VEGETATION MAPPING OF BANKS ISLAND WITH PARTICULAR REFERENCE TO AULAVIK NATIONAL PARK

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ABSTRACT

Landsat 5 Thematic Mapper data were used to classify vegetation types on Banks Island in the Canadian Arctic Archipelago. Digital image enhancements were used to classify land cover types by entering information from 531 training areas, including 359 within the boundaries of Aulavik National Park (ANP), visited during summers 1993–1997. A draft classification was verified by a ground inspection of 201 sites. The resulting map had a 25 m resolution and was differentiated into 10 land cover classes. Accuracy assessment of the classification ranged from 67-100%, averaging ca. 90% over all verified plots. The 10 land cover classes included: sedge-dominated dry tundra (covering 22.2% of Banks Island); wet sedge meadow (20.6%); hummock tundra (15.3%); mesic meadow (10.6%); stony/sandy barren (8.7%); grass-dominated dry tundra (8.2%); successional dry tundra (3.8%); water/snow/ice (5.7%); bare ground (3.6%); and unclassified/clouds and shadow (1.3%). The classification was most accurate when classes could be differentiated by microtopography, as with hummock tundra (97% accuracy), or by the presence of surface water, as for wet sedge meadows (95% accuracy). The accuracy was reduced when classes were distinguished by abundance and composition of plant cover (67–92%). Nevertheless, this study indicates that Landsat 5 Thematic Mapper data can be used successfully for vegetation mapping over large areas in the mid-Arctic latitudes. Intensive vegetation surveys within ANP reported 11 species of vascular plants new to the park, of which seven were new records for Banks Island.

Key Words: Landsat Thematic Mapper, remote sensing, habitat classification, Banks Island, Canadian Arctic Archipelago, Aulavik National Park

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INTRODUCTION

Remote sensing technology has been providing new opportunities and challenges for researchers working in remote areas; however, vegetation and habitat mapping in Arctic regions has received limited attention (Thompson *et al.*, 1980; Harvie *et al.*, 1982; Petersen, 1987; Dickson *et al.*, 1989; Wakelyn, 1990; Ferguson, 1991; Pearce, 1991; Brossard and Joly, 1994; Muller *et al.*, 1999; Nilsen, 1999; Nilsen *et al.*, 1999; Walker, 1999). Remote sensing studies using Landsat imagery on Banks and Devon islands in the Canadian Arctic Archipelago (Fig. 1) have shown success in mapping muskoxen habitat (Ferguson, 1991; Pearce, 1991), although these studies covered relatively small areas. There are few studies where habitats have been classified and mapped over large areas requiring multiple scenes of data (Guindon and Edmonds, 2002).

Classifying habitats over areas that include more than one scene (185 km x 172 km) present additional challenges. Neighbouring scenes overlap and rarely are their data collected from the same season or date (Fig. 2). Arctic ecosystems do provide advantage over more southerly ecosystems by being relatively two-dimensional which reduces some of the problems associated with overlapping data. However, plant cover in Arctic landscapes is often sparse (Bliss and Svoboda, 1984; Larter and Nagy, 2001a). In areas of sparse vegetation, background reflectance from rock and soil can dominate the reflectance from vegetation (Frank, 1988), which can potentially reduce the usefulness of Landsat imagery for detecting vegetation communities that may be important to Arctic wildlife.

Banks Island is the westernmost island in the Canadian Arctic Archipelago and covers an area of ca. 70,000 km^2 (Fig. 1). Vegetated areas of Banks Island have received relatively little attention with a few studies describing plant taxa and broad descriptions of vegetation types (Porsild, 1950, 1964; Mason *et al.*, 1972; Kevan, 1974; Thannheiser and Schweingruber, 1974; Wilkinson and Shank, 1974; Zoltai *et al.*, 1980). Only a small area in the north-central part of the island had ever been mapped in detail (Ferguson, 1991).

Banks Island has an abundance of resident wildlife, Peary caribou, muskoxen, Arctic wolves, hares, foxes, lemmings, and polar bears, and is a summer nesting area for migratory waterfowl. From 1985 to 1992, the muskoxen population on Banks Island had increased from ca. 29,000 to 53,000 non-calves while the endangered Peary caribou population had declined from ca. 4,900 to 1,000 (Nagy *et al.*, 1996). The number of lesser snow geese nesting on Banks Island had also increased annually at 6.3% since the 1980's, numbering an estimated 490,000 by 1995 (Kerbes *et al.*, 1999). There were wildlife management concerns that increasing densities of muskoxen and snow geese would impact the vegetation and cause habitats to deteriorate.

In 1992, Aulavik National Park (ANP) was established on the north central part of the island (Fig. 1). The area was known by the Inuvialuit to be rich in wildlife and establishing a Park was a means of protecting important wildlife habitats. After the Park establishment, various stakeholders determined that one of the top research priorities was to establish a digital map of the different land cover types of Banks Island. The digital map which could then be loaded into a Geographical Information System (GIS).

The map was seen as a key management tool that could be used to identify prime wildlife habitat and hiking routes for visitors. Ferguson (1991) had demonstrated that Landsat thematic data were useful for classifying muskox habitats on Banks Island, and in 1993 a study was initiated to use Landsat thematic data to classify vegetated (and non-vegetated) land cover types found on Banks Island. The main goals of this study were to determine and describe the major vegetated land cover types, determine the suitability of Landsat thematic mapper data for mapping vegetated cover types of Banks Island and ANP in particular, and to determine the vascular plant species richness of ANP. Plant nomenclature follows Porsild (1964) and Porsild and Cody (1980).

