Comparison of Three Methods for Mapping Tundra with Landsat Digital Data

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Abstract

Documenting the distribution of wildlife habitat on the Arctic National Wildlife Refuge (Arctic NWR) coastal plain in northeast Alaska is essential for determining potential impacts and mitigation of oil exploration and development. Landsat Thematic Mapper (TM) and ancillary data were used to map 14 cover types on a 13,000-km² portion of the Arctic NWR coastal plain. Three classification approaches were compared: supervised, unsupervised, and modeling. The model used ancillary layers representing elevation, slope, solar illumination, riparian zones, and terrain type in a postclassification sorting of the unsupervised spectral classes. Modeling resulted in the highest overall agreement with training areas (68 percent), but agreement with an independent data set was 48 percent, only slightly better than the other two approaches. Training data from an additional field season helped increase the overall agreement between the model and the independent data set to 52 percent. For wildlife studies, cover types from the map will be combined into fewer, more general, classes at acceptable levels of agreement. The TM map demonstrated a 27 percent improvement in agreement over a previous Landsat Multispectral Scanner (MSS) map, when a cover-type scheme of ten classes was compared for both maps.

Introduction

The coastal plain of the Arctic National Wildlife Refuge (Arctic NWR) in northeast Alaska is the single most promising onshore oil and gas exploration area in the United States (Clough *et al.*, 1987). Section 1002 of the Alaska National Interest Lands Conservation Act (ANILCA) of 1980 authorized limited exploration for oil and gas on a 5700-km² area of the Refuge's coastal plain "in a manner that avoids significant adverse effects on the fish and wildlife and other resources." The portion of coastal plain delineated by ANILCA for petroleum assessment, known as the 1002 area, incorporates the historical calving ground for the Porcupine caribou (*Rangifer tarandus*) herd (PCH) as well as nesting habitat of thousands of migratory shorebirds, songbirds, and waterfowl. Developing a reliable cover-type map to document important wildlife habitat on the Arctic NWR coastal plain is critical to mitigating potential impacts of oil exploration and development.

The difficulty involved in mapping cover types depends in part on the level of detail represented in a classification scheme. The coastal plain cover types identified in the most detailed scheme in this study are characterized by high spatial complexity and subtle structural differences. Cover-type maps of the area have been generated from Landsat Multispectral Scanner (MSS) data (Walker *et al.*, 1982; Markon, 1986). These maps described the general distribution of vegetation types across the coastal plain but did not provide the accurate, site-specific information needed for wildlife habitat studies (Felix *et al.*, 1987; Felix and Binney, 1989).

Landsat Thematic Mapper (TM) data became available for the eastern portion of the coastal plain in 1985. TM data provide finer spatial (30 m versus 79 m), radiometric (256 versus 64 levels), and spectral resolution than MSS data, as well as additional bands in the blue and mid-infrared wavelength regions (Lillesand and Kiefer, 1987). Preliminary work indicated that significant improvement in mapping the 1002 area was possible with TM data rather than with MSS data (Jacques, 1989).

The primary objective of this study was to determine the optimum method for producing a TM cover-type map of the eastern 1002 area that adequately addressed the needs of wildlife habitat studies. We compared three methods: a supervised classification, an unsupervised approach, and a model combining the unsupervised classification with ancillary data. Each method was assessed by comparing its map with botanical descriptions of site-specific ground conditions. The final TM map, produced from the modeling approach, was compared with the most recent MSS map (Markon, 1986) to determine the degree of improvement. Results from this study are being used to guide mapping of the western 1002.

Study Area

The eastern study area encompasses more than 13,000 km² of the Arctic NWR coastal plain and foothills in the northeast corner of Alaska. It is bounded by the Sadlerochit River to the west, the Alaska-Canada border to the east, the Beaufort Sea to the north, and the foothills of the Brooks Range to the south (Figure 1). The study area includes portions of two major North American physiographic divisions: the Interior Plains, represented by the Arctic Coastal Plain; and the Rocky Mountain System, represented by the Brooks Range (Wahrhaftig, 1965).

