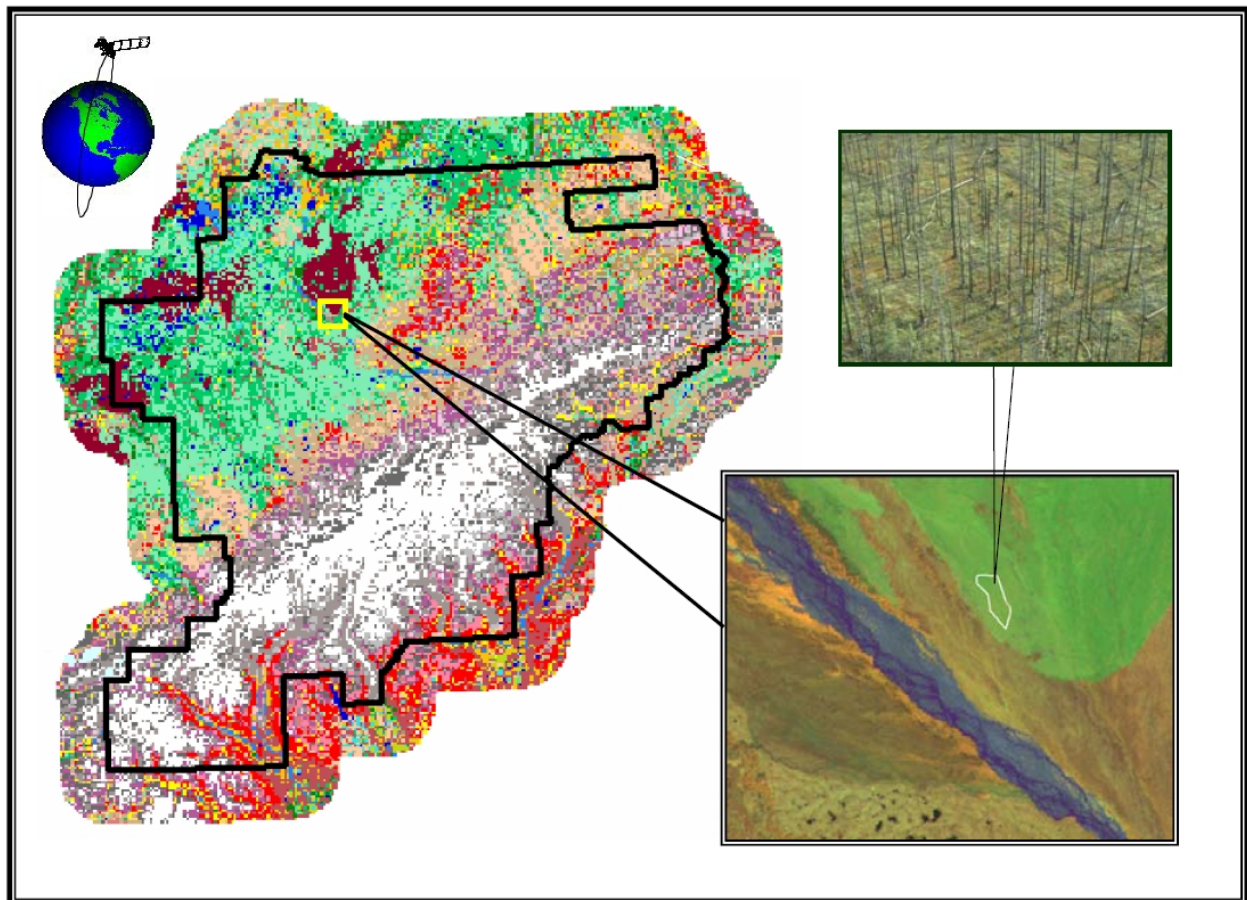




Denali National Park and Preserve Landcover Mapping Project *Volume 1: Remote Sensing Data, Procedures and Results*

Natural Resource Technical Report NPS/DENA/NRTR—2001/001



ON THE COVER

Graphic representing Landcover Map progress (photo on the ground, as it appears on satellite image and as represented in the landcover map

Graphic by EarthSat Corp.