METHODS

Data acquisition

Landsat 5 satellite imagery was purchased from Radarsat International in Vancouver to cover the entire area of Banks Island. Five full scenes and two quarter scenes of Landsat 5 Thematic Mapper data were required to cover the land area (Fig. 2). Each scene covered approximately 185 x 172 km^2 with a pixel resolution of 30 m. For proper analysis of the data, as many cloud-free images as possible were required. Peak vegetation cover is attained in late July and August. This limited the timeframe in which imagery can be obtained, since the satellite passes over each given area once every 16 days. Relatively cloud-free imagery was therefore obtained over a period of several years (Table 1).

Site visits

Prior to visiting ground inspection sites, enhanced images of 10 different areas of Banks Island were produced at a scale of 1:50,000. Enhanced images increase the contrast and detail of satellite imagery to the human eye by stretching the brightness values over the full range of the 8 bit or 256 grey levels of each Landsat channel. Depending on the area, we used the linear contrast stretch, histogram-equalization stretch, and some spatial filtering, some of the more common enhancement techniques, to create our enhanced images which covered areas averaging *ca*. 1,835 km^2 (range 410–4,150 km^2). For each enhanced image we selected internally-homogenous areas with contrastingly coloured pixels as ground inspection sites. An attempt was made to select at least 10 areas with similar reflectance values. Most areas were between 0.5 and 5 ha, but some were as large as 20 ha. All potential ground inspection sites were assigned site numbers and transcribed onto 1:50,000 National Topographic Series (NTS) maps so that approximate location coordinates could be determined. Weather and logistic constraints prevented visiting all potential ground inspection sites.

Prior to visiting ground inspection sites for ANP, three different hiking routes were chosen that traversed all major landscape types in the park. An extensive number of ground inspection sites (n=350) were visited on foot between 11 and 30 July 1996. These extensive surveys on foot had the added benefit of serving as bird surveys (Henry and Mico, 2002). Data were recorded only from ground inspection sites where the vegetation was homogenous and 90% of the site had the same vegetation type. At each area, slope (>2% incline) and aspect (estimated to the nearest 45^{o}) were recorded. Microtopography was estimated as the average height of humps above the depressions in the surface of the site. Four to eight plant species were recorded that had the largest estimated cover. Cover of substrate type was also recorded, and was defined as: boulder (rocks 50 cm diameter); stones (rock <50 cm diameter); sand (grains); mineral (fine, inorganic material usually light brown, yellow or red in colour; mixture of sand, silt and clay particles); and organic (usually brown or black derived from dead plant material).

Outside of ANP, ground inspection sites were located from the air by a crew in a helicopter. At each area, print photographs of the ground cover were taken from both the air (*ca*. 100 m above ground level) and the ground, the latitude and longitude were recorded from the global positioning system in the helicopter, and a description of plant species composition, plant cover, substrate type/colour, moisture and microtopography was recorded based upon visual inspection from the ground survey.

Supervised classifications

Following each summer's fieldwork we used data from the ground inspection sites to create training areas for each terrestrial habitat class described. Training areas were based upon photographs and descriptions of each ground inspection site visited during each summer, which had been grouped into their respective land cover types. The general location of training areas was determined based upon the coordinates associated with the ground inspection sites visited. Training areas for vegetated land cover types were created within each scene only after ground inspection sites had been visited in that scene.

For bare ground, water, snow, ice, and shadow ground cover, training areas, in addition to those visited, were also created directly from the satellite imagery where there were obvious gravel bars, sand dunes, water bodies, and snow/ice covered areas. It was necessary to increase the number of pixels covering these types of ground cover because of the large variance in pixel reflectance.

Supervised classifications, based on the field data were performed using an ARIES II (Applied Resource Image Exploitation) system. Training areas were identified within each satellite image and the maximum likelihood classifier algorithm using channels 2, 3, 4, 5, and 7 was used. The maximum likelihood classifier uses the means and standard deviations of the pixels in each training area for each channel and compares the digital values for each pixel in the scene against these statistics and assigns the pixel to the class it most likely belongs to (see Short, 1982; Schowengerdt, 1983). The spectral signature of each class should be unique, based on the means and standard deviation (and associated variance-covariance matrices) for each training area. Some confusion is inevitable in any classification but may be reduced by including a number of different channels in the signature statistics. The training areas for each scene were updated yearly as more potential training areas were visited and supervised classifications were run as more data became available. Data from all 531 training areas visited from 1993 to 1997 and those additional areas of bare ground, water, snow, and ice created directly from satellite imagery were used for the final classification (Table 1; Fig. 2).

Most classification algorithms produce maps, which tend to have a “salt and pepper” effect. Within the larger classes there are numerous scattered pixels from different categories. These may be due to a pixel, which due to its coarse resolution may in effect cover more than one vegetation class. To smooth this effect the classified images were filtered. Care must be taken not to over-smooth the data since this may reduce the amount of detail in the classification, but must be an accurate reflection of reality. A 3 x 3 filter was run over the classifications. This meant that any group of three pixels or fewer were re-assigned to the surrounding larger class. Any number of single pixels in a line was not affected since they could represent a linear feature such as a small stream or ecotone, which may be of importance in the classification.