The climate is arctic with low precipitation, very low winter temperatures, and short, cool summers. Vegetation of the coastal plain tundra is a highly interspersed mosaic of low-growing shrubs, grasses, sedges, mosses, and lichens. Taller shrubs occur along drainages and in the upper foothills and mountains. Permafrost underlies most of the study area. The active layer is approximately 15 cm to 1 m thick,

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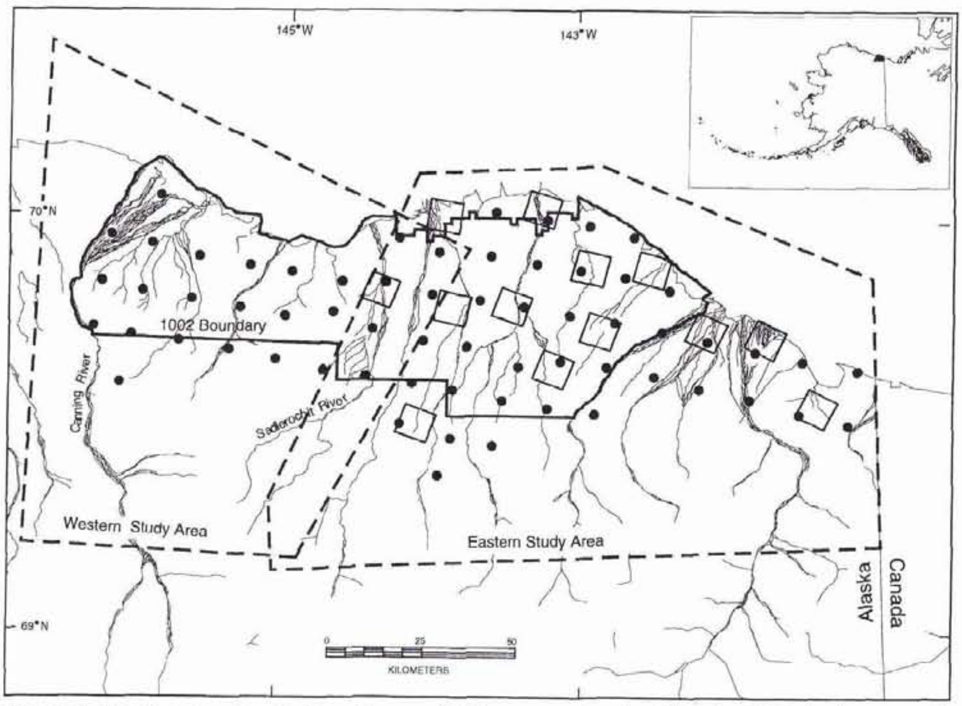

Figure 1. Study area showing locations of 13 scene subsets (256- by 256-pixel squares) used to build unsupervised signatures, and the 43 independent, systematically located sites (circles) used for final assessment of the maps.

and thaws each year between mid-May and mid-September. Garner and Reynolds (1986) give a more detailed description of the coastal plain environment.

Methods

Data Acquisition

Data layers used in the study included the Thematic Mapper image, digital elevation models (DEMs), major terrain types, riparian zones, and cover-type training areas (from both photointerpretation and field reconnaissance).

A TM scene from 7 July 1985 (I.D. #Y5049320412X0), extending from the Sadlerochit River to east of the Alaska-Canada border, was acquired from the Earth Observation Satellite Company (EOSAT) in computer-compatible tape (CCT) digital format. The scene was geo-referenced by the U.S. Geological Survey (USGS) EROS Data Center in Sioux Falls, South Dakota, to UTM Zone 7 using a second-order transformation (RMS < one pixel) and nearest-neighbor resampling. This was the most recent, nearly cloud-free TM scene available for the study area during the peak growing season (early July to mid-August).

Two types of elevation data were obtained from the (USGS) National Cartographic Information Center. Fifteen-minute DEMs, corresponding to 1:63,360-scale topographic maps, were available for approximately 83 percent of the study area. Where the finer resolution DEMs were not available, one-degree DEMs, corresponding to 1:250,000-scale maps, were used. Slope and solar-illumination layers were derived from the DEM data.