Denali National Park and Preserve Landcover Mapping Project

Volume 1: Remote Sensing Data, Procedures and Results

Natural Resource Technical Report NPS/DENA/NRTR—2001/001

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PREFACE

The final documentation for the Denali Landcover Mapping Project is presented in two volumes. Volume 1: "Remote Sensing Data, Procedures and Results" provides information on the technical aspects of map development so that Users may better interpret and understand the map's strengths and limitations. Volume 2: "Landcover Classes and Plant Associations" provides detailed ecological information (plant associations, ecoregion and climate influences, etc.) for the study area. Users are encouraged to review both documents in order to fully understand the strengths, limitations and ecological implications of the landcover products.

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We are also very appreciative to Denali Park staff for assisting with logistic support during the 1999 field season, for their positive comments and review of the draft map, and particularly for their enthusiasm for the landcover products. We especially thank Carl Roland, Denali Park Plant Ecologist, for his thoughtful input during various stages of the project.

ABSTRACT

Stevens, J. L. K. Boggs, A. Garibaldi, J. Grunblatt, and T. Helt. 2001. Denali National Park and Preserve landcover mapping project Volume 1: Remote sensing data, procedures and results. Natural Resource Technical Report NPS/DENA/NRTR—2001/001. National Park Service, Fort Collins, Colorado.

As part of the Inventory and Monitoring Program of the National Park Service (NPS), the Alaska Support Office (NPS-AKSO) commissioned Earth Satellite Corporation (Rockville, MD) and the Alaska Natural Heritage Program (University of Alaska Anchorage) to produce digital and hardcopy landcover maps and supporting documents for Denali National Park and Preserve (Denali NP&P). Using Landsat Thematic Mapper multi-spectral imagery as the primary data source and SPOT XS data as a secondary source, landcover was mapped at intermediate scales (1:63,360 - 1:100,000) with 25 classes following a modified version of the Alaska Vegetation Classification system at levels III and IV (Viereck et al. 1992). The study area was approximately 9.5 million acres and included the Park and Preserve as well as a surrounding 10 mile buffer.

The development of the Denali NP&P landcover map involved collection and analysis of field-verified datasets and the analysis and interpretation of remotely sensed imagery (satellite and aerial photography). A supervised digital image processing approach using the Maximum Likelihood (ML) classifier was performed on both Landsat TM and select SPOT XS scenes covering the study area. The base landcover map derived from the ML spectral process was then refined through iterative modeling using environmental and spectral data layers such as illumination, slope, elevation, Normalized Difference Vegetation Index (NDVI), and individual channels of the Landsat TM data. The digital image processing was guided by visual interpretation of the Landsat TM and SPOT XS data, review of available field data, spot checking of 1:60,000 high altitude color infrared photography, and input from key NPS personnel familiar with the Park.

In addition to the detailed landcover map of 25 mapping classes, a more general 16 class landcover map was also created by combining ecologically and/or spectrally similar classes. Accuracy assessments of the detailed (25 class) landcover map and the general (16 class) landcover map were performed to evaluate the reliability of the remote sensing techniques and to provide users of the map with an indication of relative confusion among mapping classes.

The results, based on a ~2 acre minimum mapping unit (MMU) dataset, showed an estimated overall accuracy of 81.6% for the detailed landcover map and 84.8% for the general landcover map. The overall accuracy provides an average classification accuracy, while the *producer's* and *user's accuracies* provide more detailed information about the errors of omission (*producer's error*) and commission (*user's error*) for the individual mapping classes.

The area (acreage) and accuracies for the general landcover types in the Denali NP&P project area were as follows:

General Landcover Classes	PARK	Park and Buffer	Park and Buffer	Park and Buffer
	Area (acres)	Area (Acres)	Producer's %	User's %
Needleaf Forest	601,786.8	1,088,427.1	92.0	84.6
Stunted Spruce	853,984.8	1,283,661.2	80.1	88.1
Broadleaf	97,062.9	253,607.6	79.8	62.0
Spruce-Broadleaf	149,929.4	509,643.9	59.4	88.8
Tall Shrub	355,788.1	729,465.2	93.8	90.2
Low Shrub (drier sites)	624,734.2	985,523.4	83.5	78.3
Low Shrub (moister sites)	279,625.9	484,598.9	83.2	81.6
Dwarf Shrub	420,740.9	625,249.4	79.2	80.4
Herbaceous - shrub	114,555.7	228,214.9	81.7	87.9
Wet herbaceous	38,426.7	74,171.7	68.0	87.4
Sparse - Bare	881,606.6	1,100,182.7	94.6	88.1
Snow - Ice	932,789.6	1,049,705.7	99.7	99.6
Water	92,093.3	169,427.3	97.6	98.7
Burn	172,528.5	296,213.5	NA	NA
Indeterminate	413,616.9	674,481.1	NA	NA
Totals	6,029,270.4	9,552,573.4	---	---

