USER'S GUIDE FOR THE LAND-COVER MAP OF THE COASTAL PLAIN OF THE ARCTIC NATIONAL WILDLIFE REFUGE

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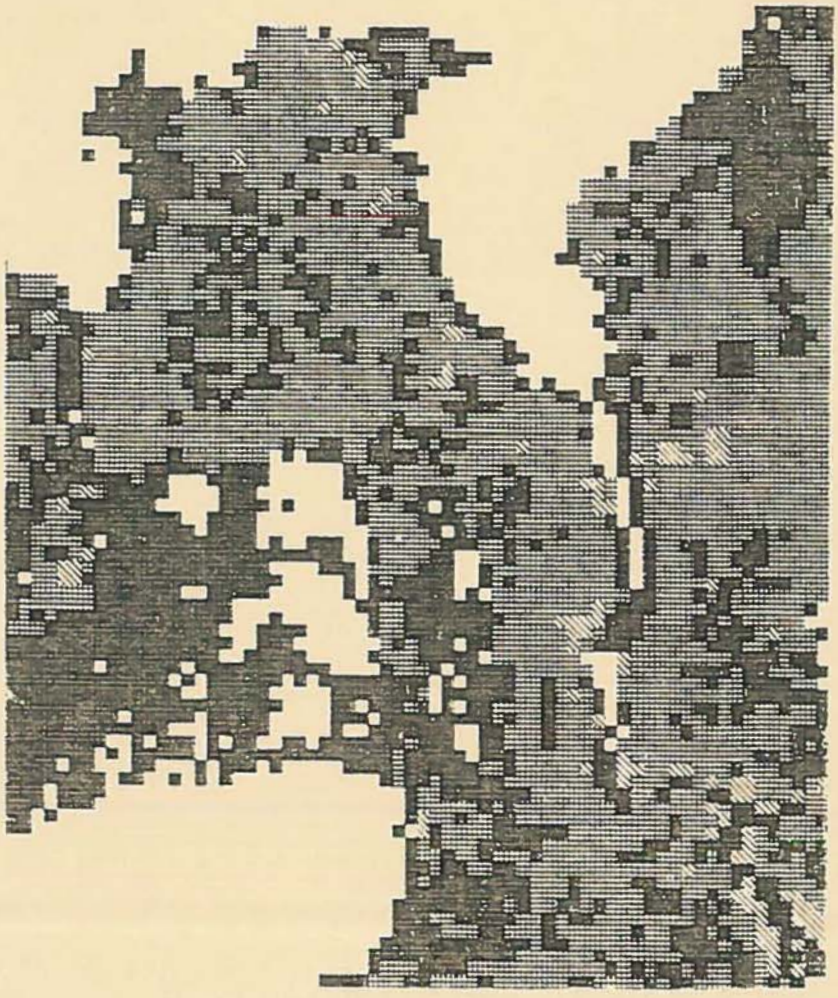

U.S. DEPT. OF THE INTERIOR
U.S. FISH & WILDLIFE SERVICE
REGION 7
ANCHORAGE, ALASKA

DECEMBER 1994

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ABSTRACT

A land-cover map of the coastal plain of the Arctic National Wildlife Refuge in northeastern Alaska was produced using LANDSAT Thematic Mapper satellite imagery, local topographical data, a map of terrain types, aerial photographs, and extensive field data from 1988-93. Methods and data used to produce the map, summary statistics, and an accuracy assessment are presented. Also presented are detailed quantitative descriptions of the land-cover classes and a cross-reference of this classification system to seven others used in northern Alaska. Sixteen land-cover classes were mapped. They included: (1) Wet Graminoid Tundra, (2) Wet Graminoid Tundra with 10-50% moist inclusions, (3) Moist Sedge-Willow Tundra with 10-50% wet inclusions, (4) Moist Sedge-Willow Tundra, (5) Moist Sedge-Dryas Tundra, (6) Moist Sedge-Tussock Tundra, (7) Moist Shrub-Tussock Tundra, (8) Moist Low-Shrub Tundra, (9) Moist Shrub Tundra on high-centered polygons, (10) Dryas-Graminoid Alpine Tundra, (11) Riparian Shrub, (12) Dryas River Terrace, (13) Partially Vegetated, (14) Barren, (15) Ice, and (16) Water. An accuracy assessment with an independent data set showed that point-by-point agreement between the mapped land-cover classes and the field-assigned classes was 50% for 16 classes. Agreement was increased to about 70% by combining similar classes into fewer, more general classes. The greater initial detail of the 16-class map allows adaptability to a wider range of studies. The User's Guide was written for resource managers and researchers working in the Arctic National Wildlife Refuge. The guide should also be useful to others working with vegetation classification and mapping in arctic tundra ecosystems.

Citation example:

Jorgenson, J. C., P. E. Joria, T. R. McCabe, B. E. Reitz, M. K. Raynolds, M. Emers, and M. A. Willms. 1994. User's guide for the land-cover map of the coastal plain of the Arctic National Wildlife Refuge. U. S. Fish Wildl. Serv., Anchorage, AK. 46p.

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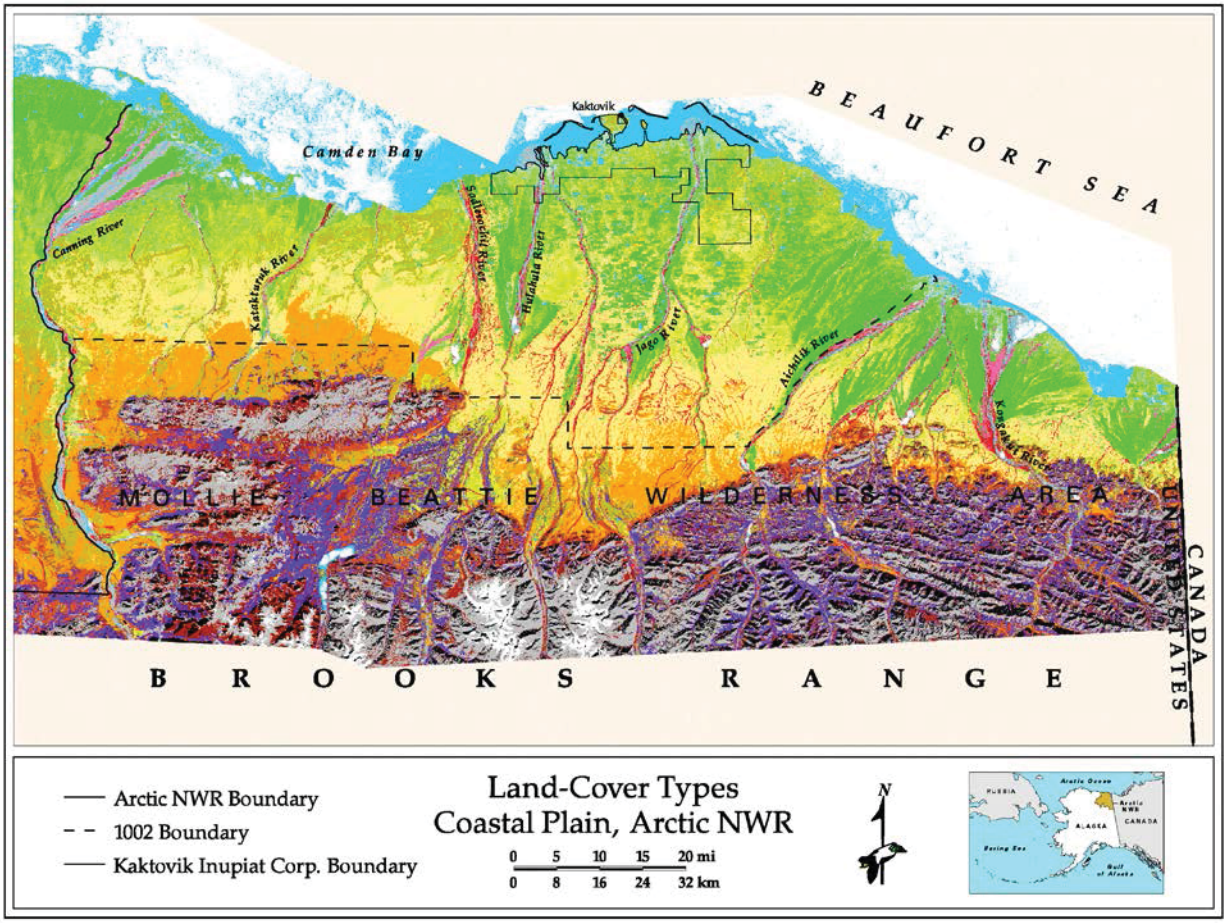

HERBACEOUS CLASSES

- WG – We Graminoid Tundra. Poorly drained tundra with sedges or grasses, with few shrubs or mosses.
- WGM – Wet Graminoid Tundra. With 10%-50% moist inclusions, often on low-centered polygons or strangmoor.
- MSW – Moist Sedge-Willow Tundra. With 10%-50% moist inclusions, often on low-centered polygons or strangmoor.
- MS – Moist Sedge-Willow Tundra. Moist tundra with sedges, mosses and willows.
- MSD – Moist Sedge-Dryas Tundra. Moist tundra with sedges, mosses, and Dryas. Sedge hummocks and frost scars give hummocky appearance.
- TT – Moist Sedge-Tussock Tundra. Moist tundra dominated by cottongrass tussocks with understory of dwarf shrubs and mosses.

SHRUB CLASSES

- STT – Moist Shrub-Tussock Tundra and Water-track Shrub Tundra. Tussock tundra dominated by erect willow and birch, or shrubby drainage complexes in foothills.
- ST – Moist Low Shrub Tundra. Upland slopes with erect willow and birch.
- SP – Moist Shrub Tundra on high-centered polygons. Shrubby polygonized tundra with herbaceous types in polygon troughs.
- AT – Dryas-Graminoid Alpine Tundra. Moist to dry alpine tundra with dwarf shrubs, graminoids, forbs, lichens, and bare ground.
- RS – Riparian Shrub. Well-drained river terraces with low or tall willows.
- DT – Dryas River Terrace. Well-drained river terraces with Dryas mat, other dwarf shrubs, forbs and lichens.

OTHER CLASSES

- PV – Partially Vegetated. 10%-15% vegetated.
- BA – Barren. <10% vegetated.
- IC – Ice. Ice and snow.
- WA – Water.
- SH – Shadow.

INTRODUCTION

PURPOSES

In response to provisions of the Alaska National Interest Lands Conservation Act (ANILCA) of 1980, extensive biological research has been conducted on the coastal plain of the Arctic National Wildlife Refuge (Arctic NWR). Section 1002 of ANILCA mandated that baseline research be conducted before the U.S. Congress could pass legislation to allow petroleum development in a portion of the coastal plain. The area of potential petroleum development is referred to as the 1002 Area and includes calving grounds of the migratory Porcupine Caribou (*Rangifer taradus granti*) Herd, year-round habitat of resident muskoxen (*Ovibos muschatus*), the fall-staging areas for Banks Island snow geese (*Chen caerulescens caerulescens*), and nesting or feeding habitat for many migratory shorebirds, songbirds, and waterfowl. A large-scale research program was initiated in 1982 to provide baseline data on wildlife, fish, hydrology, and wildlife habitat of the 1002 area. A map documenting the extent and distribution of land-cover types on the Arctic NWR coastal plain was needed to estimate the effects of potential oil exploration and development and to facilitate wildlife studies.

Satellite imagery was chosen as a cost-effective method for mapping a large remote area. A digital land-cover map was produced, based on LANDSAT Thematic Mapper (LANDSAT-TM) satellite imagery and information from aerial photographs, topographical data, and field vegetation data. LANDSAT-TM satellites gather digital data on the intensity of solar energy reflected from the earth's surface in six bands of the electromagnetic spectrum (visible through infrared). The reflectance is influenced by many factors, including vegetation cover and composition. A seventh band detects energy emitted from the earth (thermal).

In this map user's guide, we describe the methods and data used to produce the map, show the summary statistics and an accuracy assessment of the map, and describe the land-cover classes and the vegetation classification system.

STUDY AREA

The study area encompasses 18,510 km^2 of the coastal plain and adjacent mountains of the Arctic NWR in northeastern Alaska. The area is bounded by the Canning River to the west, the Alaska-Canada border to the east, the Beaufort Sea to the north, and the Brooks Range to the south (Fig. 1). The study area lies in the low arctic as defined by Polunin (1951). The climate of the coastal plain is arctic with low precipitation, very low winter temperatures, and short, cool summers (Searby and Hunter 1971). During the growing season, the immediate coastal areas have lower temperatures and more frequent cloudiness and fog, in contrast to the interior coastal plain (Haugen 1982). Permafrost underlies most of the study area. The active layer is approximately 15 to 100 cm thick and thaws each year between early June and late August. Snow begins accumulating by mid-September and remains until early June. Because of high winds, snow depth is extremely variable. It generally is shallower on ridges and hill crests and deeper in drainages.

Vegetation of the coastal plain tundra is a highly interspersed mosaic of low-growing shrubs, grasses, sedges, mosses, and lichens. Shrubs are taller along drainages and in the upper foothills and mountains. Soil moisture, nutrient availability, and snow depth and duration are important determinants of the different tundra plant communities (Webber *et al.* 1980). More detailed descriptions of the coastal plain environment are given in Walker *et al.* (1982) and Garner and Reynolds (1986).

PREVIOUS INFORMATION

Two land-cover maps of the Arctic NWR were produced from LANDSAT Multispectral Scanner (MSS) data during the 1980s. The first map encompassed the 1002 Area only (approximately 66% of the Arctic NWR coastal plain; Fig. 2) and was produced by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL; Walker *et al.* 1982). The second map covered the entire Arctic NWR and was produced by the U.S. Geological Service, EROS Alaska Field Office in Anchorage (Markon 1986).

These maps depicted the general distribution of land-cover types across the coastal plain but subsequent assessments (Felix *et al.* 1987, Felix and Binney 1989) indicated that their site-specific accuracy was inadequate for studies of wildlife habitat. Because of limited available field time, little detailed quantitative vegetation information was provided. Documentation for the two maps did not always specify quantitative distinctions between the land-cover classes, such as percent cover of shrubs, tussocks, or total vegetation. Uncertainty about the distinctions between similar classes caused problems for map users (Felix and Binney 1989 , Raynolds 1990).

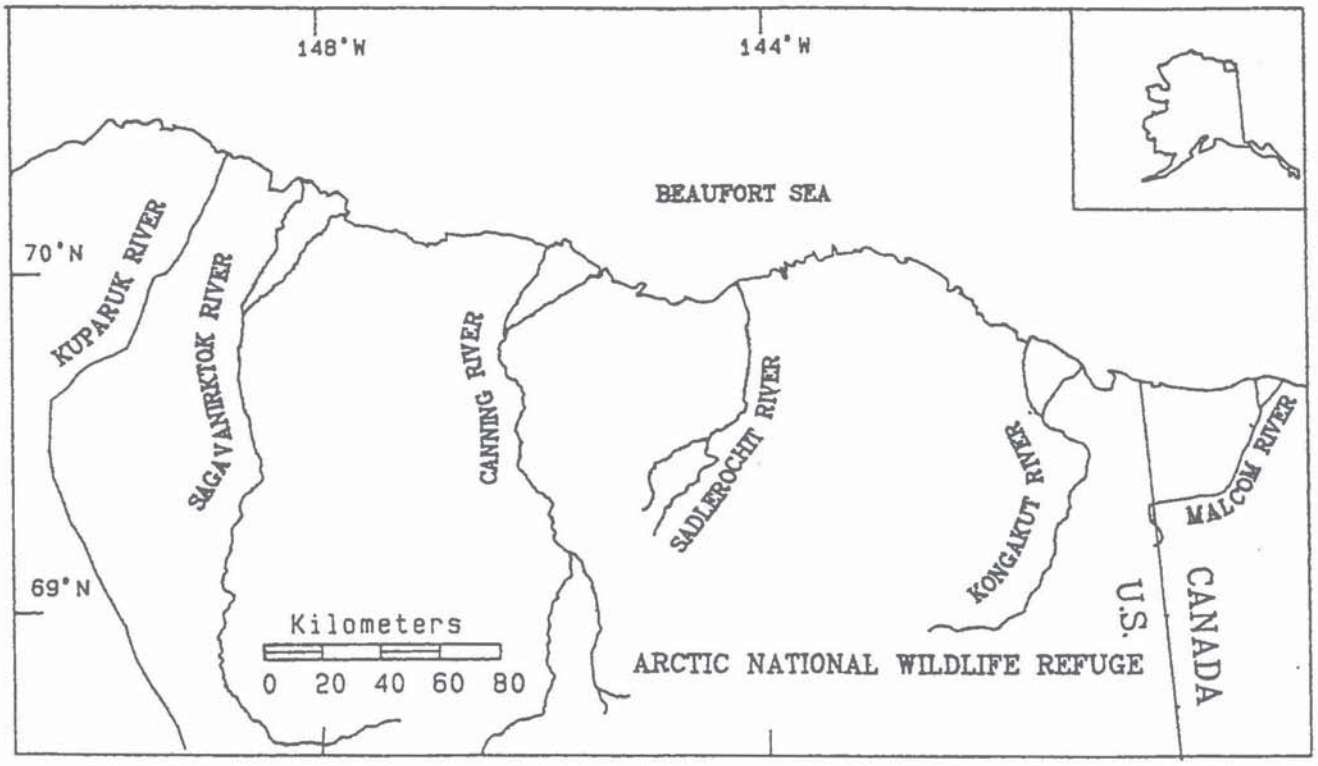

Figure 1. Location of study area, Arctic Coastal Plain, 1994.