Five major terrain types (flat thaw-lake plains, hilly coastal plains, foothills, mountainous terrain, and river floodplains), each characterized by a combination of dominant landform, soils, and vegetation, have been described and mapped by Walker *et al.* (1982) for the entire 1002 area. USGS maps and the raw TM image were interpreted to extend the terrain-type map to include the remainder of the study area. The terrain types were digitized as an information layer in a geographic information system (GIS), and used for subsequent stratification of spectral classes.

A thematic layer depicting riparian zones was used primarily to help distinquish riparian shrublands from other shrub cover types. Riparian areas were identified on 1:18,000-scale, true-color aerial photographs acquired in the summer of 1981, visually transferred onto USGS maps, and digitized.

Aerial photographs were also used to identify training areas for the classifications. Most of the photographs were color infra-red (CIR), acquired at a scale of 1:6000 during the summers of 1985 and 1988. These were supplemented with the true-color, 1:18,000-scale photos enlarged to a scale of 1:9000.

Twenty-nine training sites, each approximately 2.5 km^2, were chosen subjectively from the photographs to represent the variety of cover types in the study area. Plots of apparently homogeneous vegetation were delineated on the photographs for each site. Quantitative data were collected at 8 to 12 plots in each site. Percent cover by plant species was determined using 200 pin placements from a vertical point frame (Hays *et al.*, 1981). Landform and average heights of major shrub species were recorded. The amount of ice-wedge polygon rims, troughs, frost scars, and inclusions of other vegetation types in the plot were measured on four systematically located 50-m transects. Descriptive information, including vegetation type, landform, and species composition, was collected at approximately ten additional plots at each site.

All ground plots were classified according to a vegetation scheme based on Walker's (1983) hierarchical classification of coastal plain vegetation and on TWINSPAN and DECORANA multivariate analysis of field data, following methods described in Gauch (1982) (Table 1). The land-cover

TABLE 1. COVER TYPES AND CLOSELY RELATED TYPES (IN PARENTHESES FOLLOWING DESCRIPTIONS) OF THE ARCTIC NWR COASTAL PLAIN, MOST RELATED ALONG GRADIENTS OF MOISTURE, SHRUB COVER, SPECIES COMPOSITION, OR TOTAL PLANT COVER.

Graminoid-dominated classes:

Aquatic graminoid (AG) - Permanently flooded sites with emergent graminoids. (WA, WS)

Wet sedge tundra (WS) - poorly-drained, seasonally flooded lowland areas dominated by the sedges *Eriophorum angustifolium* and *Carex aquatilis* or other graminoids, with little shrub and moss cover. Typical locations include wet coastal areas, centers and troughs of low-centered ice-wedge polygons, lake and stream edges and drained lake basins. (AG, WSM)

Wet sedge tundra with inclusions of moist sedge-willow (WSM) - 10-50% moist sedge-willow. Typically found in low-centered polygon complexes, in strangmoor and on abandoned floodplains. (WS, MSW)

Moist sedge willow tundra with inclusions of wet sedge (MSW) - 10-50% wet sedge. Found in mixed or flat-centered polygon complexes and on abandoned floodplains. (WSM, MS)

Moist sedge-willow Tundra (MS) - better-drained flat or sloped areas dominated mainly by the same sedges as wet sedge tundra, plus mosses and willows, usually *Salix planifolia* ssp. *pulchra*. Locations include gentle slopes, foothills slopes with poor tussock development, broad drainages and flat-centered polygons. (MSW, MSD, TT)

Moist sedge-*Dryas* tundra (MSD) - similar to moist sedge-willow, but dominated more by calciphiles, mainly the sedge *Carex bigelowii* and the prostrate shrub *Dryas integrifolia*. *C. bigelowii* hummocks and frost boils give a hummocky appearance. Found on loess-covered slopes and glacial deposits in the uplands, exposed areas near the coast, and on old floodplain deposits. (MS, TT)

