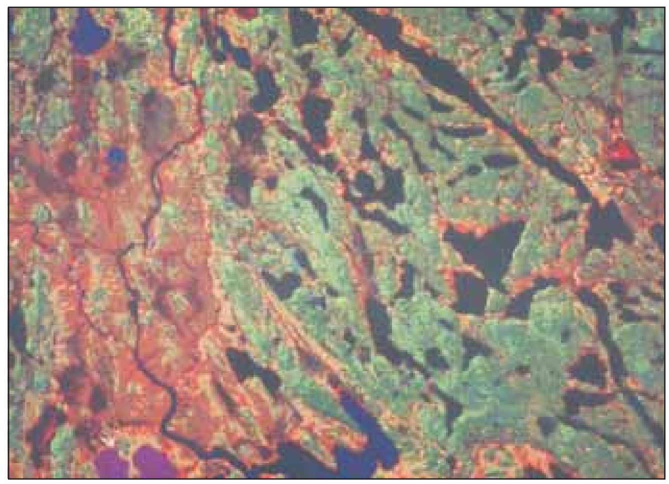
These land cover types were those that were readily identifiable from ground and low-altitude aerial inspection, had distinct vegetative, surficial terrain, and moisture characteristics, were useful for describing lowland and upland habitat availability for a variety of wildlife species, and were amenable for image classification with reasonable accuracy. Ground and aerial views of these land cover types and descriptions of their colour on the image enhancement, topographic position, surficial expression, substrate, ecological moisture regime, and vegetation are provided in Appendix 2.

Identification of species of lichens and mosses was very limited in our examination and description of terrestrial land cover types. A detailed review and summary of plant communities associated with various surficial materials in north-central Keewatin, Northwest Territories (Edlund 1982), is an excellent source for determining the species of lichens and mosses that are likely to occur in the land cover types of this study.

In some cases, there can be a clear, abrupt transition between adjacent land cover types (Fig. 2). In most cases, however, there is an irregular and gradual transition between adjacent cover types, particularly with lowland land cover types.

Figure 2
Illustration of distinct boundaries between adjacent land cover types, in this case a bedrock outcrop and a small lake

Figure 3
An example of an image enhancement using a power stretch of Band 4, a power stretch of Band 5, and a linear stretch of Band 2, displayed in red, green, and blue, respectively



3.2 Visual interpretation of enhancement

Power stretches of Bands 4 and 5 (power = 2.0) and a linear stretch of Band 2, displayed in red, green, and blue, respectively, were an effective means of displaying the image data. This enhancement, effective both for visual interpretation and for preparing colour maps for field studies, allowed discrimination of lowland and upland land cover types of interest (Fig. 3).

Active deposits, with sparse or no vegetation, were readily identified by their brightness due to high reflectance. The bedrock outcrops and boulder fields, and, to a lesser extent, lichen-heath tundra, were also readily detected by their dark coloration due to lower reflectance. The three categories of water turbidity, particularly turbid water bodies, were clearly evident.

The combination of a high biomass of graminoids within and adjacent to areas of surface water in wet sedge meadows, usually within well-defined depressions, allowed excellent detection of this land cover type. Borders of this land cover type were usually very distinct. Other lowland land cover types — hummock graminoid tundra, tussock graminoid tundra, low shrub tundra, and shrub thicket — were also fairly distinct on this enhancement. Areas of confusion were likely due to variations in surface moisture, shrub cover, and slope. This was particularly true with tussock graminoid tundra, low shrub tundra, and shrub thicket land cover types. The exposed peat land cover type associated with goose nesting colonies was readily evident, with high reflectance in Band 5 and low reflectance in Band 4.

This three-band enhancement can be an effective tool for distinguishing between uplands and lowlands within the MBS and can allow discrimination between lowland communities with little or no shrub cover and those with significant shrub cover. Ranges of colours for this three-band enhancement for each water turbidity class and terrestrial land cover type are provided in Appendix 2.

3.3 Classification of land cover

The collection of extensive ground data for the generation of training signatures proved effective in the creation of a land cover map for the Queen Maud Gulf MBS. The 13 land cover types selected provided an appropriate level of detail for mapping and addressed the land cover types of particular interest for wildlife habitat assessments.

An additional lowland cover type, coastal graminoid turf, was identified and considered to be an important land cover type. It was found in small patches along the immediate coastline of Queen Maud Gulf, particularly near the mouths of rivers and streams. It was associated with marine clay and silt deposit near the high tide line and was characterized by a mosaic of low turf islands, exposed clays and silts, water channels, or pools of shallow water. *Puccinellia phryganodes*, *Carex subspathacea*, and *Carex* *ursina* are the dominant species. Because of the small patch size and the mosaic nature, with high variations in the proportions of vegetation, exposed sediment, and water, this land cover type was not successfully classified. Although errors in classification could be manually removed from the interior, the classification for this land cover along the coastline consistently included extensive areas of shoreline sediments without graminoid turf vegetation. This land cover type is important for some species of migratory birds, and its presence can be predicted with some reliability, since it is associated with marine clay and silt deposits in the immediate vicinity of the mouths of rivers entering Queen Maud Gulf. It is rarely along bedrock-controlled shorelines. More details regarding its appearance and vegetation composition are provided with the other land cover types in Appendix 2.