Accuracy assessment

We assessed the accuracy of the resulting supervised classification following methods described by Story and Congalton (1986). A total of 201 sites were visited and sampled during the summers of 1997 and 2000 (186 from ANP, 15 elsewhere). Most sites were visited on foot in ANP (170) while others were done by helicopter. The accuracy assessment was performed on few water (n=3) and bare ground (n=2) sites and was not performed on snow and shadows since the reflectance values of these cover types were so unique that their classification was assumed to be highly accurate. Because the ANP vegetated land cover types had been assessed separately prior to the completion of the classification for Banks Island as a whole, it was not possible to separate them *a posteriori* into all 10 of the land cover types defined for Banks Island as a whole. The dwarf shrub tundra land cover type as defined for ANP was a combination of both grass- and sedge-dominated dry tundra land cover types described from the final classification for Banks Island as a whole. A limited number (n=3) of ground sites were assessed for the sedge-dominated dry tundra land cover type in 2000.

Georeferencing

There are a number of distortions inherent in the satellite imagery, which is due to the satellite’s orbit, motion, the earth’s rotation, curvature, sensor motion as well as atmospheric distortions. To rectify some of these errors geometric corrections were performed to match an existing grid system. The images were registered to the Universal Transverse Mercator (UTM) projection grid based on meters and at the same time the pixel size was resampled to 25 m. 1:250,000 digital NTS maps were used to obtain the reference grid points for known points on the imagery. This is especially important if other data are required to be overlain on the classified imagery. The imagery was georeferenced to the North American Datum 1983 (NAD 83).

RESULTS

Land cover types

Ten land cover classes were recognized for Banks Island (Table 2; Fig. 3). These land cover types were: sedge-dominated dry tundra (22.2%); wet sedge meadow (20.6%); hummock tundra (15.3%); mesic meadow (10.6%); stony/sandy barren (8.7%), grass-dominated dry tundra (8.2%); successional dry tundra (3.8%); water/snow/ice (5.7%); bare ground (3.6%); unclassified/clouds and shadow (1.3%). Cover types specific to Aulavik National Park are presented in Table 3.

Sedge-Dominated Dry Tundra (Fig. 4)

Sedge-dominated dry tundra was characterized by moderately steep and rolling slopes that were moist but well drained, with vegetation cover of 25–60%. What distinguished these areas from grass-dominated dry tundra was a vegetation cover dominated by sedges (*Carex* spp.) and *Dryas integrifolia* rather than by grasses and saxifrages. *Salix Arctica*, lichen and a variety of forbs (*Astragalus* spp., *Oxytropis* spp., *and Draba* spp.) were also commonly found.

Wet Sedge Meadow (Fig. 4)

Wet-sedge meadow occurred where the soil was waterlogged or under water. This land cover types was usually close to ponds or in wet depressions, but also occurred on slopes below permafrost seepages. Vegetative cover was nearly 100% except for areas of standing water. The vegetation was dominated by *Carex aquatilis* var. *stans* and *Eriophorum scheuchzeri* with some *Equisetum* spp., *Pedicularis* spp., and *Dupontia Fisheri* present. *Dryas integrifolia* and *Salix Arctica* may be found on small elevated and drier microsites.

Hummock Tundra (Fig. 4)

The surface of hummock tundra was dominated by earth hummocks, generally 20–40 cm high separated by narrow gaps, which were found on moderate to steep slopes with relatively stone-free soil and cover. Vegetation cover was 30–70% with *Dryas integrifolia* predominating. *Carex* spp., *Salix Arctica*, lichen, *Cassiope tetragona*, *Oxytropis* spp., and *Pedicularis* spp. were also often present.

Mesic Meadow (Fig. 4)

Mesic meadow was a very variable vegetation type found in humid depressions associated with areas of moderately rolling slopes. Often this type was found adjacent to wet sedge meadows but further away from the moisture source. There was a build-up of organic matter in the upper soil horizon mostly from undecomposed graminoids and moss. Vegetative cover was 50–75%, sometimes nearing complete when adjacent to wet sedge meadows. Grasses, *Saxifraga* spp. and other forbs predominated. *Juncus* spp. and *Salix Arctica* were often present with the willow growth often having a definite vertical component unlike its prostrate form in other vegetation types. This cover type was more common on north and west Banks Island.

Stony/Sandy Barren

Stony/sandy barren was characterized by <10% plant cover, which was patchily distributed and generally found in microsites that collected moisture, small cracks and depressions. This included areas on windblown ridges, high rocky uplands, gravel beds and sand dunes. Among the few plants found here were small mats of *Dryas* spp. and *Saxifraga oppositifolia*, a few scattered stems of *Draba* spp., some xeric sedges, occasional stunted *Salix Arctica*, and small lichen fragments.

Grass-Dominated Dry Tundra

Grass-dominated dry tundra occurred on moderately steep and rolling slopes, which were moist but well drained. Vegetation was generally associated with the drainage rills and depressions which pattern this landscape. Vegetation cover was 25–60%. Most commonly grasses (*Alopecurus alpinus* and *Poa* spp.), *Salix Arctica*, *Saxifraga* spp. and a variety of forbs (*Draba* spp., *Pedicularis* spp., *Astragalus alpinus*, and *Polygonum vivparum*) can be found. Moss cover and the rarity of *Dryas integrifolia* distinguished these areas from sedge-dominated dry tundra. This cover type tended to be distributed more to the north and west of Banks Island.

