Detection and Classification of Muskox Habitat on Banks Island, Northwest Territories, Canada, Using Landsat Thematic Mapper Data

ROBERT S. FERGUSON

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ABSTRACT. The feasibility of using Landsat Thematic Mapper data for mapping muskox summer habitat was tested on northern Banks Island, Northwest Territories. Digital image enhancement and classification techniques were examined to determine if summer foraging habitats could be detected and mapped using Thematic Mapper imagery. Interpretations of the satellite data were verified in the field during the summers of 1988 and 1989. The most important summer foraging habitats for muskoxen included the wet sedge meadow, graminoid tundra and graminoid/dwarf shrub tundra cover types. These lowland habitats were generally distinguishable on enhanced colour images and were easily differentiated from upland areas. The most suitable colour composite for differentiating muskox summer habitats was the near-infrared (band 4), shortwave infrared (band 5) and red (band 3) spectral bands displayed in red, green and blue respectively. Upland cover types, including dwarf shrub tundra, hummocky tundra and dwarf shrub/lichen barrens, were more difficult to differentiate because of spectral variability resulting from differences in plant cover and site characteristics. The classified image had an overall accuracy of 88%. The summer habitats of particular importance to muskoxen had classification accuracies of 84-89%. Detection of important foraging habitats on Thematic Mapper imagery is attributable to the spectral distinctiveness of wet graminoid communities and the high spectral sensitivity and spatial resolution of the infrared sensors, which allow detection of differences in surface moisture and vegetation physiognomy.

Key words: muskox habitat, remote sensing, arctic Canada, digital classification, Landsat Thematic Mapper data, Banks Island, habitat mapping, Ovibos moschatus, periglacial environments

INTRODUCTION

Recent advances in remote sensing technologies present new opportunities and challenges for researchers working in remote areas. However, few studies have examined the advantages and limitations of using satellite data for mapping wildlife habitats of the Canadian Arctic. Vegetation and terrain mapping using Landsat Multispectral Scanner (MSS) data have been conducted in northern Canada (Harvie et al., 1982; Petersen, 1987; Thompson et al., 1980) and in Alaska (reviewed by Shasby and Carnegie, 1986). Landsat Thematic Mapper (TM) data, with improved spatial, spectral and radiometric properties, have been used in boreal and arctic regions of Canada to map wetland habitats (Dickson et al., 1989; Walekyn, 1990) and in northern Norway to map reindeer (Rangifer tarandus) ranges (Tommervik and Lauknes, 1987). TM data have not been tested thoroughly in arctic regions.

This project investigated the feasibility of using Landsat TM data as the primary basis for a muskox (Ovibos moschatus) habitat inventory on Banks Island, Northwest Territories. The objectives were to: 1) determine if the summer foraging habitats of muskoxen could be detected by visual interpretation of Landsat TM imagery; 2) classify and map muskox summer habitats and other arctic tundra cover types using digital analysis of TM data; 3) assess the accuracy of the classification; and 4) determine the advantages and limitations of inventorying muskox habitats of the arctic tundra using Landsat data. This project was completed under the Northwest Territories Technology Enhancement Program, a cooperative program between the Canada Centre for Remote Sensing and the Department of Renewable Resources, Government of the Northwest Territories.

The muskoxen of Banks Island are of interest to wildlife management agencies because of rapid population growth. Comparable surveys suggest that the population has increased from approximately 18 300 animals in 1979-80 (Vincent and Gunn, 1981) to 34 200 animals in 1989 (B. McLean, pers. comm. 1989). Management concerns relate to the increasing population densities and their possible negative effects on food supply, habitat condition and incidence of disease (Blake et al., 1989; Gunn et al., 1989; McLean et al., 1986).