LANDSAT-TM data for the coastal plain became available after the LANDSAT-MSS maps were completed. LANDSAT-TM provided finer spatial (30 m vs. 79 m), radiometric (256 vs. 64 levels), and spectral resolution than MSS data and additional bands in the blue and mid-infrared wavelength regions (Lillesand and Kiefer 1987). As part of the continued research in the 1002 area, a LANDSAT-TM mapping effort for the Arctic NWR coastal plain was initiated in 1988. Preliminary evaluation indicated that LANDSAT-TM data could be used to create an improved map compared to the previous LANDSAT-MSS-derived products (Jacques 1989).

LANDSAT-TM MAP PRODUCTION

METHODS

Data Acquisition

Digital Data

Spatial data used to produce the map included two LANDSAT-TM images, Digital Elevation Models (DEMs), manually delineated terrain types and riparian zones, and portions of the 1985 LANDSAT-MSS map (to fill in areas that were obscured by clouds on the LANDSAT-TM data). Each of these data themes comprised a layer in a Geographic Information System for the production of the map.

Two LANDSAT-TM images in computer-compatible tape (CCT) digital format were purchased from the Earth Observation Satellite Company (EOSAT). One image from 7 July 1985 (I.D.# Y5049320412X0) extended from the Sadlerochit River to the Malcolm River, in Canada (Fig. 1). The image was nearly cloud-free. The second image, from the Sadlerochit River west to the Kuparuk River in the Prudhoe Bay area, was from 15 July 1986 (I.D.# Y5086620524X0). Portions of each were used in the final map (Fig. 2). Approximately 52% of the 1986 image in the Arctic NWR was covered by cloud and cloud-cast shadow (Fig. 3). Most of the cloud-affected area was in the mountains. Attempts to purchase a more cloud-free image of the area during the peak growing season (early July to mid-August) were unsuccessful. The two images were geo-referenced by the U.S. Geological Survey (USGS) EROS Data Center in Sioux Falls, South Dakota, to UTM Zones 6 and 7 using a second-order transformation (RMS <one pixel) and nearest-neighbor resampling.

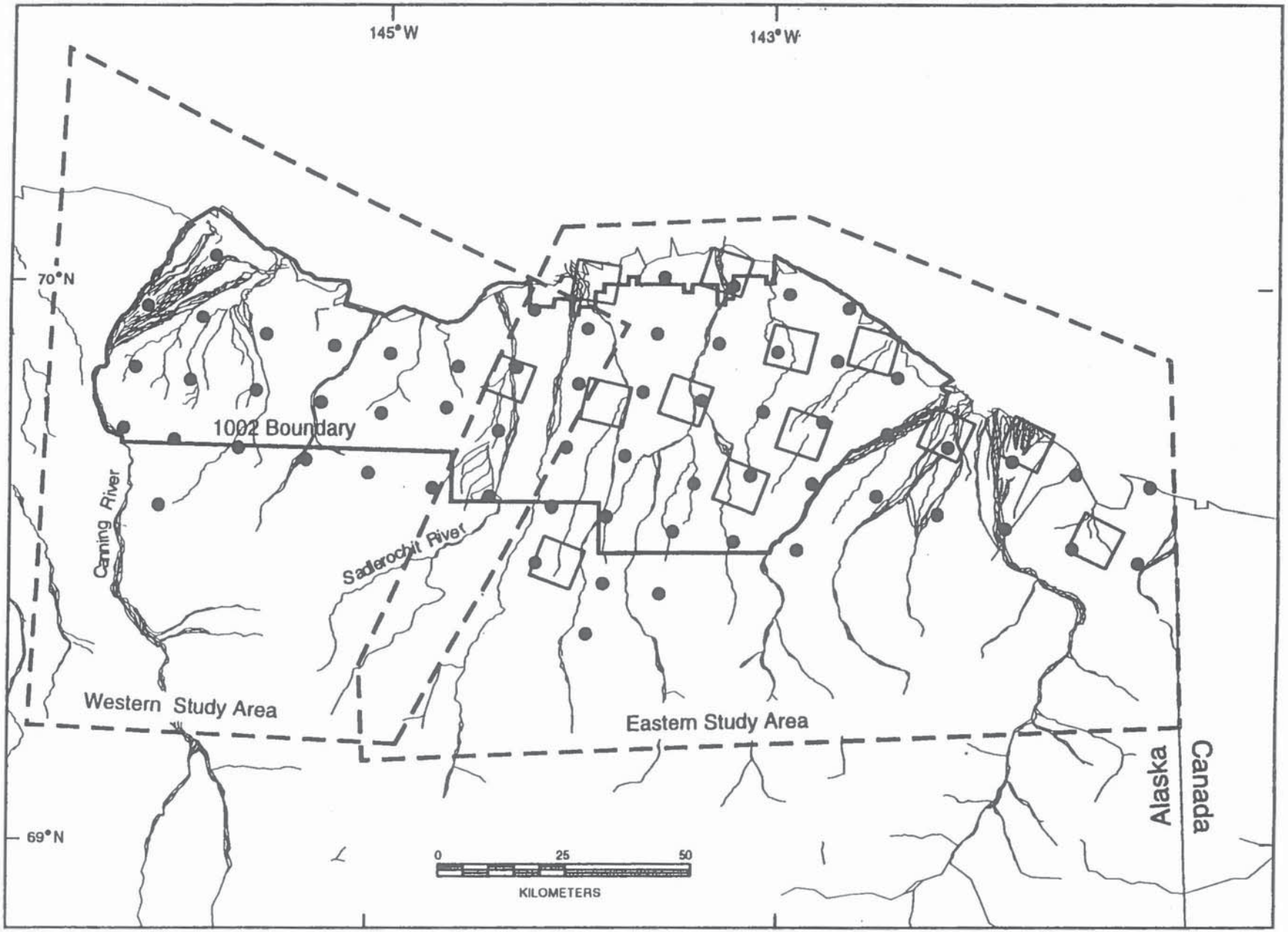

Figure 2. Study area showing the areas mapped using the eastern and western LANDSAT-TM scenes, the 13 scene subsets (squares) used to build unsupervised signatures, and the sample points used in the accuracy assessment (circles), Arctic NWR, Alaska, 1994.

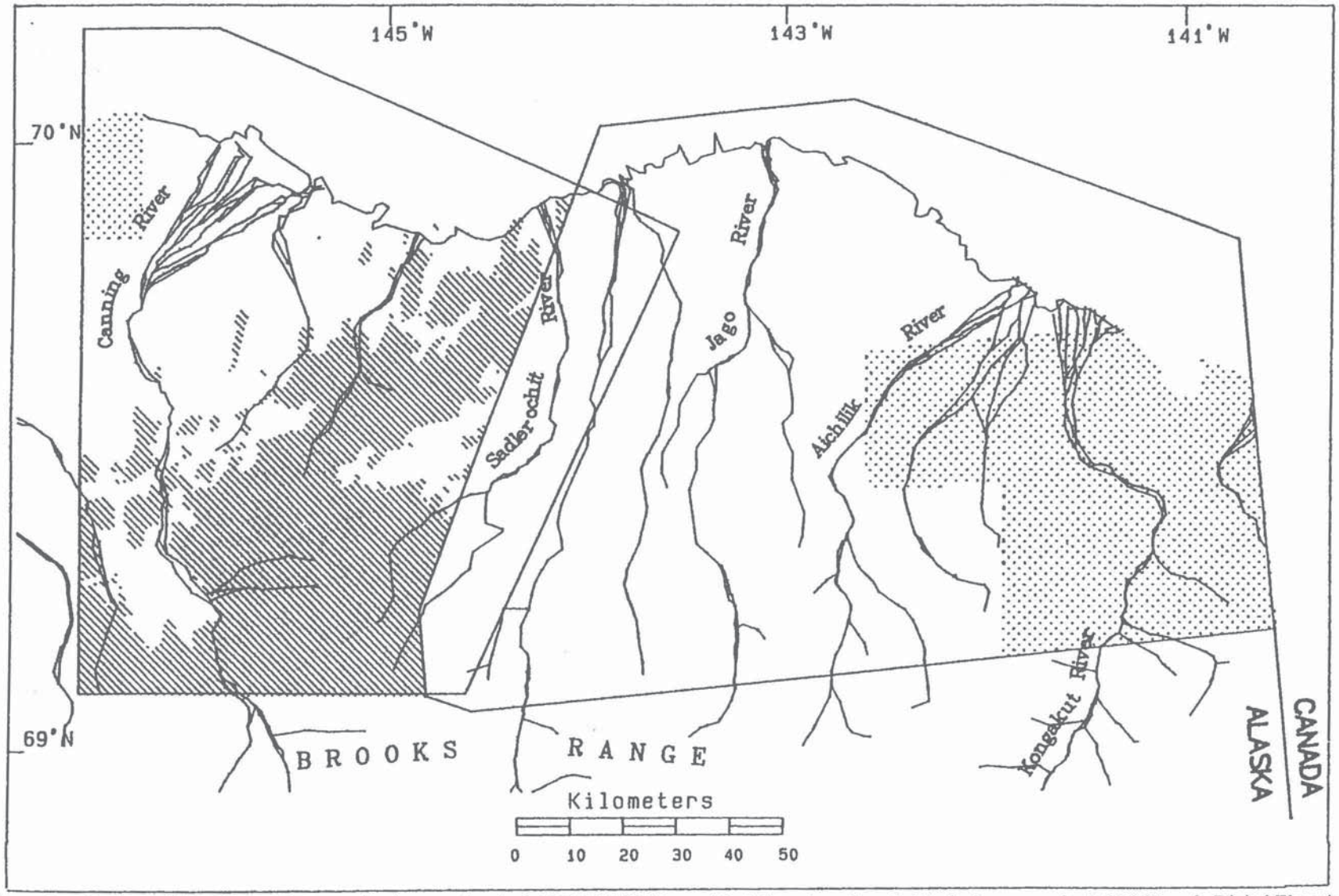

Figure 3. Portions of the study area that were cloud-covered on the LANDSAT-TM image (shaded), and portions that lacked coverage by 1:63,360-scale Digital Elevation Models (DEMs), for which 1:250,000 DEMs were used (stippled), Arctic NWR, Alaska, 1994.

Elevation data were obtained from the USGS National Cartographic Information Center. Fifteen-minute DEMs that corresponded to 1:63,360-scale topographic maps were available for approximately 82% of the study area. Where the 15-minute resolution DEMs were not available, 60-minute DEMs that corresponded to 1:250,000-scale maps were used (Fig. 3). Slope and solar-illumination data layers were derived from the elevation data.

A map of physiographic terrain types was digitized (Fig. 4). Five major terrain types of the 1002 area (flat thaw-lake plains, hilly coastal plains, foothills, mountains, and river floodplains), each characterized by a combination of dominant landform, soils, and vegetation, had been mapped and described in detail by Walker *et al.* (1982). USGS maps and the LANDSAT-TM image were interpreted to extend the terrain type map to the whole study area.

A map of riparian zones was digitized from active floodplains, islands, and low river terraces that were identified on 1:18,000-scale, true-color, aerial photographs. This data layer was used to distinguish riparian vegetation types, which were spectrally confused with upland types. These riparian types were specifically associated with the coarse mineral soils, high nutrient flux, and deep summer thaw of the riparian areas, while the other types usually did not occur there.

Field Vegetation Data

Two sets of field data were acquired. The set described in this section was used as training data for the development of the map. A second independent set of field data was used to assess the accuracy of the map, and is described in the Accuracy Assessment section. Most of the field vegetation data that were used to develop the map were collected in the summers of 1989 and 1990, before the preliminary classifications of the LANDSAT-TM data. Therefore, field study sites were chosen based on distributions of vegetation types on the ground, not on distributions of spectral classes in the LANDSAT-TM images. General areas of representative vegetation were identified from 1:60,000-scale (approximately 1 inch = 1 mile) color infra-red (CIR) photographs. Field study sites were chosen in areas where 1:6000-scale CIR photographs were available (approximately 10 inches = 1 mile). Fifty-one study sites (approximately 2.5 km square) were chosen subjectively from the aerial photographs by botanists familiar with the area, to represent the variety of land-cover types on the coastal plain.

For each study site, areas of apparently homogeneous vegetation were delineated on the photographs, based on photo-interpretation. Areas of mosaics of small patches of several different types of vegetation also were delineated. At 8-12 areas at each site, a 60-m X 60-m study plot (the size of four LANDSAT-TM pixels) was established at a central and representative location. If the vegetation was not homogeneous inside the original photo-interpreted plot boundaries, they were redrawn in the field. Percent cover of plant species was determined at each study plot by point-sampling with 20 placements of a 10-pin vertical point frame (Hays *et al.* 1981). Sampling was done at even intervals along four systematically located 60-m transects. The percentage of ice-wedge polygon rims and troughs, frost scars, and inclusions of other vegetation types in each plot were measured along the same four transects. Landform type and average heights of major shrub species (measured at point-frame locations) also were recorded. At 8-12 additional study plots at each site, only descriptive information was collected, including vegetation type, landform, and dominant species. Inclusions of different vegetation types were measured on a 100-m transect or estimated.

All study plots were classified according to the vegetation scheme in Table 1, which was based on Walker's hierarchical classification of northern Alaska tundra vegetation (1983). Code names for land-cover types used in the text and tables are listed in Table 1. The land-cover classes are arranged along gradients of soil moisture, percent of shrubs in the vegetation canopy, and total percent plant cover. These are the features of coastal plain vegetation that most influence the spectral reflectance patterns of Landsat MSS data (Walker 1983). These features also are greatly affected by topography. Therefore, this vegetation scheme was deemed suitable to map land cover using LANDSAT-TM spectral data combined with topographic data.

Data from two previous studies also were included in the field data set. Sixty-five plots from a 1987 accuracy assessment of the two LANDSAT-MSS maps and 27 plots from caribou habitat studies were used. Additional field data were gathered in the summers of 1991 to 1993 at 28 study sites that had vegetation or spectral classes that were particularly difficult to define, based on preliminary results. An additional 12 sites were located in the mountains and upper foot-

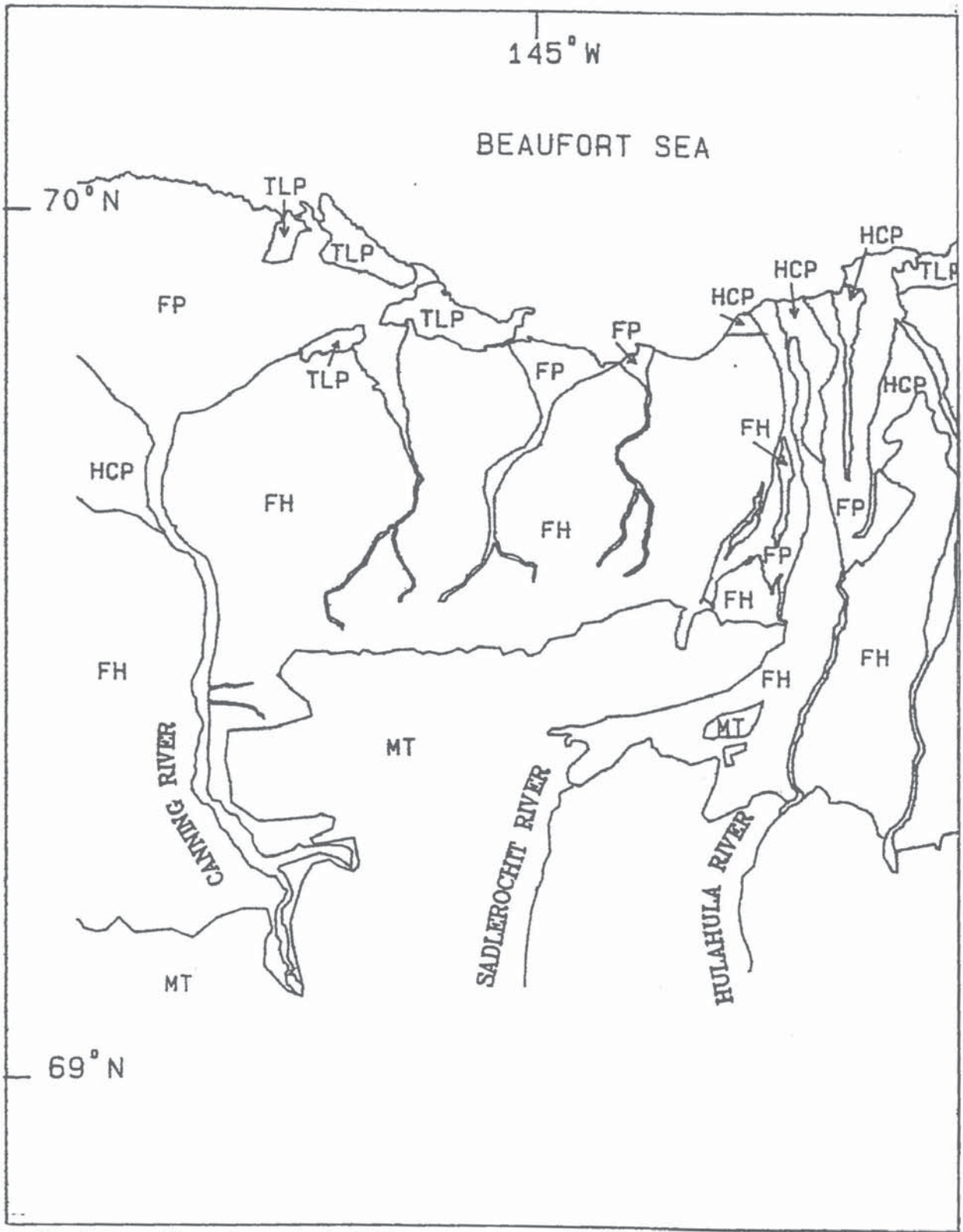

Figure 4. Terrain types of the study area, Arctic NWR, Alaska, 1994. TLP=Thaw-lake plains; FP=Floodplains; HCP=Hilly coastal plains; FH=Foothills; MT=Mountains