Moist sedge-tussock tundra (TT) - Dominated by the tussock-forming sedge *Eriophorum vaginatum*. The main vegetation type on moderate slopes in the foothills and also common on high-centered polygons in the lowlands. (MS, ST, MSD)

Shrub-dominated classes:

Moist shrub tundra on high-centered polygons (SP) - A lowland complex of shrub tundra on polygons with wetter types in polygon troughs. Shrubs include *Betula nana*, *S. planifolia* ssp. *pulchra* or dwarf ericaceous shrubs. Often has senescent tussocks overgrown by shrubs and moss. (ST, TT)

Moist shrub tundra (ST) - Dominated by erect shrubs, mainly the low deciduous shrubs *B. nana* and *S. planifolia* ssp. *pulchra*. Shrub height is usually 20-50 cm. Includes shrub-dominated tussock tundra in the upper foothills, often interspersed with shrubby drainages, and densely shrubby slopes in the mountains. (SP, TT)

Riparian shrub (RS) - River terraces dominated by erect willows, typically with a forb understory. (DT, SP)

Dryas river terrace (DT) - dry terraces dominated by *D. integrifolia*, forbs and lichens. (RS, PV)

Dryas-graminoid alpine tundra (AT) - Gentle to steep slopes in the mountains and upper foothills, often drier and higher on slopes than moist shrub tundra. Includes all moist and dry alpine tundra dominated by prostrate rather than erect shrubs. Often has bare ground and lumpy surface due to solufluction. (PV, MSD)

Other classes:

Partially vegetated (PV) - 10-50% vegetated. Mainly steep slopes and floodplains. (DT, BA, RS)

Barren (BA) - < 10% vegetated. (PV)

Water (WA) - all water cover types. (AG)

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). They are also greatly affected by elevation and slope. Therefore, this vegetation scheme was deemed suitable to map land cover using Landsat TM spectral data combined with DEM data. Wildlife biologists were consulted to assure that the final scheme included cover types relevant to wildlife habitat studies, such as moist sedge-tussock tundra for caribou and riparian shrub for muskoxen (*Ovibos moschatus*). A more detailed description of the vegetation scheme used to label ground plots is presented in Jorgenson *et al.* (1994).

Additional training areas were photo-interpreted where the vegetation type could be identified confidently without ground visits. The outlines of all training plots were digitized, creating a training layer of 434 polygons.

Independent data for final assessment of the TM-based maps were collected systematically in 1989, providing statistical estimates of cover-type distribution on the coastal plain (the mountainous areas in the south were not sampled). A grid with 12.2-km square cell size was positioned randomly over the Arctic NWR coastal plain, rendering 43 sites centered at grid intersections in the area covered by this map (Figure 1). At each site, intersections on a second grid with 400-m square cell size were used to center 12 plots, each 15 metres in diameter. Vegetation type, estimated percent cover of all species with over 5 percent cover, landform, moisture regime, and the geographic extent of the vegetation type were recorded for each plot. Ground plots were used in the map assessments if (1) the cover type was homogeneous for a radius ≥ 50 m (resulting in an assessment bias to the extent that "edge" pixels were excluded); and (2) they could be located at a specific row and column in the image, based on physical features visible in the raw TM data, or if field notes indicated the cover type was extensive enough to compensate for slight location errors. The intent was to focus the assessment on the capabilities of TM, not on the geographic registration of ground plots. As a result, only 235 of the 516 systematic plots were included in the assessment.

