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Ducks Unlimited, Inc.

National Petroleum Reserve-Alaska Earth Cover Classification



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Cover

The cover photo depicts the remoteness of the area and the need to use helicopters for data collection.

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National Petroleum Reserve - Alaska Earth Cover Classification

Technical Report 40
September 2002

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Abstract

The National Petroleum Reserve in Alaska (NPR-A) includes more than 9.3 million hectares (23.0 million acres) and is located on the North Slope of Alaska. The northern half of the NPR-A falls within the Arctic Coastal Plain physiographic province which contains one of the largest and most stable collections of wetlands in North America. Currently, with the potential for oil development extending into areas, other than Prudhoe Bay, an Environmental Impact Statement (EIS) is being prepared for the Northeastern Planning Area of the NPR-A.

The objective of this project was to create an updated and detailed earth cover inventory in computer database format for the entire NPR-A. The purpose of the project was to develop a tool for aiding in the management of the NPR-A and for developing baseline information that could be used in other studies. This inventory is currently included in the Environmental Impact Statement for the Northeastern Planning Area of the NPR-A. It is also included in the waterfowl earth cover selection analysis that created selection indexes based on earth cover types for seven different waterfowl species.

Landsat Thematic Mapper (TM) satellite imagery was chosen as the primary source for this mapping because it is a cost effective data source for regional mapping, can be processed using automated mapping techniques, and is collected on a repeat cycle, providing a standardized data source for future database updates. In addition, TM imagery includes a mid-infrared band, which is sensitive to both vegetation and soil moisture content and has proven useful in identifying water and wetland features. Eight Landsat TM satellite scenes and three *Système Pour l'Observation de la Terre* (SPOT) satellite scenes were used to classify the NPR-A into earth cover categories. An unsupervised clustering or seeding technique was used to determine the location of field sites and a custom field data collection card was used to record field information. After initial on-the-ground sampling, a helicopter was used to access field sites throughout the project area. Global positioning system (GPS) technology was used to navigate to preselected sites and record locations of new selected sites. Data were collected on 1,667 field sites during a three year field season from 1994 through 1996. A portion (46%) of these field sites were set aside for accuracy assessment.

A combined supervised/unsupervised classification technique was performed to classify the satellite imagery into seven major classes and seventeen minor classes. As each scene was completed it was mosaicked and edge matched with adjacent scenes to produce a seamless database of the NPR-A.

The results of this classification suggest dominant earth cover of the NPR-A at 43% shrub, 31% moist tundra, 11% water, 6% flooded tundra, 5% wet tundra, 2% aquatic, and 2% barren ground. The overall accuracy of the major categories was 85%, with a 75% overall accuracy for the minor categories. The cooperators in this project included Bureau of Land Management-Alaska; Ducks Unlimited, Inc.; U.S. Fish and Wildlife Service; and North Slope Borough.

National Petroleum Reserve – Alaska

Earth Cover Classification

Introduction

Presidential declaration established the 9.3 million hectare (23.0 million acre) Naval Petroleum Reserve No. 4 in 1923. In 1976, management responsibility of the Reserve was transferred to the Department of the Interior and the area was renamed the National Petroleum Reserve in Alaska (NPR-A). NPR-A is located on the North Slope of Alaska, much of which falls within the Arctic Coastal Plain physiographic province. The Arctic Coastal Plain contains one of the largest and most stable collections of wetlands in North America (Wellein and Lumsden, 1964). Lake and emergent marsh coverage is estimated at 50 % of the total area (Hussey and Michelson, 1966). These wetlands support large numbers of breeding and postbreeding waterfowl, loons, terns, gulls, and shorebirds, including the federally listed spectacled and Steller's eiders (listed as Threatened under the Endangered Species Act of 1973, as amended). The king eider migration is estimated at one million birds passing Point Barrow (King and Lensink, 1971). The interspersed tundra habitats are used by caribou, brown bear, polar bear, foxes, lemmings, ptarmigan, passerines, and raptors.

The NPR-A contains shallow soils overlying continuous permafrost and mimics desert precipitation levels with less than 10.9 cm (4.3 inches) during the average year. The cool summer growing season is approximately 6 weeks in length with continuous 24 hour daylight. In the northern

part of the NPR-A that falls within the Arctic Coastal Plain, there are millions of thermokarst pits and large oriented-thaw-lakes. This region of the NPR-A has little or no relief. The southern part of the NPR-A is part of the Arctic Foothills Province and is typified by rolling hills and tussock tundra/dwarf shrub vegetation.

The most prominent features of the arctic coastal plain are the large oriented-thaw-lakes and second or later generation wetland landscape (Black and Barksdale, 1949; Walker and Acevedo, 1987; Markon and Derksen, 1994). Morphology of the oriented-thaw-lakes changes with stages of development (Figure 1). At the first stages, the formation of low centered polygons are caused by ice wedges. The second stage consists of low centered polygons connecting to form small round ponds. During the third stage the small ponds connect to form a mature oriented lake showing NNW-SSE axis. Prevailing winds cause faster erosion at the head and foot of the lake. In the fourth stage, all but the deepest parts of the lake are drained due to an outlet that was cut through the permafrost by the eroding head and foot of the lake. During the fifth and final stage, the polygonal substrate begins to reassert influence but the shoreline of the lake bed is still present. The satellite imagery used in this study can be used to identify the different stages of oriented-thaw-lake basin development (Figure 2).

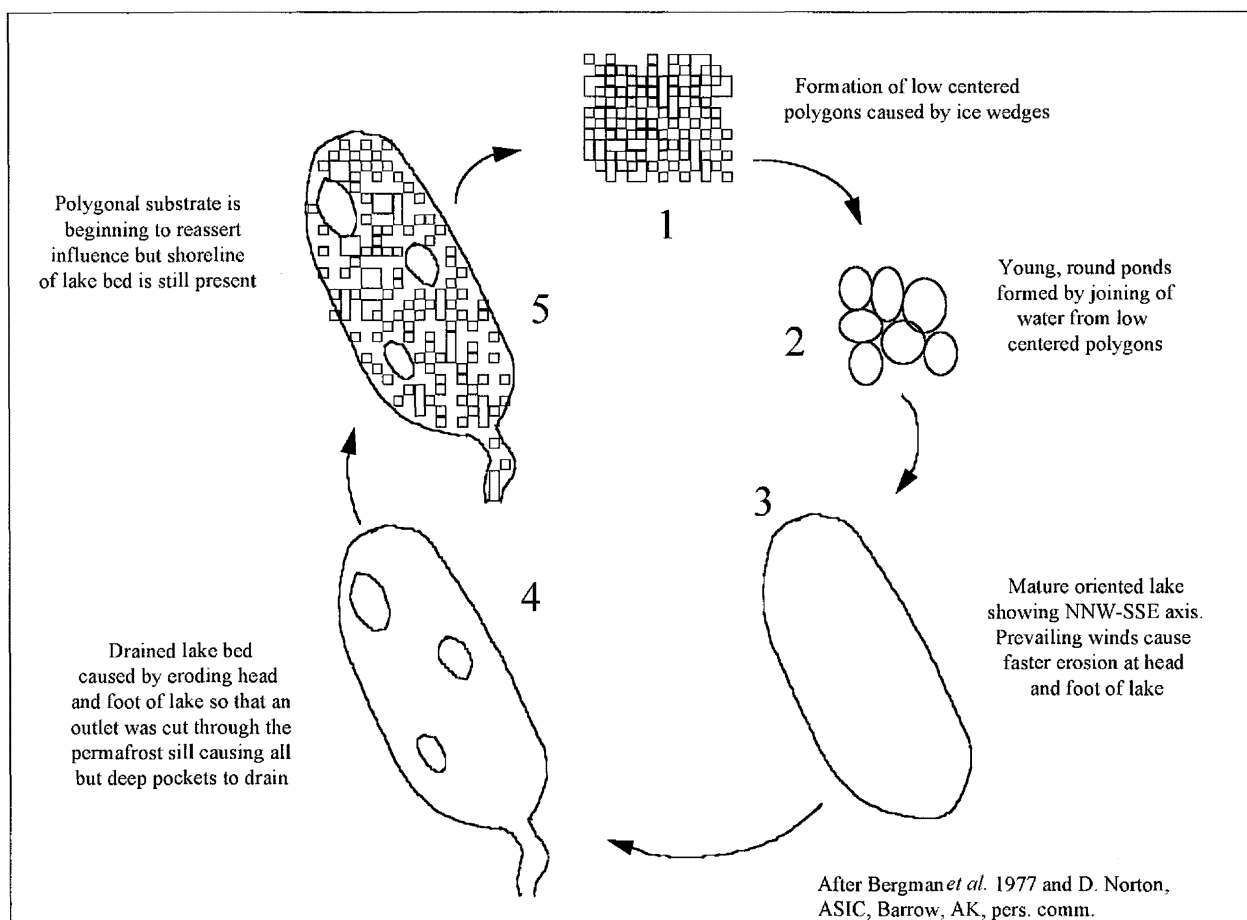


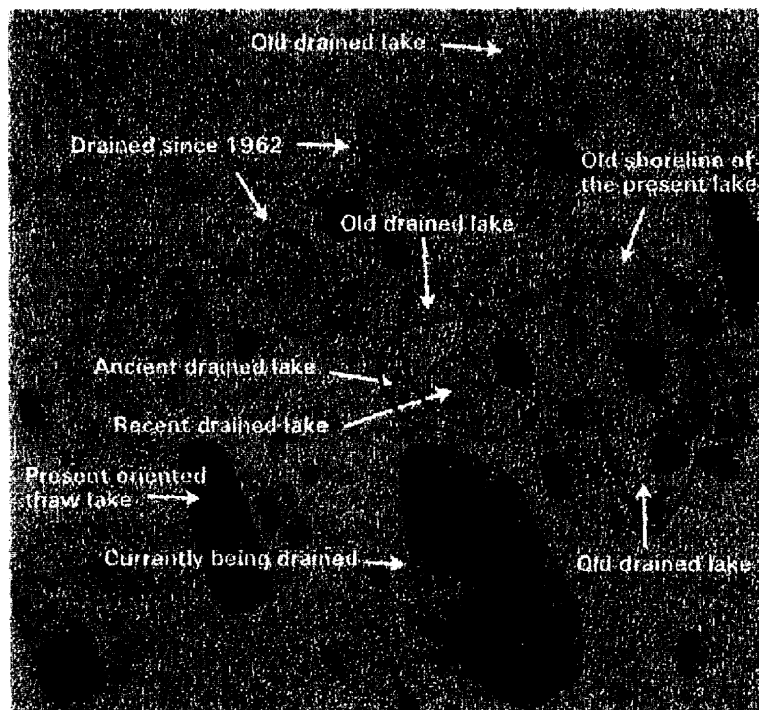
Figure 1. The morphology of the oriented -thaw-lakes of the NPR-A.

Land management decisions are often made about this region which has little or no information regarding the size, distribution, and type of earth cover categories. Federal and state agency resources staff responsible for managing projects and addressing public issues is relatively small in relation to the huge land mass in Alaska. Previous work has concentrated on the Teshekpuk Lake area using *Système Pour l'Observation de la Torre* (SPOT) satellite imagery from 1986 (Markon and Derksen, 1994) and the NPR-A using Landsat MSS data from 1977 (Morrissey and Ennis, 1981). The arctic coastal plain is very difficult to evaluate because of the numerous wetland basins,

lack of roads, rapidly changing weather conditions, and numerous cloud cover days.

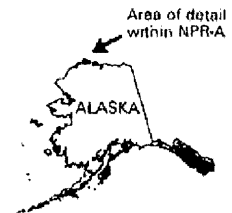
Landsat Thematic Mapper (TM) satellite imagery was chosen as the primary mapping source because it is a cost effective data source for regional mapping, can be processed using automated mapping techniques and is collected on a repeat cycle, providing a standardized data source for future database updates. In addition, TM imagery includes a mid-infrared band, which is sensitive to both vegetation and soil moisture content and is useful in identifying water and wetland features.

Different Stages of Lake Development



Landsat Thematic Mapper Scene
Path 79/Row 10 Shifted 21% South
July 8, 1992

Band Combination : 4,3,2



Source : Carson and Hussey 1982

Figure 2. An example of ancient and present oriented-thaw lakes.

The need for natural resources data in this area of Alaska is a priority due to heightened interest in onshore oil development. In the past, the oil exploration and development has been principally east of the NPR-A in the vicinity of Prudhoe Bay. Currently, with the potential for oil development extending into other areas, an Environmental Impact Statement has been completed for the Northeastern Planning Area of the NPR-A (USDOI, BLM 1998). As development in the arctic expands, identification of critical wildlife habitats is essential to make viable land use decisions. This earth cover inventory is currently being included in the Environmental Impact Statement for the Northeastern Planning Area of the NPR-A. It is also used in the waterfowl earth cover selection analysis that created selection indexes for seven different waterfowl species (Morton *et al.* 1998).

The NPR-A project is split into three phases due to the immense size of the project area, limited field access caused by harsh climate regime, and lack of aircraft support infrastructure. These phases were planned for completion in 1995, 1996, and 1998. The cooperators in this project include BLM-Alaska, Ducks Unlimited, U.S. Fish and Wildlife Service, North Slope Borough and Pacific Meridian Resources.

Project Objective

The objective of this project is to develop a baseline earth cover inventory using Landsat TM and SPOT XS satellite imagery in geographic information system (GIS) form for the NPR-A. This project will result in a GIS database that can be used for improved natural resources planning, such as monitoring the condition of various wetland

communities. These data will also be valuable in modeling the type of habitat that is being used by various wildlife species, such as the threatened spectacled and Steller's eiders.

Project Area

The NPR-A is located on the North Slope of Alaska and encompasses 9.3 million hectares (23.0 million acres) (Figure 3). Due to its immense size, the project area was divided into a Western, Eastern, and Southern phase. (Figure 3). The Western phase was completed in May 1995 and is dominated by the large, flat expanses of lake and wetland complexes of the Arctic Coastal Plain. The Eastern phase was completed in May 1996 and is composed of the large flat expanses of lake and wetland complexes typical of the Arctic Coastal Plain in the north, and shrub and herbaceous types in the Arctic Foothills Province to the south. The Southern phase was completed with this report and is characterized by upland shrub and herbaceous types intermixed with wetland complexes of the Arctic Foothills Province and large bare and sparsely vegetated mountains and river valleys of the Brooks Range. The boundary of the NPR-A was buffered by 3 km along the coast and 15 km inland for the final classification.

The NPR-A encompasses three Physiographic regions. The first region is the Arctic Coastal Plain, which is an emergent portion of the coastal shelf that has characteristically long cold winters and short cool summers (Carson and Hussey, 1962). In areas near the coast, snow remains on the ground until late June and ice is on the deeper lakes until late July. Shallow soils remain frozen from mid-September to

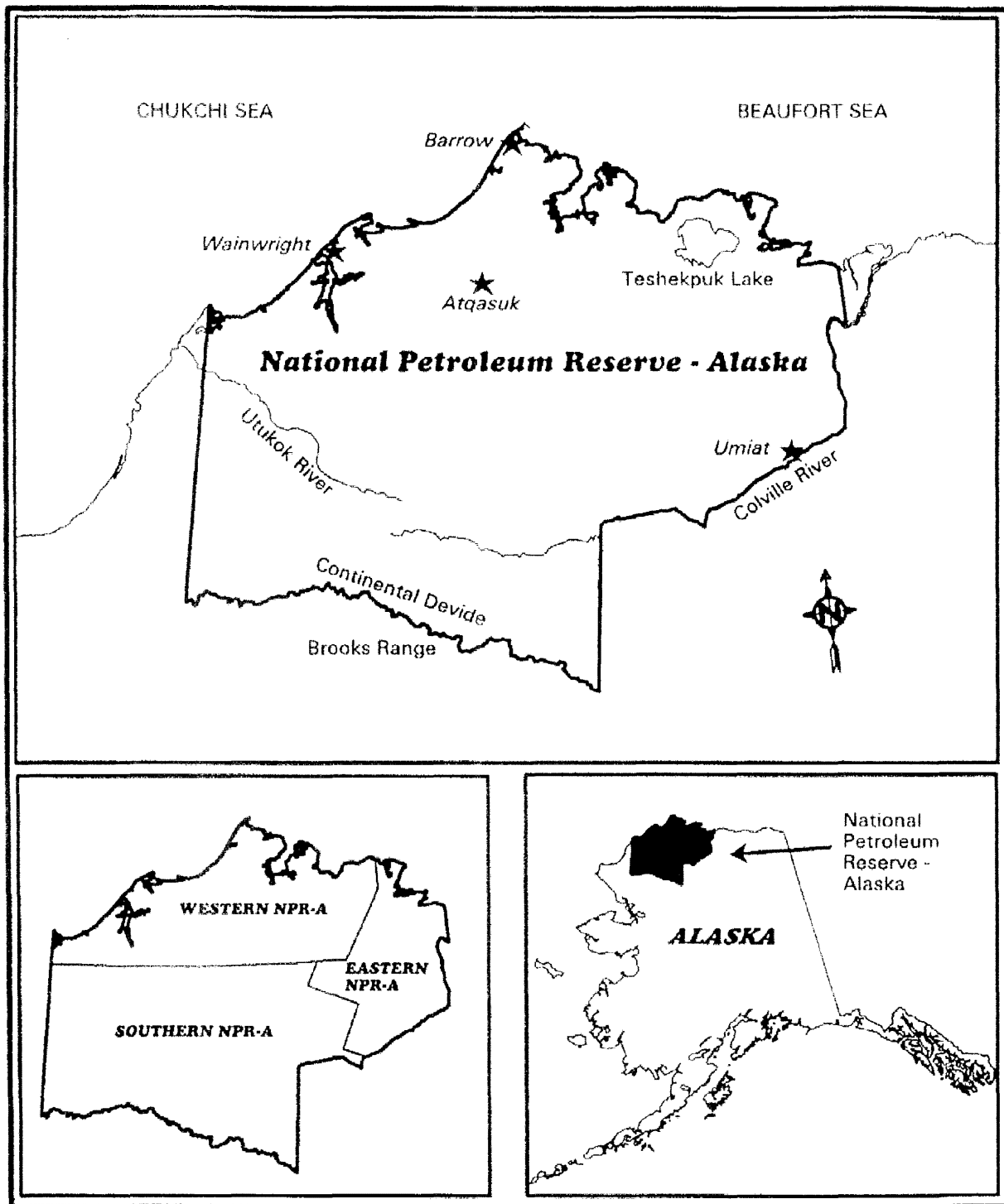


Figure 3. The Project Location for the NPR-A Earth Cover Mapping.

mid-May and are underlain by continuous permafrost, which contains marine silts, sands, and gravels of the Pleistocene Gubik Formation (Felix and Binney, 1989; Carson and Hussey, 1962). In the Arctic Coastal Plain the size of the lakes ranges from a few meters to approximately 7 km by 2 km (4.3 miles by 1.2 miles) (Black and Barksdale, 1949). The only major relief in the Arctic Coastal Plain is caused by the gentle undulations characteristic of most continental shelves (Carson and Hussey, 1962). The local relief is consistent with most tundra regions where there is permafrost below 24-48 cm (9-19 inches). It consists of polygonal patterned ground caused by the accumulation of ice in large contraction cracks and thaw basins. The diameter of the polygonal areas range from 3 to 30 meters (10 to 100 feet) (Carson and Hussey, 1962). The vegetation is composed of tundra with low-growing plants, including dwarf shrubs, sedges, grasses, forbs, mosses, and lichens (Felix and Binney, 1989; Derksen *et al.* 1981).