The summer food habits and feeding ecology of muskoxen have been described for a wide geographic area, including Alaska (O'Brien, 1988; Robus, 1984), Greenland (Ferns, 1977; Thing, 1984; Thing et al., 1987), the Union of Soviet Socialist
Republics (Rapota, 1984) and several localities within the Canadian Arctic (Parker, 1978; Parker and Ross, 1976; Tener, 1965; Thomas and Edmonds, 1984; Wilkinson et al., 1976). Geographic variations in diet have been noted, but most studies agree that the predominant forage plants are graminoids, especially hydrophytic sedges (Carex spp. and Eriophorum spp.), and willows (Salix spp.). Willows are more prevalent in the summer diet in Greenland and Alaska than in the Canadian Arctic, where graminoids are predominant (Thing et al., 1987). Parker (1978) reported that the most important graminoids for muskoxen on the Queen Elizabeth Islands are Carex aquatilis var. stans, Eriophorum triste and E. scheuchzeri. Thomas and Edmonds (1984) determined that use of feeding sites on eastern Melville Island is related to the abundance of Carex aquatilis var. stans. This sedge is also an important component in the foraging areas and diets of muskoxen on Banks Island (Wilkinson et al., 1976) and the Taimyr Peninsula, U.S.S.R. (Rapota, 1984). The close relationship that exists between the summer distribution of muskoxen and the presence of well-vegetated lowland and riparian habitats is well documented (Henry et al., 1986; O'Brien, 1988; Parker and Ross, 1976; Thing et al., 1987; Thomas et al., 1981).

Remote sensing by satellite involves measuring and recording the levels of electromagnetic radiation reflected from the earth's surface (Sabin, 1978). The principal sensors used in the Landsat series of satellites are the MSS and TM sensors, which are capable of detecting minimum areas of approximately 57 m × 79 m and 30 m × 30 m respectively (Richards, 1986). Reflectance values from each minimum area ("pixel"), recorded in different parts of the electromagnetic spectrum, have brightness values in the range 0-63 for the MSS sensor and 0-255 for the TM sensor. Bands 1-4 represent the blue, green, red and near-infrared portions of the electromagnetic spectrum respectively. Bands 5 and 7 represent different regions of the shortwave infrared portion of the spectrum. Band 6 is a thermal infrared band. The reflectance values recorded by the sensors for each pixel represent an average measure of reflectance obtained from the composite of surficial features (e.g., vegetation, bare soil, rock and water).

Landsat TM data are strongly influenced by vegetation type, pattern and abundance (Kenk et al., 1988). Vegetation in the Arctic is dominated by low herbaceous perennials, prostrate shrubs, graminoids, bryophytes and lichens (Billings and Mooney, 1968; Bliss et al., 1973; Edlund and Alt, 1989). In the Canadian Arctic Archipelago, the polar desert (<5% vascular plant cover) and polar semi-desert (5-20% vascular plant cover) landscapes predominate (Bliss and Svoboda, 1984). In areas where plant cover is sparse, background reflectance from soil or bare rock often dominates the reflectance from vegetation (Frank, 1988). This can potentially reduce the usefulness of Landsat imagery when attempting to recognize and inventory vegetation communities of importance to arctic wildlife.

**STUDY AREA**

This study was carried out in north-central Banks Island (Fig. 1). The study area (1835 km²) is bisected by the Thomsen River, which flows in a general south to north direction. Elevations west of the Thomsen River range from 30 to 225 m above sea level (asl). The topography is characterized by rounded, irregularly shaped uplands with undulating plains, small lakes, wet sedge meadows and narrow drainages in the intervening lowlands. Rolling uplands are drained by the Muskox River and its numerous tributaries and by smaller streams such as Able and Baker creeks, which empty into the Thomsen River.

East of the Thomsen River, the topography is more rugged and elevations are more variable, ranging from 30 m asl along the Thomsen River valley to over 365 m asl at the eastern limit of the study area. These highlands form the western edge of the Parker River Plateau, an elevated plateau of Devonian sandstone with deeply dissected valleys and gorges (Zoltai et al., 1980). A general overview of the geology, phytogeography and glacial history of northern Banks Island is provided by Zoltai et al. (1980). The flora of northern Banks Island has been described by Porsild (1955), Steere and Scotter (1979), Wilkinson et al. (1976) and Zoltai et al. (1980).