Image Analysis

Supervised Classification

A spectral signature, comprised of the mean vector and covariance matrix for the six non-thermal TM bands, was extracted from each of the 434 training polygons. The signatures were grouped according to cover type and evaluated for within-type divergence. The Jeffries-Matusita (JM) Distance, a measure of statistical separability of signature pairs, was used to quantify divergence and to identify atypical training sites (Swain and Davis, 1978). Because only pair-wise comparisons were possible, it was necessary to first combine all signatures for a cover type into a single, generalized signature with which individual training site signatures for that type could be compared. JM values range from 0 to 1.414, with larger values signifying greater separability of signature pairs. A JM value of 1.342, indicating a maximum overlap of 5 percent between signatures, was chosen as the threshold for identifying signatures that were different from the generalized cover type. Training site signatures with a JM value ≥ 1.342 were flagged as outliers. Outliers were compared with the generalized signatures of all other cover types. If they were more similar to a different cover type, they were deleted. If they were most similar to their original label, they

Table 2. Overall Agreement between each of Three Classification Methods and Reference Data for 15 Cover Types on the Arctic NWR Coastal Plain.

Classifications	Training	Independent Data
Supervised	56%	43%
Unsupervised	52%	46%
Model	68%	48%

were retained as spectrally distinct examples of that cover type.

To further reduce the number of signatures, individual signatures in the same cover type were compared and combined if their JM distance was ≤ 1.000 (indicating a maximum overlap of 25 percent). Additionally, signatures derived from training sites with less than 30 pixels were deleted (except for water and aquatic graminoid classes because small training sites were typical of these categories). The result was 244 signatures, 84 of which were from combined signatures. Offshore water and ice were not represented in the photo-interpreted training areas. Signatures for these categories were extracted from the raw image before performing a maximum-likelihood classification (Swain and Davis, 1978) to produce the supervised classification map.

Unsupervised Classification

A modified clustering approach (Fleming, 1975) was used to develop unsupervised, statistical signatures based on all pixels in 16 subsets of the TM scene. The subsets, each containing 256 rows and 256 columns, were chosen to represent the spectral and land-cover variation in the scene, based on visual interpretation of the TM image. Thirteen of the subsets were located in the study area (Figure 1), and three were from a portion of the scene that extended onto the coastal plain of Canada, with the expectation of later mapping this area. A total of 440 spectral signatures, each composed of a mean vector and variance-covariance matrix for the six, non-thermal, TM bands, were derived from the subsets. Signatures were considered redundant and were deleted when their mean values (± 1 s.d.) overlapped in each of the six TM bands with a previously considered signature. This reduced the total to 131 signatures, which were used in an unsupervised, maximum-likelihood classification of the entire TM scene.

Spectral classes that could be identified visually as belonging to the same cover type (e.g., ice or water) were combined, reducing the number of map classes in the classified image from 131 to 110. Frequency distributions were produced comparing 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. These frequency distributions, and the spatial distribution of each spectral class across the entire scene, were considered in a subjective labeling of the spectral classes.

Modeled Classification

Ancillary data layers were used in a post-classification sorting of the unsupervised classes, in an attempt to improve the results of the baseline, spectral-only classification (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 cover types.

Proximity analysis was also used in the formulation of decision rules. Spectral classes consistently associated with a single cover type were defined as representative of that type. Individual pixels of other spectral classes that were less consistently associated were labeled as that cover type if they were adjacent to a pixel of a representative spectral class. The effect was a selective smoothing of the classification, with representative pixels acting as "magnets" to attract similar, neighboring pixels.

Many of the 110 spectral classes were modeled separately to test different decision rules and sequences of rules to improve the sorting for the class. Output of the individual class models was evaluated by cross-referencing with the training areas. Once individual classes had been tested and evaluated, all decision rules were combined in a single model to produce a map. The map was then visually evaluated to determine whether decisions based on the training data were suitable for the scene as a whole. Changes to the decision rules were made as necessary. The process was repeated through several iterations before the modeled map was produced.

Results and Discussion

Preliminary Assessment of the Three Methods

Overall agreement between the maps produced from the three classification approaches and the training set pixels ranged from 52 percent to 68 percent, with the modeled map having the highest level of agreement (Table 2). Estimates of agreement derived from training sets are typically inflated, because (1) the same data are part of both the classification and testing process; and (2) by design, training data are good, homogeneous examples of cover types (Lillesand and Kiefer, 1987). Levels of agreement with the independent data were much lower and varied less between the three approaches (43 to 48 percent), though agreement with the model was still highest.