Successional Dry Tundra

Successional dry tundra was characterized by plant cover of 10–25%, occurring on upper slopes, plateaus, and large areas often associated with frost heaves and old dried up drainages and pond beds. Their substrate was generally flat and usually stony or gravelly with some clay or sand. *Dryas integrifolia* and *Saxifraga* spp. predominated, with xeric sedges, lichen, *Draba* spp., *Astragalus alpinus*, and *Papaver radicatum* often present.

Water/Snow/Ice

Water, including lakes, rivers, streams and bays, made up the majority of this land cover class; snow/ice represented 0.2% of the total coverage of Banks Island. Snow banks were still noticeable in late July in some of the steeper drainages, especially to the north of the island. There was still ice cover on some of the deeper lakes in late July.

Bare Ground

Areas classified as bare ground were characterized by the virtual absence of vegetation. This included areas such as gravel bars associated with the major braided river and stream drainages, sand dunes, mud flats, and rock and boulder, fields most noticeable in areas of the north and east, and the elevated areas to the extreme south of the island.

Unclassified, Clouds/Shadow

Unclassified areas represented 0.79% of Banks Island and were those areas that could not be classified given the available training sites. Cloud cover was present in one small area of scene 60-9 (Figs. 2 and 3) which created shadow. Additional shadows were found below steep hills particularly to the north of the island. Because of the light reflectance associated with the cloud and the dark reflectance associated with the shadow these areas were mapped separately. These areas represented 0.46% of Banks Island.

Accuracy assessment

The accuracy of nine land cover types was assessed but no accuracy assessment was done of the clouds/shadow/unclassified cover type (Table 4). Because water and bare ground had such unique reflectance values the few sites used to assess accuracy were 100% accurate. Classification accuracy was highest for hummock tundra and wet sedge meadow, at 97 and 95% respectively, and lowest for mesic meadow at 66.7% (Table 4). The 86.7% accuracy assessment for the dwarf shrub tundra cover type represents the combination of both grass and sedge-dominated dry tundra cover types and cannot be used to assess the two cover types individually. The limited accuracy assessment (n=3) of the sedge-dominated dry tundra cover type was favourable (100% accuracy). Whether this indicates a higher accuracy for the sedge-dominated dry tundra than the grass-dominated dry tundra is unknown.

Vascular plants in Aulavik National Park

A total of 169 species of vascular plants were recorded during site visits. Eleven species were newly recorded for Aulavik National Park of which four species had been previously recorded from southern Banks Island (Table 5). These recordings indicate a significant northward range extension of the known range of *Poa Williamsii*, *Potentilla biflora*, and *Oxytropis nigrescens*. All specimens are deposited in the Parks Canada Herbarium, Inuvik.

DISCUSSION

Creating the final classification

Since it was difficult to obtain cloud-free Landsat imagery within one summer, various years and months of imagery were used. This added to the complexity of the analysis since the sun angle changes from 37 degrees in early July to 29 degrees in mid-August thus changing the reflectance values. The greater change is in the difference in biomass. At the beginning of July we have the start of green up while in mid-August we have maximum biomass or the beginning of vegetation decline. As well there are differences in moisture regimes from one year to the next (Larter and Nagy, 2003; N. Larter, unpubl. data). This difference and edge effect is quite clearly evident in south-western Banks Island.

Not all land cover types that were classified were found in all scenes, nor were all scenes collected from the same year. Therefore joining the scenes to create one final classification, which required dealing with edge effects from the overlap of images, was not simple. Because the images overlapped, the order by which images were overlaid on top of one another to produce a final composite image could result in composite images with slightly dissimilar island wide percentages of the different cover types. In order to provide the most appropriate composite image, where images overlapped the image with the fewest training areas was overlain by the image with the most training areas. By doing so all the data were used to the fullest extent (see Guindon and Edmonds, 2002), and we believe that we present the most accurate final composite classification of land cover types on an island wide basis.

Initially an attempt was made to separate the wet sedge meadow cover type into two categories: sloped meadows associated with seepage slopes, and the more typical depression meadows associated with lakes, streams and low-lying areas. Although it was possible to make the distinction in the individual scenes where both meadow types were present, when overlaying the scenes to create a final composite classification it became obvious that the separation of the two types was responsible for a large proportion of the edge effect. It was decided to combine the two into a single wet sedge meadow cover type to reduce the problems of edge effect. Both types have similar species composition and standing crop (N. Larter, unpubl. data).

Accuracy assessment

The classification was most accurate when land cover types could be differentiated by microtopography, as with hummock tundra, or by the presence of surface water, as for wet sedge meadow. Accuracy was reduced when classes were distinguished by percent and composition of plant cover; however for all classes, except mesic meadow, accuracy was still >85%.