The second ecological zone is the Arctic Foothills Province. This region is characterized by low, rolling hills and east-west-trending ridges covered by dwarf shrub and tussock tundra. The Arctic Foothills Province starts about 90 miles inland from the coast and continues to the Brooks Range. The elevation ranges from 500 feet to 1150 feet. The region is underlain by continuous permafrost as in the Arctic Coastal Plain, but the lakes are fewer and deeper. The third region is the Brooks Range, characterized by

large bare and sparsely vegetated mountains and river valleys. The southern boundary of the NPR-A is the continental divide of the Brooks Range.

Data Acquisition

The entire 9.3 million hectare NPRA was mapped using eight Landsat Thematic Mapper (TM) images and three SPOT XS images. The SPOT images were used in the Eastern phase in an area where no suitable Landsat TM imagery was available. The ancillary data used in this project included: National Aeronautics and Space Administration (NASA) 1:60,000 aerial photographs (color prints, 1977; color infrared prints 1985; and color infrared transparencies, 1979); Digital hydrographic data from United States Geological Survey (USGS) Digital Line Graph data edited by the North Slope Borough (1993); National Wetlands Inventory (NWI) 1:63,360 hard copy maps from the U.S. Fish and Wildlife Service; and point locations of eider sightings from the U.S. Fish and Wildlife Service surveys in the spring of 1994.

For the Western Phase, two Landsat TM images were used to classify the project area (Figure 4). One Landsat Thematic Mapper image and three SPOT XS satellite images were used to classify the Eastern phase and portions of five Landsat TM images were used to classify the Southern phase (Figure 4) (Table 1).

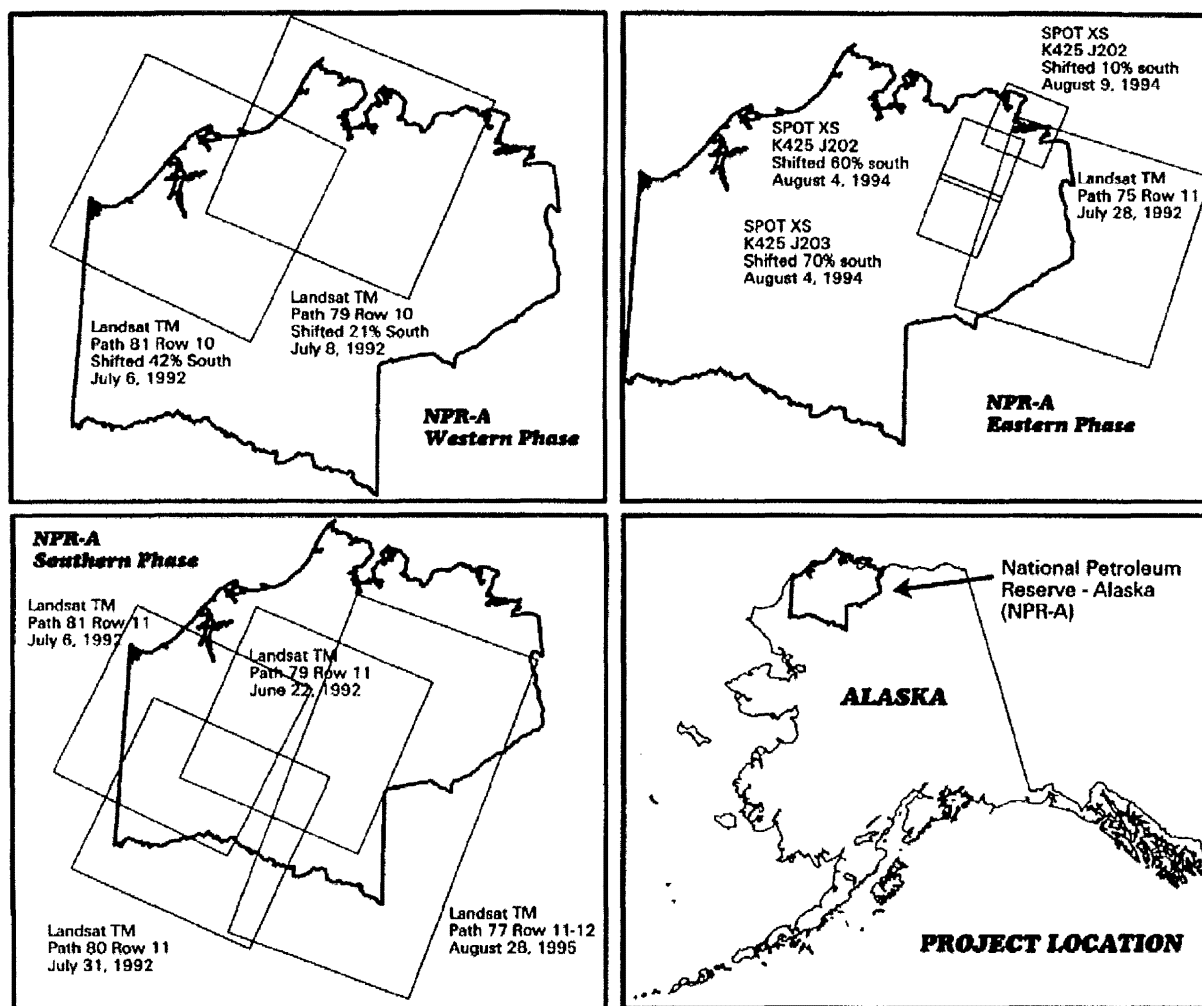


Figure 4. Scene Location for the Western, Eastern, and Southern NPR-A.

Table 1. The satellite imagery used for the NPR-A earth cover mapping project.

PHASE #	SENSOR	PATH/ROW	% SHIFT	DATE
1	Landsat Thematic Mapper (TM)	81/10	42%	6-Jul-92
1	Landsat Thematic Mapper (TM)	79/10	21%	8-Jul-92
2	Landsat Thematic Mapper (TM)	75/11	0%	28-Jul-92
2	SPOT XS	k425/j202	10%	9-Aug-94
2	SPOT XS	k425/j202	60%	4-Aug-94
2	SPOT XS	k425/j203	70%	4-Aug-94
3	Landsat Thematic Mapper (TM)	77/11	0%	28-Aug-95
3	Landsat Thematic Mapper (TM)	77/12	0%	28-Aug-95
3	Landsat Thematic Mapper (TM)	80/11	0%	31-Jul-92
3	Landsat Thematic Mapper (TM)	81/11	0%	6-Jul-92
3	Landsat Thematic Mapper (TM)	79/11	0%	22-Jun-92

Methods

Classification Scheme

The first step in any mapping project is the definition of a classification system that categorizes the features of the earth to be mapped. The system is derived by anticipated uses of the map information and discernable features of the earth (e.g., satellite imagery, aerial photography, or field information) used to create the map. A classification system has two critical components: (1) a set of labels (e.g., forest, shrub, water); and (2) a set of rules, or a system of assigning labels. It is important that the rules for assigning labels be both mutually exclusive and totally exhaustive (Congalton 1991). Any area to be classified

should fall into one and only one category or class and every area should be included in the classification.

The classification scheme for the land cover inventory was developed through a series of meetings with biologists familiar with the vegetation and previous work, i.e. Markon and Derkson 1994. The classification scheme consisted of seven major categories and seventeen subcategories (Table 2). The definitions for the classification scheme, a decision tree, and written descriptions were developed in order to eliminate any confusion in the classification (see Appendices A-C). Examples of each class are located in Appendix D.

Table 2. The classification scheme for the NPR-A earth cover classification.

<u>1.0 Water</u>	<u>5.0 Moist Tundra</u>
1.1 Clear	5.1 Sedge/Grass
Meadow	
1.2 Turbid	5.2 Tussock Tundra
1.3 Ice	5.3 Moss/Peat/Lichen
<u>2.0 Aquatic</u>	<u>6.0 Shrub</u>
2.1 Carex aquatilis	6.1 Dwarf
2.2 Arctophylla fulva	6.2 Low
	6.3 Tall
<u>3.0 Flooded Tundra</u>	<u>7.0 Barren Ground</u>
3.1 Low-centered Polygons	7.1 Dunes/Dry Sand
3.2 Non-patterned	7.2 Sparsely Vegetated
<u>4.0 Wet Tundra</u>	<u>7.3 Other</u>

Image Preprocessing

The Landsat TM images were purchased with the terrain corrected for the Western and Eastern phase. The SPOT XS images from the Eastern phase were purchased with only system distortions corrected (not georeferenced) due to funding limitations. The three SPOT XS scenes were georeferenced and resampled to a 30 meter pixel size using ground control points (GCP) on the overlap areas on the existing Landsat TM scenes and USGS 1:63,360 quadrangles. SPOT XS images have a spatial resolution of 20 meters, whereas the Landsat TM images have a spatial resolution of 30 meters. Therefore, the SPOT XS images were resampled to 30 meters. The root mean square (RMS) error of the three SPOT scenes were 0.98 pixels for scene K425/J202 (9 Aug. 1994), 0.15 pixels for scene K425/J202 (4 Aug. 1994), and 1.16 pixels for scene K425/J203 (4 Aug. 1994) (Table 3). The Landsat TM scenes for the Southern phase were also purchased terrain corrected

with the exception of Path 79 Row 11 (22 June 1992) and Path 81 Row 11 (6 August 1992). These two scenes were georeferenced using the overlapping terrain corrected scenes and USGS 1:63,360 quadrangles. The RMS for Path 79 Row 11 (22 June 1992) was 1.19 pixels and Path 81 Row 11 (6 August 1992) was 0.84 pixels.

An unsupervised clustering and seeding technique was used to initially generate spectrally unique areas within the study area. These spectrally unique areas were then refined and selected as sample sites for the field work using aerial photography and a preliminary decision tree of the land cover classification. These spectrally unique areas were plotted on field maps for field verification and the coordinates of their center points were programmed for use with aircraft global positioning systems. In addition, 1:63,360 scale quadrangle color infrared plots of the Landsat TM data were produced for the placement of additional field sample sites and for navigational purposes in the helicopters.

Sensor	Path/Row	% Shift	Date	Number of GCP Points	X RMS	Y RMS	Total RMS
SPOT XS	k425/j202	10% S	8/9/94	37	0.63	0.74	0.98
SPOT XS	k425/j202	60% S	8/4/94	45	0.11	0.1	0.15
SPOT XS	k425/j203	70% S	8/4/94	48	0.61	0.98	1.16
Landsat TM	79/11	0%	6/22/92	66	0.92	0.59	1.19
Landsat TM	81/11	0%	8/6/92	76	0.62	0.57	0.84

Table 3. The number of GCP points and RMS error of the SPOT scenes.

Field Verification

The purpose of field data collection is to assess, measure, and document the on-the-ground vegetation variation within the project area. This variation will then be correlated with the spectral variation in the satellite imagery during the image classification process. Low-level helicopter surveys are a very effective field data collection method since a much broader area can be covered with an orthogonal view from above, similar to a satellite sensor. Helicopter surveys are sometimes the only transportation alternative in Alaska due to vast remote areas that are difficult to access (Figure 5).

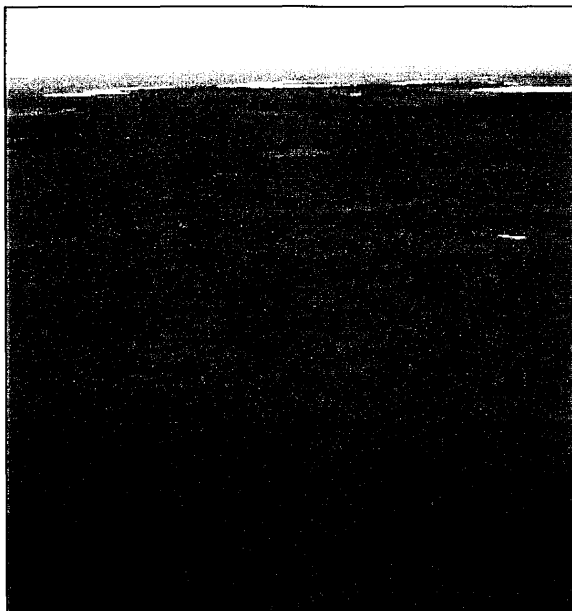


Figure 5. Helicopters are used in this remote and vast project area to effectively acquire data.

In order to obtain a reliable and consistent field sample, a custom field data collection card (Kempka *et al.* 1994) was developed and used to record field information (Figure 6). A five person helicopter crew performed the field assessment. Each crew had a pilot, biologist, recorder, navigator,

and alternate. The navigator, operates the GPS equipment and interprets the satellite image derived field maps and occupies the co-pilot seat. The biologist has the most knowledge about the vegetation, and the recorder, records species percentages and other data on the field form, occupy the remaining two seats in the back of the helicopter. The alternate is responsible for flight following, data entry of the previous day's work, and substituting in case of sickness. On the first day, sampling was performed by landing the aircraft on the ground to verify and standardize the classification and sampling techniques. After the first day, the majority of the sites were observed in flight to determine the percent cover for each species and an overall earth cover class. Ground verification was performed when identification of dominant vegetation and/or species was uncertain.

Classification

Every image is unique and can present challenges in the classification process. The approach that was used in this project has been tried and proven successful for many years (Figure 7). The image processor's site specific experience and knowledge in combination with high quality ancillary data can overcome some of the spectral differences to produce a high quality and extremely useful product. Therefore, the image processor should be actively involved in the field data collection and hopefully have first hand knowledge of every training site.

Generation of New Bands

New bands can be derived from the raw data by simple operations like dividing one band by another or complex statistical computations like principle components transformations. The idea behind generating

National Petroleum Reserve Alaska - Field Form

Site Number: <u>926</u>	Soil Type: <u>IS/DY</u>	Observer: <u>IS/DY</u>	Obs. Date: <u>8/16/96</u>	Obs. Level: <u>1234</u>	% Slope (Avg): <u> </u>	Aspect (Avg): <u> </u>	Elev'n: <u> </u>
Air Photo: <u> </u>			Photo Source: <u> </u>		1:63K Quad: <u>Utukok R.D-3</u>		
LAT (GPS): <u> </u> Degrees <u> </u> Min. <u> </u> Seconds			LONG (GPS): <u> </u> Degrees <u> </u> Min. <u> </u> Seconds			GPS/Local Time: <u> </u> Hr. <u> </u> Min. <u> </u> Seconds	

WATER	BARREN GROUND	FLOODED TUNDRA	WET TUNDRA	MOIST TUNDRA	SHRUB	AQUATIC	
Clear	Dunes/Dry Sand	Low Centered Polygon		Sedge/Grass Meadow	Dwarf	Carex aquatilis	☒ High ☐ Centered ☐ Polygons ☐ Present
Turbid	Other	Non-Pattern		Tussock Tundra	Low	Ardophylla fulva	
Ice	Sparse Vegetation			Moss/Peat/Lichen	Tall		

NOAA Coastwatch Classification

Vioreck Classification

% Coverage	SHRUBS	Height
	Tundra dwarf birch	Betula nana
	Arctic bell-heather	Cassiope tetragona
	Black crowberry	Empetrum nigrum
	Greenland Labrador tea	Ledum palustre
	Cloudberry	Rubus chamaemorus
<u>15</u>	Willow	Salix spp.
	Bog blueberry	Vaccinium uliginosum
	Mountain cranberry	Vaccinium vitis-idaea
	Mountain avens	Dryas spp.
	Diapensia	Diapensia lapponica
	Shrubby cinquefoil	Potentilla fruticosa
	Alder	Alnus crispa
	Bearberry	Arotostaphylos spp.
	Andromeda	Andromeda spp.