Supervised classifications have been considered more effective than unsupervised classifications for characterizing information classes that are only marginally separable, because of the analyst's increased control in defining signatures (Ferguson, 1991; Matthews, 1991; Swain and Davis, 1978). However, of the three approaches, the supervised classification demonstrated the lowest level of agreement with the independent data. Comparison of signatures from the training areas provided some measure of the spectral confusion between cover types in the current scheme. Approximately 11 percent (46) of the signatures were identified as outliers, or different from the generalized signature for their cover type. Of these, 44 were more similar to another cover type and were deleted, one was most similar to its original type, and one showed complete spectral separability (JM = 1.414) from all generalized signatures.

The generalized signatures were also compared before and after outlier signatures were removed. Those pairs with a JM distance ≤ 1.000 are listed in Table 3. Spectral separability was poor even after outlier signatures were removed, indicating that either ancillary data must be used or the vegetation scheme altered (e.g., some types combined) if satisfactory separation of the remaining cover types was to be achieved.

Ancillary data are often used in attempts to improve spectral-based classifications. The data may be used before (stratification), during (typically, as added bands), or following (post-classification sorting) the spectral classification (Hutchinson, 1982). The post-classification sorting used in this model improved overall agreement with the training set by nearly 16 percent over a spectral-only (unsupervised) classification (Table 2), most likely because it used more of the available information to fit the training data. However, there was little improvement in agreement with the independent set. The modeling created a map more closely tai-

TABLE 3. JEFFRIES-MATUSITA (JM) DISTANCE FOR COVER-TYPE PAIRS WITH LEAST SPECTRAL DIVERGENCE (JM ≤ 1.000), BEFORE AND AFTER OUTLIER SIGNATURES WERE REMOVED.

Cover Types		JM Distance All Signatures	JM Distance Minus Outliers
MS	MSD	0.419	0.444
AG	WS	0.718	0.727
MSW	MS	0.777	0.848
RS	DT	0.800	0.805
MSW	MSD	0.800	0.893
MSW	DT	0.839	0.883
MS	TT	0.843	0.907
TT	SP	0.851	0.866
MSD	TT	0.904	0.887
WSM	MS	0.907	0.925
WSM	MSW	0.933	0.932
WS	MSW	0.949	0.902
WSM	MSD	0.953	1.024
AG	WSM	0.974	1.028

lored to the characteristics of the training set, not necessarily to those of the coastal plain as a whole. This may be due to inadequacies in the training data, the modeling process, or the independent data.

The training areas were not systematic or random samples of the study area, and the cover types were not sampled in proportion to their occurrence. Therefore, fitting the model to maximize agreement with the training data would have reproduced the biases of the sampling. The entire map was visually evaluated after each iteration of the modeling process by botanists with considerable field experience in the study area. This may not have been an adequate substitute for representative data. There is some evidence that analyst familiarity with a study area is not sufficient, or even predictably related, to improved labeling of spectral classes (McGwire, 1992). However, random or systematic sampling of remote areas, at sufficient intensity to include rare cover types, is usually impractical. Greater reliance on subjective labeling by those familiar with an area is typically the only affordable alternative.

Another possibility was that the sample size (235 pixels) of the independent set was too small to reflect the changes the model made to the entire map, indicating that the independent set was also too small to assess the entire map. To test this, the cover types assigned to these pixels in the unsupervised classification were compared with their label in the modeled classification. Approximately 39 percent of the 235 pixels were assigned to a different class as a result of the modeling. This is similar to the change the model caused in the training areas (39 percent) and for all coastal plain pixels (42 percent), suggesting that the independent set was indeed reflecting changes made to the entire map.