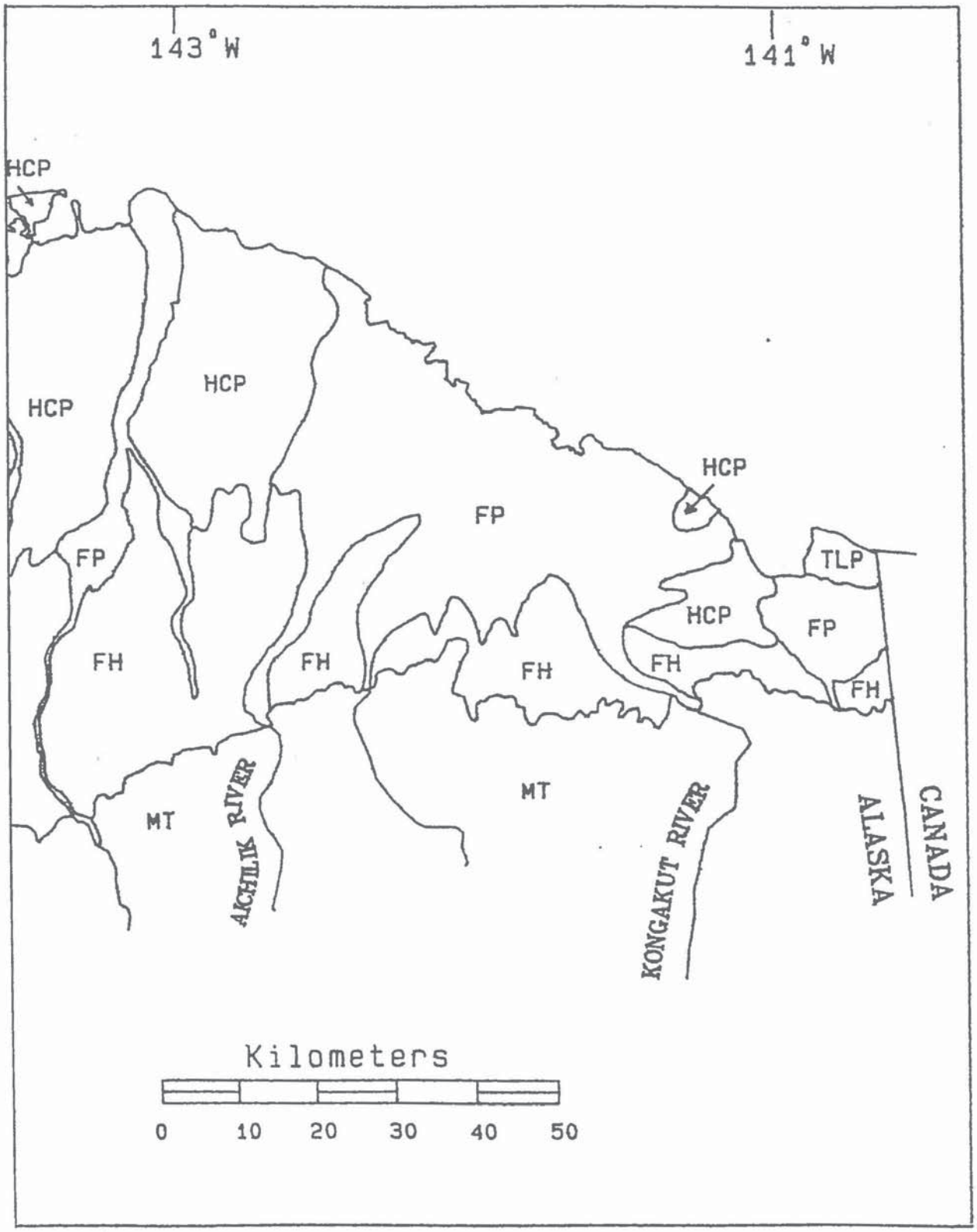
143°W
141°W
HCP
HCP
HCP
HCP
HCP
FP
FP
TLP
HCP
FP
FH
FH
FH
FH
FH
MT
MT
ACHILIK RIVER
KONGAKUT RIVER
ALASKA
CANADA
Kilometers
0
10
20
30
40
50

Table 1. Land-cover classes for the map of the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1994.

HERBACEOUS CLASSES

WG - Wet Graminoid Tundra
- poorly drained tundra with sedges and grasses, but few shrubs or mosses.

WGM - Wet Graminoid Tundra with 10-50% moist inclusions
- often on low-centered polygons or strangmoor.

MSW - Moist Sedge-Willow Tundra with 10-50% wet inclusions
- often on low-centered polygons or strangmoor.

MS - Moist Sedge-Willow Tundra
- moist tundra with sedges, mosses, and willows.

MSD - Moist Sedge-Dryas Tundra
- moist tundra with sedges, mosses, and *Dryas*. Sedge hummocks and frost scars give a hummocky appearance.

TT - Moist Sedge-Tussock Tundra
- moist tundra dominated by cottongrass tussocks, with understory of dwarf shrubs and mosses.

SHRUB CLASSES

STT - Moist Shrub-Tussock Tundra and Water-track Shrub Tundra
- tussock tundra dominated by erect willow and birch, or shrubby drainage complexes in foothills.

ST - Moist Low Shrub Tundra
- upland slopes with erect willow and birch.

SP - Moist Shrub Tundra on high-centered polygons
- shrubby polygonized tundra with herbaceous types in polygon troughs.

AT - Dryas-Graminoid Alpine Tundra
- moist to dry alpine tundra with dwarf shrubs, graminoids, forbs, lichens, and bare ground.

RS - Riparian Shrub
- well-drained river terraces with low or tall willows.

DT - Dryas River Terrace
- well-drained river terraces with a *Dryas* mat, other dwarf shrubs, forbs, and lichens.

OTHER CLASSES

PV - Partially Vegetated
- 10-50% vegetated.

BA - Barren
- <10% vegetated.

IC - Ice

WA - Water

SH - Shadow

hills, which had not been adequately sampled before. Between 3 and 15 study plots were done at each site, depending on the problems addressed.

The field plots then were located on the LANDSAT-TM image. Clear acetate was placed on the aerial photographs, and the extent of homogeneous vegetation around each study plot was delineated based on photo-interpretation and field notes. LANDSAT-TM data of the area covered by each aerial photograph were displayed on a computer screen at approximately the same scale as the photographs. Using geographic features such as lakes and drainages, the acetate overlay was aligned over the computer screen, and the outlines of the homogeneous areas (polygons) were digitized at the screen. This process created a GIS file of vegetation types that had been verified on the ground for all pixels in the polygons. This training data layer was then cross-referenced with the spectral data and all other data layers to develop rules to assign LANDSAT-TM spectral classes to land-cover types. The data layer had 84,584 pixels for the eastern LANDSAT-TM image and 69,420 pixels for the western image.

Data Classification

Eastern LANDSAT-TM image

Three methods for producing a map from LANDSAT-TM data were tested on the eastern LANDSAT-TM image: a supervised classification, with spectral signatures for the land-cover types derived from the digitized field data polygons; an unsupervised approach, with spectral signatures determined by a statistical clustering algorithm without reference to field data; and a model that combined the unsupervised classification with ancillary data such as elevation and terrain type. Accuracy assessments indicated that the model was the best approach. This method is described below. The three methods and their assessments are described in detail by Joria and Jorgenson (in press).

A modified clustering approach (Fleming 1975) was used to develop unsupervised, statistical signatures based on all pixels in 16 subsets of the LANDSAT-TM image. The subsets, each of which contained 256 rows and 256 columns, were chosen to represent the land-cover variation in the image based on botanical knowledge of the study area. Thirteen of the subsets were in the study area (Fig. 2), and three were from a portion of the image that extended onto the coastal plain of Canada. A total of 440 spectral signatures were derived from the subsets. Each signature was composed of a mean vector and variance-covariance matrix for the six visible and infrared LANDSAT-TM bands. The thermal band was not used. Signatures were considered redundant and were deleted when their mean values (+ 1 s.d.) overlapped in each of the six LANDSAT-TM bands with a previously considered signature. This procedure reduced the total to 131 signatures, which were used in an unsupervised, maximum-likelihood classification of the entire LANDSAT-TM image.

Spectral classes that were visually identified in the image as belonging to the same cover type (*e.g.*, ice or water) were combined, reducing the number of classes in the classified image from 131 to 110. The distribution of each spectral class across the satellite image was viewed in conjunction with color-infrared aerial photographs, especially where the class was most common. Cross-tabulated frequency distributions were produced from a comparison of the training and classification pixels to determine the most common cover type associated with each of the 110 spectral classes and the most common spectral class for each cover type. Because most spectral classes represented more than one vegetation type, the ancillary, non-spectral data layers were used to refine the sorting of spectral classes into vegetation types (Hutchinson 1982). Each spectral class was cross-tabulated with the training, terrain type, elevation, sun-shading, and slope layers. These tables were used to guide the development of decision rules for splitting each spectral class into separate land-cover types. For example, pixels of the same spectral class could be Shrub-Tussock Tundra in high-elevation sloping foothills, and Riparian Shrub on a flat area in a riparian zone.

Proximity analysis also was used in the formulation of decision rules. Some spectral classes were associated consistently with a single land-cover type and were defined as representative of that type. Individual pixels of other spectral classes that were associated less consistently with a land-cover type were labeled as that type if they were adjacent to one of the representative pixels. The effect was a selective smoothing of the classification; representative pixels acted as "magnets" to attract similar, neighboring pixels. For example, pixels of one spectral class were labeled Moist Sedge-Willow Tundra if they were adjacent to a pixel of a spectral class that was consistently Moist Sedge-Willow Tundra but were labeled Tussock Tundra if elsewhere. Many of the 110 spectral classes were modeled separately to test different decision rules

to improve the sorting for the class. Output of the individual class models were evaluated by cross-referencing with the training areas. When individual classes had been tested and evaluated, all decision rules were combined in a single model to produce an interim map. The interim map then was evaluated visually by botanists who were familiar with the study area to determine whether decisions based on the training data seemed suitable for the whole image. Changes to the decision rules were made as necessary. The process was repeated through several iterations before the final modeled map was produced.

Western LANDSAT-TM image

Spectral classes for the western LANDSAT-TM image were developed in three stages. First, the entire western image was systematically sampled by an unsupervised clustering program to produce 40 spectral classes. Classes representing clouds, shadow, haze, ice, or water were combined into six classes. The remainder of the image was re-clustered into 40 new classes, classified, and combined with the six classes (above) into a single file of 46 classes. One large class was subsequently split into two, resulting in 47 final spectral classes.

Ancillary data layers, comparable to those used in modeling the eastern LANDSAT-TM image, were developed and a similar modeling process was performed on the 47 spectral classes. Pixels that represented cloud or cloud-shadow were not used in the map. Instead, pixels from a digital file of the 1985 LANDSAT-MSS map were substituted after they had been modified by slope and elevation decision rules that were based on a 1993 aerial reconnaissance.

Production of the Final Map

In early 1993, preliminary maps of the two separate LANDSAT-TM images were completed. The maps were evaluated during the summer field season. Enlargements of the maps were made for 17 areas that represented a variety of vegetation and terrain types. These areas were visited by helicopter, and botanists noted which map classes seemed correct and which needed further refinement. Final changes were made to the models based on the 1993 field investigations, and the two separate maps were joined. The eastern map was used for the area where the two images overlapped because that area was mainly cloud-covered on the western image.

RESULTS: MAP PRODUCTS

The attached land-cover map of the coastal plain and adjacent mountains of the Arctic NWR shows the 16 most detailed land-cover classes at a scale of 1:500,000.

The map is available through the U.S. Fish and Wildlife Service as an ERDAS 7.5 digital file, geo-referenced to UTM (Universal Transmercator) Zone 6 at 30-m resolution. The two LANDSAT-TM image maps also are available separately; the western image is geo-referenced to UTM Zone 6 and the eastern to Zone 7. The other data layers with DEM topographical data, digitized field data polygons, accuracy assessment pixel locations, terrain types, and riparian zones also are available. The raw LANDSAT-TM data are the property of EOSAT and cannot be redistributed to other users.

Because the final map and all data layers are in digital format, they can easily be used for any GIS application with geo-referenced data. Users can display, manipulate, derive summary statistics, update, analyze, and plot the data layers as needed for studies of wildlife or habitats to provide information toward better informed resource management decisions. Additional data layers can be added to the GIS as more resource information becomes available and as new management needs are identified.

Users can print portions of the map at larger scales for use in the field or for specific studies. Acetate overlays that correspond with areas of USGS topographic maps also can be produced.

ACCURACY ASSESSMENT OF THE MAP

METHODS

The land-cover map was developed with the training, field data set and then assessed with an independent field data set. The independent data set was collected systematically in 1989 and 1990. The mountainous areas in the Brooks Range were not sampled. Systematic sampling involved randomly positioning a grid with a 12.2-km square cell size over the Arctic NWR coastal plain to locate 63 study sites that were centered at grid intersections (Fig. 2). At each site, intersections on a second randomly positioned grid with 400-m square cell size were used to center 12 sample points with 15-m diameters. There were 756 sample

points. Vegetation type, estimated percent cover of all species with over 5% cover, landform, moisture regime, and the geographic extent of the vegetation type were recorded at each point.

A sample point was used in the map assessments if it could be located at a specific row and column in the LANDSAT-TM image, based on physical features visible on the classified image or the raw LANDSAT-TM data, and if field notes indicated the land-cover type was extensive enough (≥ 50 m radius) to compensate for slight locational errors. A point also was used if field notes and patterns on the aerial photos indicated the land-cover type was extensive enough to compensate for larger location errors. Sample points that were cloud-covered on the western image were not used, because they could not be located on the LANDSAT-TM data. Based on these criteria, 318 sample points were used for the independent accuracy assessment.

Only the central pixel from each sample point was used in the accuracy assessment. The percent agreement between the mapped land-cover classes of the 318 pixels and the vegetation types assigned in the field was calculated and used as an estimate of the accuracy of the map.

Besides being used in the accuracy assessment, the independent data set also provided statistical estimates of the area covered by different land-cover classes. All 756 systematic sample points were used to estimate the proportions of the different classes on the coastal plain and in major terrain types. These independent estimates then were compared with the proportions of classes on the map.

RESULTS AND DISCUSSION

The agreement between the final map and 318 independent field samples was 50% for 16 land-cover classes. Agreements for the eastern and western LANDSAT-TM images were the same. This level of agreement is for the coastal plain only, because sampling was not conducted in the mountains. Including the mountains would probably have increased the levels of agreement because of fewer land-cover types and the prevalence there of the barren land-cover type.

Percent agreement by land-cover type are shown in Table 2. The number of pixels that are classified on the map as the same land-cover type as the field type appear in bold type on the major diagonal in the table. Land-cover types are ordered in the table such that adjacent cover types are closely related, primarily along a moisture gradient. The vertical and horizontal spread along the major diagonal, therefore, indicates the degree and direction of error in the misclassifications. Points of the tussock tundra classes (TT and STT) had relatively high levels of agreement, whereas those of the non-tussock moist sedge types (MSW, MS, MSD) had low agreement. Most errors were between closely related land-cover types that typically are adjacent in the field and intergrade into each other. Therefore, many errors are border-line errors and occur because of the lack of distinct transitions from one land-cover type to the next. Approximately 86% of the assessment pixels were classified as the correct type or one of the closely related types shown in parentheses in Appendix 1. Appendix 1 lists the percentages of the land-cover types that make up each of the mapped land-cover classes, based on the accuracy assessment pixels.

The agreement level of 50% suggests that 16 land-cover classes may be too many to distinguish accurately in this area using currently available satellite and ancillary data. The map includes six land-cover classes dominated by graminoids and six dominated by low shrubs. Almost all of the vegetation in the mapped area is less than 0.5 m tall and the structural and floristic differences are not great, especially when compared to other regions that include forest types. Although land-cover types in the classification scheme were distinct, land-cover types in the field were in a continuum. Subtle transition zones between land-cover types are characteristic of the vegetation of low arctic tundra (Bliss 1988), and the common occurrence of complex mosaics of two to four different cover types in an area smaller than a LANDSAT-TM pixel often made it difficult to assign land-cover types in the field.

Joria and Jorgenson (in press) showed that the spectral separability of the land-cover classes was poor, and that the model using ancillary data only slightly improved the accuracy levels.

The accuracy assessment is based on agreement between mapped land-cover type and field-determined type checked at systematically located single pixels, the most rigorous method available. Other methods commonly used include checking agreement at large blocks of pixels of the same mapped type, comparing percentages of mapped types on portions of a map to percentages determined in the field, or a reconnais-

Table 2. Contingency table to assess the accuracy of the land-cover map of the Arctic NWR coastal plain, Alaska, with 16 land-cover classes. Table compares mapped land-cover classes to field-assigned classes for an independent systematically-sampled data set of 318 points. Land-cover class codes are defined in Table 1.

		INDEPENDENT DATA SET																
		WG	WGM	MSW	MS	MSD	TT	STT	SP	ST	AT	RS	DT	PV	BA	WA	Total	Percent Agreement:
	WG	2	1	1									1				5	40%
	WGM	7	19	4	4	6			1			1	2				44	43%
	MSW	4	9	12	8				2								35	34%
	MS			4	15	4	5										28	54%
COASTAL	MSD		5	4	11	18	14	1			2		1				56	32%
PLAIN	TT		1	6	2	8	51	3	6								77	66%
MAP	STT		1		1	1	5	13		2	2						25	52%
	SP		1				1		6								8	75%
	ST				1			1		2							4	50%
	AT									1	1						2	50%
	RS											2	3			1	6	33%
	DT											1	6				7	86%
	PV		2								1		1	1	1		6	17%
	BA		1												8		9	89%
	WA											1			1	4	6	67%
	Total:	13	40	31	42	37	76	18	15	5	6	5	14	1	10	5	318	
Percent Agreement:		15%	47%	39%	36%	49%	67%	72%	40%	40%	17%	40%	43%	100%	80%	80%		

Overall agreement (diagonal/total): 50%

Table 3. Contingency table to assess the accuracy of the land-cover map of the Arctic NWR coastal plain, Alaska, with 13 land-cover classes. These classes are derived from the 16 classes on the map legend by combining the two types of wet graminoid tundra (WG, WGM) into one WG class and the three types of non-tussock sedge tundra (MS, MSD, MSW) into one MS class. Table compares mapped land-cover classes to field-assigned classes for an independent systematically sampled data set of 318 points. Land-cover class codes are defined in Table 1.