**METHODS**

*Image Processing*

Landsat TM data for northern Banks Island, recorded on 5 August 1986, were acquired as computer compatible tapes...
and a colour transparency (scale, 1:1 000 000). The transparency was used to identify a relatively cloud-free and snow-free study area. Panchromatic aerial photographs (approximate scale, 1:100 000) of northern Banks Island, taken in 1961, were also examined to provide information on topographic features.

Digital analyses of Landsat data were performed on an ARIES III system (Applied Resource Image Exploitation System, DIPIX) at the Northwest Territories Centre for Remote Sensing in Yellowknife. Digital image enhancements (including histogram equalizations, linear and power stretches, and logarithmic and principal components transformations) were produced and various band combinations were used to increase the visual interpretability of the raw data. Digital image classifications were created using both unsupervised and supervised techniques. An unsupervised classification defines the “natural groupings” of the multispectral data based on their reflectance values. Unsupervised classification techniques assign each pixel to a spectral class by a statistical algorithm that groups pixels having similar reflectance values. The algorithm used for all classifications (both unsupervised and supervised) was the “maximum likelihood classifier,” using bands 1-5 and 7.

Supervised classification procedures assign pixels to specific classes by comparing the reflectance value of each pixel with the spectral signatures of known training areas (i.e., areas having known land cover types). The number of pixels used to generate spectral signatures for the known cover types (described below) ranged from 970 to 4597. The separability of spectral signatures was measured statistically by calculating the autocorrelation distance (ACD) between each pair of signatures, where an ACD value > 2.0 indicates <10% correlation between spectral signatures (Dipix Systems Limited, 1987). Detailed descriptions of ARIES functions and the fundamentals of digital image analysis and classification are provided by Schowengerdt (1983) and Short (1982).

An accuracy assessment of the supervised classification was performed following Story and Congalton (1986). Accuracy was determined by sampling 196 areas (representing seven cover types) distributed throughout the study area and is expressed as the percentage of the image that has been classified correctly when compared with reference data (“ground truth”). Sampling units varied in size according to cover type and generally comprised >20 pixels. It was not possible to assess accuracy on a pixel-by-pixel basis because of difficulties in determining precise locations of pixels on the ground.

Field Studies

Field work was carried out from 30 July to 10 August 1988 and from 9 to 25 July 1989 to obtain information on land cover types. The colour enhancement and unsupervised classification were used to identify homogeneous areas for field sampling. The following information was recorded for each cover type by walking linear transects across representative areas: landform (ridgetop, plateau, terrace, slope, lowland, wetland); topography (level, undulating, hummocky, slope aspect, degree of slope); microtopographic features (earth hummocks, striping, ice-wedge polygons, sorted and non-sorted circles, frost fissures); substrate (bedrock, boulders, sand, gravel, till, clay/silt, peat); surface moisture (hydric, hygic, mesic, xeric); and living (green) vegetation. Vegetation descriptions included the dominant growth form (dwarf shrubs, forbs, grasses/sedges, mosses, lichens), species composition, visual estimates of total plant cover (<10%, 25%, 50%, 75%, > 90%) and average height (cm). (Nomenclature for vascular plants follows that of Porsild and Cody [1980], and the terminology of periglacial features follows French [1976]). Colour photographs from ground level and from the air were taken at many sites to secure a permanent photographic record for future reference. The field data were used to “train” the computer to recognize specific cover types, based on their spectral signatures, during the supervised classification procedures.

RESULTS

Cover Types

Seven terrestrial cover types differing in topography, vegetation and surface moisture (Table 1) were defined for the Banks Island study area. Two additional cover types (water bodies and ice and snow cover) were also included because they are important sources of moisture during the growing season. The following descriptions of the cover types are listed in order of generally increasing elevation and decreasing surface moisture availability.

Water Bodies: Water bodies include the open water of lakes, rivers, streams and tundra ponds.