% Coverage	HERBACEOUS
	Moss
	Bryoid spp.
	Common marsh marigold
	Calla palustris
	Milkweed
	Astragalus spp.
	River Beauty
	Epiobium latifolium
	Lichen
	Lichen
	Arctic poppy
	Papaver spp.
	Lousewort
	Pedicularis spp.
	Arctic sweet coltsfoot
	Petasites frigidus
	Buckwheat
	Polygonum spp.
	Marsh cinquefoil
	Potentilla palustre
	Buttercup
	Hanunculus spp.
	Saxifrage
	Saxifraga spp.
	Groundsel
	Senecio spp.
	Low starwort
	Stellaria spp.
	Lupine
	Lupinus arcticus
	Looseweed
	Oxytropis spp.
	Hedysarum
	Hedysarum spp.
	Silene
	Silene acaulis

<u>15</u>	Subtotal % Cover
-----------	------------------

% Coverage	GRASS/SEDGE/...
<u>60</u>	Broadleaf arctic bentgrass
	Arctagrostis latifolia
	Pendant grass
	Arctophylla fulva
	Water sedge
	Carex aquatilis
	Sedge cother
	Carex spp.
	Bigelow sedge
	Carex bigelowii
	Tufted hairgrass
	Deschampsia cespitosa
	Horsetail
	Equisetum spp.
	Tussock cotton-grass
	Eriophorum vaginatum
	Mare's tail
	Hippuris spp.
	Hush
	Juncus spp.
	Woodrush
	Luzula spp.
	Wool bluegrass
	Poa lanata
<u>5</u>	Arctic bluegrass
	Poa arctica
	Alkali grass
	Puccinellia spp.
	Cotton-grass A.
	Eriophorum angustifolium
<u>15</u>	Cotton-grass R.
	Eriophorum russeolum
	Foxtail
	Alopecurus alpinus
	DuPontia
	DuPontia fischeri
	Lyme grass
	Elymus spp.

% Coverage	NON-VEGETATED
	Clear water
	Gravel
	Ice
<u>5</u>	Mud
	Plant Debris
	Rock
	Sand
	Silt
	Turbid Water

<u>85</u>	Subtotal % Cover
<u>166</u>	GRAND TOTAL % COVER

C#	<u>B1 F33</u>
COMMENTS	

Figure 6. Field data collection card for the NPR-A.

new bands is that unique information will be derived from the process and will enhance the classification. The possibilities of generating new bands from the raw imagery are infinite. A few of the more popular ones are principle components, tassel cap, band ratios, and Normalized Difference Vegetation Index (NDVI). It is beyond the scope of this project to generate and test every possible combination. However, based on past experience and some analysis from the Western phase (see Phase 1 TM data for this project). The new bands were generated by dividing the digital number (DN) of band 4 by the DN of band 3 and by calculating the first principal component of the visible bands (bands 1-3). From past experience in Alaska and other vegetation studies the 4/3 ratio was chosen for this project (Congalton *et al.* 1993). The 4/3 ratio typically reduces the shadow effects and enhances the differences between vegetation types. The first principal component of the visible bands was used to reduce the processing time since the visible bands are typically highly correlated and their first principal component will typically account of 99% of the variation. These new bands were subset with bands 3, 4, and 5 to produce a five-banded file to be used in the classification.

Removal of Clouds and Shadows

The clouds and cloud shadows are removed from the image before the classification is started. This eliminates the confusion in distinguishing the clouds or cloud shadows from actual earth cover types. Clouds are removed using an unsupervised classification and manual on-screen editing. The clouds are separated from the shadows and the two classes are recorded to their prospective class number. The cloud/shadow layer is then combined with

the rest of the classified image during the last step in the classification process.

Seeding Process

The field sites designated as training areas were “seeded” (generate statistics from the imagery) in ERDAS Imagine using spectral bounds as the limit for seed growth. The standard deviations of the seeded areas were kept to about 3 and all seeded areas were required to be more than 15 pixels (approximately 3.75 acres) in size. Along with the field training areas, additional “seeds” were generated for water, turbid water, ice, and snow. These classes were easily recognized on the imagery and aerial photography. The output of the seeding process in Imagine is a signature file that contains all of the statistics for the training areas. The signature file is then used in the modified supervised/unsupervised classification.

Generation of Unsupervised Signatures

An unsupervised classification is generated using the five banded image described in the “Generation of New Bands” section. One hundred and fifty signatures were derived from the unsupervised classification using the ISODATA program in Imagine. The output of this process is a signature file similar to that of the seeding process containing 150 unsupervised signatures. A maximum likelihood classification of the 150 unsupervised signatures is generated using the supervised classification program in Imagine.

Modified Supervised/Unsupervised Classification

A modified supervised/unsupervised classification approach (Chuvieco and

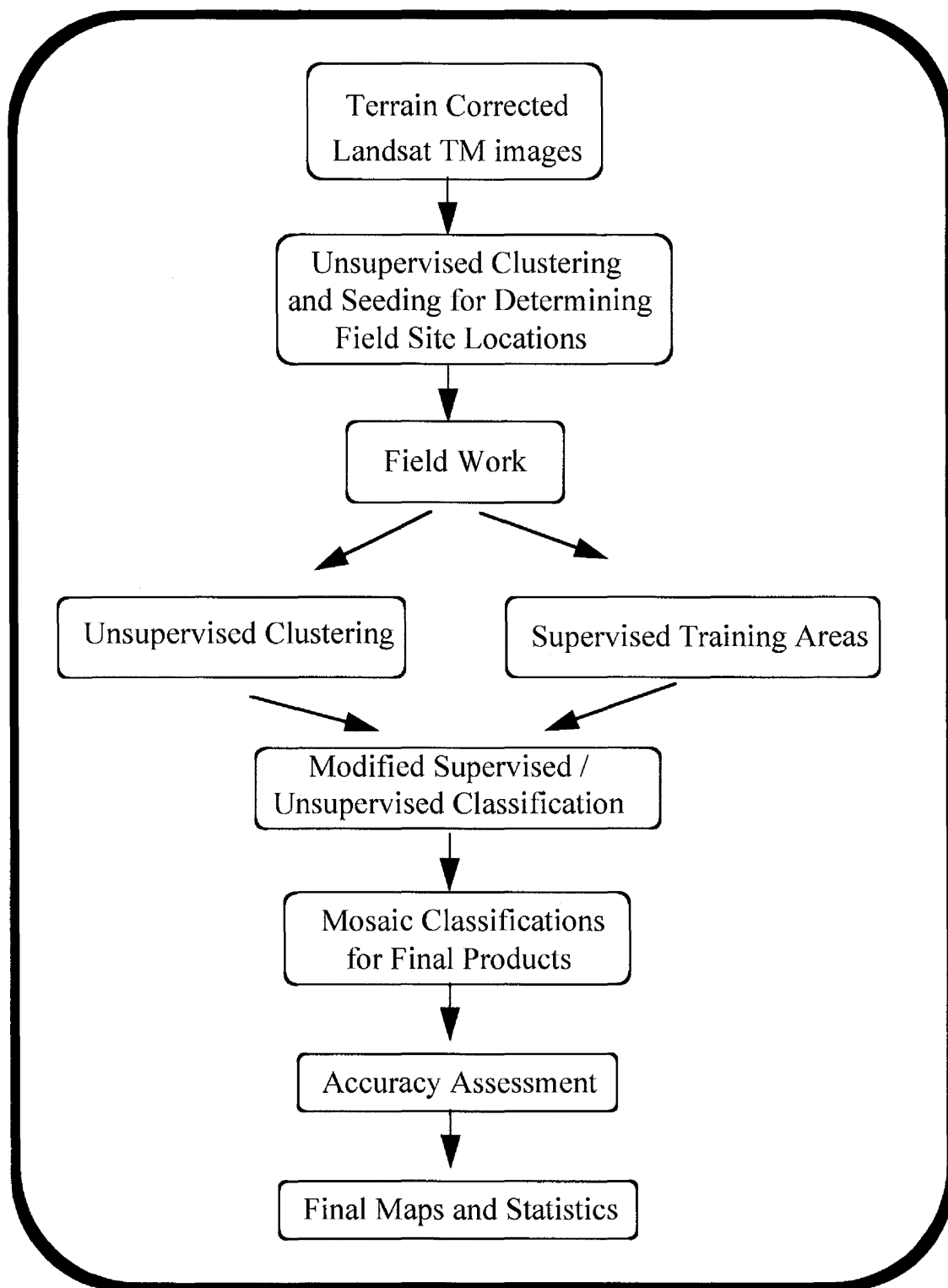


Figure 7. The classification process of the NPR-A.

Congalton, 1988) was used. This approach uses a statistical program to group the spectrally unique signatures from the unsupervised classification with the signatures of the supervised training areas. In this way, the spectrally unique areas were labeled according to the supervised training areas. This is a repetitive process because all of the supervised signatures will not cluster perfectly with the unsupervised signatures the first time. The unsupervised signatures that match well with the supervised signatures were inspected and removed from the classification process. The remaining confused clusters were grouped into general categories (forest, shrub, non-vegetation, etc.) and re-run through the process. The process was repeated until all of the spectral classes were adequately matched and labeled. This classification approach provides three major benefits: (1) aids in labeling unsupervised classes by grouping them with known supervised training sites; (2) helps identify classes that possess no spectral uniqueness, (i.e. training sites that are spectrally inseparable); and (3) identifies areas of spectral reflectance present in the imagery that were not represented by a training site.

Editing and Modeling

The final classification step was to model the remaining confusion and make final edits. There may be a few problem areas in the classification that the spectral data cannot separate, but a simple model can take care of the problem. For instance, water may be classified where there are terrain shadow effects, which can be easily modeled out of the classification using Digital Elevation Models (DEM's). In the end, there may be a few classification problems which cannot be addressed with either spectral separation or modeling.

When this happens, the image processor must use aerial photographs and on screen digitizing to remedy the classification situation.

Accuracy Assessment

The purpose of quantitative accuracy assessments is the identification and measurement of map errors. Primary motivations for accuracy assessment are: to understand the errors in the map (so they can be corrected), and to provide an overall assessment of the map's reliability (Gopal and Woodcock, 1992). Factors to consider when designing an accuracy assessment, include how to determine the sample size, how to allocate this sample, and which sampling scheme to employ. Congalton (1991) suggests that as a rule 50 samples be selected for each map category. This empirical value derived from many projects. A second method of determining sample size is using the multinomial distribution and specifying a given confidence in the estimate (Tortora 1978). The results of this calculation tend to favor Congalton's rule. Once the sample size is determined, it then is allocated among categories in the map. Only a strictly proportional allocation is possible. However, the smaller categories in areal extent will have only a few samples that may severely hamper future analysis. The other extreme is to force a given number of samples from each category. Depending on the extent of each category, this approach can significantly bias the results. Finally, a sampling scheme must be selected. A purely random approach has excellent statistical properties, but is practically difficult and expensive to apply. A purely systematic approach is easy to apply, but could result in limited sampling areas.

Error Matrix

The standard method for assessing the accuracy of a map is to build an error matrix (also known as a confusion matrix or contingency table). The error matrix compares the reference data (field site or photo interpreted site) with the classification. The matrix is a square array of numbers set in rows and columns that express the number of sites assigned to a particular category in the reference data relative to the number of sites assigned to a particular category in the classification. The columns usually represent the reference data while the rows indicate the classification (Lillesand and Kiefer, 1994). An error matrix is an effective way to represent accuracy since the individual accuracy of each category is described with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the classification. A commission error occurs when an area is wrongly included in a category where it does not belong. An omission error is excluding that area from the category in which it does belong. Every error is an omission from the correct category and a commission to a wrong category. It is important that the error matrix and accuracy assessment is based on the assumption that the reference data is 100% correct. This assumption is not always true, especially when the reference data is derived from aerial photographs.

By clearly showing errors of omission and commission, the error matrix can be used to compute overall accuracy, producer's and user's accuracy (Story and Congalton, 1986). Overall accuracy is the sum to the major diagonal (i.e., the correctly classified samples) divided by the total number of samples in the error matrix. This value is the most commonly reported accuracy assessment statistic. Producer's and user's

accuracies are ways of representing individual category accuracy instead of just the overall classification accuracy.

Kappa Analysis

A Kappa analysis is performed on the error matrix as a further measure of accuracy (Congalton 1991). Cohen's coefficient of agreement (Kappa) is a measure of overall agreement in the error matrix after chance agreement is removed from consideration. Kappa attempts to provide a better measure of agreement by adjusting the overall accuracy for chance agreement or the agreement that might be contributed solely by chance matching of the two maps. The result of the Kappa analysis is the KHAT statistic. Landis and Koch (1977) characterized the possible ranges for KHAT into three groupings: a value greater than 0.80 (i.e., 80%) represents strong agreement; a value between 0.40 and 0.80 (i.e., 40 - 80%) represents moderate agreement; and a value below 0.40 (i.e., 40%) represents poor agreement.

In addition to calculating KHAT, confidence intervals can be calculated using the approximate large sample variance. The large sample variance can then be used to test if the agreement between the classification and reference data is significantly different from zero or a random classification with the Z statistic. The Z statistic in the Kappa analysis can also be used to test if a classification is significantly different from another classification. A Z statistic of 1.98 or less means that the classification is not significantly different from a random classification at the 99% confidence level.

Alaskan Perspective

Obtaining adequate reference data for performing an accuracy assessment can be

extremely expensive in remote areas. Aircraft is the primary mode of transportation throughout most of Alaska. Aerial photographs are available for most of Alaska, but at a scale which, in most cases make it difficult and sometimes impossible to distinguish certain vegetation classes. Ideally, field work would be performed during one summer, the classification would be performed during the winter, and the reference data would be collected the next summer. This procedure would allow a stratified random sample of the classification and ensure adequate sampling of all the classes. Unfortunately, this methodology is not typically feasible due to the cost of obtaining the field data.

For this project, the field work for obtaining the training sites for classifying the imagery and the reference data for the accuracy assessment was accomplished at the same time. Special care was taken during the preprocessing stage and in the field to make sure adequate samples were obtained. However, funding limitations did not allow for the number of samples suggested for each class (50) for the accuracy assessment. The first priority for the field data was to make the best map possible, so few field sites were withheld for the accuracy assessment. Obviously, this means that there is little measure of confidence for those classes in the accuracy assessment. However, withholding a percentage of sites for the accuracy assessment does give us some confidence in the classification and guides the image processor to certain areas of confusion in the classification.

Some Considerations

While the accuracy assessment performed in this project is by no means a robust test of the classification, it does give the user some

confidence in using the classification. It also provides enough detail for the end user to determine where discrepancies in the classification may cause a problem while using the data. It is also important to note the variations in the dates of the imagery, aerial photographs, and field data. For this project, the date of the imagery varied from June 22 to August 28 and from 1992 to 1995. The aerial photographs were from 1977 to 1985, and the field data was collected from July and August 1994 through 1996. Differences due to environmental changes from the different sources may have a major impact on the accuracy assessment. This difference was apparent during the collection of one particular field site in 1995. The field crew arrived at a site that the imagery showed to be an aquatic site and there was only bare sand remaining from a drained lake.

A major assumption of quantitative accuracy assessments is that the label from the reference information represents the "true" label of the site and that all differences between the remotely sensed map classification and the reference data are due to classification and/or delineation error (Congalton and Green, 1993).

Unfortunately, error matrices can be inadequate indicators of map error because they are often confused by non-map error differences. Some of the non-map errors that can cause confusion are: registration differences between the reference data and the remotely sensed map classification, digitizing errors, data entry errors, changes in land cover between the date of the remotely sensed data and the date of the reference data, mistakes in interpretation of reference data, and variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation.

Results

Field Verification

The field verification for the Southern phase occurred from August 3 to August 19, 1996. During that time period, 600 field sites were visited (Table 4). Approximately 49% (293) of the field sites were reserved for the accuracy assessment. Field camps were located at Ivotuk and along Carbon Creek. The field crew consisted of Jim Sisk as the vegetation caller, Dave Yokel as the recorder, and Robb Macleod as the navigator. At one time during the field work, approximately four inches of snow fell during the night at Carbon Creek. However, most of the snow had melted by mid-afternoon.

Over the three field seasons, field information was collected on 1,667 sites throughout the NPR-A (Table 5). From 1,667 field sites where collections were made, approximately 44% (740) were reserved for the accuracy assessment. The training sites were fairly well distributed throughout the project area (Figure 8). Additional analysis was performed on the field site database to extract additional information about the plant species within each class. The field data from all three phases were used in the analysis. The first analysis was to sum all of the species that occurred in each of the earth cover classes (Table 6). The most diverse class (class that had the highest number of plant species) was the sedge/grass meadow class with 47 different species. The dwarf shrub class was the next most diverse classes with 45 different species, followed by the low shrub class with 40 and sparse vegetation at 38.

The next analysis summed all of the species that were recorded during the field collection to produce a list of all species that were observed during the field work (Appendix E). The final analysis looked at all of the species that occurred in a class and calculated the percentage of occurrence of that species within that class (Appendix F).

Classification

The final results of the classification are: 43% shrub, 31% moist tundra, 11% water, 6% flooded tundra, 5% wet tundra, 2% aquatic, and 2% barren ground. The area and percentage for each of the seven major classes (Table 7) and the seventeen minor classes (Table 8) were calculated. The Western and Eastern classifications were then mosaicked with the Southern classification in order to produce a continuous and seamless classification of the entire NPR-A (Figure 9). The classification of the Southern phase had some unique difficulties compared to the Western and Eastern phases. Due to the large percentage of tussock tundra and dwarf shrub in the southern region and the intermixing of these classes, it was often difficult to separate these two classes. The presence of the dwarf shrub mountain avens (*Dryas spp.*) around the Brooks Range created some confusion between the dwarf shrub class and the sparse vegetation and barren ground classes. There was also a spectral difference between the dwarf shrub classes with a large percentage of mountain avens and those shrub classes with birch (*Betula spp.*) and willow (*Salix spp.*) species. Since this spectral difference was

Table 4. The number of field sites and accuracy assessment sites for each phase

CLASS NAME	1994		1995		1996	
	TOTAL FIELD SAMPLES	ACCURACY ASSESSMENT	TOTAL FIELD SAMPLES	ACCURACY ASSESSMENT	TOTAL FIELD SAMPLES	ACCURACY ASSESSMENT
Clear Water	14	49 *	12	8	25	25
Turbid Water	6	3	25	13	4	4
Ice	5	20 *	0	0	0	0
Carex Aquatilis	30	12	51	17	2	0
Arctophylla Fulva	31	16	15	5	25	6
Low Centered Polygons	54	20	31	15	26	8
Non-pattern	53	24	24	6	32	14
Wet Tundra	100	29	24	8	98	38
Sedge/Grass Meadow	68	27	42	17	55	26
Tussock Tundra	70	22	35	15	57	28
Moss/Lichen	18	0	3	1	6	0
Dwarf Shrub	54	7	81	31	133	78
Low Shrub	55	24	28	12	52	24
Tall Shrub	0	0	28	11	9	3
Dunes/Dry Sand	21	11	12	5	0	0
Sparsely Vegetated	23	5	23	9	26	14
Other	18	0	13	5	50	25
Total	620	269	447	178	600	293

* Additional accuracy assessment sites were generated using random location on the imagery and aerial photography.