INDEPENDENT DATA SET

		WG	MS	TT	STT	SP	ST	AT	RS	DT	PV	BA	WA	Total	Percent Agreement:
	WG	**29**	15			1			1	3				49	59%
	MS	18	**76**	19	1	2		2		1				119	64%
	TT	1	16	**51**	3	6								77	66%
	STT	1	2	5	**13**		2	2						25	52%
COASTAL	SP	1		1		**6**								8	75%
PLAIN	ST		1		1		**2**							4	50%
MAP	AT						1	**1**						2	50%
	RS								**2**	3			1	6	33%
	DT								1	**6**				7	86%
	PV	2						1		1	**1**	1		6	17%
	BA	1										**8**		9	89%
	WA								1			1	**4**	6	67%
	Total:	53	110	76	18	15	5	6	5	14	1	10	5	318	
Percent Agreement:		55%	69%	67%	72%	40%	40%	17%	40%	43%	100%	80%	80%		

Overall agreement (diagonal/total): 63%

sance with no quantitative accuracy assessment. Results from the different methods are not directly comparable.

We calculated agreement statistics for the most recent LANDSAT-MSS map of the Arctic NWR (Markon 1986) using the same independent data that was used to test the LANDSAT-TM map. First, a generalized scheme that was compatible with both maps was created. It involved combining some classes on each map into more general categories, resulting in 10 classes in common. When the same methodology, land-cover type scheme, and ground plots were used to assess the two maps, the LANDSAT-TM map showed 62% agreement, and the LANDSAT-MSS map had 35% agreement.

The accuracy estimate of the map can be increased by combining closely related classes into more generalized classes. For example, the two types of wet graminoid (WG and WGM) may be combined, as well as the three types of non-tussock moist sedge (MSW, MS and MSD), resulting in a map with 63% agreement for the 13 classes (Table 3). Users of the map can choose between detail and map accuracy to best suit their projects. Wildlife biologists often use only six to eight habitat categories because of sample size limitations. For example, the LANDSAT-TM map has 74% agreement for six classes currently in use for a caribou habitat study and 68% for seven classes for muskox habitat studies. Although the agreement for the map with all 16 land-cover classes is low, all classes were retained and provided with this user's guide, because the greater initial detail allows the map to be more adaptable to a wider range of studies.

Table 4 provides another assessment of the map accuracy. It shows the percentages of each land-cover class on the entire map and in different terrain types. Each terrain type has a characteristic suite of land-cover classes. For comparison, the table also shows the percentages of land-cover classes as estimated by the 756 field-sampled points in the independent systematic sample. The distributions of coastal plain land-cover classes on the map and in the systematic sample seem very similar. Comparisons also are good for the separate foothills, hilly coastal plain, and floodplains terrain types, which had adequate numbers of systematic sample points for comparisons. One discrepancy is that the map has only about one half the Moist Sedge-Willow land-cover class indicated by the systematic sample. That class commonly occurs in narrow drainages and as inclusions, smaller than one pixel, in most other classes, which may explain its under-representation on the map.

MAPPED LAND-COVER CLASSES

METHODS

A unified vegetation classification scheme was developed for the coastal plain and adjacent mountains of the Arctic NWR. The classification was designed to be compatible with land-cover classes that can be mapped with satellite imagery and ancillary data. It was based on field data that quantitatively defined the land-cover classes and the distinctions between them.

The vegetation classification scheme was based on a hierarchical classification system for northern Alaska tundra by Walker (1983) and on TWINSPAN and DECORANA multivariate analysis of field data, following methods described in Gauch (1982). A hierarchical system provides information at different levels of detail, with lower level units grouped within higher level units, allowing users to choose the level of detail needed. During the development of the LANDSAT-TM map, the scheme was altered slightly to provide a group of land-cover classes that were more compatible with the information content of the LANDSAT-TM spectral data and ancillary data. Cross-tabulations of ground-truth vegetation types with LANDSAT-TM spectral classes, terrain type, slope, and elevation indicated which land-cover types could be distinguished reasonably well by spectral data, which had the possibility of being mapped with spectral plus ancillary data, and which could not be separated and therefore had to be combined into more general cover types. For example, percent slope was useful in separating several land-cover types that were represented by the same spectral classes. Definitions of boundaries between similar classes were altered, based on the level of vegetation differences that could be detected by satellite. For example, the distinction between barren and partially vegetated classes was changed from 5% to 10% vegetation cover because LANDSAT-TM seemed unable to detect less than 10% vegetation cover. For some land-cover classes, descriptions were expanded to include marginal types that could not be distinguished. For example, descriptions of broad shrubby drainages in the foothills (often a mosaic of dense shrubs, Moist Sedge-Willow Tundra and Tussock Tundra) were incorporated into the Shrub-Tussock Tundra type. Aquatic Graminoid Tundra (emergent grasses and sedges in permanently flooded areas) was combined with Wet Graminoid Tundra, which is flooded only seasonally.

The land-cover classes were given names that could be easily understood by the non-botanists for whom the map was intended. Therefore, some names include

Table 4. Percentages of land-cover classes on the land-cover map of the Arctic NWR coastal plain, 1994, and in different terrain types. For comparison, the numbers in parentheses are the percentages for the land-cover classes, as estimated by an independent systematic field sample of 756 on the coastal plain within the Arctic NWR.

Land-Cover Class	Entire Map[a]	Entire ANWR Coastal Plain[b]	ANWR Mountains	ANWR Foothills	ANWR Hilly Coastal Plain	ANWR Thaw-Lake Plain	ANWR Flood-plain	ANWR Riparian[c] Zone
Wet Graminoid Tundra (WG)	1	2 (4)	<1	<1 (0)	4 (5)	18	4(5)	1
Wet Graminoid with moist inclusions (WGM)	7	13 (9)	<1	1 (0)	21 (9)	23	31 (20)	1
Moist Sedge-Willow with wet inclusions (MSW)	5	8 (10)	<1	4 (7)	10 (10)	23	12 (13)	2
Moist Sedge-Willow Tundra (MS)	5	10 (20)	1	9 (17)	16 (36)	6	9 (16)	2
Moist Sedge-Dryas Tundra (MSD)	8	14 (12)	3	16 (12)	20 (5)	8	6 (14)	1
Moist Sedge-Tussock Tundra (TT)	11	24 (22)	<1	36 (33)	24 (29)	<1	5 (2)	1
Shrub-Tussock Tundra(STT)	7	11 (6)	2	20 (11)	<1 (0)	0	<1 (0)	2
Low-Shrub Tundra (ST)	4	2 (1)	8	5 (2)	0 (0)	0	<1 (0)	<1
Shrub Tundra on High Polygons (SP)	1	1 (4)	<1	2 (5)	1 (0)	<1	1 (0)	0
Dryas-Graminoid Alpine Tundra (AT)	7	2 (1)	20	3 (4)	0 (0)	0	<1 (0)	<1
Riparian Shrub(RS)	1	2 (2)	<1	1 (0)	<1 (0)	<1	4 (4)	18
Dryas River Terrace (DT)	1	2 (3)	<1	<1 (0)	<1 (0)	<1	6 (10)	14
Partially Vegetated (PV)	5	2 (2)	14	2 (1)	<1 (0)	<1	3 (6)	8
Barren (BA)	12	4 (2)	32	1 (0)	1 (0)	2	11 (6)	33
Ice (IC)	14	1 (0)	3	<1 (0)	<1 (0)	4	1 (0)	3
Water(WA)	5	2 (0)	<1	<1 (0)	2 (1)	16	5 (5)	13
Shadow (SH)	5	<1 (0)	16	1 (0)	<1 (0)	<1	<1 (0)	<1
Total Percent	100	100	100	100	100	100	100	100
Total Hectares	2,429,435	1,039,521	701,932	548,595	166,960	27,139	296,827	103,796

a Entire map including off-shore water and ice and a small area of land west of the refuge.

b Includes foothills, hilly coastal plain, thaw-lake plain, and floodplain terrain types within the Arctic NWR.

c Riparian zone is included within the floodplain terrain type.

landform as well as vegetation terminology (*e.g.* Dryas River Terrace), while others refer only to vegetation (*e.g.* Wet Graminoid Tundra).

Wildlife biologists were consulted to ensure that the final scheme included land-cover types relevant to wildlife habitat studies. For example, *Eriophorum vaginatum* tussocks and diamond-leaf willow (*Salix planifolia*) are considered important for summer caribou habitat, so *E. vaginatum* tussock tundra was mapped separately from upland Moist Sedge-Dryas Tundra, which is characterized by *Carex bigelowii* hummocks (called tussocks by some authors), and has much less *E. vaginatum* and *S. planifolia*. (See Fig. 11 and 13.) Riparian zones were digitized to allow mapping of riparian vegetation types, which are important to a variety of wildlife species.

Complexes of different vegetation types are very common on the Arctic tundra and present problems in mapping. We mapped only three common complexes (WGM, MSW, and SP). Each of the three can be combined with the most similar other class to produce a map with fewer classes (WGM combined with WG, MSW combined with MS, SP combined with ST). For all of the land-cover classes, up to 50% of a mapped area can be, and frequently is, covered by inclusions of other unspecified classes. For example, Moist Sedge-Dryas Tundra often occurs in a mosaic with Wet Graminoid on floodplains and Moist Sedge-Willow Tundra elsewhere.

RESULTS: LAND-COVER CLASSES FOR THE ARCTIC NWR COASTAL PLAIN

The following descriptions of the land-cover classes for the coastal plain of the Arctic NWR include characteristics of each class useful for distinguishing it in the field, as well as examples of typical plant communities. Each community is described by a list of dominant plant species. Species in the shrub and herb layer are listed first; species in the ground layer (mosses, liverworts, and lichens) are listed after a slash (/). Species within each layer are separated by hyphens and are listed in their general order of dominance. Species nomenclature follows Hultén (1968) for most vascular plants, Argus (1973) for willows, Crum and Anderson (1981) for mosses, and Thomson (1984) for lichens. Subspecies names are not included.

Tables 5-16 present percent cover statistics for plant species and lifeforms of the vegetation plots that represent each land-cover class. A species was included in a table if its mean percent cover was at least 1% and it occurred in at least 20% of the plots for that land-cover class (constancy > 0.20). The percent cover was based on point-sampling with a vertical point-frame and is the actual cover of each species, not measured relative to other species present. The total vegetation cover can be greater than 100%, and usually is, because of multiple overlapping layers of vegetation. For comparisons of the tabled data with data from other studies, users should be aware that point-sampling of plant species percent cover, as done here, produces similar results to those from subjective ocular estimates of cover in quadrats, another common method, except that the percent cover for graminoid and forb species is typically lower than an ocular estimate. See Floyd and Anderson (1987) for a comparison of the methods.

Figures 5 - 22 are color photographs of examples of the land-cover classes.

Appendix 2 (inside back cover) shows the levels of the hierarchical classification scheme used for the LANDSAT-TM map and provides a cross-reference to seven other classification systems that have been used in northern Alaska. The highest level in the classification simply divides land-cover into herbaceous-dominated, shrub-dominated, and other and is shown in Table 1, but not in Appendix 2. The first column on Appendix 2 is the next level, which is broad soil moisture classes based on moisture at the end of the growing season. The second column is the mapped land-cover classes. The third column shows subdivisions of the mapped classes as needed for comparison with the other classification systems.

HERBACEOUS CLASSES

WET GRAMINOID TUNDRA (WG)

Characteristics:
- Occurs on flat tundra or in drainages, with poorly drained soil.
- Sedge or grass dominated, minimal moss and shrub cover.
- Mapped unit is mainly Wet Sedge Tundra, but includes the following vegetation types:
  - Aquatic Graminoid (permanently flooded sites with more than 10 cm of standing water; in ponds and on lake margins).
  - Salt Marsh (along coast and deltas).
  - Wet Sedge and Wet Grass (seasonally flooded sites with up to 10 cm of standing water, sometimes dry by mid-summer; found in bottoms of low-centered polygons and strangmoor, on river floodplains, and lake and stream margins).

Typical Plant Communities:

Wet Sedge
* *Carex aquatilis - Eriophorum angustifolium - Pedicularis sudetica/Scorpidium scorpioides - Drepanocladus* spp. - *Campylium stellatum.*
* *Carex aquatilis - C. chordorrhiza - Eriophorum angustifolium - E. russeolum - Carex rariflora/ Drepanocladus* spp. - *Oncophorus wahlenbergii.*
* *Carex chordorrhiza - Eriophorum russeolum - Carex rariflora - C. saxatilis - C. membranacea - C. holostoma - Pedicularis sudetica / Scorpidium scorpioides - Drepanocladus* spp. - *Campylium stellatum.*

Wet Grass
* *Dupontia fisheri - Eriophorum angustifolium - Carex aquatilis - Hierochloë pauciflora/Campylium stellatum* (acidic coastal wet grass meadow).

Aquatic Graminoid
* *Arctophila fulva* (grass marsh in deep permanent water on pond edges and in thermokarst pits, up to 1 m deep).
* *Carex aquatilis - Eriophorum angustifolium - E. scheuchzeri - Dupontia fisheri/Drepanocladus* spp. - *Calliergon giganteum* (sedge marsh in shallower permanent water, up to 30 cm deep).
* *Carex aquatilis - Carex saxatilis - Equisetum fluviatile - Potentilla palustre - Caltha palustris - Hippuris vulgaris/Drepanocladus* spp. - *Calliergon giganteum - Meesia triquetra* (sedge marsh in permanent shallow water, up to 30 cm deep, in abandoned river channels and beaded streams).

Salt Marsh
* *Carex subspathacea - Dupontia fisheri - Stellaria humifusa - Cochlearia officinalis* (coastal sedge meadow).
* *Puccinellia phryganodes - Carex ursina - C. subspathacea - Salix ovalifolia* (coastal alkali-grass meadow).

Table 5. Summary vegetation cover statistics for 28 plots [a] of Wet Graminoid Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD [b]	RANGE	CONSTANCY [c]
COVER TYPE				
Total vegetation	72	32	22-149	1.00
Deciduous shrubs	4	5	0-17	0.79
Evergreen shrubs	1	3	0-10	0.36
Sedges	24	13	6-59	1.00
Grasses	1	3	0-12	0.29
Forbs and Horsetails	2	3	0-16	0.79
Mosses and Liverworts	35	26	3-82	1.00
Lichens	1	4	0-18	0.25
Bare ground and Litter	29	18	1-67	1.00
Water [d]	20	29	0-86	0.61
PLANT SPECIES				
SHRUBS				
Salix planifolia	2	4	0-16	0.50
Salix ovalifolia	1	3	0-17	0.32
SEDGES and GRASSES				
Carex aquatilis	12	8	1-31	0.81
Eriophorum angustifolium	6	8	0-35	0.89
Eriophorum russeolum	2	2	0-7	0.71
MOSSES and LIVERWORTS				
Drepanocladus-like spp.	12	14	0-51	0.86
Campylium stellatum	5	12	0-54	0.50
Scorpidium scorpioides	4	7	0-27	0.50
Liverwort	2	4	0-15	0.50
Calliergon giganteum	2	4	0-17	0.39
Meesia triquetra	2	3	0-14	0.46
Sphagnum spp.	1	3	0-14	0.30
Bryum spp.	1	2	0-7	0.32
Dicranum-like spp.	1	3	0-12	0.43
Tomenthypnum nitens	1	3	0-10	0.43

a Table includes wet sedge plots, but no aquatic graminoid, salt marsh, or wet grass.

b Standard deviation of the mean.

c The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100% .

d Water is included in bare ground and litter category.

WET GRAMINOID TUNDRA WITH MOIST INCLUSIONS (WGM)

Characteristics:

- Wet Graminoid Tundra with 10%-50% inclusions of moist types, usually on low-centered polygons or strangmoor (string-bog).

Typical Plant Communities:

* This mapped unit is a complex of communities listed under Wet Graminoid, Moist Sedge-Willow and Moist Sedge-Dryas Tundra. Typical surface forms include:

Low-centered polygons:
Wet polygon centers are usually Wet Graminoid communities dominated by *Carex aquatilis* and *C. chordorrhiza*.
Moist polygon rims are usually Moist Sedge-Willow or Moist Sedge-Dryas communities dominated by *Eriophorum angustifolium /Salix planifolia* or *Carex bigelowii/Dryas integrifolia*, but can be shrub-dominated.

Strangmoor:
Wet inter-strang areas (flarks) are Wet Graminoid communities dominated by *Carex aquatilis, C. chordorrhiza*, or *Dupontia fisheri*.
Moist strangs (raised ridges) are usually Moist Sedge-Willow or Moist Sedge-Dryas communities dominated by *Eriophorum angustifolium/ Salix planifolia* or *Carex bigelowii /Dryas integrifolia*, but the highest edges can be shrub-dominated.