Wet Sedge Meadow: Wet sedge meadows occur on level, hydric lowlands (Fig. 2) and support a nearly continuous cover of sedges, especially Carex aquatilis var. stans, and other hydrophytic species growing in shallow (<10 cm) water (e.g., Eriophorum scheuchzeri, Dupontia fisheri, Pedicularis

TABLE 1. Ecological moisture regime classes1 of the Banks Island study area

<table>
<thead>
<tr>
<th>Moisture class</th>
<th>Description</th>
<th>Primary water source</th>
<th>Topographic position</th>
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<tbody>
<tr>
<td>Xeric</td>
<td>Water removed very rapidly in relation to supply; soil is moist for brief periods following precipitation.</td>
<td>Seepage from snowbeds and ice lenses.</td>
<td>Gently sloping terrain and lowlands particularly those located downslope from persistent snowbeds.</td>
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<tr>
<td>Mesic</td>
<td>Water removed somewhat slowly in relation to supply; soil remains moist for a significant but sometimes short period of the year.</td>
<td>Seepage (and limited seepage).</td>
<td>Moderately sloping terrain, including the middle and upper parts of slopes and raised surfaces in lowlands.</td>
</tr>
<tr>
<td>Hygic</td>
<td>Water removed slowly enough to keep the soil moist to wet for most of the growing season.</td>
<td>Precipitation.</td>
<td>Elevated, wind-blown sites such as the upper slopes and summits of hills, ridges, plateaus and bedrock outcrops.</td>
</tr>
<tr>
<td>Hydric</td>
<td>Water removed so slowly that the water table is at or above the soil surface all year.</td>
<td>Permanent water table; water held at surface due to underlying permafrost.</td>
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1 Adapted from Walmsley et al. (1980).
sudetica, Saxifraga hirculus var. propinqua, Senecio congestus, Caltha palustris var. arctica and mosses). The substrate is typically water-saturated peat, and meltwaters from upslope snowpacks collect on the surface in depressional areas at the base of slopes. Wet sedge meadows also occur in the shallow water of low-centred polygons (Fig. 3) and bordering tundra lakes and ponds (Fig. 2). The depressional area of a polygon typically features either a central area of open water ringed by emergent plant growth, especially sedges (Carex aquatilis var. stans) and Arctophila fulva, or a nearly continuous cover of sedges and mosses growing in water-saturated peat. These polygons are generally restricted to the valley bottoms of the Thomsen and Muskox rivers.

**Graminoid Tundra:** Graminoid tundra occupies mesic to hygic sites in lowlands and on gentle slopes (Fig. 4) and is characterized by a continuous cover of graminoid species, particularly Eriophorum triste, but also Carex spp., Dupontia fisheri, Arctagrostis latifolia spp. latifolia and Alopecurus alpinus. The peaty substrates of this cover type also support mosses, dwarf willows (Salix spp.) and a variety of herbs (e.g., Melandrium apetalum spp. arcticum, Cerastium regeli, Petasites frigidas, Pedicularis sudetica, Ranunculus nivalis and Saxifraga hirculus var. propinqua). Plant growth is most luxuriant along watercourses and on gentle slopes located downslope from snowbeds (Fig. 5). During winter, wind-blown snow accumulates on south- and east-facing slopes in deep drifts, which often persist until late July or early August. Meltwaters from these drifts are an important source of moisture for graminoid tundra plants. The plant associations that develop downslope from persistent drifts are often termed snowpatch fens (Tarnocai and Zoltai, 1988). They are generally associated with gentle slopes where runoff moves downslope as a broad flowing sheet rather than in well-defined channels (cf. Graminoid/Dwarf Shrub Tundra).

**Graminoid/Dwarf Shrub Tundra:** This diverse and variable cover type is intermediate between graminoid tundra and dwarf shrub tundra in terms of topographic position, moisture regime and vegetation. The vegetation (75-100% cover) is typically a mosaic of graminoids and dwarf shrubs, with graminoids (Eriophorum triste, Arctagrostis latifolia spp. latifolia and Alopecurus alpinus) and mosses dominant in moist depressional areas, and a mixture of herbs and dwarf shrubs (particularly Dryas integrifolia and Salix spp.) on the drier substrates of elevated sites. Sites having good represen-
moderate-to-steep slopes below snowbeds where meltwaters and precipitation move downslope in narrow runnels with intervening areas of higher ground.