Table 5. The total number of field sites and accuracy assessment site for all phases.

CLASS NAME	1994-1996	
	TOTAL FIELD SAMPLES	ACCURACY ASSESSMENT
Clear Water	51	82
Turbid Water	35	20
Ice	5	20
Carex Aquatilis	83	29
Arctophylla Fulva	71	27
Low Centered Polygons	111	43
Non-pattern	109	44
Wet Tundra	222	75
Sedge/Grass Meadow	165	70
Tussock Tundra	162	65
Moss/Lichen	27	1
Dwarf Shrub	268	116
Low Shrub	135	60
Tall Shrub	37	14
Dunes/Dry Sand	33	16
Sparsely Vegetated	72	28
Other	81	30
Total	1667	740

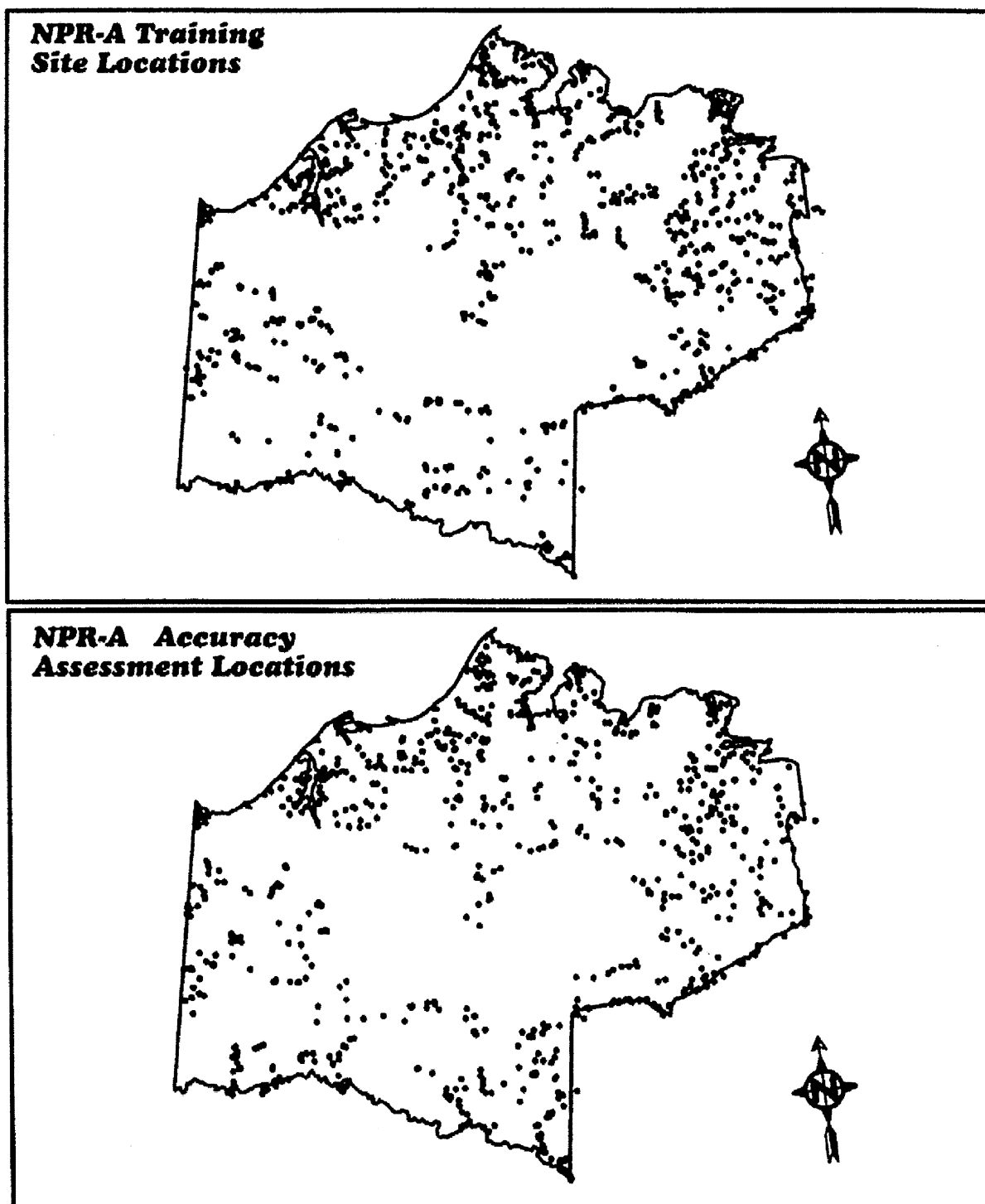


Figure 8. The spatial distribution of the field sites for all three phases.

Table 6. Sum of species that occurred in each earth cover class.

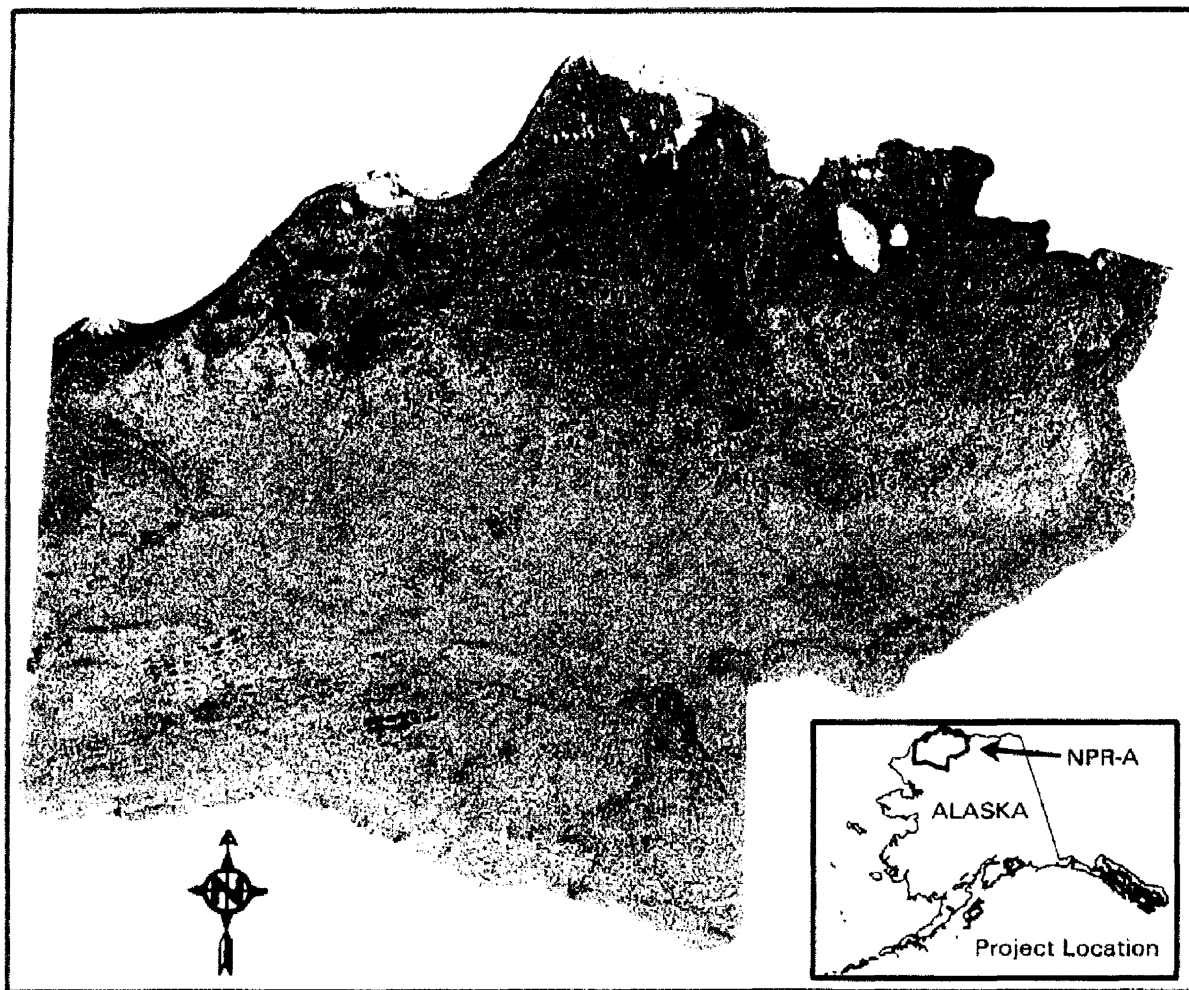
Sedge/Grass Meadow	47
Dwarf Shrub	45
Low Shrub	40
Sparse Vegetation	38
Wet Tundra	37
Low Centered Polygon	33
Tussock Tundra	30
Carex Aquatilis	26
Non-Pattern	23
Tall Shrub	20
Other	19
Dunes/Dry Sand	18
Byroid	16
Arctophila Fulva	10
Clear Water	10
Total # of Species	63

Table 7. The area and percentage of the seven major classes.

Class Name	Hectares	Acres	Percentage
Water	981,416.70	2,425,135.19	10.53%
Aquatic	178,231.23	440,419.27	1.91%
Flooded Tundra	577,889.82	1,427,997.85	6.20%
Wet Tundra	429,816.69	1,062,100.92	4.61%
Moist Tundra	2,898,785.34	7,163,059.62	31.10%
Shrub	4,001,825.88	9,888,734.07	42.94%
Barren Ground	217,315.71	536,999.19	2.33%
Clouds/Shadows/Other	34,751.70	85,873.38	0.37%
TOTAL	9,320,033.07	23,030,319.50	100.00%

Table 8. The area and percentage of the seventeen minor classes.

Class Name	Hectares	Acres	Percentage
Clear Water	489,986.28	1,210,783.32	5.26%
Turbid Water	412,079.31	1,018,270.87	4.42%
Ice	79,351.11	196,081.00	0.85%
Carex aquatilis	147,527.64	364,548.99	1.58%
Arctophylla fulva	30,703.59	75,870.28	0.33%
Low Centered Polygons	356,298.84	880,434.23	3.82%
Non-pattern	221,590.98	547,563.62	2.38%
Wet Tundra	429,816.69	1,062,100.92	4.61%
Sedge/Grass Meadow	515,337.84	1,273,428.43	5.53%
Tussock Tundra	2,288,946.51	5,656,113.99	24.56%
Moss/Lichen	94,500.99	233,517.20	1.01%
Dwarf Shrub	3,664,280.34	9,054,640.29	39.32%
Low Shrub	336,564.00	831,668.34	3.61%
Tall Shrub	981.54	2,425.44	0.01%
Dunes/Dry Sand	27,019.35	66,766.31	0.29%
Sparsely Vegetated	95,681.43	236,434.13	1.03%
Barren Ground Other	94,614.93	233,798.75	1.02%
Clouds/Cloud Shadows	24,767.28	61,201.32	0.27%
Mountain Shadows	9,984.42	24,672.06	0.11%
TOTAL	9,320,033.07	23,030,319.50	100.00%



Legend

Clear Water	Wet Tundra	Dunes/Dry Sand
Turbid Water	Sedge/Grass Meadow	Sparsely Vegetated
Ice	Tussock Tundra	Barren Ground Other
Carex aquatilis	Moss/Lichen	Clouds/ Cloud Shadows
Arctophila fulva	Dwarf Shrub	Mountain Shadow
Flooded Tundra - LCP	Low Shrub	
Flooded Tundra - NP	Tall Shrub	

Scale 1 : 2,900,000

50 0 50 100 Miles

Figure 9. The mosaicked classification of the entire NPR-A.

easy to separate, an alternative classification was developed that differentiates these two sub-types of the dwarf shrub class.

Accuracy Assessment

The overall accuracy of the major classes for the Southern phase was 81% and the overall accuracy of the minor classes for the Southern phase was 73%. The classification for both the major and minor classes was significant when using the Z statistic from the Kappa analysis (Table 9).

All classes with the exception of turbid water were included in the accuracy assessment. The turbid water was not included because of the temporal difference in the field data collection and the satellite image acquisition date. In addition, there were no accuracy assessment points for the ice category because there was no ice on any of the images. The moss/lichen, carex aquatilis, and dunes/dry sand classes were also not existent in the accuracy assessment for the Southern phase due to the rare occurrence of these classes in this portion of the NPR-A.

Due to the complex nature of the environment and the classification scheme, the error matrix of the classification should be studied (Appendix G). Most errors occurred between the dwarf shrub and tussock tundra classes and the dwarf shrub and barren classes. Fourteen of the dwarf shrub accuracy assessment sites were classified as tussock tundra. Likewise, eight of the tussock tundra accuracy assessment sites were classified as dwarf shrub. These

two classes presented many problems in the classification due to their close association in habitat preferences. Six of the dwarf shrub accuracy assessment sites were also classified as either sparsely vegetated or other. These errors were most likely due to the spectral similarity of the prostrate dwarf shrub *Dryas spp.* that grows in association with barren sites.

The overall accuracy of the major classes for the entire NPR-A was 85% and the overall accuracy of the minor classes for the entire NPR-A was 75%. The classification for both the major and minor classes was significant when using the Z statistic from the Kappa analysis (Table 10). These accuracies were obtained by combining the error matrices from all three phases and generating the overall accuracy and Kappa analysis from that matrix (Appendix G).

A comparison between the Western, Eastern and Southern NPR-A classification accuracy assessments was made to determine if there is any significant difference between the classifications. The accuracy of the major classes for the Eastern classification had a 4% higher overall accuracy and a 3% higher KHAT accuracy than the Western classification (Table 11). The accuracy of the minor classes for the Eastern classification had a 2% lower overall accuracy and a 2% lower KHAT accuracy than the Western classification. The Southern phase had the lowest overall and KHAT accuracy of the three phases. However, the differences were not significant when compared in the Kappa analysis (Table 12).

Table 9. The accuracy assessment of the Southern NPR-A classification.

	Overall Accuracy	Khat Accuracy	Z statistic
Major categories	81%	76%	25.83 *
Minor categories	73%	68%	22.75 *

* Significant at the 99% confidence level

Table 10. The accuracy assessment of the entire NPR-A classification.

	Overall Accuracy	KHAT Accuracy	Z statistic
Major categories	85%	82%	51.99*
Minor categories	75%	72%	41.40*

* Significant at the 99% confidence level

Table 11. Comparison between the overall and KHAT accuracy of the three phases.

	Overall Accuracy	KHAT Accuracy	Z statistic
Western NPR-A Major classes	84%	81%	33.16 *
Western NPR-A Minor classes	77%	74%	29.07 *
Eastern NPR-A Major classes	88%	84%	28.15 *
Eastern NPR-A Minor classes	75%	72%	20.52 *
Southern NPR-A Major Classes	81%	76%	25.83 *
Southern NPR-A Minor Classes	73%	68%	22.75 *

* Significant at the 99% confidence level.

Table 12. Significance test of the Western, Eastern, and Southern NPR-A accuracy assessment.

* Significant at the 99% confidence level.

	Z statistic	Significant*
Western vs Eastern Major classes	1.1375	NO
Western vs Eastern Minor classes	-0.3445	NO
Western vs Southern Major classes	1.1452	NO
Western vs Southern Minor classes	1.4396	NO
Eastern vs Southern Major classes	2.0811	NO **
Eastern vs Southern Minor classes	0.9388	NO

** Significant at the 95% confidence level

Final Products

The primary product of this project is a digital database of the seventeen earth cover classes for the NPR-A and associated Metadata (Appendix H). Hard copy maps were also created of the entire project area at a scale of 1:250,000 and selected 1:63,360

scale maps were also produced. For viewing purposes and future analysis, the 1667 field sites were digitized from the field maps into ArcInfo and the field site database was related to the ArcInfo coverage. The result was ArcInfo coverage of field sites with the attribute data. A final report describing the analysis and technical design was also produced.

Conclusions

The National Petroleum Reserve in Alaska is expected to experience increased use during the next decade. Management issues require current information on land cover inventory and critical habitat data for more than 9.3 million hectares of the NPR-A. Phases were completed in 1995, 1996, and 1998, respectively. This joint project by the BLM-Alaska, Ducks Unlimited, U.S. Fish and Wildlife Service, and North Slope Borough has provided a low cost and efficient means to gain valuable information on the earth cover types in the NPR-A.

The Southern portion of the project used portions of five Landsat Thematic Mapper satellite scenes to classify the project area into earth cover categories. Use of rotary aircraft (helicopters) and global positioning system (GPS) technology were used to acquire field data at 600 sites. Three hundred seven of which were used in the computer aided classification process as training sites and 293 were used for accuracy assessment. The classification scheme consisted of seven major categories

and seventeen subcategories. A modified supervised/unsupervised classification approach was used to classify the imagery. The classification of the Southern phase of the NPR-A was then mosaicked with the Western and Eastern phases to produce a seamless classification of the NPR-A. Results of this classification suggest dominant habitats for the NPR-A are 43% shrub, 31% moist tundra, 11% water, 6% flooded tundra, 5% wet tundra, 2% aquatic, and 2% barren ground. The overall accuracy of the major categories was 85%, with a 75% overall accuracy for the minor categories.