During field visits, aerial inspections, and digital analyses of the imagery, we attempted to identify a spectral class for a land cover type called transitional low shrub tundra. This class would have represented an intermediate form between the low shrub cover of a tussock graminoid tundra (<25%) and the more dense shrub cover of the low shrub tundra (50–75%). However, variations in shrub cover within sample areas, and probably subtle variations in moisture and slope, resulted in low classification accuracy when we tried to separate these classes. We therefore used the current low shrub land cover type to include a range of 25–75% shrub cover.

Land cover maps in electronic format are provided with this report on the accompanying CD-ROM.

3.4 Accuracy of classification

We can ascertain the accuracy of our classification with some confidence by using a large, independent sample of ground sites identified during field visits. We have used an accuracy assessment procedure following Story and Congalton (1986), which provides a means of evaluating the reliability of the maps. Producer's accuracy represents how well a specific area of land of the MBS can be mapped. It is derived by calculating the percentage of reference areas of a particular land cover type that were correctly classified and therefore represents the probability that a reference sample will be correctly classified. This accuracy value provides an estimate of omission error.

A sample area used for accuracy assessment was considered correctly classified if >50% of the pixels were correctly classified and the shape of the training area was clearly defined by the correct land cover type (i.e., misclassified pixels were scattered within the sample area).

However, there are also errors of commission when land cover types are misclassified. Users of classified maps are equally, or perhaps more, concerned about how well the maps represent what is actually on the ground. If a user travels to a site indicated on the map as a particular land cover type, the user's accuracy estimate provides an estimate of the probability that the particular land cover type is actually present at that site.

3.4.1 Water

During aerial inspections of water bodies, both observers were generally in agreement regarding assignment of water bodies to one of the three turbidity categories. The classification of the 15 lakes with water samples resulted in all five clear lakes, four of the five moderately turbid lakes, and all five turbid lakes being correctly classified based on the distinct differences in measured turbidity and Secchi disk values (Table 2).

Table 2
Turbidity and Secchi disk measurements of lakes of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut (mean and range of values)

Lake	Turbidity (mg/L)	Secchi disk (m)
Clear (n = 5)	4.5 (2–8)	2.8 (2.0–4.0)
Moderately turbid (n = 5)	15.8 (11–28)	0.9 (0.6–1.4)
Turbid (n = 5)	323.0 (54–945)	0.2 (0.1–0.4)

Overall classification accuracy for water turbidity types was 84%, but both producer's and user's accuracy values indicated that we were more successful in detecting and mapping turbid water and clear water (Table 3). This was expected, since the range of turbidity of moderately turbid lakes was broad. No turbid lakes were classified as clear lakes, and no clear lakes were classified as turbid lakes.

Clear lakes were most common in regions of extensive bedrock outcrop and lichen-heath tundra with bedrock-controlled shorelines. Turbid lakes were most common in the alluvial and glacio-lacustrine plains of major drainages where fine silts and clays were characteristic of shoreline substrates. Thaw lakes were common in these areas and were frequently very turbid. Moderately turbid lakes tended to occur on the peripheries of these two types of areas.

3.4.2 Land

Overall classification accuracy for terrestrial land cover types was 89%, and producer's and user's accuracy values indicated that most individual land cover types were well classified (Table 4).

Wet sedge meadow was very distinct and was classified accurately, reflecting its hygric conditions, high biomass, and occurrence within well-defined basins. Occasional misclassifications of shrub thicket or low shrub tundra may be attributed to the occurrence of shrub growth in hydric situations along some drainages and low shorelines of lakes. Hummock graminoid tundra and tussock graminoid tundra were occasionally confused but were still well separated in the classification. Misclassifications may have resulted from inclusions of one land cover type within another, which were not deleted during delineation and editing of some training areas. There was similar overlap of land cover types with varying shrub cover (tussock graminoid tundra, low shrub tundra, and shrub thicket), but classification accuracy was still high for these land cover types.

Classification accuracy of upland land cover types was high, but some misclassifications were expected, since these land cover types were defined by the proportion of exposed substrate and vegetation. Lichen-heath tundra includes exposed boulders, rock outcrop, or sands and gravel, and, in turn, a portion of the bedrock and boulder field land cover type contains depressions that support lichen, moss, and heath growth.

The high reflectance of exposed sediments resulted in a very high classification accuracy, and these areas were

Table 3
Producer’s and user’s accuracies of classification of water bodies of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

	Reference data (number of sites sampled)				
Classified data	Clear	Moderately turbid	Turbid	Row total	User’s accuracy[a] (% correct)
Clear	**206**	40	0	246	84
Moderately turbid	36	**186**	19	241	77
Turbid	0	20	**214**	234	91
Column total	242	246	233	**721**	
Producer’s accuracy[b] (% correct)	85	76	91		
		Overall accuracy = 84%			

[a] User’s accuracy indicates the probability that a unit from a classified map actually represents that type on the ground.
[b] Producer’s accuracy indicates the probability that an area on the ground will be classified accurately.