**Dwarf Shrub Tundra**: Dwarf shrub tundra is characteristic of moist, well-drained sites, including the middle and upper parts of slopes (Fig. 6) and raised surfaces (e.g., solifluction lobes and terraces) in lowlands. The substrate is variable, ranging from fine-textured clays to coarse sands and stony till, but typically lacks peat development. Small, non-sorted polygons are characteristic of the surface micro-relief, and cryoturbated surfaces are often present. Vegetation is diverse and is dominated by dwarf shrubs (*Salix arctica*, *Dryas integrifolia* and, less frequently, *Cassiope tetragona ssp. tetragona*), lichens and a variety of herbs (*Pedicularis arctica*, *P. capitata*, *Parrya arctica*, *Arnica alpina ssp. angustifolia*, *Potentilla vahliana*, *Polygonum viviparum*, *Cerastium spp.*). Graminoids are a minor and localized component of this cover type, often occurring near bird perches and lemming burrows, and include species tolerant of dry to moist conditions (e.g., *Alopecurus alpinus*, *Festuca brachyphylla*, *Poa spp.* and *Carex rupestris*). Plant cover varies in response to differences in micro-relief and changes in moisture availability, but is generally between 50 and 75%.

**Hummocky Tundra**: Hummocky tundra is characterized by the presence of earth hummocks, a non-sorted, polygonal expression of patterned ground often covering extensive areas. Individual hummocks are roughly hemispherical in shape, measure up to 45 cm in diameter and are separated from adjacent hummocks by narrow furrows and cracks, producing a very uneven surface (Fig. 7) with a micro-relief of 10-35 cm. Hummocky tundra occurs predominantly on moderate to steep slopes in relatively stone-free soils. The moisture regime of hummocky tundra is complex: the tops of hummocks tend to be dry, while the furrows channel meltwater downslope and tend to be wetter. Vegetation cover is usually discontinuous (approximately 50%) and is characterized by dwarf shrubs (*Dryas integrifolia*, *Salix arctica* and *Cassiope tetragona ssp. tetragona*), herbs (*Oxyria digyna*, *Oxytropis arctica*, *O. glutinosa*, *Cardamine digitata* and *Pedicularis arctica*) and lichens, with mosses occurring in the furrows. On sheltered, south-facing slopes adjacent to snowbeds, hummocky tundra is frequently very lush. Under these conditions, a variety of flowering plants often form a continuous ground cover (e.g., *Polemonium boreale*, *Arnica alpina ssp. angustifolia*, *Saxifraga cernua*, *S. nivalis*, *Papaver radicatum*, *Castilleja elegans*, *Pedicularis arctica*, *Cerastium spp.*, *Petasites frigidus* and *Erigeron erioides*).

**Dwarf Shrub/Lichen Barrens**: This cover type occurs predominantly on upper slopes and on the tops of hills, ridges, plateaus and other elevated, wind-blown sites where winter snow cover is light and moisture availability is low. Surficial deposits are coarse-textured, frequently stony and very rapidly drained (Fig. 8). The primary source of moisture is summer precipitation. Microtopographic relief occurs on many uplands in the form of non-sorted stripes, frost fissures and fissure polygon terrain. Individual polygons generally range from 25 to 45 m in diameter. Vegetation is discontinuous, typically 25-50% cover, and is dominated by mat and cushion plants (e.g., *Oxytropis arctobia*, *Saxifraga oppositifolia* and *Silene acaulis ssp. acaulis*), prostrate shrubs (*Dryas integrifolia* and *Salix arctica*), lichens (particularly *Thamnolia spp.*), and xeric sedges (*Carex rupestris*). Forbs are sparsely distributed and include *Saxifraga tricuspidata*, *Astragalus spp.*, *Draba spp.*, *Pedicularis arctica*, *Potentilla vahliana*, *Taraxacum spp.* and *Erigeron compositus* and *Papaver radicatum*. 