Mesic meadow was the most variable of all the vegetated land cover types. It had no unique microtopographical features and was found both on slopes and within depressions. Vegetation cover included an erect growth form of *Salix Arctica,* a variety of forbs, and cover in a number of areas was >75%. These features likely increased the variation in reflectance of this land cover type. The association between moisture and vegetation in sedge- and grass-dominated dry tundra classes often results in patches of vegetation in and adjacent to rills and depressions and adjacent to non-vegetated patches. This provides a distinct patterning when viewed from the air. Mesic meadow did not have this patterning having less distinctive between vegetated and non-vegetated patches with non-vegetated patches being rarer in sedge- and grass-dominated dry tundra. There was more of a continuum of greater and lesser vegetated areas in mesic meadows. Because of this continuum and a lack of vegetated patterning it is not surprising that the accuracy in classifying this vegetated land cover types was lower than for the other vegetated land cover types.

Land cover types

Wet sedge meadows have been described previously from a number of islands in the Canadian Arctic Archipelago, Victoria (Edlund, 1983), Devon (Muc and Bliss, 1977), and Ellesmere (Bergeron and Svoboda, 1989; Henry *et al.*, 1990). Because they are associated with standing water, these are distinct and readily recognizable areas. Ferguson (1991) described wet sedge meadows from the Thomsen area of north-central Banks Island and found that they could be accurately (89%) classified with Landsat Thematic Mapper data. Similarly, our study found that this land cover type could be accurately (95%) classified over a larger area.

Mesic meadows are common throughout the Arctic, but variable in appearance because of the variation in the upright versus prostrate growth of willows, degree of vegetative cover, and lack of vegetative patterning found in this cover type. Other authors have termed what we describe mesic meadow as sedge-willow meadow (Edlund, 1983) or graminoid tundra (Ferguson, 1991). Although Ferguson (1991) had lower than average accuracy in classifying graminoid tundra (84%) as compared to other cover types in his study, he was better able to accurately classify graminoid tundra than our study was for mesic meadow (67%). However, graminoid tundra only represented 4.5% of his 1,835 km^2 study area and it is likely that he did not encounter the variability in this cover type that the present study did when considering the entire island.

Ferguson (1991) described hummock tundra for Banks Island. Unlike the results from this study which indicated a high accuracy (97%) in classifying this land cover type, Ferguson (1991) found considerable overlap with this and another cover type termed dwarf shrub tundra and pooled the two types together because neither cover type was an important foraging area for muskoxen. Peary caribou forage in hummock tundra during the snow free and the snow seasons (Larter and Nagy, 2001b). Because this land class is found on steeper slopes and has its unique microtopography, the snow conditions for this land cover class are generally more severe, based upon the combination of snow depth, density and resistance, than in the other upland habitats (Larter and Nagy, 2000). Winter snow conditions affect the foraging behaviour of Peary caribou and therefore it was important to be able to classify accurately this land cover type.

Sedge-dominated dry tundra had previously been described as “upland barren” habitat for Banks Island (see Larter and Nagy, 2001a; 2001c). This land cover class would incorporate the lesser vegetated areas of Ferguson's (1991) dwarf shrub tundra and the greater vegetated areas of his dwarf shrub/lichen barrens. This land cover class is similar in appearance and plant biomass to grass-dominated dry tundra except that the dominant graminoid is sedge (*Carex* spp.) rather than grass (*Alopecurus alpinus* and *Poa* spp.), and *Dryas integrifolia* is more common than *Saxifraga* spp. Both sedge- and grass-dominated dry tundra are important foraging habitats for Peary caribou (Larter and Nagy, 2001b; N. Larter, unpubl. data).

Successional dry tundra is similar to the descriptions of "polar semi-desert" by other authors (Bliss, 1975; Bliss and Svoboda, 1984). This land cover class is widely distributed on dry sites north of 70^{o} (Bliss, 1975) and been described for other islands of the Canadian Arctic Archipelago by Bliss and Svoboda (1984).

Areas classified in this study as stony/sandy barrens are sometimes termed "polar deserts" for Russia (Aleksandrova, 1970) and for several of the Canadian High Arctic Islands (Billings, 1973; Muc and Bliss, 1977; Bliss *et al.*, 1984; 1994). This land cover class is widely distributed on uplands throughout the Canadian Arctic Archipelago. Ferguson (1991) described such a cover type as "sparsely vegetated ground". Similar to the findings in this study he reported that this cover type could be accurately classified with Landsat Thematic Mapper data (92% and 98% accuracy, respectively). This land cover type is an important winter foraging habitat for Peary caribou (Larter and Nagy, 2001b).

Relationship of land cover types to topography

Depressions are usually filled with water as permafrost prevents drainage. Along the edges of watercourses, hydrophilic plants form wet sedge meadows in water saturated soils. *Carex aquatilis* var. *stans* and *Eriphorum* spp. dominate and form lush green lawn-like communities that grow to about 20 cm, with some areas of up to 40 cm height and standing crops during July averaging 750 kg/ha (Larter and Nagy, 2003; N. Larter, unpubl. data). As soon as the profile rises above the water table and the substrate becomes drier the community changes to a mesic meadow. As one moves further upslope and the soils become increasingly dry, the community changes to a sedge- or grass-dominated dry tundra type and then to a stony/sandy barren type. On steeper slopes with fine substrate, hummock tundra covers large areas. The upper parts of these slopes are usually very dry and dominated by stony/sandy barrens. Successional dry tundra was generally found on dried out watercourses and ponds; however it may occur as a transition between stony/sandy barrens and the sedge- and grass-dominated dry tundra.