Table 6. Summary vegetation cover statistics for 41 plots of Wet Graminoid Tundra with moist inclusions, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	79	26	38-151	1.00
Deciduous shrubs	7	5	1-22	1.00
Evergreen shrubs	4	3	0-12	0.80
Sedges	19	9	3-44	1.00
Grasses	1	5	0-28	0.24
Forbs	2	2	0-7	0.90
Mosses and Liverworts	42	21	8-56	1.00
Bare ground	29	12	8-56	1.00
Water[c]	4	7	0-25	0.49
PLANT SPECIES				
SHRUBS				
Dryas integrifolia	3	3	0-12	0.66
Salix planifolia	2	3	0-17	0.61
Salix reticulata	1	1	0-5	0.51
Salix arctica	1	2	0-9	0.51
SEDGES and GRASSES				
Eriophorum angustifolium	8	7	0-39	0.95
Carex aquatilis	6	4	0-18	0.95
Eriophorum russeolum	2	2	0-7	0.61
Carex rariflora	1	2	0-10	0.39
MOSSES and LIVERWORTS				
Drepanocladus-like spp.	12	9	0-38	0.98
Tomenthypnum nitens	6	6	0-25	0.90
Campylium stellatum	5	4	0-13	0.85
Sphagnum spp.	2	3	0-18	0.41
Scorpidium scorpioides	4	5	0-21	0.51
Dicranum-like spp.	2	3	0-12	0.78
Bryum spp.	2	4	0-22	0.59
Calliergon giganteum	1	2	0-10	0.59
Liverworts	1	2	0-11	0.71
Aulacomnium turgidum	1	1	0-66	0.68
Meesia triquetra	1	2	0-14	0.34
Hylocomium splendens	1	2	0-10	0.54
Algae	2	4	0-21	0.37

a Standard deviation of the mean.

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%.

c Water is included in bare ground and litter category.

MOIST SEDGE-WILLOW TUNDRA WITH WET INCLUSIONS (MSW)

Characteristics:

- Moist Sedge-Willow Tundra with 10%-50% inclusions of Wet Graminoid, usually on flat-centered polygons or strangmoor.

Typical Plant Communities:

* This mapped unit is a complex of communities listed under Moist Sedge-Willow and Wet Graminoid. Typical surface forms and communities are listed under Wet Graminoid with Moist Inclusions.

Table 7. Summary vegetation cover statistics for 94 plots of Moist Sedge-Willow Tundra with wet inclusions, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	103	20	59-167	1.00
Deciduous shrubs	15	9	1-44	1.00
Evergreen shrubs	4	6	0-24	0.69
Sedges	20	10	5-55	1.00
Grasses	1	3	0-18	0.45
Forbs	3	3	0-17	0.89
Mosses and Liverworts	54	18	12-102	1.00
Lichens	4	5	0-31	0.83
Bare ground	20	9	3-42	1.00
PLANT SPECIES				
SHRUBS				
Salix planifolia	8	8	0-35	0.73
Dryas integrifolia	3	4	0-16	0.50
Salix reticulata	3	4	0-24	0.63
Salix ovalifolia	1	3	0-17	0.26
Salix phlebophylla//rotundifolia	1	2	0-9	0.35
SEDGES and GRASSES				
Eriophorum angustifolium	11	8	0-40	0.99
Carex aquatilis	6	5	0-29	0.95
FORBS and HORSETAILS				
Equisetum variegatum	1	3	0-14	0.34
MOSSES and LIVERWORTS				
Tomenthypnum nitens	9	9	0-49	0.91
Drepanocladus-like spp.	8	7	0-33	0.96
Sphagnum spp.	7	13	0-58	0.49
Hylocomium splendens	4	6	0-37	0.76
Campylium stellatum	4	5	0-27	0.83
Dicranum-like spp.	3	4	0-18	0.74
Aulacomnium palustre	3	4	0-20	0.61
Bryum spp.	2	3	0-14	0.64
Ptilidium ciliare	2	5	0-26	0.44
Aulacomnium turgidum	2	3	0-15	0.70
Calliergon giganteum	2	2	0-8	0.57
Polytrichum spp.	1	2	0-10	0.53
Distichium capillaceum	1	3	0-20	0.32
Liverworts	1	2	0-11	0.57
LICHENS				
Peltigera spp.	1	2	0-11	0.59
Eriophorum vaginatum tussocks	1	2	0-9	0.14

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

MOIST SEDGE-WILLOW TUNDRA (MS)

Characteristics:

- Moist, more or less well-drained soil.
- Occurs on gentle slopes, in drainages, on moist old river terraces, and on flat-centered polygons or poorly developed high-centered polygons.
- Usually dominated by sedges and willows, with variable moss cover.
- Usually dominated by *Eriophorum angustifolium*, *Carex aquatilis*, and *Salix planifolia.*
- Less than 12% tussock cover; less than 30% hummocks and frost scars.

Typical Plant Communities:

* *Eriophorum angustifolium - Carex aquatilis - Salix planifolia/Drepanocladus* spp.
* *Eriophorum angustifolium - Carex bigelowii - Carex aquatilis - Salix planifolia - S. reticulata-/Tomenthypnum nitens - Hylocomium splendens.*
* *Eriophorum angustifolium - Equisetum variegatum - Carex bigelowii - C. aquatilis - Dryas integrifolia - Salix reticulata - S. phlebophylla/Tomenthypnum nitens - Drepanocladus* spp. (old river terraces).
* *Carex aquatilis - Eriophorum angustifolium - Salix planifolia* or *Salix lanata/Campylium stellatum - Drepanocladus* spp. - *Tomenthypnum nitens* (lush sedge-willow in water-tracks, old river channels, or moist slopes).

Table 8. Summary vegetation cover statistics for 83 plots of Moist Sedge-Willow Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	115	22	67-189	1.00
Deciduous shrubs	16	7	3-36	1.00
Evergreen shrubs	5	6	0-28	0.78
Sedges	16	9	0-43	0.99
Grasses	1	1	0-7	0.53
Mosses and Liverworts	67	18	20-105	1.00
Lichens	4	6	0-36	0.88
Bare ground	15	9	0-40	0.99
PLANT SPECIES				
SHRUBS				
Salix planifolia	8	8	0-30	0.75
Dryas integrifolia	5	5	0-26	0.75
Salix reticulata	3	3	0-12	0.78
Salix phlebophylla/ rotundifolia	2	4	0-21	0.53
SEDGES and GRASSES				
Eriophorum angustifolium	9	6	0-25	0.96
Carex aquatilis	3	4	0-23	0.66
Carex bigelowii	2	3	0-15	0.67
Eriophorum vaginatum	1	2	0-7	0.54
FORBS and HORSETAILS				
Equisetum variegatum	2	4	0-25	0.36
Petasites frigidus	1	3	0-20	0.33
MOSSES and LIVERWORTS				
Tomenthypnum nitens	21	15	0-68	0.99
Hylocomium splendens	8	8	0-35	0.83
Drepanocladus-like spp.	8	8	0-38	0.93
Ptilidium ciliare	4	7	0-26	0.59
Dicranum-like spp.	4	5	0-25	0.76
Campylium stellatum	4	6	0-34	0.70
Aulacomnium palustre	3	4	0-22	0.76
Aulacomnium turgidum	3	3	0-16	0.69
Sphagnum spp.	3	8	0-54	0.35
Bryum spp.	2	4	0-28	0.59
Calliergon giganteum	1	2	0-11	0.47
Other liverworts	1	2	0-7	0.45
LICHENS				
Peltigera spp.	2	2	0-13	0.69
Eriophorum vaginatum tussocks	1	2	0-8	0.39

a Standard deviation of the mean.

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

MOIST SEDGE-DRYAS TUNDRA (MSD)

Characteristics:

- Moist, more or less well-drained soil.
- Similar to Moist Sedge-Willow Tundra except dominated more by calciphilous (non-acidic) species.
- Plant communities are characterized by *Carex bigelowii*, *Dryas integrifolia*, *Tomenthypnum nitens*, and often are rich in forbs.
- Has a hummocky appearance because of mounds formed by *Carex bigelowii*, mosses, and frost action.
- Commonly has bare ground because of frost action.
- Occurs on a variety of sites where chronic disturbance maintains non-acidic soils. Disturbance includes loess deposition, frost action, and flooding. Sites include foothills slopes mantled by recently-deposited loess, glacial deposits, river floodplains, and exposed high-centered polygons near the coast.
- On foothills slopes, may look similar to Tussock Tundra, especially when seen from the air, and often has about 4% *Eriophorum vaginatum* tussocks mixed in with the *Carex bigelowii* hummocks.

Typical Plant Communities:

* *Carex bigelowii - Eriophorum vaginatum - Dryas integrifolia - Salix reticulata/Tomenthypnum nitens - Hylocomium splendens - Dicranum* spp. *- Ptilidium ciliare - Peltigera* spp. (foothills slopes).
* *Carex bigelowii - Dryas integrifolia - Salix phlebophylla - S. reticulata - Arctagrostis latifolia/ Tomenthypnum nitens - Dicranum* spp. *- Hylocomium splendens - Aulacomnium* spp. - crustose lichens - *Peltigera* spp. *- Thamnolia* spp. (coastal tundra with frost-scars).
* *Carex bigelowii - Eriophorum angustifolium - Dryas integrifolia - Salix reticulata - Salix phlebophylla - S. arctica/ Tomenthypnum nitens - Hylocomium splendens - Dicranum* spp. - exposed soil (river floodplains).
* *Carex bigelowii - C. aquatilis - C. misandra - Eriophorum angustifolium - Dryas integrifolia - Equisetum variegatum/Tomenthypnum nitens - Dicranum* spp. *Drepanocladus* spp. - crustose lichen - exposed soil (river floodplains).
* *Carex bigelowii - Eriophorum vaginatum - Dryas integrifolia - Salix phlebophylla - S. reticulata - Cassiope tetragona - Equisetum arvense - Arctagrostis latifolia - Lupinus arcticus - Rumex arcticus - Polygonum bistorta/Tomenthypnum nitens - Hylocomium splendens - Aulacomnium acuminatum - Thamnolia* spp. *- Cladonia* spp. *- Cetraria* spp. (forb-rich MSD in uplands).

Table 9. Summary vegetation cover statistics for 101 plots of Moist Sedge-Dryas Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	117	23	61-170	1.00
Deciduous shrubs	12	8	1-48	1.00
Evergreen shrubs	13	5	0-28	0.99
Sedges	11	8	0-42	0.98
Grasses	1	1	0-7	0.58
Forbs	5	3	1-13	1.00
Mosses and Liverworts	63	18	15-105	1.00
Lichens	11	9	0-49	0.99
Bare ground	15	8	1-40	1.00
PLANT SPECIES				
SHRUBS				
Dryas integrifolia	10	5	0-30	0.96
Salix phlebophylla/ rotundifolia	5	5	0-24	0.78
Salix reticulata	3	3	0-18	0.88
Cassiope tetragona	2	3	0-14	0.50
Salix planifolia	1	2	0-10	0.46
SEDGES				
Carex bigelowii	6	5	0-21	0.91
Eriophorum angustifolium	2	3	0-13	0.72
Eriophorum vaginatum	1	2	0-10	0.48
MOSSES and LIVERWORTS				
Tomenthypnum nitens	24	15	1-59	1.00
Hylocomium splendens	10	9	0-32	0.90
Dicranum-like spp.	8	6	0-29	0.94
Ptilidium ciliare	4	6	0-30	0.72
Drepanocladus-like spp.	4	5	0-26	0.78
Aulacomnium turgidum	3	4	0-21	0.76
Polytrichum spp.	2	2	0-14	0.62
Aulacomnium palustre	1	2	0-8	0.64
Campylium stellatum	1	2	0-12	0.47
Distichium capillaceum	1	2	0-11	0.36
LICHENS				
Peltigera sp.	3	3	0-11	0.74
Crustose lichens	2	2	0-9	0.71
Thamnolia spp.	2	2	0-6	0.68
Cetraria cucullata	1	2	0-13	0.57
Cetraria islandica	1	2	0-11	0.67
Eriophorum vaginatum tussocks	1	2	0-9	0.36

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

MOIST SEDGE-TUSSOCK TUNDRA (TT)

Characteristics:

- Greater than 12% cover of *Eriophorum vaginatum* tussocks.
- Occurs on slopes and on high-centered or flat polygons.
- Cover of erect shrubs (*Salix planifolia, Betula nana*) is less than 25% and less than the cover of tussocks.
- Tussock Tundra, including Shrub-Tussock Tundra, is the most common vegetation type on gentle slopes mantled by the aging, increasingly acidic loess that covers most of the Arctic NWR coastal plain.
- More acidic communities have more ericaceous shrubs and *Hylocomium splendens*; less acidic ones have more *Dryas integrifolia* and *Tomenthypnum nitens*.

Typical Plant Communities:

* *Eriophorum vaginatum - Vaccinium vitis-idaea - Ledum palustre - Betula nana - Salix planifolia - Rubus chamaemorus - Polygonum bistorta - Senecio atropurpureus /Dicranum* spp. *- Hylocomium splendens - Sphagnum* spp. *- Aulacomnium turgidum* (foothill TT).
* *Eriophorum vaginatum - Carex bigelowii - Salix planifolia - Betula nana - Vaccinium vitis-idaea - Ledum palustre - Petasites frigidus /Hylocomium splendens - Dicranum* spp. *- Ptilidium ciliare - Sphagnum* spp. *- Tomenthypnum nitens.* (foothill TT).
* *Eriophorum vaginatum - Carex bigelowii - Dryas integrifolia - Salix glauca - S. reticulata/ Tomenthypnum nitens - Ptilidium ciliare* - forbs (*Lupinus arcticus, Saussurea angustifolia, Polygonum bistorta, Draba alpina, Lloydia serotina*) (foothill TT, less acidic than other TT).
* *Eriophorum vaginatum - Carex bigelowii - Dryas integrifolia - Salix planifolia - S. reticulata - Vaccinium vitis-idaea - Cassiope tetragona - Polygonum bistorta/Hylocomium splendens - Ptilidium ciliare - Tomenthypnum nitens - Aulacomnium turgidum - Dicranum* spp. *- Peltigera* spp. (coastal TT on high or flat-centered polygons).

Table 10. Summary vegetation cover statistics for 62 plots of Moist Sedge-Tussock Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			CONSTANCY[b]
	MEAN	SD[a]	RANGE	
COVER TYPE				
Total vegetation	119	21	82-168	1.00
Deciduous shrubs	15	7	4-35	1.00
Evergreen shrubs	17	9	0-36	0.98
Sedges	15	8	3-45	1.00
Grasses	1	1	0-5	0.49
Forbs	5	3	0-17	0.98
Mosses and Liverworts	59	14	31-90	1.00
Lichens	8	5	2-25	1.00
Bare ground	15	7	3-34	1.00
PLANT SPECIES				
SHRUBS				
Vaccinium vitis-idaea	7	6	0-19	0.89
Salix planifolia	6	5	0-18	0.87
Betula nana	6	5	0-17	0.75
Ledum palustre	5	5	0-18	0.76
Dryas integrifolia	3	4	0-16	0.48
Salix phlebophylla/ rotundifolia	2	3	0-10	0.48
Salix reticulata	2	2	0-11	0.48
Cassiope tetragona	1	2	0-9	0.54
SEDGES and GRASSES				
Eriophorum vaginatum	10	7	1-38	1.00
Carex bigelowii	3	3	0-12	0.81
Eriophorum angustifolium	2	2	0-10	0.67
FORBS				
Rubus chamaemorus	1	2	0-11	0.35
Pyrola grandiflora	1	1	0-5	0.63
MOSSES and LIVERWORTS				
Hylocomium splendens	12	7	0-41	0.98
Sphagnum spp.	10	11	0-44	0.73
Dicranum-like spp.	9	7	0-26	0.95
Tomenthypnum nitens	9	11	0-47	0.90
Aulacomnium turgidum	5	3	0-14	0.94
Ptilidium ciliare	3	4	0-19	0.76
Drepanocladus-like spp.	2	3	0-14	0.73
Aulacomnium palustre	2	2	0-9	0.83
Polytrichum spp.	2	2	0-8	0.87
LICHENS				
Peltigera spp.	5	3	1-12	1.00
Eriophorum vaginatum tussocks	20	8	7-38	1.00

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

SHRUB-DOMINATED CLASSES

MOIST SHRUB-TUSSOCK TUNDRA AND WATER-TRACK SHRUB TUNDRA (STT)

Shrub-Tussock Tundra Characteristics:

- Greater than 12% cover of *Eriophorum vaginatum* tussocks.
- Tussocks overgrown with shrubs, usually *Betula nana*, *Salix planifolia*, and ericaceous shrubs.
- Cover of erect shrubs (*Betula nana*, *Salix planifolia*) is greater than 25% or greater than cover of tussocks.
- Occurs in foothills and lower elevations in the mountains.

Water-track Shrub Tundra Characteristics:

- Includes water-track tundra (shrubby drainages interspersed on tussock tundra slopes), and broad foothills drainages with >25% cover of Moist Low-Shrub Tundra (usually dense *Betula nana*) in complex with Moist Sedge-Willow and Tussock Tundra or Shrub-Tussock Tundra.

Typical Plant Communities:

* *Betula nana - Salix planifolia - Vaccinium vitis-idaea - Ledum palustre - Eriophorum vaginatum - Carex bigelowii - Polygonum bistorta/ Hylocomium splendens - Aulacomnium* spp. - *Sphagnum* spp. - *Dicranum* spp. - *Tomenthypnum nitens - Peltigera* spp.(STT).
* *Vaccinium vitis-idaea - Cassiope tetragona - Betula nana - Salix planifolia - Ledum palustre - Eriophorum vaginatum/Hylocomium splendens - Dicranum* spp. - *Aulacomnium turgidum - Sphagnum* spp. - *Peltigera* spp. - *Cladonia* spp. (STT).
* *Salix planifolia - Betula nana - Vaccinium vitis-idaea - Vaccinium uliginosum - Eriophorum angustifolium - E. vaginatum - Carex bigelowii - Petasites frigidus/Sphagnum* spp. - *Hylocomium splendens - Aulacomnium palustre - Dicranum* spp. - *Peltigera* spp.(water-track tundra slopes).