The spatial complexity and subtle transition zones that characterize coastal plain and foothill vegetation have made the area difficult to classify at several different resolutions or levels of detail. Results from a study of the foothill region, using 20-m resolution SPOT XS data and a cover-type scheme with six categories, indicated a 56 percent overall agreement with reference data (Stow *et al.*, 1989). Interpretation of 1:6000-scale CIR aerial photos of the coastal plain was found to be correct only 75 percent of the time when compared with ground data (Raynolds and Felix, 1986). Even reliable ground, or reference, data are difficult to obtain. Previous studies in the Arctic NWR have shown that it is common for two trained observers to assign different vegetation types to the same area (USFWS-Arctic NWR unpublished data).

Some of the confusion in the modeled map reflects this difficulty in classifying plots on the ground (Table 4). Although categories in the vegetation scheme are distinct, subtle transition zones between cover types on the coastal plain make it difficult to distinguish types in the field. Ground plots used in the final assessments had been assigned a qualitative confidence level from one to three, with one being most similar to the definition for that cover type. Agreement of the modeled map with Level 1 plots is 56 percent, and decreases with decreasing confidence in ground calls (41 percent and 37 percent for Levels 2 and 3, respectively).

Assessment of the Final Map

The preliminary results indicated that modeling was slightly more promising than the other two approaches. Training data from an additional field season were used to further refine the model. In order to avoid bias, the botanists who refined the decision rules were not shown any previous assessments with the independent data. Agreement with the expanded training set was 59 percent, less than the 68 percent agreement produced for the earlier model and training set. This is due, in part, to more emphasis being placed on visual analysis of the overall map when formulating decision rules for the final model, rather than optimizing agreement with the training data. In the final map, aquatic graminoid was no longer treated as a separate class, but was included in the wet sedge (WS) class.

Results from this final map are shown in Table 5. Cover types are ordered in the table so that adjacent types are closely related, primarily along a moisture gradient. The degree of spread from the major diagonal in the table therefore indicates the magnitude of error in the misclassifications. The overall agreement with the independent data rose from 49 percent for the earlier model (with AG included in WS) to 52 percent for the final map. Approximately 82 percent of the assessment pixels were classified as the correct type or one of the closely related types listed in Table 1.

Final assessments using the independent data refer only to the coastal plain, because mountainous areas to the south were not included in the systematic ground sampling. Including the mountains would likely increase the levels of agreement slightly, due to the prevalence of the barren (BA) cover type in this area. In the assessment, barren plots were mapped correctly, or as partially vegetated ground, 80 percent of the time. Barren plots misclassed as water appeared as slightly submerged, barren alluvial fans or riparian gravel in the raw TM data. The confusion between barren and water classes in both contingency tables is most likely due to the difference in dates between scene acquisition and ground-truthing, with higher water levels at the time the TM scene was acquired.

The 14 map classes may be combined to fit the more general types required by some of the specific wildlife habitat studies. For example, analysis of caribou habitat required a map generalized to just six categories (Table 6). At this level of detail, the map provided sufficiently reliable information (74 percent agreement) for wildlife biologists to strat-

TABLE 4. FREQUENCY OF MODEL CLASSIFICATION AGREEMENT WITH GROUND PLOTS OF VARYING CONFIDENCE LEVELS (LEVEL 1 = MOST CONFIDENT GROUND PLOT REPRESENTS THAT COVER TYPE).

Ground Plot Confidence Level:	Number of Plots Agree (Row %)	Disagree (Row %)	Total (Col. %)
1	64 (56)	51 (44)	115 (49)
2	38 (41)	54 (59)	92 (39)
3	10 (37)	17 (63)	27 (12)
All Levels:	112 (48)	123 (52)	234 (100)

Table 5. Contingency Table Comparing Final Map (Modeled Approach) and Independent, Assessment Data.