The vegetation transitions moving upslope from and away from water sources on Banks Island are similar to that of the mid-Arctic ecosystem defined by Polunin (1951) and those described in Edlund (1983) and Edlund and Alt (1989). The dominant vegetation on Banks Island is characterized by an abundance of dwarf shrubs with legumes and other forbs occurring intermittently. Some areas along the north coast and to the northeastern highlands are characterized by a high Arctic transition (Edlund, 1983), that is dominated more by extensive *Dryas-Saxifraga* barrens with few forbs.

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Table 1. Details of the satellite images purchased and the years when ground verification was conducted. Q indicates the quarters of the image that were purchased for the study.

Image Track - Row	**Image Date**	**Year(s) ground verification**
58 - 8	19 July, 1994	1995
58 - 9	27 July, 1991	1994, 1995
58 - 10	21 July, 1991	1993, 1994
60 - 9	6 July, 1990	1993, 1994
61 - 7 Q3, Q4	12 August, 1995	1996, 1997
61 - 8	12 August, 1995	1996, 1997

Table 2. Extent of each land cover type from the final classification for Banks Island after excluding water/snow/ice from the images except that found on the land mass.

Land Cover Type	**area covered (km^2)**	**area covered (%)**
Water/Snow/Ice	3,994.7	5.66
Bare Ground	2,513.3	3.56
Stony/Sandy Barren	6,166.7	8.74
Successional Dry Tundra	2,707.1	3.84
Grass-Dominated Dry Tundra	5,786.9	8.2
Sedge-Dominated Dry Tundra	15,642.8	22.18
Hummock Tundra	10,801.7	15.31
Mesic Meadow	7495.5	10.63
Wet Sedge Meadow	14,551.7	20.63
Unclassified/Clouds/Shadow	877.1	1.25
Total	**70,537.5**	**100**

Table 3. Extent of each land cover type from the final classification for Aulavik National Park, Banks Island.

Land Cover Type	area covered (km^2)	area covered (%)
Water/Snow/Ice	273	2.5
Rocky/Sandy Barren [1]	1,327	11.7
Successional Dry Tundra	2,763	24.5
Dwarf Shrub Tundra [2]	1,469	12.9
Hummock Tundra	2,795	24.8
Mesic Meadow	1,689	15
Wet Sedge Meadow	769	6.8
Unclassified/Clouds/Shadow	197	1.8
Total	**11,282**	**100**

[1] Rocky/Sandy Barren land cover class as defined for ANP combines the Bare Ground and Stony/Sandy Barren land cover classes as defined for the land cover classification for Banks Island as a whole.

[2] Dwarf Shrub Tundra land cover class as defined for ANP combines both the Grass- and Sedge-Dominated Dry Tundra land cover classes as defined for the land cover classification for Banks Island as a whole.

Table 4. Accuracy of the supervised classification of Landsat images for different land cover classes.

Cover Class	**Plots checked**	**% accuracy**
Water	3	100
Bare Ground	2	100
Wet Sedge Meadow	41	95.1
Mesic Meadow	21	66.7
Hummock Tundra	36	97.2
Successional Dry Tundra	27	85.2
Stony/Sandy Barren	38	92.1
Dwarf Shrub Tundra [1]	30	86.7
Sedge-Dominated Dry Tundra [2]	3	100
Total	**201**	

[1] All plots checked were in ANP where the Dwarf Shrub Tundra land cover class, as defined, combines both the Grass- and Sedge-Dominated Dry Tundra land cover classes as defined for the land cover classification for Banks Island as a whole.

Table 5. New records of vascular plants occurring in Aulavik National Park, Banks Island. Nomenclature follows Porsild (1964) and Porsild and Cody (1980). * indicates plants which have been recorded previously for southern Banks Island but not in Aulavik National Park.

Family Name	**Species Name**
Gramineae	*Poa Hartzii* Gand.
Gramineae	*Poa Williamsii* Nash
Caryophyllaceae	*Arenaria ulginosa* Schleich.
Cruciferae	*Draba crassifolia* Grah.
Cruciferae	*Draba glabella* Pursch. *
Cruciferae	*Halmolobos mollis* (Hook.) Rollins *
Saxifragaceae	*Saxifraga tenuis* (Wahlenb.) H. Sm. *
Rosaceae	*Potentilla biflora* Willd.
Rosaceae	*Geum Rossi* (R.Br.) Ser.
Leguminosae	*Oxytropis nigrescens* (Pall.) Fisch
Ericaeae	*Vaccinium uliginosum* L.s.lat. *