Table 11. Summary vegetation cover statistics for 18 plots of Moist Shrub-Tussock Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	139	23	97-191	1.00
Deciduous shrubs	26	11	6-44	1.00
Evergreen shrubs	18	10	4-34	1.00
Sedges	17	8	4-35	1.00
Grasses	1	<1	0-2	0.67
Forbs	5	3	1-16	1.00
Mosses and Liverworts	64	12	42-89	1.00
Lichens	10	5	3-19	1.00
Bare ground	12	8	4-29	1.00
PLANT SPECIES				
SHRUBS				
Betula nana	14	8	3-32	1.00
Salix planifolia	10	5	2-17	1.00
Vaccinium vitis-idaea	9	3	0-15	0.94
Ledum palustre	8	6	0-19	0.89
Cassiope tetragona	5	4	0-12	0.33
Rubus chamaemorus	2	2	0-4	0.39
Salix phlebophylla/ rotundifolia	2	3	0-9	0.39
Vaccinium uliginosum	2	1	0-3	0.33
SEDGES and GRASSES				
Eriophorum vaginatum	12	8	3-33	1.00
Carex bigelowii	4	3	0-10	0.83
Eriophorum angustifolium	3	2	0-7	0.56
Arctagrostis latifolia	1	<1	0-1	0.67
FORBS				
Petasites frigidus	2	2	0-6	0.50
Pyrola grandiflora	2	1	0-5	0.78
Polygonum bistorta	1	1	0-4	0.83
MOSSES				
Hylocomium splendens	18	9	8-42	1.00
Sphagnum spp.	13	12	0-38	0.94
Dicranum-like spp.	8	4	2-20	1.00
Aulacomnium turgidum	7	5	1-19	1.00
Tomenthypnum nitens	6	4	1-13	1.00
Ptilidium ciliare	4	3	0-10	0.78
Aulacomnium palustre	3	3	0-11	0.89
Drepanocladus spp.	2	2	0-6	0.72
Polytrichum sp.	2	2	0-6	0.83
LICHENS				
Peltigera spp.	6	4	1-14	1.00
Cetraria cucullata	2	1	0-5	0.56
Crustose lichens	2	1	0-4	0.44
Cladonia spp.	1	1	0-3	0.50
Dactylina arctica	1	1	0-3	0.56
Thamnolia spp.	1	1	0-2	0.39
Eriophorum vaginatum tussocks	15	6	0-28	0.94

a Standard deviation of the mean.

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

MOIST LOW-SHRUB TUNDRA (ST)

Characteristics:

- Occurs on slopes in upper foothills and on sheltered sites on lower slopes in mountains.
- Dominated by erect shrubs 20-50 cm tall, sometimes as tall as 1 m or more.
- Soils often saturated, with hummocks or lobes from solifluction.
- Dominant willow species usually either *Salix glauca* or *S. planifolia.*

Typical Plant Communities:

* *Betula nana - Salix* spp. - *Vaccinium uliginosum* - sedge spp. - *Ledum palustre - Vaccinium vitis-idaea - Empetrum nigrum - Lupinus arcticus - Equisetum arvense/Hylocomium splendens - Tomenthypnum nitens - Sphagnum* spp. (shrubby slopes).
* *Betula nana - Vaccinium uliginosum - Ledum palustre - Salix phlebophylla - Salix* spp. - *Carex bigelowii/Dicranum* spp. - *Hylocomium splendens - Tomenthypnum nitens - Peltigera* spp. - *Cetraria cucullata* (shrubby slopes).
* *Salix glauca* or *S. planifolia - Betula nana - Carex bigelowii - Petasites frigidus/Hylocomium splendens - Dicranum* spp. - *Polytrichum* spp. - *Rhytidium rugosum - Peltigera* spp. (shrubby slopes in higher foothills and mountains).
* *Salix planifolia - S. reticulata - Dryas integrifolia - Cassiope tetragona - Carex bigelowii - Equisetum arvense - Petasites frigidus - Boykinia richardsonii - Dodecatheon frigidum - Geum glaciale/ Hylocomium splendens - Tomenthypnum nitens* (lush, late snowmelt areas along streams and slopes).

Table 12. Summary vegetation cover statistics for 29 plots of Moist Shrub Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	140	22	98-179	1.00
Deciduous shrubs	34	12	17-64	1.00
Evergreen shrubs	9	8	0-25	0.86
Sedges	10	7	0-28	0.93
Grasses	1	1	0-4	0.66
Forbs	8	6	2-27	1.00
Mosses and Liverworts	65	23	14-101	1.00
Lichens	13	18	0-96	0.93
Bare ground	10	7	2-26	1.00
PLANT SPECIES				
SHRUBS				
Salix planifolia	13	11	0-41	0.86
Betula nana	11	10	0-39	0.83
Vaccinium vitis-idaea	4	5	0-18	0.62
Vaccinium uliginosum	3	5	0-21	0.52
Salix glauca	2	5	0-23	0.34
Ledum palustre	2	3	0-13	0.52
Salix reticulata	2	4	0-17	0.41
Dryas integrifolia	1	3	0-13	0.34
SEDGES and GRASSES				
Carex bigelowii	4	4	0-13	0.79
Eriophorum vaginatum	2	3	0-9	0.59
Eriophorum angustifolium	2	3	0-9	0.52
Carex aquatilis	1	5	0-25	0.21
FORBS				
Petasites frigidus	2	3	0-13	0.59
Polygonum bistorta	1	1	0-6	0.76
MOSSES and LIVERWORTS				
Hylocomium splendens	16	10	0-36	0.97
Sphagnum spp.	10	14	0-48	0.59
Dicranum-like spp.	6	5	0-19	0.86
Tomenthypnum nitens	6	8	0-32	0.97
Aulacomnium turgidum	4	5	0-22	0.72
Aulacomnium palustre	3	4	0-15	0.79
Rhytidium rugosum	2	4	0-13	0.45
Ptilidium ciliare	2	4	0-16	0.38
Aulacomnium acuminatum	2	3	0-8	0.48
Drepanocladus-like spp.	2	3	0-15	0.66
LICHENS				
Peltigera spp.	5	4	0-15	0.93
Cladonia spp.	2	5	0-22	0.55
Cetraria cucullata	2	3	0-11	0.59
Eriophorum vaginatum tussocks	3	4	0-10	0.48

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

MOIST SHRUB TUNDRA ON HIGH-CENTERED POLYGONS (SP)

Characteristics:

- Occurs on high-centered polygons and raised areas along drainages.
- Shrub-dominated; variable shrub cover (from erect birch communities with closed canopies to dwarf ericaceous mats).
- Area between high polygons may be shallow troughs or deep thermokarst pits; vegetation in these areas may be Wet Graminoid or Moist Sedge-Willow.
- May have up to 12% cover of *Eriophorum vaginatum* tussocks. (*Eriophorum vaginatum* is often mainly dead and overgrown with shrubs.)

Typical Plant Communities:

* *Betula nana - Ledum palustre - Vaccinium vitis-idaea - V. uliginosum - Cassiope tetragona/ Dicranum* spp. - *Racomitrium lanuginosum - Cetraria* spp. - *Sphorophorus globosus* - crustose lichens (birch/ericaceous shrub polygons).
* *Betula nana - Salix planifolia - Vaccinium vitis-idaea - Rubus chamaemorus - Carex aquatilis - Eriophorum angustifolium/Sphagnum* spp. - *Dicranum* spp. - *Hylocomium splendens - Polytrichum* spp. (birch/willow shrub polygons).
* *Salix planifolia - Betula nana - Vaccinium vitis-idaea - Carex aquatilis - C. bigelowii - Eriophorum angustifolium - Pyrola grandiflora /Hylocomium splendens - Aulacomnium turgidum - A. palustre - Sphagnum* spp. - *Dicranum* spp. - *Polytrichum* spp. - *Peltigera aphthosa* (willow/birch shrub polygons).
* *Salix planifolia - Betula nana - Vaccinium vitis-idaea - Carex aquatilis - C. bigelowii - Eriophorum angustifolium - Pyrola grandiflora/Hylocomium splendens - Aulacomnium turgidum - A. palustre - Sphagnum* spp. - *Dicranum* spp. - *Polytrichum* spp. - *Peltigera aphthosa* (willow/birch shrub polygons).

Table 13. Summary vegetation cover statistics for 46 plots of Moist Shrub Tundra on High-Centered Polygons, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	131	24	83-189	1.00
Deciduous shrubs	23	13	2-61	1.00
Evergreen shrubs	15	12	0-49	0.87
Sedges	11	9	0-40	0.96
Grasses	1	1	0-7	0.61
Forbs	6	6	0-31	0.89
Mosses and Liverworts	67	15	43-105	1.00
Lichens	10	7	2-33	1.00
Bare ground	12	7	0-32	0.98
PLANT SPECIES				
SHRUBS				
Betula nana	12	10	0-43	0.83
Vaccinium vitis-idaea	9	8	0-34	0.80
Salix planifolia	9	9	0-32	0.87
Ledum palustre	4	5	0-15	0.70
Cassiope tetragona	1	2	0-8	0.41
SEDGES and GRASSES				
Eriophorum angustifolium	5	7	0-34	0.87
Carex aquatilis	3	3	0-10	0.78
Eriophorum vaginatum	2	3	0-10	0.70
FORBS				
Rubus chamaemorus	3	6	0-28	0.50
MOSSES and LIVERWORTS				
Sphagnum spp.	12	13	0-53	0.87
Dicranum-like spp.	11	9	0-39	0.96
Hylocomium splendens	10	9	0-38	0.93
Aulacomnium turgidum	6	5	0-19	0.83
Polytrichum spp.	5	5	0-20	0.93
Aulacomnium palustre	4	4	0-12	0.67
Tomenthypnum nitens	3	4	0-13	0.74
Ptilidium ciliare	3	3	0-11	0.65
Drepanocladus-like spp.	2	2	0-9	0.72
Other liverworts	2	4	0-27	0.37
Aulacomnium acuminatum	1	2	0-8	0.35
LICHENS				
Peltigera spp.	3	3	0-14	0.85
Crustose lichens	2	2	0-7	0.61
Eriophorum vaginatum tussocks	1	2	0-7	0.39

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one vegetation type expressed as the percentage of plots with that species, 1.00 =100%

DRYAS-GRAMINOID ALPINE TUNDRA (AT)

Characteristics:

- Prostrate shrub, sedge or grass, forb communities.
- On slopes in mountains and foothills, drier and often higher on slope than Moist Low-Shrub Tundra.
- Soils often moist and lumpy from solifluction.
- Bare ground common.
- Varied communities from variation in slope stability and micro-site conditions.
- May have high horsetail (*Equisetum* spp.) cover.
- Can be similar to Moist Sedge-Dryas Tundra, but shrub-dominated rather than graminoid-dominated.
- Mapped unit includes all moist or dry alpine tundra if >50% vegetated and shrubs mainly <20 cm tall.

Typical Plant Communities:

* *Dryas integrifolia - Salix reticulata - S. arctica - Equisetum arvense - Carex bigelowii/ Tomenthypnum nitens - Hylocomium splendens* (Dryas/sedge/horsetail community - on toeslopes of higher foothills and mountains).
* *Dryas integrifolia - Cassiope tetragona - Salix reticulata - Vaccinium uliginosum - Carex bigelowii - Lupinus arcticus - Boykinia richardsonii - Geum glaciale/Rhytidium rugosum - Tomenthypnum nitens* (Dryas-ericaceous shrub, late snowmelt communities).
* *Dryas integrifolia* (or *D. octopetala*) *- Empetrum nigrum - Vaccinium uliginosum - V. vitis-idaea - Cassiope tetragona - Arctostaphylos alpina - Rhododendron lapponicum-Carex bigelowii - Carex podocarpa - Arctagrostis latifolia - Lupinus arcticus - Arnica alpina - Aconitum delphinifolium - Delphinium brachycentrum/ Racomitrium lanuginosum - Dicranum* spp. *- Thamnolia* spp. (lush alpine slopes).
* *Dryas octopetala - Salix rotundifolia - Hierochloë alpina - Festuca rubra - Saxifraga tricuspidata - Oxytropis nigrescens - Senecio resedifolius - Arnica frigida/Cetraria nivalis - Ochrolechia frigida - Alectoria* spp. - crustose lichens (dry south-facing alpine slopes).
* *Dryas* spp./*Cetraria* spp. - *Cladonia* spp. (Dryas-lichen).

Table 14. Summary vegetation cover statistics for 8 plots of Dryas-Graminoid Alpine Tundra, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	114	19	81-137	1.00
Deciduous shrubs	18	11	7-41	1.00
Evergreen shrubs	21	8	12-30	1.00
Sedges	7	8	0-22	0.88
Grasses	1	2	0-5	0.50
Forbs	5	4	2-10	1.00
Mosses and Liverworts	46	24	10-81	1.00
Lichens	14	8	5-26	1.00
Bare ground	18	11	5-40	1.00
PLANT SPECIES				
SHRUBS				
Dryas integrifolia	13	11	0-30	0.88
Salix reticulata	4	4	0-10	0.75
Arctostaphylos spp.	4	4	0-11	0.88
Betula nana	3	7	0-20	0.50
Vaccinium vitis-idaea	3	4	0-11	0.50
Cassiope tetragona	3	4	0-11	0.63
Vaccinium uliginosum	3	3	0-10	0.63
Salix phlebophylla/ rotundifolia	2	2	0-5	0.75
Salix arctica	1	2	0-7	0.38
GRASSES and SEDGES				
Carex bigelowii	5	4	0-12	0.75
Eriophorum angustifolium	2	5	0-13	0.38
FORBS				
Equisetum arvense	1	2	0-4	0.38
MOSSES and LIVERWORTS				
Tomenthypnum nitens	15	15	0-37	0.88
Dicranum-like spp.	7	7	0-19	0.88
Rhytidium rugosum	5	5	0-15	0.75
Hylocomium splendens	5	4	1-12	1.00
Drepanocladus-like spp.	2	4	0-11	0.38
Aulacomnium turgidum	2	3	0-9	0.63
Racomitrium lanuginosum	2	2	0-7	0.50
Polytrichum spp.	1	2	0-5	0.63
Distichium capillaceum	1	2	0-4	0.50
LICHENS				
Cetraria cucullata	4	2	1-8	1.00
Peltigera spp.	2	2	0-6	0.75
Thamnolia spp.	2	2	0-5	0.88
Crustose lichens	2	2	0-7	0.75
Cladonia spp.	2	2	0-4	0.75

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one vegetation type expressed as the percentage of plots with that species, 1.00 =100%

RIPARIAN SHRUB (RS)

Characteristics:
- Open (<40% shrub cover) or closed (>40% shrub cover) willow communities.
- On gravel bars and floodplains of streams and rivers, and extending up stream banks and river bluffs.
- Soils coarse and well-drained, but with subsurface water available to the willow roots.
- Over 50% vegetative cover.
- Willows often have a forb and moss understory.

Typical Plant Communities:
* *Salix glauca - S. planifolia - S. reticulata - Dryas integrifolia - Polygonum bistorta - Petasites frigida - Pyrola grandiflora - Lupinus arcticus - Anemone parviflora - Oxytropis maydelliana/ Tomenthypnum nitens - Hylocomium splendens - Peltigera aphthosa.*
* *Salix lanata - S. glauca - S. reticulata - Arctostaphylos rubra - Equisetum variegatum - Astragalus umbellatus - Oxytropis maydelliana/ Tomenthypnum nitens - Hylocomium splendens - Campylium stellatum - Hypnum* spp. *- Dicranum* spp.
* *Salix alaxensis - S. glauca - S. planifolia - Betula nana - Calamagrostis canadensis - Arctagrostis latifolia - Equisetum arvense - Polemonium acutiflorum - Valeriana capitata - Dodecatheon frigidum - Parrya nudicaulis/ Hylocomium splendens.*
* *Salix alaxensis - S. glauca - Hedysarum* spp. *- Oxytropis borealis - O. campestris - O. deflexa - Astragalus alpinus - Artemisia arctica - Bromus pumpellianus - Festuca rubra - Poa* spp. *- Agropyron macrourum.*

Table 15. Summary vegetation cover statistics for 28 plots of Riparian Shrub, Arctic NWR, Alaska, 1994.

	PERCENT COVER			
	MEAN	SE[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	121	28	67-181	1.00
Deciduous shrubs	31	10	12-49	1.00
Evergreen shrubs	4	6	0-22	0.64
Sedges	2	3	0-14	0.64
Grasses	5	10	0-40	0.79
Forbs	20	17	1-64	1.00
Mosses and Liverworts	50	22	17-96	1.00
Lichens	3	4	0-17	0.82
Bare ground	18	10	3-45	1.00
PLANT SPECIES				
SHRUBS				
Salix lanata	7	10	0-35	0.75
Salix alaxensis	6	10	0-40	0.57
Salix glauca	6	6	0-29	0.71
Salix reticulata	5	5	0-21	0.86
Dryas integrifolium	4	6	0-19	0.64
Arctostaphylos spp.	2	3	0-11	0.46
Salix planifolia	2	7	0-36	0.25
Salix hastata	1	2	0-8	0.32
SEDGES and GRASSES				
Poa spp.	2	5	0-21	0.29
FORBS				
Equisetum variegatum	5	6	0-20	0.71
Hedysarum spp.	3	7	0-24	0.39
Lupinus arcticus	2	4	0-16	0.39
Astragalus umbellatus	2	3	0-17	0.50
Petasites frigida	1	4	0-19	0.25
Pyrola grandiflora	1	3	0-9	0.39
Astragalus alpinus	1	3	0-13	0.29
Polygonum bistorta	1	2	0-6	0.50
MOSSES and LIVERWORTS				
Tomenthypnum nitens	14	17	0-52	0.86
Hylocomium splendens	9	9	0-40	0.89
Drepanocladus-like spp.	6	7	0-28	0.82
Dicranum-like spp.	5	7	0-30	0.64
Bryum spp.	3	5	0-21	0.64
Campylium stellatum	3	4	0-15	0.57
Aulacomnium palustre	1	2	0-11	0.39
Distichium capillaceum	1	3	0-11	0.29
LICHENS				
Peltigera spp.	2	2	0-8	0.64

a Standard deviation of the mean

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

DRYAS RIVER TERRACE (DT)

Characteristics:
- Dominated by *Dryas integrifolia*.
- Occurs on well-drained river terraces, with little microrelief.
- On dry sites lichens are common; on moister sites *Cassiope tetragona* and mosses may be common.