This seamless earth cover classification for the NPR-A will be an invaluable tool for managers and researchers in the future. It will also be a good base to monitor changes in the NPR-A. The classification procedures worked well to produce an accurate classification in a relatively short time. The field data were also entered into a database that can be accessed for future projects.

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APPENDICES

APPENDIX A

The definitions for the classification scheme

1.0 WATER ($\geq 80\%$ water)

- 1.1 Clear Water - (depth ≥ 1 meter)
- 1.2 Turbid Water - (depth < 1 meter)
- 1.3 Ice - (ice $\geq 60\%$)

2.0 AQUATIC ($\geq 50\%$ water and $< 80\%$ water and $> 10\text{cm}$ in depth)

- 2.1 *Carex aquatilis* - ($> 15\%$ *Carex aquatilis* and $< 15\%$ *Arctophila fulva*)
- 2.2 *Arctophila fulva* - ($> 15\%$ *Arctophila fulva* and $< 15\%$ *Carex aquatilis*)

3.0 FLOODED TUNDRA ($\geq 25\%$ water and $< 50\%$ water and $< 10\text{cm}$ in depth)

- 3.1 Low Centered Polygons ($\geq 5\%$ Sedge/Grass)
- 3.2 Non -pattern ($< 5\%$ sedge/Grass)

4.0 WET TUNDRA ($\geq 10\%$ and $< 25\%$ water)

5.0 MOIST TUNDRA ($< 10\%$ water, $< 40\%$ shrub, composed mostly of sedges, grasses, rushes and moss/peat/lichen complex)

- 5.1 Sedge/Grass Meadow - ($\geq 50\%$ sedge/grass and $< 40\%$ tussock cotton grass)
- 5.2 Tussock Tundra - ($\geq 40\%$ tussock cotton grass)
- 5.3 Moss/lichen - ($\geq 50\%$ moss and/or lichen)

6.0 SHRUB ($< 10\%$ water and $\geq 40\%$ shrub)

- 6.1 Dwarf - ($\leq 30\text{cm}$ in height)
- 6.2 Low - ($> 30\text{cm}$ in height and $< 1.5\text{ m}$)
- 6.3 Tall - ($\geq 1.5\text{ m}$ in height)

7.0 BARREN GROUND (0-30% vegetated)

- 7.1 Dunes/dry sand - ($< 10\%$ vegetation and $\geq 50\%$ dry sand)
- 7.2 Sparsely Vegetated - (10-30% vegetated)
- 7.3 Other - ($< 10\%$ vegetation and $< 50\%$ sand)

APPENDIX B

The decision tree for the classification

A)	Ice.....	Ice
	Water.....	B
B)	$\geq 80\%$ water	C
	$< 80\%$ water.....	D
C)	depth ≥ 1 meter.....	Clear Water
	depth < 1 meter.....	Turbid Water
D)	$\geq 50\%$ water and $< 80\%$ water.....	E
	$< 50\%$ water.....	F
E)	$> 15\%$ <i>Arctophila</i> and $< 15\%$ <i>Carex aquatilis</i>	<i>Arctophila fulva</i>
	$< 15\%$ <i>Arctophila</i> and $> 15\%$ <i>Carex aquatilis</i>	<i>Carex aquatilis</i>
F)	$\geq 25\%$ water and $< 50\%$ water.....	G
	$< 25\%$ water.....	H
G)	$\geq 5\%$ sedge/grass.....	Flooded Tundra LCP
	$< 5\%$ sedge/grass.....	Flooded Tundra NP
H)	$\geq 10\%$ water and $< 25\%$ water.....	Wet Tundra
	$< 10\%$ water.....	I
I)	$> 30\%$ vegetated.....	J
	$\leq 30\%$ vegetated.....	O
J)	$< 40\%$ shrub.....	K
	$\geq 40\%$ shrub.....	M
K)	$\geq 40\%$ tussock cotton grass.....	Tussock Tundra
	$< 40\%$ tussock cotton grass.....	L
L)	$\geq 50\%$ graminoids.....	Sedge/Grass Meadow
	$< 50\%$ graminoids	Moss/lichen
M)	Shrubs ≤ 30 cm in height.....	Dwarf Shrub
	Shrubs > 30 cm in height.....	N
N)	Shrubs < 1.5 meters in height.....	Low Shrub
	Shrubs ≥ 1.5 meters in height.....	Tall Shrub

- O) $\geq 10\%$ vegetated.....Sparsely Vegetated
 $< 10\%$ vegetated.....P
- P) $\geq 50\%$ sand.....Dunes/Dry Sand
 $< 50\%$ sand.....Other

APPENDIX C

The written descriptions for the classification scheme

1.1 Clear Water - Fresh or saline waters with little or no particulate matter. Clear water areas are typically deep (greater than one meter). The clear water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage of these species.

1.2 Turbid Water - Waters that contain particulate matter or shallow (<1m), clear water bodies that are spectrally different from class 1.1. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. The turbid water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage of these species.

1.3 Ice - May last into late summer on lakes and larger ponds. Ice is present year-round in many of the larger lakes.

2.1 Carex aquatilis - Associated with lake or pond shorelines and composed of 50 - 80% clear or turbid water that was greater than 10 centimeters deep. The dominant species was *Carex aquatilis*. A small percentage of *Arctophila fulva*, *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris* may be present.

2.2 Arctophila fulva - Associated with lake or pond shorelines and composed of 50 - 80% clear or turbid water that was greater than 10 centimeters deep. The dominant species was

Arctophila fulva. A small percentage of *Carex aquatilis*, *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris* may also be present.

3.1 Flooded Tundra-Low Centered Polygons

Polygon features that retain water throughout the summer. This class is composed of 25 - 50% water; *Carex aquatilis* is the dominant species in the permanently flooded areas. The drier ridges of the polygons are composed mostly of *Eriophorum russeolum*, *Eriophorum vaginatum*, *Sphagnum* spp., *Salix* spp., *Betula nana*, *Arctostaphylos* spp., and *Ledum palustre*.

3.2 Flooded Tundra-Non-pattern -

Continuously flooded areas are composed of 25-50% water. *Carex aquatilis* are the dominant species. Other species may include *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris*. Non-pattern is distinguished from low centered polygons by the lack of polygon features and associated shrub species that grow on the dry ridges of low centered polygons.

4.0 Wet Tundra - Associated with areas of super saturated soils and standing water. Wet tundra often floods in early summer and usually drains excess water during dry periods but remains saturated throughout the summer. It is composed of 10-25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum*

angustifolium, and other sedges, grasses, and forbs.

5.1 Sedge/Grass Meadow - Dominated by the sedge family. This class commonly consists of a continuous mat of sedges and grasses with a moss and lichen understory. The dominant species were *Carex aquatilis*, *Eriophorum angustifolium*, *Eriophorum russeolum*, *Arctagrostis latifolia* and *Poa arctica*. Associated genera include *Cassiope* spp., *Ledum* spp., and *Vaccinium* spp..

5.2 Tussock Tundra - Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Tussock tundra is common throughout the Arctic Foothills and may be found on well-drained sites in all areas. Cottongrass tussocks are the dominant landscape elements, while moss is the common understory. Lichen, forbs, and shrubs are also present in varying densities. Associated genera include *Salix* spp., *Betula nana*, *Ledum palustre*, and *Carex* spp..

5.3 Moss/Lichen - Associated with low lying lakeshores and dry sandy ridges dominated by moss and lichen species. As this type grades into a sedge type, graminoids such as *Carex aquatilis* may increase in cover, forming an intermediate zone.

6.1 Dwarf Shrub - Associated with ridges and well-drained soils and dominated by shrubs less than 30 centimeters in height. It is the most species diverse because of the relative dryness of the sites where this cover type occurs. Major species included *Salix* spp., *Betula nana*, *Ledum palustre*, *Dryas*

spp., *Vaccinium* spp., *Arctostaphylos* spp., *Eriophorum vaginatum*, and *Carex aquatilis*. This class frequently occurs over a substrate of tussocks.

6.2 Low Shrub - Associated with small streams and rivers, but also occurring on hillsides in the southern portion of the NPR-A. This class is dominated by shrubs between 30 centimeters and 1.5 meters in height. Major species included *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre*.

6.3 Tall Shrub - Found along the Colville River and some of its major tributaries, and dominated by *Salix* spp. over 1.5 meters in height. This class may also contain significant presence of *Alnus crispa* over 1.5 meters in height.

7.1 Dunes/Dry Sand - Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with less than 10% vegetation. Plant species may include *Poa* spp., *Salix* spp., *Astragalus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.

7.2 Sparsely Vegetated - Occurred primarily along the coast in areas affected by high or storm tides, in recently drained lake or pond basins, and where there is bare mineral soil that is being re-colonized with vegetation. Dominated by non-vegetated material with 10-30% vegetation. The vegetation in these areas may include rare plants but some of the more commonly found species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragalus* spp.,

Carex spp., *Stellaria* spp.,
Arctostaphylos spp., and *Puccinellia*
phryganodes.

7.3 Barren Ground/Other - Associated with
river and stream gravel bars,

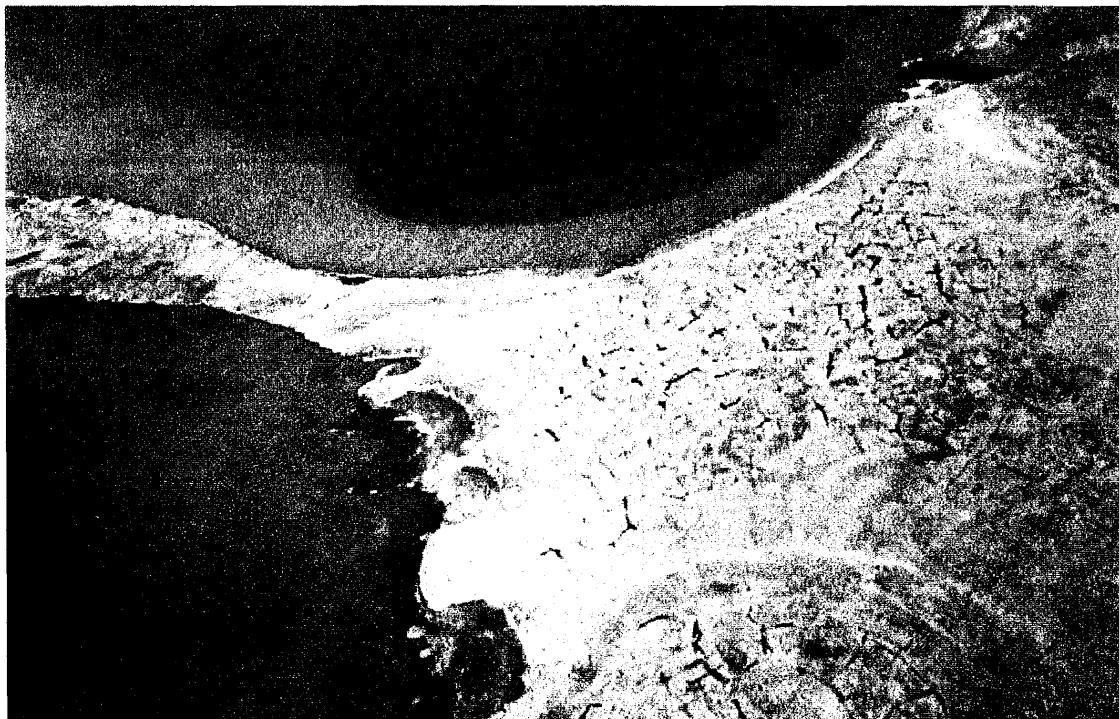
mountainous areas, and urban areas.
Includes less than 10% vegetation.
May incorporate dead vegetation
associated with salt burn from ocean
water.

APPENDIX D

Examples of the earth cover classes for the NPR-A



CLEAR WATER (Not including islands)