Table 4
Producer’s and user’s accuracies of classification of land cover types of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

	Reference data (number of sites sampled)[a]											
Classified data	WSM	HGT	TGT	LST	ST	MLT	LHT	BBF	AD	EP	Row total	User’s accuracy[b] (% correct)
WSM	**98**				1						99	99
HGT		**43**	8	1							52	83
TGT		10	**48**	1		10	2				71	68
LST	1		7	**73**	3						84	87
ST	1			9	**38**						48	79
MLT						**43**	2				45	96
LHT						3	**96**	1			100	96
BBF						1	8	**65**			74	88
AD						1			**35**		36	97
EP										**12**	12	100
Column total	100	53	63	84	42	58	108	66	35	12	**621**	
Producer’s accuracy[c] (% correct)	98	81	76	87	90	74	89	98	100	100		
						Overall accuracy = 89%						

[a] Abbreviations used: WSM = wet sedge meadow; HGT = hummock graminoid tundra; TGT = tussock graminoid tundra; LST = low shrub tundra; ST = shrub thicket; MLT = moss-lichen tundra; LHT = lichen-heath tundra; BBF = bedrock and boulder field; AD = active deposits; EP = exposed peat.
[b] User’s accuracy indicates the probability that a unit from a classified map actually represents that type on the ground.
[c] Producer’s accuracy indicates the probability that an area on the ground will be classified correctly.

effectively mapped within the MBS. The unique surface characteristics of the exposed peat in goose nesting colony areas, a relatively dry yet dark surface with minimal biomass, and the low reflectance in Band 4 and high reflectance in Band 5 also resulted in a high classification accuracy.

Errors of commission were usually associated with assignment of land cover type to the most similar land cover type (e.g., low shrub tundra versus shrub thicket, or bedrock versus lichen-heath tundra). The distribution of classified pixels rather than entire sample areas used in the accuracy assessment allows an examination of this situation (Table 5). For example, bedrock and boulder fields were rarely classified within wet sedge meadows. When this did occur, it may have resulted from the occurrence of small outcrops of bedrock within or along the periphery of the sample areas that were included during their delineation and that were not excluded by editing. Because of these close associations of land cover type, the occurrence of patches of lichen-heath within bedrock areas, for example, likely represents the composite nature of the land cover type rather than errors of commission.

The land cover maps were “smoothed” to eliminate small patches of land cover such that minimum contiguous areas are restricted to three or more pixels. This process removes some of the “speckling” effect caused by scattered single or double pixel patches. Speckles may represent error in classification due to pixel averaging or actual small patches of one land cover type embedded within another. The producer’s and user’s accuracies were calculated using the raw classification data, and the values presented in Table 4 may be biased somewhat low.

Table 5
Distribution of pixel classifications within test samples of land cover types of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

		Reference data[a,b]									
		WSM	HGT	TGT	LST	ST	MLT	LHT	BBF	AD	EP
Classified data	WSM	**16 693**	159	310	57	145	24	430	58	0	0
	HGT	61	**6 392**	2 420	929	6	258	5	8	0	0
	TGT	28	1 296	**10 748**	901	56	1 669	274	9	1	8
	LST	167	571	1 895	**9 901**	897	23	60	2	8	1
	ST	322	3	55	1 938	**2 941**	0	0	0	0	0
	MLT	426	88	148	54	1	**6 553**	1 119	41	4	21
	LHT	127	4	49	70	0	991	**15 502**	705	0	4
	BBF	51	0	0	0	0	172	2 856	**8 296**	1	1
	AD	50	23	25	13	26	112	22	111	**5 993**	1
	EP	16	4	47	0	0	207	39	8	0	**560**

[a] Abbreviations used: WSM = wet sedge meadow; HGT = hummock graminoid tundra; TGT = tussock graminoid tundra; LST = low shrub tundra; ST = shrub thicket; MLT = moss-lichen tundra; LHT = lichen-heath tundra; BBF = bedrock and boulder field; AD = active deposits; EP = exposed peat.
[b] Surface water present in WSM (402 pixels), in BBF (22 pixels), and in AD (54 pixels).

4. Management and research opportunities

Digital analysis of LANDSAT and other satellite imagery is an effective way to create land cover maps for wildlife habitat assessment. Reasonable mapping accuracy can be obtained if sufficient ground sampling is conducted to develop classification signatures and if a reasonable mapping scale is selected. Costs of satellite image products, image processing, and field studies are relatively high, but the time and costs associated with conventional procedures (air photo acquisition and interpretation and manual mapping) would, in most cases, not allow mapping of such a large and remote area.

The total area for each land cover type can be readily calculated from the classified maps (Table 6), and land cover maps of varying scale and with various combinations of land cover types can be readily generated.

Creation of habitat maps from digital satellite imagery allows production of geo-referenced maps, which in turn can allow production of hardcopy map products as well as integration with other digital databases and maps in a GIS. The latter will become an increasingly important advantage of using digital remote sensing products for land cover mapping.

These maps will facilitate the primary objective, the review of the MBS boundaries. These land cover maps will also facilitate a variety of wildlife research and monitoring activities within the MBS, including the use of selected land cover types by a variety of wildlife species using past, current, and future population survey data (e.g., Butler et al. 1995).