Typical Plant Communities:
* *Dryas integrifolia - Salix reticulata - Oxytropis nigrescens - Equisetum variegatum/ Tomenthypnum nitens - Dicranum* spp. - *Lecanora epibryon - Pertusaria* spp.
* *Dryas integrifolia - Salix phlebophylla - S. reticulata - Cassiope tetragona - Carex scirpoidea - C. misandra/Tomenthypnum nitens - Dicranum* spp. - crustose lichens - *Thamnolia* spp. - *Cetraria* spp.
* *Dryas integrifolia - Salix reticulata - S. phlebophylla - Equisetum variegatum - Oxytropis nigrescens - O. maydelliana - Astragalus umbellatus - Pedicularis kanei - P. capitata/ Tomenthypnum nitens - Dicranum* spp. - *Distichium capillaceum - Bryum* spp. - *Hylocomium splendens*.

Table 16. Summary vegetation cover statistics for 30 plots of Dryas River Terrace, Arctic NWR, Alaska.

	PERCENT COVER			
	MEAN	SD[a]	RANGE	CONSTANCY[b]
COVER TYPE				
Total vegetation	115	33	63-207	1.00
Deciduous shrubs	18	11	2-56	1.00
Evergreen shrubs	20	11	2-52	1.00
Sedges	2	3	0-17	0.70
Grasses	0	1	0-4	0.23
Forbs	10	10	1-39	1.00
Mosses and Liverworts	51	20	7-100	1.00
Lichens	9	12	0-50	0.80
Bare ground	19	11	4-47	1.00
PLANT SPECIES				
SHRUBS				
Dryas integrifolia	19	10	2-52	1.00
Salix phlebophylla/ rotundifolia	6	7	0-26	0.77
Salix reticulata	5	4	0-14	0.97
Arctostaphylos spp.	2	7	0-39	0.37
Salix ovalifolia	1	5	0-26	0.20
SEDGES and GRASSES				
Carex bigelowii	1	3	0-15	0.37
FORBS				
Equisetum variegatum	5	6	0-20	0.90
Astragalus alpinus	2	4	0-17	0.23
Oxytropis nigrescens	2	3	0-12	0.53
Astragalus umbellatus	1	3	0-15	0.37
MOSSES				
Tomenthypnum nitens	16	13	0-49	0.97
Dicranum-like spp.	8	8	0-34	0.80
Hylocomium splendens	5	10	0-52	0.77
Drepanocladus-like spp.	5	7	0-23	0.80
Campylium stellatum	4	7	0-30	0.67
Distichium capillaceum	4	6	0-23	0.40
Bryum spp.	2	4	0-4	0.73
LICHENS				
Crustose lichens	3	4	0-18	0.67
Thamnolia spp.	2	3	0-11	0.53
Cetraria cucullata	1	2	0-7	0.43

a Standard deviation of the mean.

b The constancy of occurrence of a species in plots of one land-cover type expressed as the percentage of plots with that species, 1.00 = 100%

OTHER CLASSES

PARTIALLY VEGETATED (PV)

Characteristics:
- 10% - 50% vegetative cover.
- Occurs on river deltas, active floodplains, and gravel outcrops on ridges, bluffs, and mountain slopes.
- Typical vegetation communities include Wet Graminoid on coastal delta areas, Dryas River Terrace or Riparian Shrub on river terraces, and Dryas-Graminoid Alpine Tundra in the mountains.

Typical Plant Communities:
* Dry sand and river cobbles and combinations of the following: *Salix alaxensis*, *Artemisia arctica* (*A. borealis*, *A. glomerata*), *Oxytropis campestris* (*O. arctica*, *O. borealis*, *O. nigrescens*), *Astragalus alpinus*, *Epilobium latifolium*, *Androsace chamaejasme*, *Arctagrostis latifolia*, *Bromus pumpellianus*, *Poa alpina* (*P. arctica*, *P. glauca*), *Trisetum spicatum* (active river floodplains).
* Dry rocky/scree alpine slopes with *Dryas octopetala*, *Festuca rubra, F. brachyphylla*, *Hierochloë alpina*, *Saxifraga tricuspidata*, *Draba alpina*, *Smelowskia calycina*, *Dianthus repens*, *Alectoria* spp, *Thamnolia* spp., crustose lichens.
* Moist rocky alpine slopes with combinations of *Dryas integrifolia* (or *D. octopetala*), *Ledum palustre*, *Empetrum nigrum*, *Vaccinium uliginosum*, *Cassiope tetragona*, *Rhododendron lapponicum*, *Arctostaphylos alpina*, *Betula nana*, *Carex podocarpa*, *Arnica alpina*, *Aconitum delphinifolium*, *Racomitrium lanuginosum*, *Dicranum* spp., *Thamnolia* spp.
* Wet mudflats with combinations of *Salix ovalifolia*, *Carex subspathacea*, *Carex ursina*, *Puccinellia phryganodes*, *Stellaria humifusa*, *Cochlearia officinalis*, *Sedum rosea*.
* Dry dunes with *Elymus arenarius*, *Dupontia fisheri*.

BARREN (BA)

Characteristics:
- Less than 10% vegetative cover (but crustose lichens on rocks can be >10%).
- Vegetation communities similar to those in Partially Vegetated.

WATER (WA)

Characteristics:
- Includes aquatic graminoid areas with low graminoid cover.

ICE (IC)

Characteristics:
- Includes snow.

Figure 5. Wet Graminoid Tundra (WG).

Figure 6. Wet Graminoid Tundra with moist inclusions (WGM) in low-centered polygons, with wet sedge in centers and troughs and moist sedge on rims.

Figure 7. Wet Graminoid Tundra with moist inclusions (WGM) in strongmoor.

Figure 8. Moist Sedge-Willow Tundra with wet inclusions (MSW) in flat-centered polygons, with moist sedge-willow centers and wet slough troughs.

Figure 9. Moist Sedge-Willow Tundra (MS).

Figure 10. Moist Sedge-*Dryas* Tundra (MSD) near the coast.

Figure 11. Moist Sedge-Dryas Tundra (MSD) on gentle slope in the foothills.

Figure 12. Moist Sedge-Tussock Tundra (TT) with approximately 12% tussock cover (minimum tussock cover for this class).

Figure 13. Moist Sedge-Tussock Tundra (TT) with approximately 20% tussock cover (average tussock cover for this class)..

Figure 14. Moist Shrub-Tussock Tundra (STT) with 17% tussock cover and 38% erect shrub cover (*Salix planifolia* and *Betula nana*).

Figure 15. Shrubby drainage complex (included in STT). Patches of Moist Low-Shrub Tundra (dark green) and Tussock Tundra (pale green) with Moist Sedge-Willow Tundra (tan) in broad drainages through Tussock Tundra in the foothills.

Figure 16. Moist Low Shrub Tundra (ST).

Figure 17. Moist Shrub Tundra on high-centered polygons (SP) with shallow troughs.

Figure 18. Moist Shrub Tundra on high-centered polygons (SP).

Figure 19. *Dryas*-Graminoid Apline Tundra (AT).

Figure 20. Riparian Shrub (RS).

Figure 21. Dryas River Terrace (DT).

Figure 22. Partially Vegetated (PV) river corridor with approximately 20% vegetative cover.

GLOSSARY

Glossary definitions are adapted from Gabriel and Talbot (1984) and Johannsen and Sanders (1982).

Active layer
The layer of ground that freezes and thaws each summer in permafrost regions.

Algorithm
A series of well-defined steps for carrying out a specific process (*e.g.*, a computer program).

Alpine
The landscape above the upper limit of tree growth. In the tree-less arctic, the landscape in the mountains.

Ancillary data
Secondary data pertaining to the area of interest, such as topographic or climatological data; may be digitized and used in the analysis process in conjunction with the primary remote sensing data.

Arctic
High latitude region from which tree growth is usually absent because of unfavorable environmental conditions of low temperatures, short growing season, etc.; more or less following the 10 degree C. mean daily isotherm for the warmest month of the year.

Aspect
The direction towards which a slope faces.

Barren
An area devoid or nearly devoid of vegetation. Less than 10% vegetation on this map.

Calciphilous
Applied to an organism that prefers to grow in or can grow only in habitats rich in calcium. These habitats are non-acidic (high pH).

Color-infrared film (CIR)
Photographic film that is sensitive to energy in the visible and near-infrared wavelengths. It is especially useful for detecting changes in the condition of the vegetative canopy that often are exhibited in the near infrared region of the spectrum.

Classification
The orderly arrangement of objects according to their differences and similarities.

Cluster analysis
Analysis of a set of data to detect the inherent tendency of the points to form groups (clusters), in which the members of each group are more similar to each other than to the other groups, based on a series of measurements.

Community Type (Plant)
A recognizable unit of vegetation that is relatively uniform in structure and floristic composition, consisting of competing plants of one or more species in a common location.

Cover
The area of ground covered by the vertical projection of the plant.

Data layer in GIS
A digital file of geographically-referenced data, such as spectral classes, terrain types, or elevation. GIS users can display, compare, or combine multiple data layers to extract information on interrelationships.

Decision rule
The criterion used to discriminate between different classes in a classification.

DEM topographic data
Digital elevation model where each pixel contains elevation data for the respective area.

Digital data
Data displayed, recorded, or stored in binary notation.

Digital vegetation map
A vegetation map composed of digital data.

Digitize
To convert data (such as points, lines, or polygons on a map or aerial photograph) from a continuous to a discrete, digital format.

Electromagnetic spectrum
The ordered array of all electromagnetic radiation that moves with the velocity of light, characterized by wavelength or frequency.

Ericaceous
Members of the Ericaceae (heath family), *e.g.*, blueberry, cranberry, heather.

Floodplain
The nearly level portion of a river valley that is built of stream sediments and is covered with water when the river overflows during flood stages.

Forb
A broad-leaf herbaceous plant, *e.g.*, fireweed.

Frost scars
Small patches of bare soil produced by frost action, often scattered through the vegetation in tundra areas. They are sufficiently disturbed by frost action to disrupt plant colonization.

Geo-referenced data
Data that has been spatially labeled according to the geographic coordinate system to which it conforms.

Geographic information system (GIS)
A data-base management system used to store, retrieve, manipulate, analyze, and display spatial information.

Graminoid
Plants that are grasslike in appearance even though they may not be grasses in a taxonomic sense. Grasses, sedges, rushes, and cattails are all graminoids.

Ground truth data
Reliable data obtained about the earth's surface features (such as vegetation and landforms) to aid in interpretation of remotely sensed data. Ideally, data collected in the field.

Habitat type
A recognizable group of plant communities or sites resembling one another in their ability to supply the life-needs of a given plant or animal.

Habitat
The particular kind of environment in which a plant or animal is living or the environment in which the life-needs of an individual, population, or community are supplied.

Hectare
A metric measure of surface, equal to 10,000 square meters or 2.47 acres.

Hummock
A microtopograhic elevated area caused by frost heave or by hummock-forming species such as mosses and the sedge *Carex bigelowii*.

Land-cover type
A unit of biophysical cover essentially similar in composition and development throughout its extent.

Landform
One of the many features that, taken together, make up the surface of the earth, *e.g.*, mountain, river bluff.

LANDSAT-Multispectral Scanner (MSS)
A scanning, detecting system aboard an earth-orbiting LANDSAT satellite. It records reflected or emitted energy from the earth's surface in four discrete wavelength intervals, from the visible to the near-infrared.

LANDSAT-Thematic Mapper (TM)
A scanning, detecting system aboard an earth-orbiting LANDSAT satellite. It records reflected and emitted energy from the earth surface in seven discrete wavelength intervals, from visible to mid-infrared to thermal infrared.

Loess
Predominantly silt-sized soil material transported and deposited by wind. Recent calcareous loess or older acidified loess cover most of the Arctic Coastal plain and foothills and originate from silty glacial outwash.

Maximum-likelihood classification
A statistically based classifier that uses the mean vector and variance-covariance matrix of spectral signatures to determine the class in which pixels have the highest probability of being a member.

Multivariate analysis
Statistical analysis of many variables simultaneously, to make use of multidimensional relationships and correlations within the data.

Permafrost
Perennially frozen ground, or ground in which a temperature below 0 degrees C. has existed continuously for two or more years. Permafrost is defined exclusively on the basis of temperature and no moisture or ice need be present.

Photo-interpretation
The process of examining photographic images for the purpose of identifying objects and judging their significance. In vegetation mapping, the identification of vegetation types and landforms by their color, texture, shape, and juxtaposition on an aerial photograph.

Physiographic
Dealing with the physical features of the earth's surface and the description of landscape.

Pixel
Term derived from "picture element". In a remotely sensed image, a data element with both spatial and spectral aspects. The spatial variable defines the size of the area on the ground represented by the data and the spectral variable defines the intensity of the spectral response for that cell in a particular band.

Polygons (ice-wedge)
A form of patterned ground characteristic of earth subjected to intensive frost action. There are two major forms:

Low-centered polygons
Polygons bordered by active ice wedges that are covered by low ridges of peat that cause the margins of the polygon to be higher than the surface of the center (Fig. 6).

High-centered polygons
Polygons bordered by eroding ice wedges that have permitted the polygon margin to collapse into the thermal contraction cracks. Generally, a later developmental stage of ice-wedge polygon associated with improved drainage (Fig. 17).

Polygon (mapping sense)
A plane figure defining an area, consisting of three or more points connected by line segments.

Proximity analysis
As used here, a method of assigning a map class to a pixel based on the map classes of adjacent pixels, rather than only on that pixel's own attributes.

Radiometric resolution
The sensitivity of a detector to differences in signal strength as it records reflected or emitted energy.

Remote sensing
The acquisition of information about an object or phenomenon by a recording device that is not in physical or intimate contact with the object or phenomenon under study.

Riparian
Streamside environment or vegetation growing in close proximity to a watercourse, lake, or spring and often dependent on its roots reaching the water table.

Satellite image
A matrix of pixels representing energy reflected or emitted from a geographic area on the earth's surface and recorded by a detector aboard an orbiting satellite. A full LANDSAT-TM image represents approximately 185 x 185 km of the earth's surface.

Sedge
A plant in the family Cyperaceae, grass-like in appearance, but with solid stems that are often triangular in cross-section. Members of the genus *Carex* and cotton-grasses are sedges. The Arctic Coastal Plain is dominated by sedges, not grasses.

Shrub
Height:
Dwarf shrub - < 0.2 meter tall
Low shrub - 0.2 - 1.5 meter tall
Tall shrub - > 1.5 meter tall
Growth form:
Prostrate shrub - low-lying, sprawling
Erect shrub - upright, ascending

Slope
The inclination of the land surface from the horizontal measured in a numerical ratio, percent, or degrees.

Smoothing
The averaging or generalizing of pixel values based on adjacent areas to produce less variability and more gradual transitions.

Solar-illumination
A relative measure of the incident radiation from the sun on an earth feature, derived from the sun elevation and azimuth, and the feature's slope and aspect.

Solifluction
Downslope movement ("flowing soil") of earth materials resulting from frost action in areas with cold arctic or alpine climates. Solifluction prevents the development of typical soil profiles and influences the development of plant cover.

Solifluction lobe
Tongue-like mass of solifluction debris commonly with steep front and relatively gentle upper surface.

Spectral data
Data representing the intensity of reflected or emitted energy within discrete bandwidths of the electromagnetic spectrum; for mapping, it is the energy of earth features recorded by satellites.

Spectral class
A class that is inherent in the remote sensor data and must be identified and then labeled by the analyst.

Spectral signature
The spectral characteristics of an object or class of objects on the earth's surface.

Strangmoor
A common landscape of wet, nearly flat tundra consisting of alternating, low sinuous ridges ("strang") and wet sedgy hollows ("flarks"). The ridges form perpendicular to the local hydrologic gradient, from mass movement of saturated soil. Vegetation is usually moist sedge-willow on the strang and wet sedge in the flarks (Fig. 7).

Supervised classification
A computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where the possible classes have been defined based on representative training samples of known identity.

Terrain type
A landscape unit based on dominant landform.

Thermal bands
A general term for far-infrared wavelengths.

Thermokarst
A permafrost-related landscape characterized by a peculiar topography of pits, hummocks, depressions, and small ponds caused by the melting of ground ice and the settling of the ground surface.

Training data
Data of a known information type (*e.g.*, land-cover type) at a specific location, to which unknown data may be compared for classification or interpretation.

Tundra
A term applied to both the landscape and vegetation beyond the temperature limits of tree growth. Dwarf shrubs and low herbaceous plants predominate, often with many lichens and mosses, on a permanently frozen subsoil. Tundra occurs both to the north and west of treeline in Alaska and at elevations above treeline on mountains.

Tussock
A plant form that is tufted, bearing many stems arising as a large dense cluster from the crown. Formed particularly by the cottongrass *Eriophorum vaginatum*.

Universal Transverse Mercator
A planar map projection based on a series of 60 zones worldwide, each covering 6° of longitude in a north-south strip.

Unsupervised classification
A computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where, in contrast with supervised classification, the possible classes have been defined based only on inherent data characteristics rather than on training samples.

Variance-covariance matrix
A matrix showing how band intensity values from all pixels used in a spectral signature change in relation to each other.