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![FIG 6. Dwarf shrub tundra vegetation is characteristic of moist, well-drained slopes. The dominant dwarf shrubs are *Dryas integrifolia* (shown here in bloom) and *Salix arctica.*](image1)

![FIG 7. Hummocky tundra is characterized by the presence of earth hummocks and occurs predominantly on moderate to steep slopes.]()

![FIG 8. The dwarf shrub/lichen barrens cover type (foreground) is characteristic of coarse-textured substrates on ridgetops and other elevated sites.](image2)
Sparsely Vegetated Ground: Sparsely vegetated ground (<10% vascular plant cover) represents a diversity of landforms, topographic positions, substrates and moisture gradients. In lowlands, fluvial processes associated with the Thomsen and Muskox rivers produce cutbanks, mudflats, and sand and gravel bars largely devoid of vegetation (Fig. 9). In upland areas, sparsely vegetated habitats occur on exposed outcrops of frost-shattered bedrock (Fig. 10) and on the surrounding debris-mantled slopes and cryoplanation surfaces. These topographic expressions are most conspicuous east of the Thomsen River, where consolidated outcrops of sandstone, siltstone and shale of the Parker River Plateau are a prominent feature of the landscape (Zoltai et al., 1980). Sparsely vegetated ground also appears on coarse-textured substrates on the tops of wind-blown hills and ridges. Localized slope failures, characterized by the sudden downslope movement of the active layer and its vegetation cover, also account for the presence of bare substrates on sloping terrain.

Ice and Snow: This cover type includes ice-covered water bodies and snow-covered terrestrial features.

Visual Interpretation of TM Image

The most suitable colour composite for visually interpreting the land cover types was the near-infrared (band 4), shortwave infrared (band 5) and red (band 3) bands displayed in red, green and blue respectively. Image quality was improved by using a power contrast stretch of band 4 and linear contrast stretches of bands 5 and 3. These radiometric enhancements were superior to the histogram equalizations and logarithmic and principal components transformations.

Bands 4 and 5 were particularly useful for recognizing areas of lush vegetation growing on hygric and hydric sites. These areas include the wet sedge meadow, graminoid tundra and graminoid/dwarf shrub tundra cover types. They were easily differentiated from upland cover types, but the graminoid-dominated communities could not always be separated from each other (Fig. 11). Spectral overlap between wet sedge meadow and graminoid tundra and between graminoid tundra and graminoid/dwarf shrub tundra reflects the ecological continuums that exist between contiguous cover types.

On the ground, sharp boundaries between ecologically similar habitat types rarely occur. Instead, one cover type generally grades into adjacent ones in response to gradual environmental changes along topographic and moisture gradients.

The upland cover types (dwarf shrub tundra, hummocky tundra and dwarf shrub/lichen barrens) were not always separable. They exhibited wide variation in colour and tone as a result of differences in the type and amount of exposed substrate, extent of plant cover, degree and orientation of slope and the presence of microtopographic features. For example, terrain with earth hummocks, frost fissures or other surface irregularities that create shadows had lower reflectance than similar terrain without these features.

Most types of sparsely vegetated ground were readily discernible, particularly highly reflective, light-coloured substrates such as dry sand and gravel deposits, frost-shattered bedrock and eroded cliff faces (as well as ice and snow cover). Dark-coloured substrates (e.g., mudflats) were sometimes confused with hummocky tundra and other upland cover types, especially those under shadow on northern exposures.

Unsupervised Classification

The unsupervised classification was useful for identifying spectrally homogeneous areas and selecting sampling areas, but it was of limited value as a representation of a cover type map. Problems centred on producing a classification that exhibited both a reasonable number of classes (16 or fewer).
and good separation of the cover types of interest. Classifications with a reasonable number of classes assigned pixels representing the cover types of interest (i.e., those with continuous plant cover) to a single class. The remaining classes represented various open water classes and predominantly unvegetated terrestrial surfaces. Classifications that differentiated highly vegetated areas resulted in so many classes (>48) that visual interpretability was poor and cover type patterns were obscured.

**Supervised Classification**

The supervised classification had an overall accuracy of 88% (Table 2). Accuracy for individual classes ranged from 72 to 100%, and only two of seven classes had accuracies <80%. The cover types of greatest importance to muskoxen (wet sedge meadow, graminoid tundra and graminoid/dwarf shrub tundra) had classification accuracies of 84-89%. Misclassified areas were generally placed in an ecologically similar cover type rather than in a dissimilar one (Table 3).