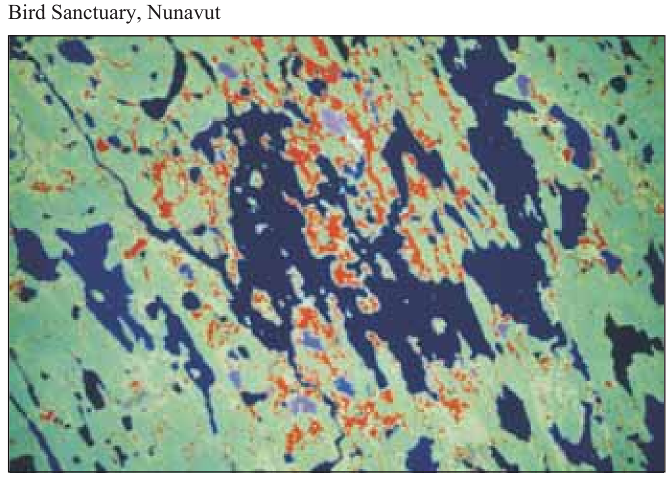
In the vicinity of nesting colonies of Ross' and Snow geese, there is clear evidence of degradation of mesic graminoid communities caused by nest building and foraging by geese (Fig. 4). This damage has also been documented at various locations along the western coast of Hudson Bay (Kerbes et al. 1990). Remote sensing has been effective in detecting and mapping the exposed dry peat along the western coast of Hudson Bay (A. Didiuk, unpubl. data) and during this project and provides a means of evaluating the spatial extent of this damage, the rate of increase of area of damage, and recovery of vegetation.

Remote sensing in Arctic regions can be hampered by a variety of logistical constraints (Ferguson 1991). Availability of imagery can be limited due to cloud cover (particularly in coastal regions), the relatively short growing season, and

Table 6
Summary of areal extent of land cover types of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

Land cover type	Area (km^2)	% of total
Offshore water	6 463	10.3
Fresh water		
Clear	7 214	11.5
Moderately turbid	3 222	5.1
Turbid	1 231	2.0
Total	11 667	18.6
Wet sedge meadow	4 857	7.7
Hummock graminoid tundra	2 594	4.1
Tussock graminoid tundra	4 534	7.2
Low shrub tundra	4 959	7.9
Shrub thicket	1 045	1.7
Moss-lichen tundra	3 370	5.4
Lichen-heath tundra	15 937	25.3
Bedrock and boulder field	5 810	9.2
Active deposits	1 381	2.2
Exposed peat	276	0.4
Total	62 893	100.0

Figure 4
Areas classified as exposed peat (red) in the vicinity of Ross' and Snow goose nesting colonies at Karrak Lake in the Queen Maud Gulf Migratory Bird Sanctuary, Nunavut



orbital frequencies of remote sensing satellites. Field inspections in these areas can only be conducted using a helicopter, which requires the costly placement of fuel for the helicopter. However, the relatively slow rate of natural change in land cover type compared with more southern regions (e.g., forest fires) and very limited land use (e.g., forestry or agriculture) suggest that land cover classifications may be accurate for longer time periods.

5. Recommendations

Current information regarding the environment in "protected" and other areas of Nunavut and the Northwest Territories will be required to assess the implications of increased mineral exploration and various types of resource extraction. Land cover mapping using satellite imagery and digital processing technologies is an effective means of creating terrain maps for impact assessment.

Increasing populations of Snow Geese and other species of geese in the central Arctic and elsewhere raise concerns regarding habitat destruction, disease, and conflicts with agriculture on migration and wintering areas. Monitoring of goose species and their nesting and brood-rearing habitats will require habitat mapping in order to develop effective survey designs to monitor population size and distribution, to monitor habitat change over time, and to understand habitat requirements and preferences by the various species.

Creation of land cover maps similar to those prepared for this project is recommended for other migratory bird sanctuaries within Nunavut where large numbers of waterfowl nest and other wildlife species reside, and where habitat degradation concerns may exist. Areas of first consideration include the McConnell River, J. Dewey Soper, and Harry Gibbons migratory bird sanctuaries in the eastern Arctic.

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Appendix 1
Dates and track and frame identifiers of LANDSAT TM images used for land cover classification of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

Satellite	Image date	Image size	Track	Frame
LANDSAT5	16 July 1989	full scene	39	13
LANDSAT5	5 August 1991	quadrat 8	41	13
LANDSAT5	14 July 1989	full scene	41	13
LANDSAT5	19 August 1988	full scene	42	13
LANDSAT5	5 August 1986	quadrat 12	43	12
LANDSAT5	5 August 1986	quadrat 3	43	12
LANDSAT5	20 July 1992	full scene	43	13

Appendix 2
Land cover types of Queen Maud Gulf Migratory Bird Sanctuary, Nunavut

CLEAR WATER BODIES

Bands 4,5,2 Enhancement: Dark blue to black.

Topographic Position: Most commonly found in areas with bedrock-controlled shorelines.

Turbidity: Clear; substrate and submerged features are clearly visible except in deepest parts of water body.