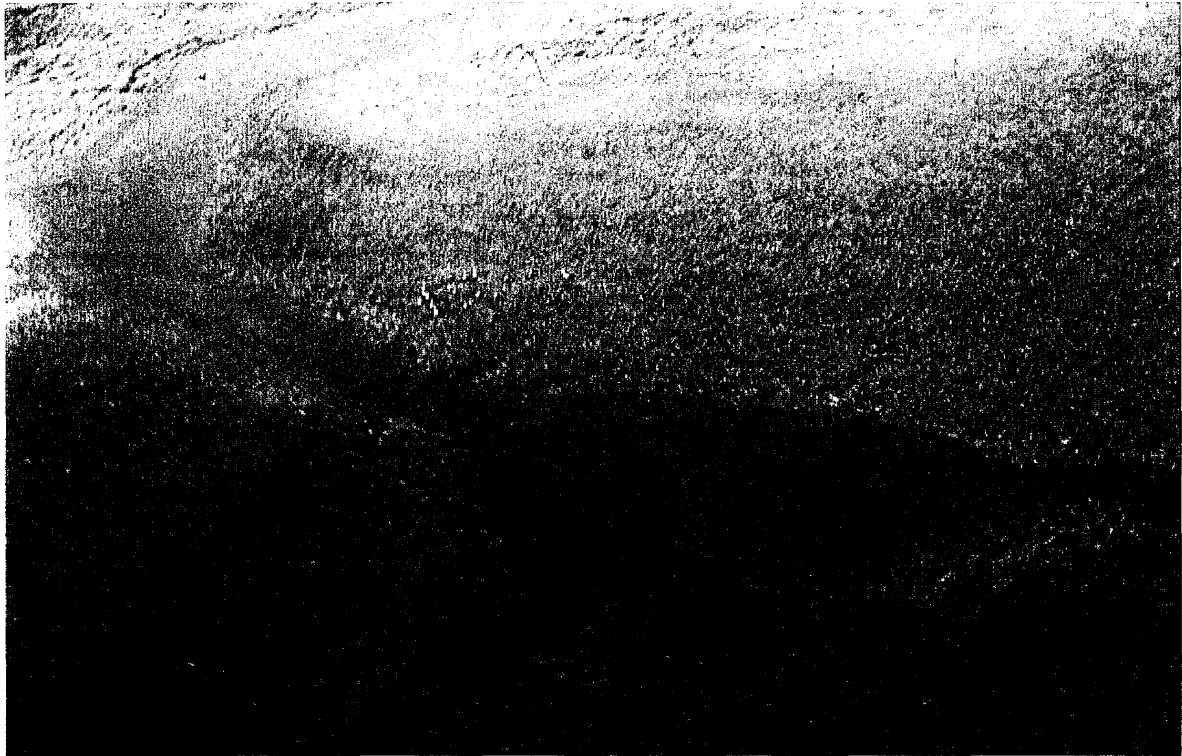
TURBID WATER



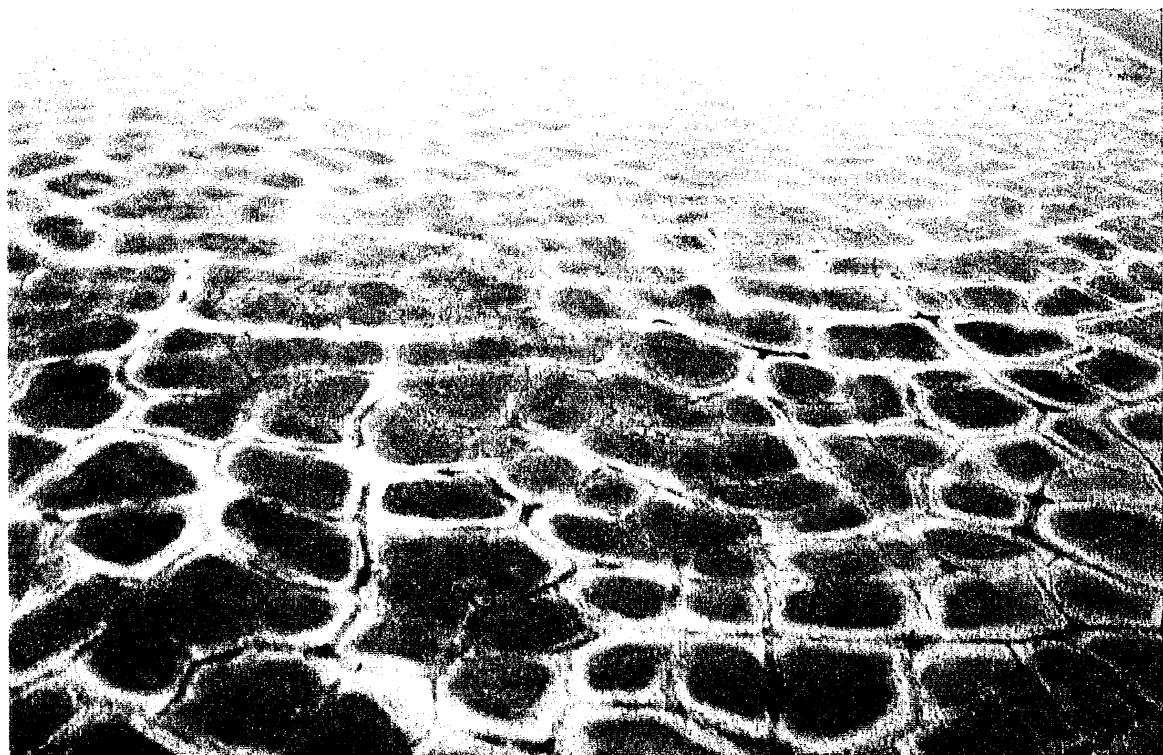
ICE



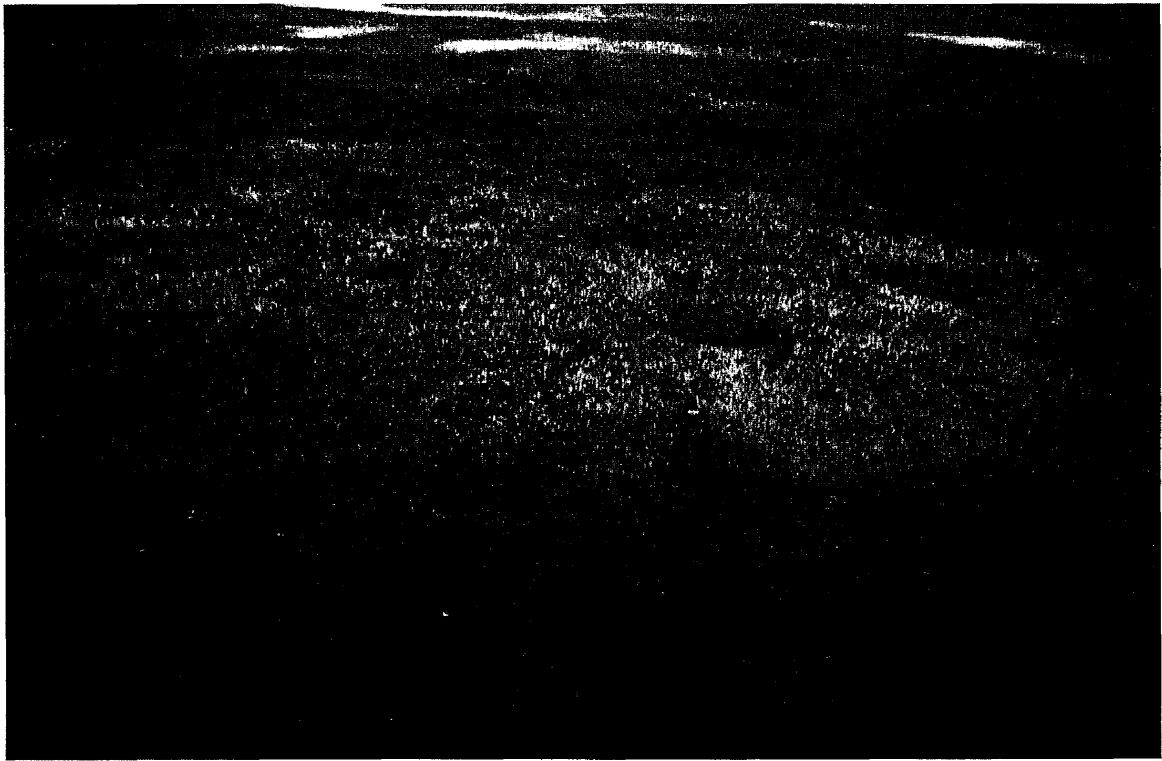
CAREX AQUATILIS



ARCTOPHILA FULVA



FLOODED TUNDRA LOW CENTERED POLYGONS



FLOODED TUNDRA NON-PATTERN



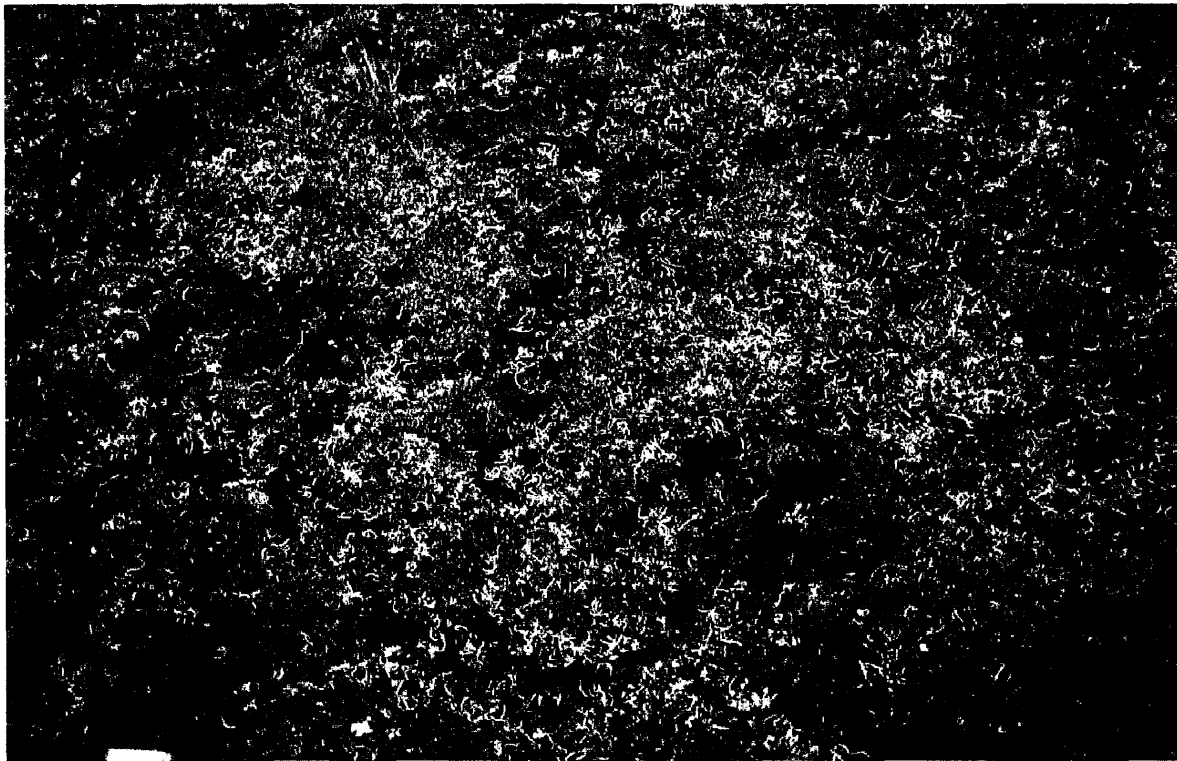
WET TUNDRA



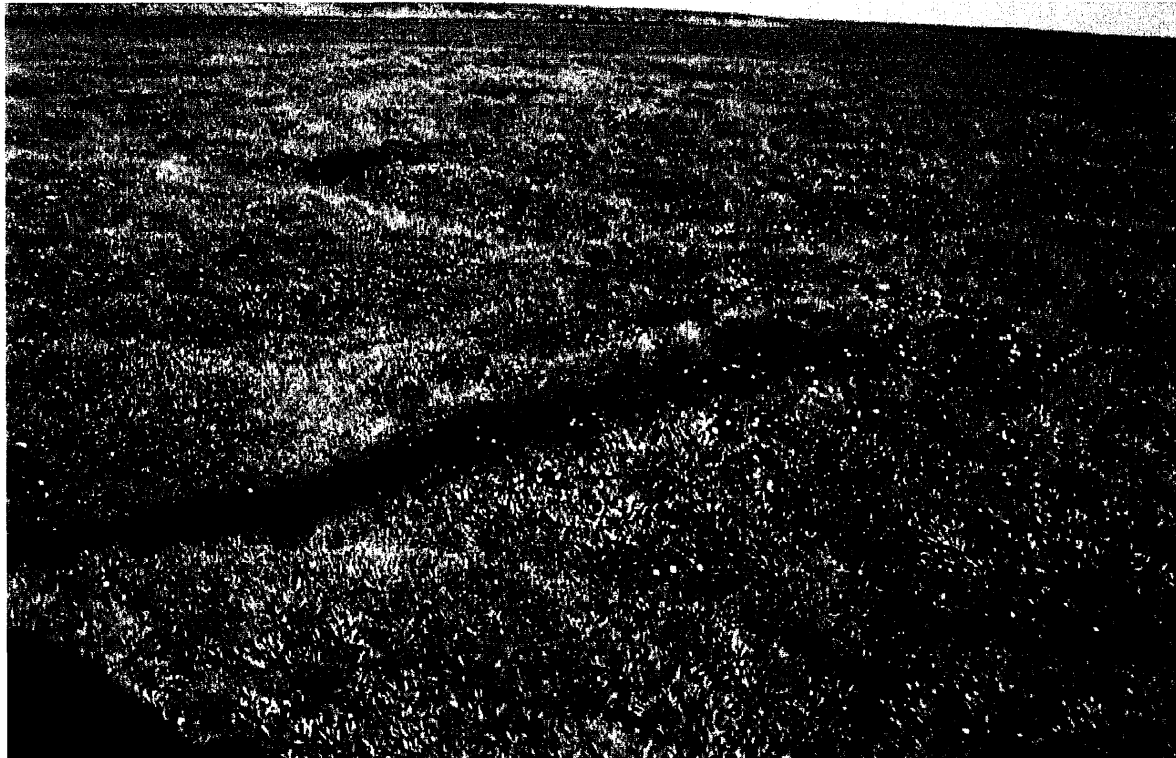
SEDGE/GRASS MEADOW



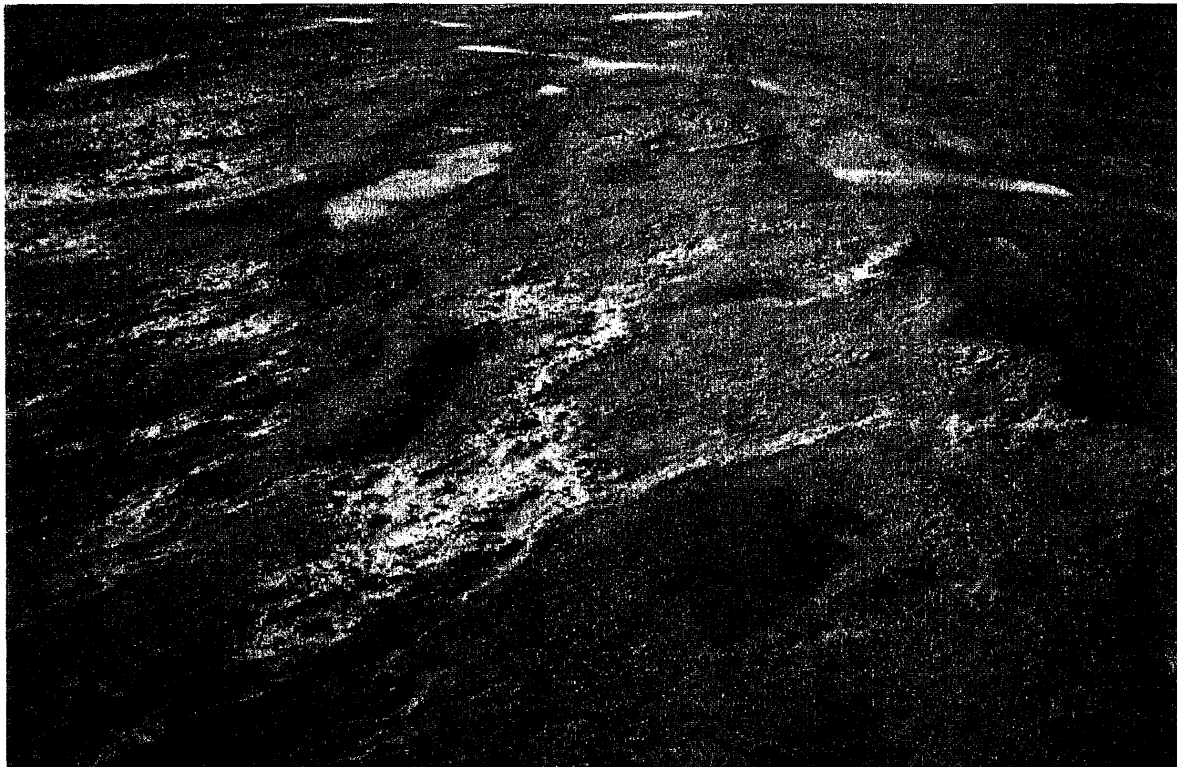
TUSSOCK TUNDRA



MOSS/LICHEN



DWARF SHRUB



DWARF SHRUB - DRYAS



LOW SHRUB



TALL SHRUB



DUNES/DRY SAND



SPARSELY VEGETATED



BARREN GROUND/OTHER

APPENDIX E

All species that were observed during the field data collection from 1994-1996

<u>Latin-Name</u>	<u>Common-Name</u>
Agropyron spp	Wheatgrass
Alnus spp	Alder
Alopecurus alpina	Foxtail
Andromeda polifolia	Bog rosemary
Arctagrostis latifolia	Broadleaf arctic bentgrass
Arctophila fulva	Pendant grass
Arctostaphylos spp	Bearberry
Arenaria spp	Sandwort
Artemisia	Artemisia
Astragalus spp	Milk vetch
Betula glandulosa	Tundra dwarf birch
Boykinia Richardsonii	Boykinia
Caltha palustris	Common marsh marigold
Carex aquatilis	Water sedge
Carex spp	Sedge other
Cassiope tetragona	Arctic bell-heather
Castilleja spp	Paintbrush
Cochlearia officinalis	Scurvy grass
Deschampsia caespitosa	Tufted hairgrass
Diapensia lapponica	Diapensia
Dryas spp	Mountain Avens
Dupontia fischeri	Dupontia
Elymus spp	Lyme grass
Empetrum nigrum	Black crowberry

Latin-Name	Common-Name
Epilobium latifolia	River beauty
Equisetum spp	Horsetail
Eriophorum angustifolium	Tall cotton-grass
Eriophorum russeolum	Russet cotton-grass
Eriophorum spp	Cotton-grass
Eriophorum vaginatum	Tussock cotton-grass
Geum spp	Geum
Grass	Grass
Hedysarum spp	Sweet-vetch
Hippuris spp	Marestail
Juncus spp	Rush
Ledum palustre	Labrador tea
Lichen	Lichen
Lupinus arcticus	Arctic lupine
Luzula spp	Woodrush
Moss	Moss
Oxytropis spp	Locoweed
Papaver spp	Arctic poppy
Pedicularis spp	Sudetan lousewort
Petasites frigidus	Arctic sweet coltsfoot
Poa lanata	Wool bluegrass
Poa spp	Arctic bluegrass
Polygonum spp	Buckwheat
Potentilla fruticosa	Shrubby cinquefoil
Potentilla palustris	Marsh cinquefoil
Puccinellia	Alkali grass
Puccinellia phryganoides	Creeping alkali grass

Latin-Name	Common-Name
Pyrola spp	Wintergreen
Ranunculus spp	Buttercup
Rhododendron spp	Rhododendron
Rubus chamaemorus	Cloudberry
Salix spp	Willow
Saxifraga spp	Saxifrage
Senecio congestus	Marsh groundsel
Silene acaulis	Moss campion
Sphagnum spp	Sphagnum moss
Stellaria spp	Low starwort
Vaccinium uliginosum	Bog blueberry
Vaccinium vitis-idaea	Mountain cranberry
Total number of plant species or species groups = 63	

APPENDIX F

All species observed sorted by class during field data collection from 1994-1996

Arctophila fulva		Number of Sites = 43
LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Arctophila fulva	Pendant grass	31.88
Caltha palustris	Common marsh marigold	0.81
Carex aquatilis	Water sedge	2.53
Cassiope tetragona	Arctic bell heather	0.05
Clear water	Clear water	60.14
Eriophorum spp	Cottongrass	0.02
Hippuris spp	Marsetail	0.47
Lichen	Lichen	0.00
Moss	Moss	0.26
Mud	Mud	2.09
Potentia palustris	Marsh cinquefoil	0.12
Ranunculus spp	Buttercup	0.23
Turbid water	Turbid water	1.40

Total Cover Types = (13)

Barren Ground/Other		Number of Sites = 69
LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Arctostaphylos spp	Bearberry	0.01
Betula glandulosa	Tundra dwarf birch	0.06
Carex aquatilis	Water sedge	0.00
Carex spp	Sedge-Other	0.01
Cassiope tetragona	Arctic bell-heather	0.01
Clear water	Clear water	0.96
Draba spp	Mustard	0.00
Dryas spp	Mountain avens	0.42
Epilobium latifolia	River beauty	0.01
Geum spp	Geum	0.03
Grass	Grass	0.09
Gravel	Gravel	21.70
Ledum palustre	Labrador tea	0.01

Lichen	Lichen	1.46
Moss	Moss	0.28
Mud	Mud	14.04
Plant debris	Plant debris	0.22
Poa spp	Arctic bluegrass	0.04
Puccinellia phryganoides	Creeping alkali grass	0.14
Rock	Rock	46.48
Salix spp	Willow	0.51
Salt burn veg	Salt burn veg	3.70
Sand	Sand	7.64
Saxifraga spp	Saxifrage	0.06
Silene acaulis	Moss campion	0.01
Silt	Silt	0.65
Turbid water	Turbid water	1.45

Total Cover Types = (27)

Barren Ground/Other **Number of Sites = 69**

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Alopecurus alpina	Foxtail	0.23
Andromeda polifolia	Bog rosemary	0.02
Arctophila fulva	Pendant grass	0.23
Arctostaphylos spp	Bearberry	0.01
Betula glandulosa	Tundra dwarf birch	0.28
Caltha palustris	Common marsh marigold	0.02
Carex aquatilis	Water sedge	28.08
Carex spp	Sedge other	1.78
Cassiope tetragona	Arctic bell-heather	0.23
Clear water	Clear water	59.53
Dryas spp	Mountain avens	0.01
Eriophorum angustifolium	Tall cotton-grass	0.04
Eriophorum risseolum	Russet cotton-grass	0.16
Eriophorum spp	Cotton-grass	2.65
Eriophorum vaginatum	Tussock cotton-grass	0.09
Grass	Grass	0.27
Ledum palustre	Labrador tea	0.09
Lichen	Lichen	0.09
Moss	Moss	3.23

Mud	Mud	1.68
Pedicularis spp	Sudetan lousewort	0.01
Polygonum spp	Buckwheat	0.00
Potentilla palustris	Marsh cinquefoil	0.12
Ranunculus spp	Buttercup	0.02
Rubus chamaemorus	Cloudberry	0.04
Salix spp	Willow	0.83
Sand	Sand	0.04
Saxifraga spp	Saxifrage	0.00
Vaccinium vitis-idaea	Mountain cranberry	0.07

Total Cover Types = (29)