Narrow drainages (<2 pixels wide, or approximately 60 m), which often provide foraging areas for muskoxen and serve as useful reference features, were difficult to classify because of the spectral variability of edge pixels. Edge pixels comprised a mixture of water and other cover types in varying proportions. Supervised classification procedures placed most of these pixels in an “unclassified” category. As a result, the drainages were difficult to discern on the classified image, so they were mapped separately.

Discrimination between the dwarf shrub tundra and hummocky tundra cover types was difficult because of the variability in reflectance caused by differences in slope, substrate, extent of vegetation cover and other modifying parameters. Confusion between these cover types was circumvented by merging them into a single category (i.e., dwarf shrub tundra). This did not reduce the usefulness of the classification because neither cover type is important to muskoxen as summer foraging habitat due to a lack of graminoid species. The principal difference between these cover types is the microtopographic relief (i.e., earth hummocks) associated with hummocky tundra.

The cover types that represent good foraging habitat for muskoxen (wet sedge meadow, graminoid tundra and graminoid/dwarf shrub tundra) occupy 24.8% of the study area (Table 3). These cover types are not uniformly distributed but are concentrated in an area between the Thomsen and Muskox rivers. Although this subarea represents only 18% of the total study area, it supports 27% of the total wet sedge meadow cover type and 31% of the total graminoid tundra cover type. The three graminoid-dominated cover types occupy 33% of this subarea, an area that supports high densities of muskoxen (McLean et al., 1986; McLean and Fraser, unpubl. ms.).

**DISCUSSION**

The ability to detect the important cover types for muskoxen using Landsat TM data is attributable to the spectral distinctiveness of wet graminoid communities. Wetland areas support a lush growth of sedges, grasses and mosses, which are physiognonomically and spectrally distinct from the discontinuous cover of dwarf shrubs, forbs and lichens in upland areas. Upland and lowland sites are readily distinguished on colour composite images by visual interpretation. The high spectral and radiometric resolution of the TM sensors allows detection of differences in vegetation physiognomy and soil moisture (Lillesand and Kiefer, 1987). Throughout the Arctic, graminoid communities are restricted to places where there is abundant soil moisture during the growing season (Edlund and Alt, 1989). Thus, TM data may have widespread application for inventorying muskox habitats.

A reconnaissance-level overview of a large geographic area can be attained quickly by examining colour composite images (one Landsat scene measures 185 x 185 km, or 34 225 km²). Broad overviews of vegetation and other biophysical attributes are often useful when assessing general suitability of areas for wildlife and when selecting study sites for more intensive research. Use of Landsat data also provides flexibility because computer-generated colour plots of any part of an image can be produced easily at whatever scales are

| Column totals: | 22 28 25 25 29 25 42 196 |
| Producer’s accuracy: | 100 89 84 88 79 72 98 |
| Overall accuracy = sum of number correctly classified areas = 172 = 88% |

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<th>Classification data</th>
<th>WAT</th>
<th>WSM</th>
<th>GRT</th>
<th>GST</th>
<th>DST</th>
<th>DLB</th>
<th>SVG</th>
<th>Row totals</th>
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| Table 2. Error matrix for supervised classification of the Banks Island study area |  |
| User’s accuracy | 1 |
| Producer’s accuracy | 2 |
| Overall accuracy | 3 |

1User’s accuracy indicates the probability that an area on the ground will be classified correctly.

2Producer’s accuracy indicates the probability that a unit from a classified map actually represents that category on the ground.

3WAT = water bodies; WSM = wet sedge meadow; GRT = graminoid tundra; GST = graminoid/dwarf shrub tundra; DST = dwarf shrub tundra; DLB = dwarf shrub/lichen barrens; SVG = sparsely vegetated ground.

4Ice and snow cover on the 1986 image could not be verified during 1988 and 1989 field sampling.
desired. Wildlife survey data marked directly on these products would permit direct comparison of wildlife distribution and abundance in relation to cover types. Survey areas could also be stratified beforehand on the basis of the distribution of particular cover types and survey effort could be allocated accordingly (Falconer, 1979).