Total Suspended Solids — Average 4.5 mg/L
Secchi Disk — Average 2.8 m

MODERATELY TURBID WATER BODIES

Bands 4,5,2 Enhancement: Medium blue.

Topographic Position: Usually with portion of shoreline not bedrock-controlled; common on edges of regions of bedrock.

Turbidity: Variable; substrate and submerged features visible only in depths of <1 m; occasional aquamarine coloration.

Total Suspended Solids — Average 15.8 mg/L
Secchi Disk — Average 0.9 m

TURBID WATER BODIES

Bands 4,5,2 Enhancement: Violet to light purple.

Topographic Position: Located almost always in alluvial plains along major drainages; thaw lakes and channels in marine silts and glacio-lacustrine deposits.

Turbidity: Distinct light to medium brown colour; substrate and submerged objects not visible.

Total Suspended Solids — Average 323 mg/L
Secchi Disk — Average 0.2 m

WET SEDGE MEADOW

Bands 4,5,2 Enhancement: Dark maroon (extensive surface water) to bright red (limited surface water).

Topographic Position: Lowlands, depressions, small drainage channels, snow patch fens; occasionally adjacent to lakes and ponds.

Surficial Expression: Generally level or gently sloping areas beneath and downslope from snow beds; also low-centre polygons or localized patches in hummock and tussock terrain.

Substrate: Saturated sedge peat, some sphagnum peat, overlying poorly drained and saturated fine glacial deposits or marine silts and clays.

Moisture Regime: Hydric, with standing or gently flowing fresh water; hygric in slightly more elevated areas and in areas of drawdown of water level.

Vegetation: A complex of surface water, sedges and grasses, and exposed peat in drawdown areas. In shallow water and on saturated peats, there is a complete cover of sedges, primarily *Carex aquatilis* (*stans*), mosses, *Eriophorum angustifolium* and *Eriophorum vaginatum*, and *Dupontia fisheri*. Other grasses and forbs include *Eriophorum russeolum*, *Poa arctica*, *Carex rariflora*, *Potentilla palustris*, *Pedicularis sudetica*, *Saxifraga hirculus*, *Saxifraga foliolosa*, and *Polygonum viviparum*. Emergents in deeper water include *Arctophila fulva*, *Hippuris vulgaris*, *Carex aquatilis* (*stans*), *Caltha palustris*, and *Ranunculus gmelinii*. Coastal wet sedge meadows on marine clays are often dominated by *Arctagrostis latifolia* and *Dupontia fisheri*. Vascular plant cover ranges from 40 to 100%, averaging 85%. Height ranges from 10 to 25 cm, averaging 15 cm.

HUMMOCK GRAMINOID TUNDRA

Bands 4,5,2 Enhancement: Yellow to yellowish-green; tussocks of *Eriophorum vaginatum* more frequent in yellowish-green areas.

Topographic Position: Lowlands, generally adjacent to shorelines of drainages, lakes, and large ponds.

Surficial Expression: Usually level terrain with characteristic rounded hummocks. Diameter of hummocks 75–160 cm, average 100 cm; height of hummocks 15–35 cm, average 24 cm. Width of intervening troughs 5–45 cm, average 26 cm. In some areas, abundant frost boils with exposed mineral soil.

Substrate: Generally sedge peat overlying marine clays and silts or glacial sands, clays, and silts.

Moisture Regime: Mesic crests of hummocks; mesic to hygric intervening troughs.

Vegetation: Characteristic hummocks dominated by *Carex aquatilis* (*stans*), *Festuca brachyphylla*, and *Arctagrostis latifolia*, with occasional tussocks of *Eriophorum vaginatum*. Crests of hummocks support occasional prostrate shrubs, including *Salix arctica*, *Salix arctophila*, *Salix reticulata*, and *Dryas integrifolia*, a variety of ericaceous shrubs, including *Ledum decumbens*, *Cassiope tetragona*, *Vaccinium vitis-idaea*, and *Vaccinium uliginosum*, and herbs and grasses, including *Potentilla nivea*, *Parrya arctica*, *Cerastium alpinum*, *Stellaria longipes*, *Alopecurus alpinus*, *Saxifraga hieracifolia*, *Saxifraga cernua*, *Melandrium apetalum*, *Hierochloe alpina*, *Antennaria ekmaniana*, *Castilleja elegans*, and *Pyrola grandiflora*. Low erect shrubs, *Betula glandulosa* and *Salix planifolia*, are uncommon. Troughs support moss carpets and occasional *Carex aquatilis* (*stans*), *Eriophorum angustifolium*, *Petasites frigidus*, *Ranunculus pedatifidus*, and *Pedicularis sudetica.* Generally 100% vascular plant cover. Height ranges from 5 to 25 cm, averaging 10 cm.

TUSSOCK GRAMINOID TUNDRA

Bands 4,5,2 Enhancement: Light to medium green; darker hues may represent greater surface moisture.

Topographic Position: Lowlands, level plains adjacent to drainages, or depressions in uplands; gentle slopes between drainages and lakes.

Surficial Expression: Fairly regular pattern of distinct, hemispherical tussocks of *Eriophorum vaginatum* with intervening troughs, occasional scattered hummocks. Diameter of tussocks 15–45 cm, average 30 cm; height of tussocks 10–30 cm, average 19 cm. Width of intervening troughs 15–40 cm, average 26 cm.