Barren Ground/Other **Number of Sites = 69**

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Arctophila fulva	Pendant grass	2.79
Caltha palustris	Common marsh marigold	0.01
Carex aquatilis	Water sedge	3.17
Carex spp	Sedge other	0.35
Clear water	Clear water	93.07
Eriophorum spp	Cotton-grass	0.07
Lichen	Lichen	0.00
Moss	Moss	0.38
Mud	Mud	0.11
Potentilla palustris	Common marsh cinquefoil	0.01
Ranunculus spp	Buttercup	0.03
Salix spp	Willow	0.03

Total Cover Types = (12)

Dunes/Dry Sand **Number of Sites = 37**

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Arctagrostis latifolia	Broadleaf arctic bentgrass	0.03
Arctophila fulva	Pendant grass	0.03
Arctostaphylos spp	Bearberry	0.05
Astragalus spp	Milk vetch	0.05
Betula glandulosa	Tundra dwarf birch	0.00
Carex aquatilis	Water sedge	0.03

Cassiope tetragona	Arctic bell-heather	0.03
Clear water	Clear water	0.11
Cochlearia officinalis	Scurvy grass	0.00
Dryas spp	Mountain avens	0.08
Epilobium latifolia	River beauty	0.03
Eriophorum spp	Cotton-grass	0.08
Grass	Grass	0.30
Gravel	Gravel	0.14
Juncus spp	Rush	0.03
Lichen	Lichen	0.54
Moss	Moss	0.05
Mud	Mud	0.54
Other	Other	0.05
Plant debris	Plant debris	0.05
Poa spp	Arctic bluegrass	0.27
Puccinellia phryganoides	Creeping alkali grass	0.03
Rock	Rock	0.14
Salix spp	Willow	2.30
Sand	Sand	92.49
Silt	Silt	2.57

Total Cover Types = (26)

Total Cover Types = (12)

Dwarf Shrub **Number of Sites = 219**

LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Alnus spp	Alder	0.26
Andromeda polifolia	Bog rosemary	0.03
Arctagrostis latifolia	Broadleaf arctic bentgrass	0.18
Arctophila fulva	Pendant grass	0.00
Arctostaphylos spp	Bearberry	2.13
Arenaria spp	Sandwort	0.07
Astragalus spp	Milk vetch	0.06
Betula glandulosa	Tundra dwarf birch	8.64
Boykinia Richardsonii	Boykinia	0.07
Carex aquatilis	Water sedge	1.95

Carex spp	Sedge other	4.25
Cassiope tetragona	Arctic bell-heather	3.07
Clear water	Clear water	0.60
Deschampsia ceaspitosa	Tufted hairgrass	0.05
Diapensia lapponica	Diapensia	0.32
Dryas spp	Mountain avens	15.42
Empetrum nigrum	Black crowberry	0.65
Equisetum spp	Horsetail	0.05
Equisetum spp	Water horsetail	0.02
Eriophorum angustifolium	Tall cotton-grass	0.02
Eriophorum russeolum	Russet cotton-grass	0.23
Eriophorum spp	Cotton-grass	1.33
Eriophorum vaginatum	Tussock cotton-grass	10.51
Geum spp	Geum	0.21
Grass	Grass	0.43
Gravel	Gravel	0.02
Hedysarum spp	Sweet-vetch	0.01
Ledum palustre	Labrador tea	3.29
Lichen	Lichen	4.81
Lipinus arcticus	Arctic lupine	0.68
Luzula spp	Woodrush	0.02
Moss	Moss	7.54
Mud	Mud	3.82
Other	Other	0.07
Oxytropis spp	Locoweed	0.03
Papaver spp	Arctic poppy	0.00
Pedicularis spp	Sudetan lousewort	0.02
Petasites figidus	Arctic sweet coltsfoot	0.04
Plant debris	Plant debris	0.64
Poa spp	Arctic bluegrass	0.11
Polygonum spp	Buckwheat	0.15
Potentilla fruticosa	Shrubby cinquefoil	0.02
Pyrola spp	Wintergreen	0.01
Ranunculus spp	Buttercup	0.00
Rock	Rock	8.37
Rubus chamaemorus	Cloudberry	0.38
Salix spp	Willow	14.40

Sand	Sand	1.67
Saxifraga spp	Saxifrage	0.32
Silene acaulis	Moss campion	0.11
Vaccinium uliginosum	Bog blueberry	0.96
Vaccinium vitis-idaea	Mountain cranberry	2.23

Total Cover Types = (52)

Ice		Number of Sites = 2
LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Ice	Ice	100.00

Total Cover Types = (1 detail record)

Low Centered Polygon		Number of Sites = 87
LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Alnus spp	Alder	0.06
Andromeda polifolia	Bog rosemary	0.08
Arctophila fulva	Pendant grass	6.07
Arctostaphylos spp	Bearberry	0.23
Betula glandulosa	Tundra dwarf birch	3.61
Caltha palustris	Common marsh marigold	0.06
Carex aquatilis	Water sedge	26.38
Carex spp	Sedge other	1.86
Cassiope tetragona	Arctic bell-heather	0.74
Clear water	Clear water	32.99
Cochlearia officinalis	Scurvy grass	0.00
Deschampsia cespitosa	Tufted hairgrass	0.11
Dryas spp	Mountain avens	0.36
Empetrum nigrum	Black crowberry	0.05
Eriophorum angustifolium	Tall cotton-grass	0.29
Eriophorum russeolum	Russet cotton-grass	1.57
Eriophorum spp	Cotton-grass	5.71
Eriophorum vaginatum	Tussock cotton-grass	0.98
Grass	Grass	0.02
Juncus spp	Rush	0.00
Ledum palustre	Labrador tea	0.66

Lichen	Lichen	1.22
Lupinus arcticus	Arctic lupine	0.11
Moss	Moss	8.61
Mud	Mud	1.74
Pedicularis spp	Sudetan lousewort	0.02
Plant debris	Plant debris	0.06
Poa spp	Arctic bluegrass	0.38
Potentilla palustris	Marsh cinquefoil	0.63
Pyrola spp	Wintergreen	0.01
Ranunculus spp	Buttercup	0.00
Rubus chamaemorus	Cloudberry	0.32
Salix spp	Willow	4.43
Sand	Sand	0.23
Senecio congestus	Marsh groundsel	0.00
Vaccinium uliginosum	Bog blueberry	0.06
Vaccinium vitis-idaea	Mountain cranberry	0.07

Total Cover Types = (37)

Low Shrub **Number of Sites = 169**

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Alus spp	Alder	3.24
Arctogrostis latifolia	Broadleaf arctic bentgrass	0.15
Arctophila fulva	Pendant grass	0.79
Arctostaphylos spp	Bearberry	2.91
Astragalus spp	Milk vetch	0.25
Betula glandulosa	Tundra dwarf birch	5.33
Carex aquatilis	Water sedge	2.93
Carex spp	Sedge other	1.67
Cassiope tetragona	Arctic bell-heather	1.29
Clear water	Clear water	1.53
Dirt-bare	Dirt-bare	0.03
Dryas spp	Mountain avens	0.46
Empetrum nigrum	Black crowberry	0.05
Epilobium latifolia	River Beauty	0.09
Equisetum spp	Horsetail	0.57
Equisetum spp	Water horsetail	0.11

Eriophorum russeolum	Russet cotton-grass	0.30
Eriophorum spp	Cotton-grass	2.99
Eriophorum vaginatum	Tussock cotton-grass	1.67
Grass	Grass	0.59
Hedysarum spp	Sweet-vetch	0.80
Ledum palustre	Labrador tea	1.74
Lichen	Lichen	1.26
Lupinus arcticus	Arctic lupine	1.33
Luzula spp	Woodrush	0.00
Moss	Moss	6.54
Mud	Mud	1.80
Papaver spp	Arctic poppy	0.00
Pedicularis spp	Sudetan lousewort	0.01
Petasites frigidus	Arctic sweet coltsfoot	0.14
Plant debris	Plant debris	0.30
Poa spp	Arctic bluegrass	1.00
Polygonum spp	Buckwheat	0.00
Potentilla fruticosa	Shrubby cinquefoil	0.03
Potentilla palustris	Marsh cinquefoil	0.13
Pyrola spp	Wintergreen	0.06
Ranunculus spp	Buttercup	0.00
Rock	Rock	0.18
Rubus chamaemorus	Cloudberry	0.24
Salix spp	Willow	54.38
Sand	Sand	1.07
Saxifraga spp	Saxifrage	0.03
Senecio congestus	Marsh groundsel	0.01
Stellaria spp	Low starwort	0.00
Unknown	Unknown	0.01
Vaccinium uliginosum	Bog blueberry	1.54
Vaccinium vitis-idaea	Mountain cranberry	0.47

Total Cover Types = (47)

Moss/Lichen **Number of Sites = 15**

LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Arctostaphylos spp	Bearberry	0.67

Betula glandulosa	Tundra dwarf birch	0.67
Boykinia Richardsonii	Boykinia	1.67
Carex aquatilis	Water sedge	3.67
Carex spp	Sedge other	1.67
Cassiope tetragona	Arctic bell-heather	1.67
Clear water	Clear water	1.00
Dryas spp	Mountain avens	10.00
Empetrum nigrum	Black crowberry	0.67
Eriophorum spp	Cotton-grass	1.13
Ledum palustre	Labrador tea	0.13
Lichen	Lichen	12.87
Lupinus arcticus	Arctic lupine	1.00
Moss	Moss	20.60
Mud	Mud	0.67
Peat	Peat	12.33
Plant debris	Plant debris	3.00
Puccinellia phryganoides	Creeping alkali grass	0.67
Rock	Rock	2.00
Salix spp	Willow	5.53
Sand	Sand	11.40
Saxifraga spp	Saxifrage	0.33

Total Cover Types = (22)

Non-Patterned **Number of Sites = 115**

LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Alopecurus alpina	Foxtail	0.04
Arctophilla fulva	Pendant grass	6.90
Arctostaphylos spp	Bearberry	0.02
Betula glandulosa	Tundra dwarf birch	0.30
Carex aquatilis	Water sedge	42.77
Carex spp	Sedge other	1.54
Cassiope tetragona	Arctic bell-heather	0.11
Clear water	Clear water	35.02
Dryas spp	Mountain avens	0.04
Dupontia fischeri	Dupontia	1.17
Eriophorum angustifolium	Tall cotton-grass	0.04

Eriophorum russeolum	Russet cotton-grass	0.08
Eriophorum spp	Cotton-grass	1.77
Ledum palustre	Labrador tea	0.06
Lichen	Lichen	0.20
Moss	Moss	5.36
Mud	Mud	1.65
Poa spp	Arctic bluegrass	0.01
Potentilla palustris	Marsh cinquefoil	0.09
Ranunculus spp	Buttercup	0.05
Rubus chamaemorus	Cloudberry	0.00
Salix spp	Willow	2.01
Salt burn veg	Salt burn veg	0.07
Sphagnum spp	Sphagnum moss	0.26
Vaccinium vitis-idaea	Mountain cranberry	0.01

Total Cover Types = (25)

Sedge/Grass Meadow

Number of Sites = 205

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Alopecurus alpina	Foxtail	0.23
Andromeda polifolia	Bog rosemary	0.01
Arctagrostis latifolia	Broadleaf arctic bentgrass	0.41
Arctophila fulva	Pendant grass	1.18
Arctostaphylos spp	Bearberry	0.36
Arenaria spp	Sandwort	0.07
Artemisia	Artemisia	0.02
Astragalus spp	Milk vetch	0.01
Betula glandulosa	Tundra dwarf birch	2.15
Caltha palustris	Common marsh marigold	0.02
Carex aquatilis	Water sedge	34.23
Carex spp	Sedge other	4.23
Cassiope tetragona	Arctic bell-heather	6.78
Clear water	Clear water	2.00
Cochlearia officinalis	Scurvy grass	0.02
Deschampsia cespitosa	Tufted hairgrass	1.07
Draba spp	Mustard	0.00
Dryas spp	Mountain avens	1.35

Dupontia fischeri	Dupontia	0.90
Empetrum nigrum	Black crowberry	0.00
Equisetum spp	Horsetail	0.07
Equisetum spp	Water horsetail	0.07
Eriophorum angustifolium	Tall cotton-grass	0.15
Eriophorum russeolum	Russet cotton-grass	1.39
Eriophorum spp	Cotton-grass	4.35
Eriophorum vaginatum	Tussock cotton-grass	4.86
Grass	Grass	0.20
Juncus spp	Rush	0.15
Ledum palustre	Labrador tea	0.88
Lichen	Lichen	3.58
Lupinus arcticus	Arctic lupine	0.10
Lazula spp	Woodrush	0.46
Moss	Moss	10.20
Mud	Mud	1.05
Papaver spp	Arctic poppy	0.01
Peat	Peat	0.07
Pedicularis spp	Sudetan lousewort	0.00
Petasites frigidus	Arctic sweet coltsfoot	0.04
Plant debris	Plant debris	0.29
Poa lanata	Wool bluegrass	1.61
Poa spp	Arctic bluegrass	2.99
Polygonum spp	Buckwheat	0.00
Potentilla palustris	Marsh cinquefoil	0.97
Puccinellia	Alkali grass	0.49
Ranunculus spp	Buttercup	0.02
Rock	Rock	0.10
Rubus chamaemorus	Cloudberry	0.20
Salix spp	Willow	9.32
Sand	Sand	0.10
Saxifraga spp	Saxifrage	0.02
Stellaria spp	Low starwort	0.00
Vaccinium uliginosum	Bog blueberry	0.22
Vaccinium vitis-idaea	Mountain cranberry	0.65

Total Cover Types = (53)

Sparsely Vegetated**Number of Sites = 72**

LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Agropyron spp	Wheatgrass	0.21
Alopecurus alpina	Faxtail	0.07
Arctophila fulva	Pendant grass	0.40
Arctostaphylos spp	Bearberry	0.40
Arenaria spp	Sandwort	0.07
Astragalus spp	Milk vetch	0.10
Betula glandulosa	Tundra dwarf birch	0.14
Boykinia Richardsonii	Boykinia	0.07
Carex aquatilis	Water sedge	0.42
Carex spp	Sedge other	0.40
Cassiope tetragona	Arctic bell-heather	0.49
Clear water	Clear water	0.36
Cochlearia officinalis	Scurvy grass	0.07
Deschampsia cespitosa	Tufted hairgrass	0.14
Dryas spp	Mountain avens	4.67
Dupontia fischeri	Dupontia	0.14
Elymus spp	Lyme grass	0.35
Empetrum nigrum	Black crowberry	0.15
Epilobium latifolia	River beauty	0.24
Equisetum spp	Horsetail	0.07
Eriophorum spp	Cotton-grass	0.26
Geum spp	Geum	0.04
Grass	Grass	0.14
Gravel	Gravel	3.40
Ledum palustre	Labrador tea	0.01
Lichen	Lichen	1.63
Lupinus arcticus	Arctic lupine	0.13
Moss	Moss	1.69
Mud	Mud	9.65
Papaver spp	Arctic poppy	0.00
Peat	Peat	0.21
Pedicularis spp	Sudetan lousewort	0.00
Plant debris	Plant debris	1.28
Poa lenata	Wool bluegrass	0.01
Poa spp	Arctic bluegrass	0.26

Puccinellia phryganoides	Creeping alkali grass	0.63
Ranunculus spp	Buttercup	0.00
Rock	Rock	21.56
Salix spp	Willow	7.11
Salt burn veg	Salt burn veg	2.01
Sand	Sand	39.15
Saxifraga spp	Saxifrage	0.38
Senecio congestus	Marsh groundsel	0.00
Silene acaulis	Moss campion	0.15
Stellaria spp	Low starwort	0.28

Total Cover Types = (45)

Tall Shrub **Number of Sites = 38**

<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Alnus spp	Alder	13.79
Arctagrostis latifolia	Broadleaf arctic bentgrass	0.63
Arctostaphylos spp	Bearberry	0.13
Astragalus spp	Milk vetch	0.53
Carex aquatilis	Water sedge	0.61
Carex spp	Sedge other	0.63
Castilleja spp	Paintbrush	0.39
Clear water	Clear water	0.29
Dirt – bare	Dirt – bare	0.32
Dryas spp	Mountain avens	0.79
Epilobium latifolia	River beauty	0.18
Equisetum spp	Horsetail	0.13
Equisetum spp	Water horsetail	0.18
Eriophorum spp	Cotton-grass	0.42
Grass	Grass	2.58
Gravel	Gravel	0.13
Hedysarum spp	Sweet-vetch	0.26
Lichen	Lichen	0.53
Lupinus arcticus	Arctic lupine	3.16
Moss	Moss	2.66
Mud	Mud	1.92
Plant debris	Plant debris	1.53

Potentilla palustris	Marsh cinquefoil	0.13
Rock	Rock	0.26
Salix spp	Willow	65.42
Sand	Sand	2.32
Saxifraga spp	Saxifrage	0.08

Total Cover Types = (27)

Turbid Water	Number of Sites = 11
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<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Turbid water	Turbid water	100.00

Total Cover Types = (1 detailed record)

Tussock Tundra	Number of Sites = 169
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<u>LATIN-NAME</u>	<u>COMMON-NAME</u>	<u>AVERAGE PER CLASS</u>
Andromeda polifolia	Bog rosemary	0.07
Arctophila fulva	Pendant grass	0.03
Arctostaphylos spp	Bearberry	0.41
Betula glandulosa	Tundra dwarf birch	4.78
Boykinia Richardsonii	Boykinia	0.09
Carex aquatilis	Water sedge	2.79
Carex spp	Sedge other	1.61
Cassiope tetragona	Arctic bell-heather	2.10
Clear water	Clear water	1.22
Dryas spp	Mountain avens	0.75
Empetrum nigrum	Black crowberry	0.06
Equisetum spp	Horsetail	0.04
Eriophorum russeolum	Russet cotton-grass	0.82
Eriophorum spp	Cotton-grass	30.67
Eriophorum vaginatum	Tussock cotton-grass	26.34
Grass	Grass	0.03
Ledum palustre	Labrador tea	1.79
Lichen	Lichen	3.40
Lupinus arcticus	Arctic lupine	0.27
Luzula spp	Woodrush	0.09
Moss	Moss	8.47
Mud	Mud	0.74