The primary advantages of producing a supervised classification are the abilities to simplify the visual complexity of images by "translating" the spectral information into meaningful land cover types for presentation on habitat maps and to quantify the availability of particular habitat types. Wildlife habitat inventories typically involve determining the availability and spatial distributions of certain cover types within a geographic area. Digital analysis enables the total areas of cover types to be calculated in just a few minutes, and an accuracy assessment gives map users and producers an indication of how good the classification is (Story and Congalton, 1986). Planimetric methods of calculating areas, on the other hand, are very time consuming and labour intensive and may produce results with variable precision. The usefulness of TM data for mapping and inventorying habitats of other arctic wildlife has not been tested thoroughly, but some general observations can be made on the basis of this study. Vegetation types having discontinuous cover may be difficult to detect because background reflectance from soil or exposed rock often dominates the reflectances from the vegetation. This limitation has also been noted for alpine tundra (Frank, 1988). Additional information concerning topographic and other environmental parameters is often needed in combination with TM data to map these areas successfully (Frank, 1988; Frank and Thorn, 1985). Thus, in the Arctic, Landsat data alone are probably insufficient for discriminating upland vegetation types having discontinuous plant cover.

Remote sensing studies of arctic areas may be hampered by a lack of imagery. Landsat data are not recorded for the Queen Elizabeth Islands. In other areas, the probability of acquiring a good quality image during the period of photosynthetic activity is low due to the combined effects of a short growing season (generally < 60 days), the high incidence of cloud cover during the snow-free season (Edlund and Alt, 1989) and the orbital frequencies of the Landsat satellites (16 or 18 days). Given these limitations, several years may be required before a usable image of a particular geographic area is available.

Ideally, it is preferable to collect ground data during the same growing season in which the satellite image was recorded. In the Arctic this is seldom possible. Field studies in remote northern regions, where access is difficult and expenses are high, are by necessity planned well in advance. It is impractical to schedule field studies on the condition that "same year" imagery can be acquired. Instead, field work is generally planned after a suitable image of a particular area is obtained. Images from arctic areas have useful application for many years because arctic tundra conditions are slow to change. Unlike boreal habitats, where recurring forest fires abruptly modify successional communities, succession in arctic ecosystems is very gradual. Furthermore, arctic landscapes are not disrupted by extensive land-use activities that cause widespread changes in ground-cover patterns (e.g., forestry or agriculture). The long-term usefulness of satellite images of arctic regions may offset the high costs associated with the acquisition and field verification of satellite data.

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REFERENCES


TABLE 3. Summary of supervised classification of the Banks Island study area using Landsat TM data from 5 August 1986

<table>
<thead>
<tr>
<th>Cover type</th>
<th>Area (ha)</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water bodies</td>
<td>7,243</td>
<td>4.0</td>
</tr>
<tr>
<td>Wet sedge meadow</td>
<td>3,297</td>
<td>1.8</td>
</tr>
<tr>
<td>Graminoid tundra</td>
<td>8,186</td>
<td>4.5</td>
</tr>
<tr>
<td>Graminoid/dwarf shrub tundra</td>
<td>34,020</td>
<td>18.5</td>
</tr>
<tr>
<td>Dwarf shrub tundra</td>
<td>62,000</td>
<td>33.8</td>
</tr>
<tr>
<td>Dwarf shrub/lichen barrens</td>
<td>27,580</td>
<td>15.0</td>
</tr>
<tr>
<td>Sparsely vegetated ground</td>
<td>29,211</td>
<td>15.9</td>
</tr>
<tr>
<td>Ice and snow</td>
<td>814</td>
<td>0.4</td>
</tr>
<tr>
<td>Unclassified*</td>
<td>11,109</td>
<td>6.1</td>
</tr>
<tr>
<td>Total</td>
<td>183,460</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*The unclassified category included pixels representing clouds, highly reflective surfaces such as ice, snow and dry sand, and edge pixels between water bodies and terrestrial cover types.