Substrate: Predominantly sedge peat with very small patches of sphagnum peat in some troughs, overlying clay, sand, and marine silts.

Moisture Regime: Mesic to hygric; troughs between tussocks tend to be hygric.

Vegetation: Dominated by *Eriophorum vaginatum* tussocks, which comprise up to 80% of cover. Occasional *Eriophorum angustifolium*, *Carex aquatilis* (*stans*), and *Arctagrostis latifolia* occur on the edges of tussocks and in troughs. Low erect shrubs, *Betula glandulosa*, *Salix lanata*, and *Salix arctophila*, comprise up to 25%, average 15%, of total cover, occur on the crests and edges of tussocks, and are generally <50 cm high. Occasional species on tussocks and scattered hummocks include dwarf prostrate shrubs *Salix arctica*, *Salix herbacea*, *Salix reticulata*, and *Dryas integrifolia* and forbs *Pedicularis lapponica*, *Ledum decumbens*, *Vaccinium vitis-idaea*, *Saxifraga cernua*, *Polygonum viviparum*, *Cerastium alpinum*, and *Pyrola grandiflora*. Intervening troughs are primarily exposed peat and hydrophytic moss carpets with occasional *Caltha palustris*, *Petasites frigidus*, *Pedicularis sudetica*, *Potentilla palustris*, *Saxifraga cernua*, and *Saxifraga hieracifolia.* Between 80 and 100% vascular plant cover. Height from 5 to 40 cm, averaging 15 cm, with peat and moss carpets in troughs.

LOW SHRUB TUNDRA

Bands 4,5,2 Enhancement: Olive-brown to varying shades of orange.

Topographic Position: Lowlands, particularly level to gently sloping plains associated with high-centred polygons in mesic, sheltered sites.

Surficial Expression: Generally level to gently sloping but variable; most sites characterized by tussocks of *Eriophorum vaginatum.* Tussock heights 15–30 cm, average 20 cm; tussock widths 15–50 cm, average 30 cm. Hummock heights 15–35 cm, average 25 cm; hummock widths 60–150 cm, average 90 cm. Trough widths 15–300 cm, average 35 cm.

Substrate: Predominantly sedge peat overlying clay, silt, or alluvium; localized sand and gravel deposits in areas of high-centred polygons.

Moisture Regime: Mesic tussocks and hummocks; hygric troughs between tussocks or hummocks.

Vegetation: Low erect shrubs provide 25–75%, average 45%, total cover. Most common are *Eriophorum vaginatum* tussocks supporting low erect willows, primarily *Salix planifolia*, or a mixture of tussocks of *Eriophorum vaginatum* and larger hummocks supporting both *Salix planifolia* and *Betula glandulosa.* In hygric troughs, mosses are abundant; *Carex aquatilis* (*stans*), *Eriophorum angustifolium*, *Potentilla palustris*, *Caltha palustris*, and *Pedicularis sudetica* are common, and *Petasites frigidus*, *Petasites sagittatus*, *Saxifraga hirculus*, *Ranunculus pedatifidus*, *Arctagrostis latifolia*, and *Dupontia fisheri* occur occasionally. *Salix reticulata*, *Salix arctophila*, *Pedicularis flammea*, *Pedicularis lapponica*, *Alopecurus alpinus*, *Astragalus alpinus*, *Vaccinium vitis-idaea*, *Cerastium* sp., *Saxifraga cernua*, *Polygonum viviparum*, and *Pyrola grandiflora* occur occasionally on mesic hummocks and tussocks. Vascular plant cover ranges from 70 to 100%, average 90%, and height of shrubs from base of tussocks or hummocks ranges from 15 to 85 cm, average 30 cm.

SHRUB THICKET

Bands 4,5,2 Enhancement: Dark orange to varying shades of reddish brown.

Topographic Position: Lowlands, particularly level to gently sloping plains associated with major drainages, alluvial deposits along the shorelines on islands of major rivers, and sheltered mesic depressions along valley slopes; shorelines and islands of small and large drainages.

Surficial Expression: Generally level to gently sloping, but variable; heights and widths of tussocks of *Eriophorum vaginatum*, and widths of intervening troughs, similar to low shrub tundra.

Substrate: Sedge peat overlying clay, silt, and alluvium; localized sand and gravel deposits in areas of high-centred polygons, along drainage shorelines, and on islands.

Moisture Regime: Mesic valley slopes and levees along drainages; hygric depressions.

Vegetation: Low erect shrubs provide 75–100%, average 90%, total cover. Most common are dense thickets of *Salix planifolia* or *Betula glandulosa*. Understory is similar to low shrub tundra, with tussocks of *Eriophorum vaginatum* the most abundant ground cover. In hygric troughs, mosses are abundant, with occasional *Carex aquatilis* (*stans*) and *Eriophorum angustifolium* in more open areas. *Petasites frigidus*, *Petasites sagittatus*, *Arctagrostis latifolia*, and *Dupontia fisheri* occur occasionally. Vascular plant cover ranges from 80 to 100%, average 90%. Height of shrubs from base of tussocks ranges from 15 to 100 cm, average 50 cm.