Pedicularis spp	Sudetan lousewort	0.00
Petasites frigidus	Arctic sweet coltsfoot	0.15
Plant debris	Plant debris	0.21
Poa spp	Arctic bluegrass	0.12
Polygonum spp	Buckwheat	0.00
Ranunculus spp	Buttercup	0.00
Rock	Rock	0.09
Rubus chamaemorous	Cloudberry	0.62
Salix spp	Willow	10.74
Saxifraga spp	Saxifrage	0.02
Vaccinium uliginosum	Bog blueberry	0.06
Vaccinium vitis-idaea	Mountain cranberry	1.17

Total Cover Types = (34)

Wet Tundra **Number of Sites = 186**

LATIN-NAME	COMMON-NAME	AVERAGE PER CLASS
Andromeda polifolia	Bog Rosemary	0.08
Arctophila fulva	Pendant grass	2.87
Arctostaphylos spp	Bearberry	0.15
Astragalus spp	Milk vetch	0.01
Betula glandulosa	Tundra dwarf birch	3.88
Caltha palustris	Common marsh marigold	0.05
Carex aquatilis	Water sedge	40.09
Carex spp	Sedge other	3.12
Cassiope tetragona	Arctic bell-heather	1.57
Clear water	Clear water	14.93
Coal	Coal	0.03
Dryas spp	Mountain avens	0.61
Dupontia fischeri	Dupontia	0.11
Equisetum spp	Horsetail	0.04
Equisetum spp	Water horsetail	0.11
Eriophorum angustifolium	Tall cotton-grass	0.12
Eriophorum russeolum	Russet cotton-grass	2.57
Eriophorum spp	Cotton-grass	6.05
Eriophorum vaginatum	Tussock cotton-grass	1.37
Grass	Grass	0.24

Hippuris spp	Marestail	0.03
Ledum palustre	Labrador tea	0.85
Lichen	Lichen	1.65
Lupinus arcticus	Arctic lupine	0.05
Moss	Moss	7.50
Mud	Mud	0.98
Pedicularis spp	Sudetan lousewort	0.01
Petisites frigidus	Arctic sweet coltsfoot	0.00
Plant debris	Plant debris	0.13
Poa spp	Arctic bluegrass	0.50
Potentilla fruticosa	Shrubby cinquefoil	0.05
Potentilla palustris	Marsh cinquefoil	1.39
Puccinellia phryganoides	Creeping alkali grass	0.30
Ranunculus spp	Buttercup	0.03
Rhododendron spp	Rhododendron	0.03
Rock	Rock	0.08
Rubus chamaemorous	Cloudberry	0.17
Salix spp	Willow	7.42
Sand	Sand	0.22
Saxifraga spp	Saxifrage	0.03
Senecio congestus	Marsh groundsel	0.03
Vaccinium uliginusum	Bog blueberry	0.12
Vaccinium vitis-idaea	Mountain cranberry	0.32

Total Cover Types = (43)

APPENDIX G

Error matrices for the NPR-A classification.

Error matrix for Phase 3 (Southern) of the NPR-A Earth Cover Classification

		CLASSIFICATION																TOTAL	USERS	
		Water		Aquatic		Flooded Tun.		Wet T.	Moist Tundra			Shrub			Barren					
		CW	ICE	CA	AF	LCP	NP	WT	SGM	TT	ML	DSH	LSH	TSH	DDS	SV	OTH			
R E F E R E N C E	CW	29																29	100%	
	ICE																	0	100%	
	CA																	0	100%	
	AF	3			3													6	50%	
	LCP					4	3			1								8	50%	
	NP						13					1						14	93%	
	WT					1	2	30	1	3		1						38	79%	
	SGM							2	10	6		5	3					26	38%	
	TT										19		8	1				28	68%	
	ML																	0	100%	
	DSH									1	14		55	2			4	2	78	71%
	LSH										1		5	18					24	75%
	TSH													1	2				3	67%
	DDS																		0	100%
	SV												1				9	4	14	64%
	OTH																4	21	25	84%
Total		32	0	0	3	5	18	32	12	44	0	76	25	2	0	17	27	293		
PRODUCERS		91%	100%	100%	100%	80%	72%	94%	83%	43%	100%	72%	72%	100%	100%	53%	78%			

OVERALL ACCURACY =

213/293 =

73%

CW = water, ICE = ice, CA = carex aquatilis, AF = arctophila fulva, LCP = low centered polygons, NP = nonpattern, WT = wet tundra, SGM = sedge/grass meadow, TT = tussock tundra, ML = moss/lichen, DSH = dwarf shrub, LSH = low shrub, TSH = tall shrub, DDS = dunes/dry sand, SV = sparsely vegetated, OTH = other.

Error matrix for Phase 3 (Southern) of the NPR-A Earth Cover Classification

		CLASSIFICATION								
		Water	Aquatic	Flooded Tundra	Wet Tundra	Moist Tundra	Shrub	Barren Ground	TOTAL	USERS
R	Water	29							29	98%
E	Aquatic	3	3						6	73%
F	Flooded Tundra			20		1	1		22	91%
E	Wet Tundra			3	30	4	1		38	41%
F	Moist Tundra				2	35	17		54	85%
E	Shrub					16	83	6	105	85%
N	Barren Ground						1	38	39	96%
C	TOTAL	32	3	23	32	56	103	44	293	
E	PRODUCERS	100%	85%	72%	67%	80%	82%	96%		

OVERALL ACCURACY =

238/293 =

81%

Error matrix for all three phases of the NPR-A Earth Cover Classification

		CLASSIFICATION																TOTAL	USERS
		Water		Aquatic		Flooded Tun.		Wet T.	Moist Tundra			Shrub			Barren				
		CW	ICE	CA	AF	LCP	NP	WT	SGM	TT	ML	DSH	LSH	TSH	DDS	SV	OTH		
R E F E R E N C E	CW	29																29	100%
	ICE																	0	100%
	CA																	0	100%
	AF	3			3													6	50%
	LCP					4	3			1								8	50%
	NP						13					1						14	93%
	WT					1	2	30	1	3		1						38	79%
	SGM							2	10	6		5	3					26	38%
	TT									19		8	1					28	68%
	ML																	0	100%
	DSH								1	14		55	2			4	2	78	71%
	LSH									1		5	18					24	75%
	TSH												1	2				3	67%
	DDS																	0	100%
	SV											1				9	4	14	64%
	OTH															4	21	25	84%
Total		32	0	0	3	5	18	32	12	44	0	76	25	2	0	17	27	293	
PRODUCERS		91%	100%	100%	100%	80%	72%	94%	83%	43%	100%	72%	72%	100%	100%	53%	78%		

OVERALL ACCURACY =

213/293 =

73%

CW = water, ICE = ice, CA = carex aquatilis, AF = arctophila fulva, LCP = low centered polygons, NP = nonpattern, WT = wet tundra, SGM = sedge/grass meadow, TT = tussock tundra, ML = moss/lichen, DSH = dwarf shrub, LSH = low shrub, TSH = tall shrub, DDS = dunes/dry sand, SV = sparsely vegetated, OTH = other.

Error matrix for all three phases of the NPR-A Earth Cover Classification

		CLASSIFICATION								
		Water	Aquatic	Flooded Tundra	Wet Tundra	Moist Tundra	Shrub	Barren Ground	TOTAL	USERS
R	Water	119	2	1					122	98%
E	Aquatic	3	45	5	3				56	73%
F	Flooded Tundra		5	77	1	3	1		87	91%
E	Wet Tundra		1	12	51	10	1		75	41%
F	Moist Tundra			2	4	110	20		136	85%
E	Shrub			1		28	154	7	190	85%
N	Barren Ground						1	73	74	96%
C	TOTAL	122	53	98	59	151	177	80	740	
E	PRODUCERS	100%	85%	72%	67%	80%	82%	96%		

OVERALL ACCURACY =

629/740 =

85%

APPENDIX H

Metadata for the NPR-A earth cover classification

Metadata Information System (MIS): NPR-A Earth Cover Classification

General Description:

Coverage/Image Name: npra_classification.img

Description:

The objective of this project was to create an updated and detailed earth cover inventory in computer database format for the entire NPR-A. The purpose of the project was to develop a tool to aid in the management of the NPR-A and to develop baseline information that could be used in other studies. Due to the immense size of the project area, limited field access, and lack of aircraft support infrastructure, the NPR-A project was divided into three phases. These phases were completed in 1995, 1996, and 1998, respectively. Eight Landsat TM satellite scenes and three SPOT XS satellite scenes, were used to classify the NPR-A into earth cover categories. An unsupervised clustering or seeding technique was used to determine the location of field sites and a custom field data collection card was used to record field information. After initial on-the-ground sampling, a helicopter was utilized to gain access to field sites throughout the project area. Global positioning system (GPS) technology was used both to navigate to pre-selected sites and record locations of new sites selected in the field. Data were collected on 1,667 field sites during a three-year field season from 1994 through 1996. A portion (44%) of these field sites were set aside for accuracy assessment. A combined supervised/unsupervised classification technique was performed to classify the satellite imagery into seven major classes and seventeen minor classes. The classification scheme for the land cover inventory was developed through a series of meetings with biologists familiar with the vegetation and previous work (Markon and Derkson 1994). As each scene was completed it was mosaicked and edge matched with adjacent scenes to produce a seamless database of NPR-A earth cover types.

Layer Scale: 30 meter pixels (MMU = 10 acres)

Date Developed: October 20, 1998

Data Type: ERDAS Imagine 8.2

Source Data:

PHASE #	SENSOR	PATH/ROW	% SHIFT	DATE
1	Landsat Thematic Mapper (TM)	81/10	42%	6-Jul-92
1	Landsat Thematic Mapper (TM)	79/10	21%	8-Jul-92
2	Landsat Thematic Mapper (TM)	75/11	0%	28-Jul-92
2	SPOT XS	k425/j202	10%	9-Aug-94
2	SPOT XS	k425/j202	60%	4-Aug-94
2	SPOT XS	k425/j203	70%	4-Aug-94
3	Landsat Thematic Mapper (TM)	77/11	0%	28-Aug-95
3	Landsat Thematic Mapper (TM)	77/12	0%	28-Aug-95
3	Landsat Thematic Mapper (TM)	80/11	0%	31-Jul-92
3	Landsat Thematic Mapper (TM)	81/11	0%	6-Jul-92
3	Landsat Thematic Mapper (TM)	79/11	0%	22-Jun-92

Projection Information:

Name of Projection: UTM Zone 4

Name of Spheroid: Clarke 1866

Name of Datum: NAD 27

Map Unit: Meters

Upper Left X 249481.0

Upper Left Y 8011939.0

Data Dictionary:

<u>1.0 Water</u>	<u>5.0 Moist Tundra</u>
1.1 Clear Meadow	5.1 Sedge/Grass
1.2 Turbid	5.2 Tussock Tundra
1.3 Ice	5.3 Moss/Peat/Lichen
<u>2.0 Aquatic</u>	<u>6.0 Shrub</u>
2.1 <i>Carex aquatilis</i>	6.1 Dwarf
2.2 <i>Arctophila fulva</i>	6.2 Low
	6.3 Tall
<u>3.0 Flooded Tundra</u>	<u>7.0 Barren Ground</u>
3.1 Low-Centered Polygons	7.1 Dunes/Dry Sand
3.2 Non-Patterned	7.2 Sparsely Vegetated
<u>4.0 Wet Tundra</u>	7.3 Other

1.1 Clear Water - Fresh or saline waters with little or no particulate matter. Clear water areas are typically deep (greater than one meter). The clear water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage of these species.

1.2 Turbid Water - Waters that contain particulate matter or shallow (<1m), clear water bodies that are spectrally different from class 1.1. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. The turbid water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage of these species.

1.3 Ice - May last into late summer on lakes and larger ponds. Ice is present year round in many of the larger lakes.

2.1 *Carex aquatilis* - Associated with lake or pond shorelines and composed of 50 - 80% clear or turbid water that was greater than 10 centimeters deep. The dominant species was *Carex aquatilis*. A small percentage of *Arctophila fulva*, *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris* may be present.

2.2 *Arctophila fulva* - Associated with lake or pond shorelines and composed of 50 - 80% clear or turbid water that was greater than 10 centimeters deep. The dominant species was *Arctophila fulva*. A small percentage of *Carex aquatilis*, *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris* may also be present.

3.1 Flooded Tundra-Low Centered Polygons - Polygon features that retain water throughout the summer. This class is composed of 25 - 50% water; *Carex aquatilis* is the dominant species in the permanently flooded areas. The drier ridges of the polygons are composed mostly of *Eriophorum russeolum*, *Eriophorum vaginatum*, *Sphagnum* spp., *Salix* spp., *Betula nana*, *Arctostaphylos* spp., and *Ledum palustre*.

3.2 Flooded Tundra-Non-Pattern - Continuously flooded areas composed of 25-50% water. *Carex aquatilis* was the dominant species. Other species may include *Hippuris vulgaris*, *Potentilla palustris*, and *Caltha palustris*. Non-pattern is distinguished from low-centered polygons by the lack of polygon features and associated shrub species that grow on the dry ridges of low-centered polygons.

4.0 Wet Tundra - Associated with areas of super saturated soils and standing water. Wet tundra often floods in early summer and generally drains of excess water during dry periods but remains saturated throughout the summer. It is composed of 10-25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum angustifolium*, and other sedges, grasses, and forbs.

5.1 Sedge/Grass Meadow - Dominated by the sedge family. This class commonly consists of a continuous mat of sedges and grasses with a moss and lichen understory. The dominant species were *Carex aquatilis*, *Eriophorum angustifolium*, *Eriophorum russeolum*, *Arctagrostis latifolia* and *Poa arctica*. Associated genera include *Cassiope* spp., *Ledum* spp., and *Vaccinium* spp.

5.2 Tussock Tundra - Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Tussock tundra is common throughout the Arctic Foothills and may be found on well-drained sites in all areas of the NPR-A. Cottongrass tussocks are the dominant landscape elements, while moss is the common understory. Lichen, forbs, and shrubs are also present in varying densities. Associated genera include *Salix* spp., *Betula nana*, *Ledum palustre*, and *Carex* spp.

5.3 Moss/Lichen - Associated with low-lying lakeshores and dry sandy ridges dominated by moss and lichen species. As this type grades into a sedge type, graminoids such as *Carex aquatilis* may increase in cover, forming an intermediate zone.

6.1 Dwarf Shrub - Associated with ridges and well-drained soils and dominated by shrubs less than 30 centimeters in height. Because of the relative dryness of the sites on which this cover type occurs, it is the most species diverse. Major species included *Salix* spp., *Betula nana*, *Ledum palustre*, *Dryas* spp., *Vaccinium* spp., *Arctostaphylos* spp., *Eriophorum vaginatum*, and *Carex aquatilis*. This class frequently occurs over a substrate of tussocks.

6.2 Low Shrub - Associated with small streams and rivers, but also occurring on hillsides in the southern portion of the NPR-A. This class is dominated by shrubs between 30 centimeters and 1.5 meters in height. Major species included *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre*.

6.3 Tall Shrub - Found along the Colville River and some of its major tributaries, and dominated by *Salix* spp. over 1.5 meters in height. This class may also contain significant presence of *Alnus crispa* over 1.5 meters in height.

7.1 Dunes/Dry Sand - Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with less than 10% vegetation. Plant species may include *Poa* spp., *Salix* spp., *Astragalus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.

7.2 Sparsely Vegetated - Occurred primarily along the coast in areas affected by high or storm tides, in recently drained lake or pond basins, and where there is bare mineral soil that is being re-colonized with vegetation. Dominated by non-vegetated material with 10-30% vegetation. The vegetation in these areas may include rare plants but some of the more commonly found species included *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragalus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.

7.3 Barren Ground/Other - Associated with river and stream gravel bars, mountainous areas and urban areas. Includes less than 10% vegetation. May incorporate dead vegetation associated with salt burn from ocean water.

Classification Decision Rules:

1.0 WATER ($\geq 80\%$ water)

- 1.1 Clear Water - (depth ≥ 1 meter)
- 1.2 Turbid Water - (depth < 1 meter)
- 1.3 Ice - (ice $\geq 60\%$)

2.0 AQUATIC ($\geq 50\%$ water and $< 80\%$ water and $> 10\text{cm}$ in depth)

- 2.1 *Carex aquatilis* - ($> 15\%$ *Carex aquatilis* and $< 15\%$ *Arctophila fulva*)
- 2.2 *Arctophila fulva* - ($> 15\%$ *Arctophila fulva* and $< 15\%$ *Carex aquatilis*)

3.0 FLOODED TUNDRA ($\geq 25\%$ water and $< 50\%$ water and $< 10\text{cm}$ in depth)

- 3.1 Low Centered Polygons ($\geq 5\%$ Sedge/Grass)
- 3.2 Non -pattern ($< 5\%$ sedge/Grass)

4.0 WET TUNDRA ($\geq 10\%$ and $< 25\%$ water)

5.0 MOIST TUNDRA ($< 10\%$ water, $< 40\%$ shrub, composed mostly of sedges, grasses, rushes and moss/peat/lichen complex)

- 5.1 Sedge/Grass Meadow - ($\geq 50\%$ sedge/grass and $< 40\%$ tussock cotton grass)
- 5.2 Tussock Tundra - ($\geq 40\%$ tussock cotton grass)
- 5.3 Moss/lichen - ($\geq 50\%$ moss and/or lichen)

6.0 SHRUB ($< 5\%$ water and $\geq 40\%$ shrub)

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