FIGURES

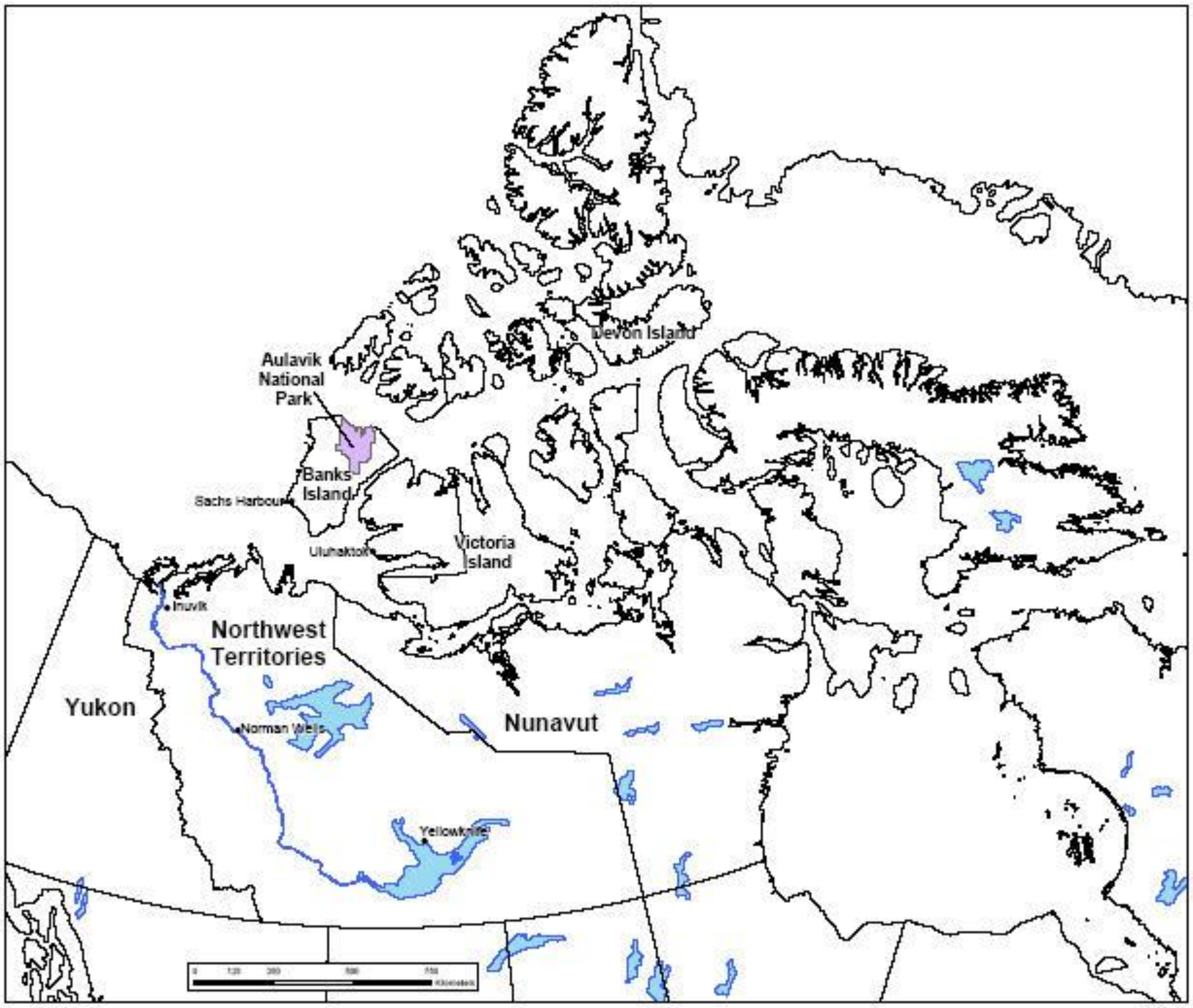

Figure 1. Banks Island and Aulavik National Park in the Canadian Arctic Archipelago.

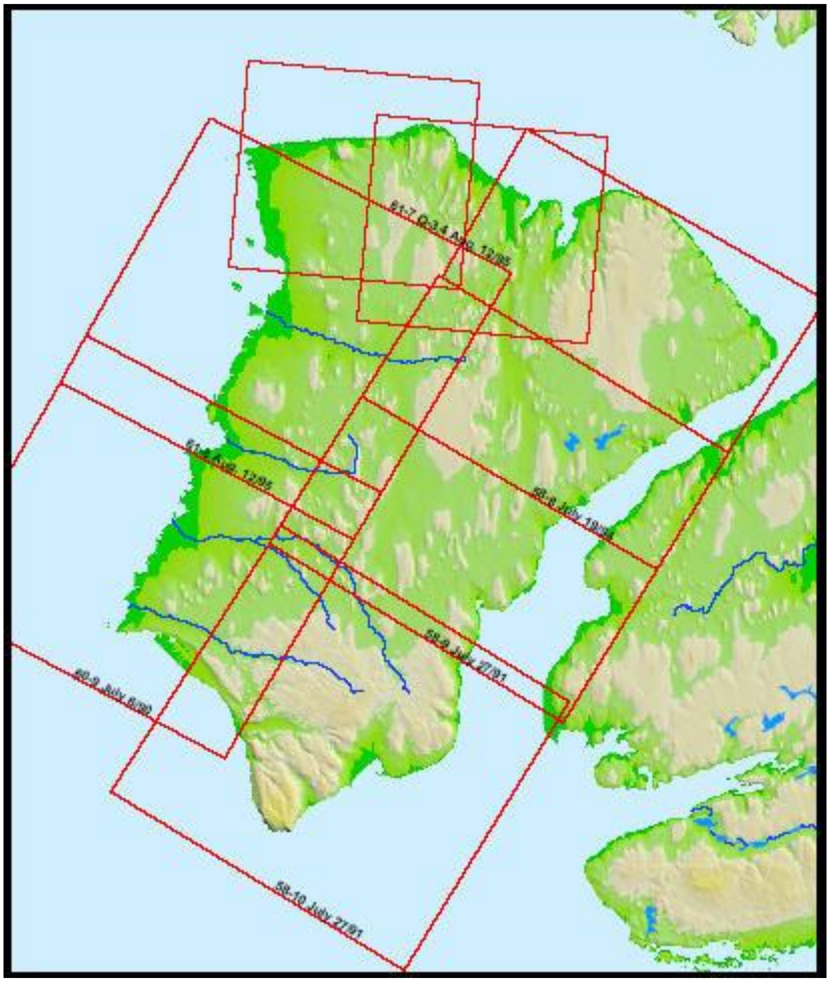

Figure 2. The location of the five full scenes and the two quarter scenes used for the land cover classification of Banks Island.