MOSS-LICHEN TUNDRA

Bands 4,5,2 Enhancement: Bright blue-green.

Topographic Position: Uplands, glacial deposits on lower slopes of eskers, long gentle slopes and terraces, and other glacial-lacustrine deposits; sand and sand-gravel deposits along major drainages.

Surficial Expression: Level to undulating, with frequent frost-crack polygons or other surface irregularities.

Substrate: Sand, gravel, and other outwash material. Exposed boulders are common; small rock outcrops are uncommon.

Moisture Regime: Xeric to mesic; may be seasonally saturated.

Vegetation: Dominated by mosses *Rhacomitrium* sp., *Aulacomnium* sp., and *Tomenthypnum* sp., which often cause a yellowish appearance, and lichens *Cladonia* sp., *Cetraria* sp., and *Alectoria* sp. Moss and lichen cover up to 90%. Ericaceous species, common but scattered, include *Ledum decumbens*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Cassiope tetragona*, *Empetrum nigrum*, and *Arctostaphylos alpina*. Prostrate shrubs are frequent but of low cover (<5%) and low height (<10 cm) and include *Dryas integrifolia*, *Betula glandulosa*, and *Salix arctophila.* Forbs are scattered and include *Arctagrostis latifolia*, *Carex vaginata*, *Hierochloe alpina*, *Luzula* sp., *Juncus* sp., *Oxytropis maydelliana*, *Silene acaulis*, *Pedicularis lapponica*, and *Pedicularis sudetica.* Small boulders or small patches of exposed sand or gravel are common. In many areas there are distinct circular patterns with dark *Alectoria* sp. lichens surrounded by yellowish growth of the grass *Hierochloe alpina.*

LICHEN-HEATH TUNDRA

Bands 4,5,2 Enhancement: Olive green to dark green.

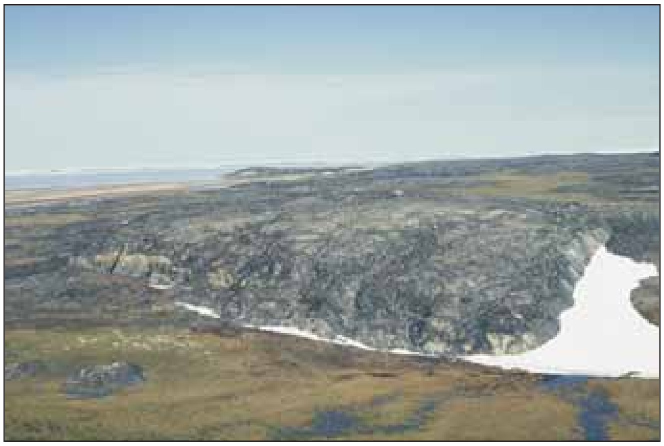
Topographic Position: Uplands, including middle to upper slopes and crests of ridges and eskers, and other moderately drained to well-drained bouldery glacial deposits; thin veneer in depressions of boulder fields and bedrock outcrops.

Surficial Expression: Rough, uneven surface due to boulders, cobbles, and small outcrops of bedrock.

Substrate: Boulder fields and unconsolidated, frost-shattered bedrock; coarse gravels and sands.

Moisture Regime: Xeric, with localized mesic sites in depressions.

Vegetation: Total vegetation cover, excluding crustose lichens, which cover part of exposed boulders and bedrock outcrops, varies, but is generally >75%. Individual areas of exposed bedrock can have <10% plant cover, and depressions frequently support nearly continuous vegetation cover. Dominant vegetation is lichen, including *Alectoria ochroleuca*, *Cladina* sp., and *Cetraria* sp., which creates a greenish-grey appearance to this cover type. Mosses are also abundant, including *Rhacomitrium lanuginosum*, and, together with the dominant lichens, form up to 75% of the vegetation cover. The balance of the vegetation is composed of ericaceous species, such as *Ledum decumbens*, *Cassiope tetragona*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Arctostaphylos alpina*, *Loiseleuria procumbens*, and *Empetrum nigrum*, occasional prostrate shrubs, such as *Dryas integrifolia* and *Betula glandulosa*, and scattered graminoids and forbs, such as *Hierochloe alpina*, *Calamagrostis lapponica*, *Oxytropis maydelliana*, *Silene acaulis*, *Potentilla nivea*, *Epilobium latifolium*, *Papaver radicatum*, *Luzula confusa*, and *Artemisia* sp. Much of the surface area of exposed boulders and rock outcrop is covered with a variety of species of crustose lichens.



BEDROCK AND BOULDER FIELD

Bands 4,5,2 Enhancement: Dark blue-green or brown-green; steep slopes of smooth, consolidated bedrock often appear as small, bright green patches.

Topographic Position: Uplands, mainly consolidated bedrock outcrops of granitic rock and boulder fields.

Surficial Expression: Broken, frequent and abrupt changes in slope and aspect due to presence of frost-shattered bedrock and large angular boulders; small depressions with lichen-heath tundra, tussock graminoid tundra, or ponds are common.

Substrate: Consolidated bedrock or boulders.

Moisture Regime: Xeric; localized mesic sites in depressions.