		Independent Data Set															
		WA	WS	WSM	MSW	MS	TT	SP	ST	RS	DT	AT	MSD	PV	BA	Total	Commission Error
Model	WA	3								1					1	5	40%
	WS		2	1	1						1					5	60%
	WSM		5	17	4	2		1		1	2		6			38	55%
	MSW		3	9	8	5										25	68%
	MS				2	13	4						3			22	41%
	TT			1	6	2	48	5					7			69	30%
	SP			1			1	6								8	25%
	ST			1		1	5		8			2				17	53%
	RS	1								2	3					6	67%
	DT									1	6					7	14%
	AT								1			1				2	50%
	MSD			4		6	4				1	2	3			20	85%
	PV			2							1	1		1	1	6	83%
	BA			1											3	4	25%
	Total:	4	10	37	21	29	62	12	9	5	14	6	19	1	5	234	
	Omission error:	25%	80%	54%	62%	55%	23%	50%	11%	60%	57%	83%	84%	0%	40%		

Overall agreement (diagonals/total): 52%
Estimated kappa for overall agreement: 0.437
95% confidence interval for estimated kappa: [0.365, 0.509]

ify ground sampling efforts, resulting in more efficient study designs. The six categories also proved to be suitable for assessments of habitat parameters and use by caribou, with numerous statistically significant differences found between categories (Griffith and Walsh, 1993; USFWS-Arctic NWR, unpublished data). Similar recombinations are being done for other species of concern. The greater initial detail allowed the map to be more adaptable to a wider range of studies.

The 52 percent level of agreement for the TM-based map represents a 15 percent improvement over the 37 percent reported for a previous map using Landsat MSS data (Felix and Binney, 1989). However, the methods used for assessing the two maps differ significantly. The assessment of the MSS map was based on relatively large areas (10 to 100 ha) identified as polygons of uniform cover type on the map. These were then visited in the field and categorized according to the predominant cover type. Assessment of the TM map is site-specific, starting with relatively small areas ($\geq$ 1 ha) identified in the field as homogeneous cover and locating these areas on the map.

A more direct comparison with the MSS map was attained by assessing it with the same, independent data used to test the TM map. The cover-type scheme in the MSS map

Table 6. An Example of a more General Grouping of Cover Types to Achieve an Acceptable Level of Agreement while Maintaining Categories that Are Relevant to a Particular Habitat Study.

		Caribou Habitat Classes Independent Data						
		1	2	3	4	5	6	
Model	1	45	4	4	6			
	2		23	5	3			
	3		1	50	13	4		
	4	2	6	6	25	1		
	5					17	1	
	6			3	1	2	13	
	Total:	47	34	68	48	24	14	235
		Overall Agreement: 74%						

1 = Tussock Tundra Slopes and Shrubby Foothills
2 = High-centered Polygons (mainly flat TT with MS troughs)
3 = Wet Tundra (Low-centered Polygons & Strangmoor)
4 = Non-tussock Moist Sedge Tundra
5 = Riparian
6 = Other

was translated into the current system. This involved combining some of the current cover types into more general categories (i.e., MSW/WSM, MS/MSD, ST/SP, and DT/AT). When the same methodology, cover-type scheme, and ground plots were used to assess the two maps, the TM map demonstrated an improvement of 27 percent (62 percent versus 35 percent for ten categories) over the earlier MSS map.

Summary and Conclusion

Of the three methods (supervised, unsupervised, and modeling) used to produce cover type maps of the Arctic NWR coastal plain, modeling produced the highest levels of agreement. Examination of signatures used in a supervised classification indicated that use of spectral data alone does not result in a high degree of discrimination between the cover types defined in the current scheme. A model using ancillary data indicated significant improvement over a spectral-only (unsupervised) classification when compared with training data. However, the improvement was shown to be only marginal when assessed with site-specific, independent data.

Confusion in the maps was shown to reflect, in part, confusion on the ground. Subtle transitions between coastal plain cover types, and the common occurrence of complex mosaics of two to four different cover types in an area smaller than a TM pixel, made it difficult to definitively label types on the ground. Ground plots that could be labeled with a high degree of confidence were more likely to be mapped correctly.

Overall agreement for the final model and independent data was 52 percent for 14 categories. Six classes relevant to caribou habitat were mapped at a 74 percent level of agreement, indicating that the map may be adapted successfully to some habitat studies. Comparison with a previous MSS map indicated a 27 percent improvement, at the class generality of ten cover types, using TM data.

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