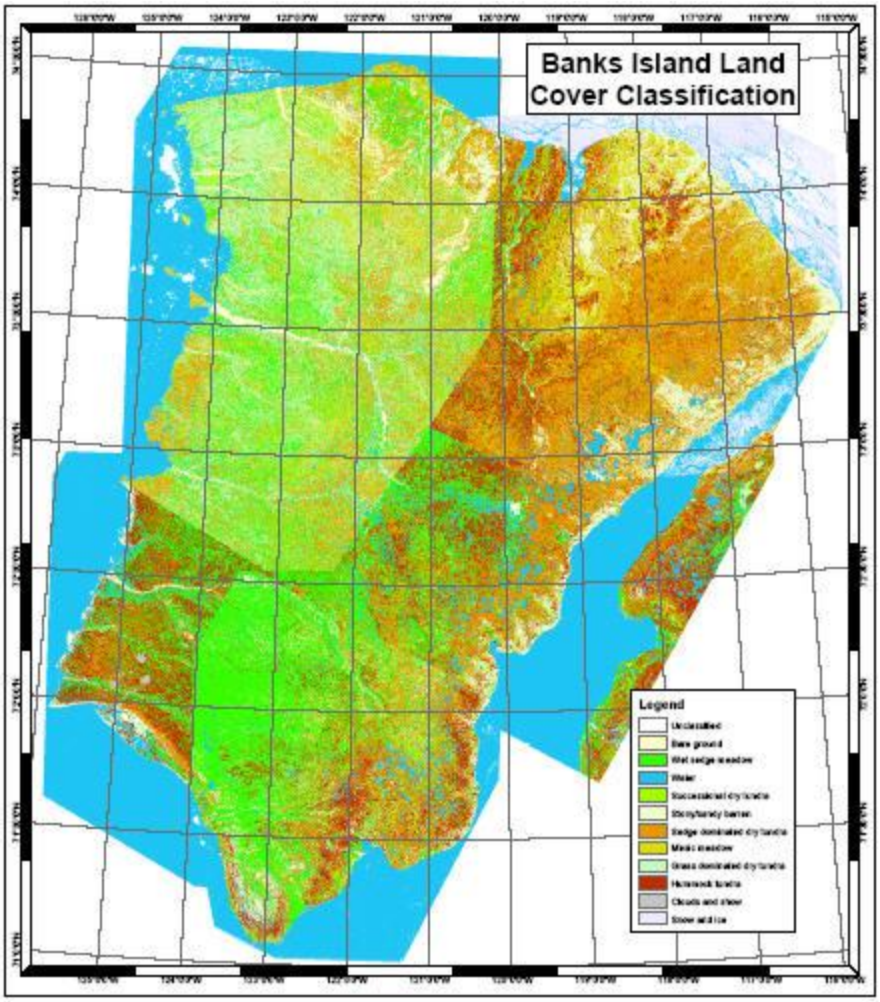

Figure 3. The final classification of ten land cover types for Banks Island based upon Landsat thematic data from 5½ scenes.

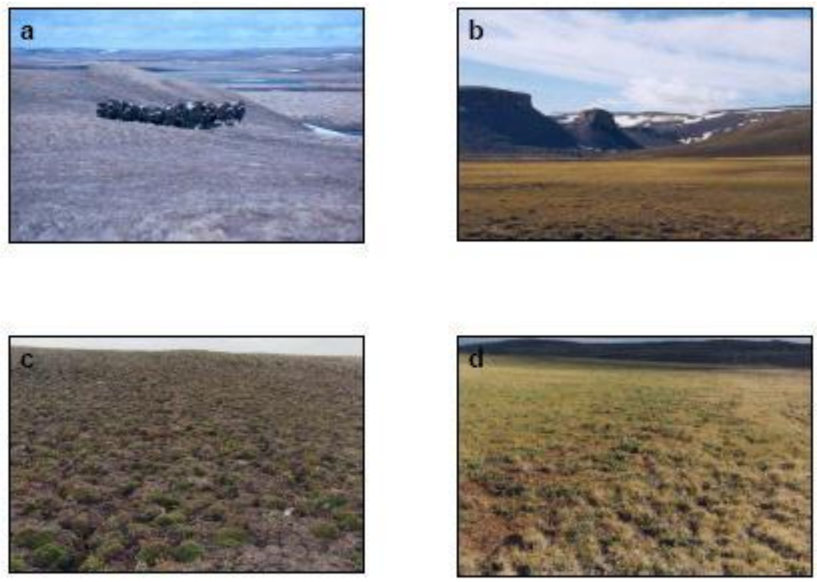

Figure 4. Examples of the four major land cover types on Banks Island: a) sedge-dominated dry tundra, b) wet sedge meadow, c) hummock tundra, and d) mesic meadow.