Vector
The sequence of intensity values for all spectral bands for a given pixel. A mean vector for a spectral signature is then the sequence of average intensity values, one per band, from all pixels used to determine the signature.

Vegetation
The mosaic of plant communities in the landscape.

Vegetation type
A recognizable unit of vegetation, or the kind of plant community of any size, rank, or stage of succession.

Vertical point frame
A piece of equipment that holds long, vertical pins, used in vegetation studies. The observer manually lowers each pin and records one or more species of plants that the pointed pin tip hits between the frame and the ground. Because a point frame usually is positioned less than 1 meter from the ground, it is best suited for sampling low-growing tundra, rangeland, or understory vegetation.

Water-track
The path of surface or subsurface water movement down a slope, usually marked by more lush vegetation than the surrounding area.

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APPENDIX 1. Percentages of field-determined land-cover types that make up each mapped land-cover class, based on the 318 accuracy assessment points. Land-cover type codes in parentheses after each heading are other types that are similar and intergrade with the main type. Land-cover map of the coastal plain of the Arctic NWR, Alaska, 1994.

Mapped as Wet Graminoid Tundra (WG) (WGM)

Vegetation Type	Frequency	Percentage
Wet Graminoid Tundra (WG)	2/5	40%
Wet Graminoid with Moist Inclusions (WGM)	1/5	20%
Moist Sedge-Willow with Wet Inclusions (MSW)	1/5	20%
Dryas River Terrace (DT)	1/5	20%

Mapped as Wet Graminoid with Moist Inclusions (WGM) (WG,MSW,MSD)

Vegetation Type	Frequency	Percentage
Wet Graminoid with Moist Inclusions (WGM)	19/44	43%
Wet Graminoid Tundra (WG)	7/44	16%
Moist Sedge-Dryas Tundra (MSD)	6/44	14%
Moist Sedge-Willow with Wet Inclusions (MSW)	4/44	9%
Moist Sedge-Willow Tundra (MS)	4/44	9%
Other	4/44	9%

Mapped as Moist Sedge-Willow with Wet Inclusions (MSW) (WGM,MS)

Vegetation Type	Frequency	Percentage
Moist Sedge-Willow with Wet Inclusions (MSW)	12/35	34%
Wet Graminoid with Moist Inclusions (WGM)	9/35	26%
Moist Sedge-Willow Tundra (MS)	8/35	23%
Wet Graminoid Tundra (WG)	4/35	11%
Other	2/35	6%

Mapped as Moist Sedge-Willow Tundra (MS) (MSW,MSD,TT)

Vegetation Type	Frequency	Percentage
Moist Sedge-Willow Tundra (MS)	15/28	54%
Moist Sedge-Tussock Tundra (TT)	5/28	18%
Moist Sedge-Willow with Wet Inclusions (MSW)	4/28	14%
Moist Sedge-Dryas Tundra (MSD)	4/28	14%

Mapped as Moist Sedge-Dryas Tundra (MSD) (WGM,MS,TT)

Vegetation Type	Frequency	Percentage
Moist Sedge-Dryas Tundra (MSD)	18/56	32%
Moist Sedge-Tussock Tundra (TT)	14/56	25%
Moist Sedge-Willow Tundra (MS)	11/56	20%
Wet Graminoid with Moist Inclusions (WGM)	5/56	9%
Moist Sedge-Willow with Wet Inclusions (MSW)	4/56	7%
Dryas-Graminoid Alpine Tundra (AT)	2/56	4%
Other	2/56	4%

Mapped as Moist Sedge-Tussock Tundra (TT) (MS,MSD,STT,SP)

Vegetation Type	Frequency	Percentage
Moist Sedge-Tussock Tundra (TT)	51/77	66%
Moist Sedge-Dryas Tundra (MSD)	8/77	10%
Moist Sedge-Willow with Wet Inclusions (MSW)	6/77	8%
Shrub Tundra on High-centered Polygons (SP)	6/77	8%
Moist Shrub-Tussock Tundra and Water-track Shrub Tundra (STT)	3/77	4%
Other	3/77	4%

Mapped as Shrub-Tussock Tundra and Water-tracks (STT) (TT,ST)

Vegetation Type	Frequency	Percentage
Shrub-Tussock Tundra and Water-tracks (STT)	13/25	52%
Moist Sedge-Tussock Tundra (TT)	5/25	20%
Moist Low-Shrub Tundra (ST)	2/25	8%
Dryas-Graminoid Alpine Tundra (AT)	2/25	8%
Other	3/25	12%

Mapped as Shrub Tundra on High-centered Polygons (SP) (TT,ST)

Vegetation Type	Frequency	Percentage
Shrub Tundra on High-centered Polygons (SP)	6/8	75%
Other	2/8	25%

Mapped as Low-Shrub Tundra (ST) (STT,AT)

Vegetation Type	Frequency	Percentage
Low-Shrub Tundra (ST)	2/4	50%
Shrub-Tussock Tundra and Water-tracks (STT)	1/4	25%
Moist Sedge-Willow Tundra (MS)	1/4	25%

Mapped as Dryas-Graminoid Alpine Tundra (AT) (ST,PV)

Vegetation Type	Frequency	Percentage
Dryas-Graminoid Alpine Tundra (AT)	1/2	50%
Low-Shrub Tundra (ST)	1/2	50%

Mapped as Riparian Shrub (RS) (DT,PV)

Vegetation Type	Frequency	Percentage
Dryas River Terrace (DT)	3/6	50%
Riparian Shrub (RS)	2/6	33%
Water (WA)	1/6	17%

Mapped as Dryas River Terrace (DT) (RS,PV)

Vegetation Type	Frequency	Percentage
Dryas River Terrace (DT)	6/7	86%
Riparian Shrub (RS)	1/7	14%

Mapped as Partially Vegetated (PV) (BA)

Vegetation Type	Frequency	Percentage
Wet Graminoid with Moist Inclusions (WGM)	2/6	33%
Partially Vegetated (PV)	1/6	17%
Dryas-Graminoid Alpine Tundra (AT)	1/6	17%
Dryas River Terrace (DT)	1/6	17%
Barren (BA)	1/6	17%

Mapped as Barren (BA) (PV)

Vegetation Type	Frequency	Percentage
Barren (BA)	8/9	89%
Wet Graminoid with Moist Inclusions (WGM)	1/9	11%

Mapped as Water (WA)

Vegetation Type	Frequency	Percentage
Water (WA)	4/6	67%
Barren (BA)	1/6	17%
Riparian Shrub (RS)	1/6	17%

Appendix 2. Cross-reference of the land-cover classification scheme used for the map of the coastal plain of the Arctic NWR, 1994, to seven other classification schemes that have been used in northern Alaska. The first four schemes were developed for mapping land-cover on the Arctic Coastal Plain with remotely sensed data, while the last three were general vegetation classification schemes. The columns in the table are meant to be compared to the columns for the current Arctic NWR map only, not among each other.

LAND-COVER CLASSIFICATION SCHEMES FOR MAPPING THE ARCTIC COASTAL PLAIN								VEGETATION CLASSIFICATION SCHEMES			
Jorgenson *et al.* 1994 Land-cover Map of the Coastal Plain of the Arctic NWR			**Walker *et al.* 1982** LANDSAT-assisted Environmental Mapping in the Arctic NWR		**Markon 1985** Arctic NWR Land-cover mapping project	**North Slope Borough/GIS Division 1984** NSB GIS	**Russell *et al* 1992** Vegetation Map of Summer Range of Porcupine Caribou Herd in Yukon	**Viereck *et al.* 1992** The Alaska Vegetation Classification		**Driscoll *et al* 1984** Ecological Land Classification Framework for the U.S.	**Cowardin *et al.* 1979** Classification of Wetlands of the U.S.
Lifeform and moisture regime	LANDSAT-TM map land-cover classes	Subdivisions	Level III LANDSAT-MSS map land-cover classes	Level IV	LANDSAT-MSS map land-cover classes	Photo-interpreted map land-cover classes	LANDSAT-MSS map land-cover classes	Level III	Level IV		
Ice	Ice (IC)	Ice	XII Ice		Ice	Ice	Ice	N/A	N/A	N/A	N/A
Water	Water (WA)	Water	I Water		Water	Water	Water	N/A	N/A	N/A	Open Water
Wet Herbaceous	Wet Graminoid Tundra (WG)	Aquatic Graminoid	II Pond/Sedge Tundra Complex or Aquatic Tundra or Shallow Water	Shallow Water	Very Wet Graminoid	Freshwater Aquatic	N/A	Wet Graminoid Herbaceous	IIIA3d Freshwater Grass Marsh	N/A	Palustrine (P) Emergent (EM) - Persistent, OW/ Permanently Flooded
				IIa Pond/Sedge Tundra Complex							
				IIb Aquatic Tundra							PEM Permanently Flooded
		Salt Marsh	III Wet Sedge Tundra	IIId Wet Sedge Tundra (Saline Facies)	Wet Graminoid	Graminoid Wetland			IIIA3h Halophytic Grass Wet Meadow, IIIA3i Halophytic Sedge Wet Meadow	VC7b Sod Forming Short Grassland Tundra	Estuarine (E), Intertidal, EM Irregularly Flooded
		Wet Sedge and Wet Grass		IIIb Wet Sedge Tundra (very wet complexes)			Wet Alluvial (Wet Graminoid)		IIIA3e Wet Sedge Meadow Tundra		PEM Semi-permanently or Seasonally Flooded
	Wet Graminoid with 10-50% moist inclusions (WGM)	Low-centered Polygons and Strangmoor		IIIc Wet Sedge Tundra (moist complexes) (Up to 40% moist inclusions)	Moist Wet Tundra Complex	Mesic Graminoid Herbaceous					
Moist Herbaceous	Moist Sedge-Willow Tundra with 10-50% wet inclusions (MSW)	Low- and Flat-centered Polygons and Strangmoor	IV Moist/Wet Sedge Tundra Complex or Dry Prostrate Shrub, Forb Tundra	IVa Moist/Wet tundra complex (Up to 40% wet inclusions)				Mesic Graminoid Herbaceous	IIIA2h Sedge-Willow Tundra		PEM/Scrub-Shrub (SS), Broadleaf Deciduous Seasonally to Semi-permanently Flooded
	Moist Sedge-Willow Tundra (MS)		V Moist Sedge, Prostrate Shrub Tundra or Moist Sedge/Barren	Va Moist Sedge, Prostrate Shrub Tundra	Moist Prostrate Dwarf Shrub						PEM/SS Seasonally Flooded
	Moist Sedge-Dryas Tundra	Floodplain MSD Tundra					Dryas/Sedge		IIIA2j Sedge Dryas		PEM/SS Broadleaf

	Moist Sedge-Dryas Tundra	Floodplain MSD Tundra Foothill MSD Tundra Coastal Frost Scar MSD Tundra	or Moist Sedge/Barren Tundra Complex	Vb Moist Sedge/Barren Tundra Complex (frost scar tundra)			Dryas/Sedge		IIIA2j Sedge Dryas Tundra		PEM/SS Broadleaf Deciduous and Evergreen Saturated
	Moist Sedge-Tussock Tundra (TT)	Acidic Tussock Tundra Alkaline Tussock Tundra	VI Moist Sedge Tussock, Dwarf Shrub Tundra	VIa Moist Sedge Tussock, Dwarf Shrub Tundra (acidic facies) VIb Moist Sedge Tussock, Dwarf Shrub Tundra (alkaline facies)	Moist Graminoid Tussock		Tussock Tundra, 0-25% Shrubs		IIIA2d Tussock Tundra	VC7a Bunch Forming, Short Grassland Tundra	
Moist Shrub	Moist Shrub-Tussock Tundra and Water-track Shrub Tundra (STT)	Shrub-Tussock Tundra Water-track Shrub Tundra	VII Moist Dwarf Shrub, Sedge Tussock Tundra or Moist Sedge Tussock, Dwarf Shrub/Wet Dwarf Shrub Complex	VIIa Moist Dwarf shrub sedge tussock tundra VIIc Moist Sedge-Tussock, Dwarf Shrub/Wet Dwarf Shrub Tundra Complex (water-track complex)	Mesic Erect Dwarf Scrub (Dwarf scrub graminoid tussock)	Low Shrub	Tussock Tundra, 26-35% Shrubs	Open Low Scrub	IIC2a Mixed Shrub-Sedge Tussock Tundra	IVB3d Cold Deciduous Mixed Dwarf Shrubland	PSS Broadleaf Deciduous and Evergreen/ PEM Saturated
	Moist Shrub Tundra on High-centered Polygons (SP)			VIIb Moist Dwarf Shrub, Sedge Tussock Tundra (birch tundra)	Moist Prostrate Dwarf Shrub		Low Shrub Tundra		IIC2d Shrub-Birch/ Ericaceous Shrub Bog or IIC2e Ericaceous Shrub Bog	IVD1a Caespitose Dwarf Shrub/Moss Tundra	PSS Deciduous and Evergreen/ PEM, Seasonally Flooded to Saturated
	Moist Shrub Tundra on High-centered Polygons (SP)			VIIb Moist Dwarf Shrub, Sedge Tussock Tundra (birch tundra)	Moist Prostrate Dwarf Shrub		Low Shrub Tundra		IIC2d Shrub-Birch/ Ericaceous Shrub Bog or IIC2e Ericaceous Shrub Bog	IVD1a Caespitose Dwarf Shrub/Moss Tundra	PSS Deciduous and Evergreen/ PEM, Seasonally Flooded to Saturated
	Moist Low-Shrub Tundra (ST)		VIII Shrub Tundra	VIIIa Shrub Tundra VIIIb Shrub Tundra (Water-track complex)	Mesic Erect Dwarf Scrub		Dense Shrub Slope		IIC2f Shrub Birch/Willow IIC2g Willow	IVB3d Cold Deciduous Mixed Dwarf Shrubland	PSS Deciduous, Saturated
	Dryas-Graminoid Alpine Tundra (AT)	Moist Dryas-Ericaceous (snowbed) Moist Dryas-Horsetail Moist-Lush Dryas-Graminoid Dry Dryas-Lichen Alpine Tundra	IX Partially Vegetated Areas	IXb Alpine Tundra	Moist Prostrate Dwarf Scrub	Dry to Mesic Graminoid Herbaceous	Heath (Carex/ Vaccinium, Betula Heath Barren)	Ericaceous Dwarf Shrub Dryas Dwarf Scrub	IID2e Cassiope Tundra IID1b Dryas Sedge Tundra IID1e Dryas Lichen Tundra	IVD1b Matted Dwarf-Shrub Moss Tundra IVD2a Lichen Dwarf Shrubland	Non-Wetland
Dry Shrub			IV Moist/Wet Sedge Tundra Complex or	IVb Dry Prostrate Shrub/Forb Tundra	Dry Prostrate Dwarf Shrub	Dwarf Shrub	Lichen Barren (Dryas Heath Barren)				

				Shrub Tundra (Water-track complex)					Willow		
Dry Shrub	Dryas-Graminoid Alpine Tundra (AT)	Moist Dryas-Ericaceous (snowbed)	IX Partially Vegetated Areas	IXb Alpine Tundra	Moist Prostrate Dwarf Scrub	Dry to Mesic Graminoid Herbaceous	Heath (Carex/ Vaccinium, Betula Heath Barren)	Ericaceous Dwarf Shrub	IID2e Cassiope Tundra	IVD1b Matted Dwarf-Shrub Moss Tundra	Non-Wetland
		Moist Dryas-Horsetail						Dryas Dwarf Scrub	IID1b Dryas Sedge Tundra	IVD2a Lichen Dwarf Shrubland	
		Moist-Lush Dryas-Graminoid									
		Dry Dryas-Lichen Alpine Tundra	IV Moist/Wet Sedge Tundra Complex or Dry Prostrate Shrub, Forb Tundra	IVb Dry Prostrate Shrub/Forb Tundra	Dry Prostrate Dwarf Shrub	Dwarf Shrub	Lichen Barren (Dryas Heath Barren)		IID1e Dryas Lichen Tundra		
	Dryas River Terrace (DT)										
	Riparian Shrub (RS)	Low - open	VIII Shrub Tundra	VIIIa Shrub Tundra	Alluvial Deciduous Scrub	Low Shrub - open	N/A	Open Low Shrub	IIC2g Willow	IIIB3c Deciduous Alluvial Shrubland	PSS Broadleaf Temporarily Flooded
		Low - closed				Low Shrub - closed		Closed Low Scrub	IIC1b Low Willow		
		Tall - open				Tall Shrub - open		Tall Open Scrub	IIB2a Willow		
		Tall - closed				Tall Shrub - closed		Tall Closed Scrub	IIB1a Willow		
Sparsely Vegetated	Partially Vegetated (10 - 50% vegetative cover) (PV)	Alpine Slopes	IX Partially Vegetated Areas	IXb PV: Alpine Tundra	Scarcely Vegetated Scree	N/A	Lichen Barren	Dry Forb Herbaceous Tundra	IIIB1c Alpine Herbs	N/A	Non-Wetland
		Active River Floodplains		IXa PV: River Bars	Scarcely Vegetated Floodplain	Graminoid and Forb Herbaceous	Alluvial Barren		IIIB1a Seral Herbs		Riverine (R) Unconsolidated Shore, Irregularly Flooded
				IXc PV: Sorted Stone Nets		N/A		N/A	N/A		Non-Wetland
		Mudflats and beaches		IXd PV: Beaches	N/A		N/A				Marine (M), Unconsolidated Shore, Irregularly Flooded
		Sand Dunes		IXe PV: Sand Dunes							Non-Wetland
	Barren (<10% vegetative cover) (BA)		X Barren Gravel or Rock	X Barren Gravel or Rock	Barren Scree or Floodplain	Barren	Unvegetated	N/A	N/A	N/A	Non-Wetland
				XI Barren Mud or Wet Gravel							M, E, or R Unconsolidated Shore, Irregularly Flooded