Vegetation: Exposed bedrock and boulders form >75% of surface, in some areas >90%. These surfaces are subject to extremes of moisture and temperature, snow cover is often blown clear in winter, and they support a variety of species of lichens that can almost completely cover rock surfaces. Crustose lichens and some foliose lichens are dominant. Depressions and large crevices of bedrock often support thick layers of mosses, such as *Rhacomitrium* sp., and lichens, such as *Alectoria* sp. and *Cetraria* sp. Vascular vegetation can occur within these moss- and lichen-dominated areas, including the ericaceous shrubs *Ledum decumbens*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Cassiope tetragona*, *Arctostaphylos alpina*, and *Loiseleuria procumbens*, the graminoids *Hierochloe alpina*, *Arctagrostis latifolia*, *Luzula confusa*, and *Poa alpigena*, the prostrate shrubs *Empetrum nigrum*, *Dryas integrifolia*, *Betula glandulosa*, and *Salix reticulata*, and the forbs *Pedicularis lapponica*, *Arnica louiseana*, *Potentialla rubricaulis*, *Saxifraga tricuspidata*, *Silene acaulis*, *Oxytropis maydelliana*, and *Papaver radicatum.* The fern *Dryopteris fragrans* occurs in crevices and other sheltered locations.

ACTIVE DEPOSITS

Bands 4,5,2 Enhancement: Light-coloured sediments of exposed lake beds, cut banks along rivers, alluvial sand and gravel deposits, or sandy blowouts are generally a bright white; reddish clays and silts are a mixture of light and medium purple; wet nearshore marine silts and clays are a uniform medium or light magenta.

Topographic Position: Lowlands and uplands; exposed beds of larger lakes with past or ongoing drawdown, eroding banks of streams and rivers with exposed marine silts and clays, aggrading areas of rivers and streams, including gravel, sand, and silt islands and spits, mesic to hydric areas of deltaic deposits.

Surficial Expression: Variable, from very flat lake beds, alluvial deposits, and deltaic deposits to low to steep, highly dissected slopes of actively eroding marine silts along rivers and streams.

Substrate: Variable; includes marine clays and silts, alluvial and glacial gravels, sands and silts, and active eolian deposits.

Moisture Regime: Variable, from xeric to hygric.

Vegetation: Usually bare substrate with no vegetation cover due to effects of active erosion or aggradation. Lower reaches of rivers and streams near the coastline, with actively eroding banks of marine silts, may have growths of *Puccinellia phryganodes* and *Alopecurus alpinus.*

EXPOSED PEAT

Bands 4,5,2 Enhancement: Bluish-green; similar to but not as bright as moss-lichen tundra.

Topographic Position: Lowlands; wet sedge meadow, hummock graminoid tundra, and tussock graminoid tundra.

Surficial Expression: Level terrain of wet sedge meadows, and level to gently sloping terrain of hummock graminoid tundra and tussock graminoid tundra.

Substrate: Shallow peat composed primarily of *Carex* sp. and *Eriophorum* sp. material.

Moisture Regime: Hygric to mesic.

Vegetation: There are two situations where exposed peat occurs. Natural drawdown of surface water in wet sedge meadow communities, in response to past and current precipitation and evaporation, exposes the peat bottoms of shallow water areas. This peat is dark brown when saturated, and, when recently exposed, little vegetation is present except for scattered graminoids such as *Carex aquatilis* (*stans*), *Eriophorum angustifolium*, or *Arctophila fulva.* In years with reduced winter snow cover and low precipitation, these areas can be found in patches within or along the periphery of wet sedge meadows. Peat is also exposed due to nest building and grazing activities of Snow Geese and Ross' Geese within and adjacent to their nesting colonies. In mesic areas of tussock graminoid tundra with high densities of nesting geese, the individual tussocks of *Eriophorum vaginatum* are shredded and used with many other vegetation species in the building of nest bowls by the geese. From arrival to hatch, the adult geese are in attendance at the nest site, where grazing on any edible vegetation is intense. Exposed peats are mesic and appear medium to dark brown.

COASTAL GRAMINOID TURF

Bands 4,5,2 Enhancement: Small orange patches on landward edge of light purple of exposed offshore silts and clay, primarily near mouths of rivers and streams. NOT MAPPED; LOCATION CAN BE PREDICTED BY TOPOGRAPHIC POSITION.

Topographic Position: Lowlands, immediate shoreline along the coastline in the vicinity of mouths of rivers and streams, inundated by high tides on a regular but not daily basis; rare small pockets along bedrock-controlled shorelines of coastline in small bays where small deposits of fine silts and clays occur.

Surficial Expression: Level ground with a mosaic of low, elevated turf islands, expanses of unvegetated silts, and shallow brackish to saline pools and channels.

Substrate: Marine silts and clays and deltaic sediments at the mouths of streams and rivers.

Moisture Regime: Hygric; moisture related to recent tidal action and onshore winds.

Vegetation: Outer islands of graminoid turf dominated by *Puccinellia phryganodes.* Inner islands of turf vegetated by *Puccinellia phryganodes*, *Carex subspathacea*, *Carex ursina*, and *Stellaria humifusa.*

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