Keywords: Alaska, Denali National Park and Preserve, landcover mapping, remote sensing, satellite imagery.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Alaska Support Office (AKSO) of the National Park Service (NPS) sought to develop a digital landcover map of Denali National Park and Preserve (Denali NP&P). The project was part of the Inventory and Monitoring Program of the NPS, a program designed to provide reliable and consistent scientific information to assess the status and trends of national park ecosystems. Vegetation mapping is conducted under the inventory portion of the program in order to provide basic information immediately useful to the parks for making resource management decisions and designing monitoring programs. The primary intent of the landcover map was to provide baseline information about the landcover resources in Denali. Other intended uses included providing information useful for modeling wildlife habitat, fire fuel availability and the occurrences of sensitive species.

The general approach and methods for producing the Denali NP&P landcover map was to derive approximately 30-35 endpoint classes from Landsat TM and SPOT XS imagery through spectral classification, environmental site modeling and raster editing procedures. Ultimately however, 25 endpoint classes were found to be both spectrally discernible and ecologically meaningful.

1.2 SCOPE OF THE PROJECT

A project team consisting of resource managers from NPS-AKSO and Denali NP&P and representatives from Earth Satellite Corporation (Rockville, MD) and the Alaska Natural Heritage Program (Anchorage, AK) met in May 1999 to discuss, plan and develop logistics for the Denali NP&P landcover mapping project. Their discussions included project objectives and goals, user needs and requirements, classification system development and mapping classes, plans and logistics for the 1999 field season, and evaluation of available datasets (satellite imagery, air photos, vegetation data, etc.) for developing the landcover map.

Landcover for Denali NP&P was mapped at intermediate scales (1:63,360 - 1:100,000) with 25 classes, using a classification based primarily on vegetation structure and form (tree, shrub or herbaceous), and to lesser extent genera and species information. The mapping classification follows, with modifications, The Alaska Vegetation Classification system at levels III and IV (Viereck et al., 1992). The landcover classification key and mapping class descriptions used for this mapping effort are provided in Appendices 5.1 and 5.2

The usefulness of the map classification to land managers can be increased dramatically when the landcover classes are linked to more detailed descriptions of plant communities such as those given in plant associations of the National Vegetation Classification System (NVCS; Grossman et al., 1998). NVCS plant associations are generally equivalent to Level V of Viereck et al., 1992. Plant associations for the Denali NP&P study area are described in Volume 2: Landcover Classes and Plant Associations.

Development of the Denali NP&P landcover map included the following stages: 1.) review of all existing vegetation data for the study area, 2.) collection and analysis of ground truth or field-verified data, 3.) analysis and interpretation of remotely sensed imagery (satellite and aerial photography), 4.) application and evaluation of spectral classifications, 5.) development and application of models using ancillary digital data to distinguish among confused landcover (spectral) classes, and 5.) numerous qualitative and quantitative evaluation steps through out the process.

1.3 DESCRIPTION OF PROJECT AREA AND ENVIRONMENT

The Denali NP&P Landcover Project Area includes approximately 6 million acres from the Park, and an additional 3.5 million acres from a 10 mile buffer surrounding the Park Boundary. Both the Park and the 10 mile buffer, a total of 9.5 million acres, were the primary area of interest for development of the landcover maps and supporting documentation. Figure 1 shows the general location of the Denali NP&P study area.

The Park encompasses a diversity of vegetation and land forms in a landscape that is largely unchanged by human development. South of the Alaska Range, coastal influences dominate producing higher rainfalls and denser forests. North of the Alaska Range interior climate prevails with boreal forests transitioning to arctic and alpine tundra. Permafrost is a strong influence in this area of the Park. The Alaska Range itself is an immense region dominated by glaciers, snowfields and rock escarpments.

The decision to use satellite imagery (both Landsat Thematic Mapper (TM) and SPOT multispectral (XS)) for the project was based on the vast project area, the level of mapping information requested by NPS, the spatial and spectral characteristics of the available sensors/data, and the time and budget resources available for the project.

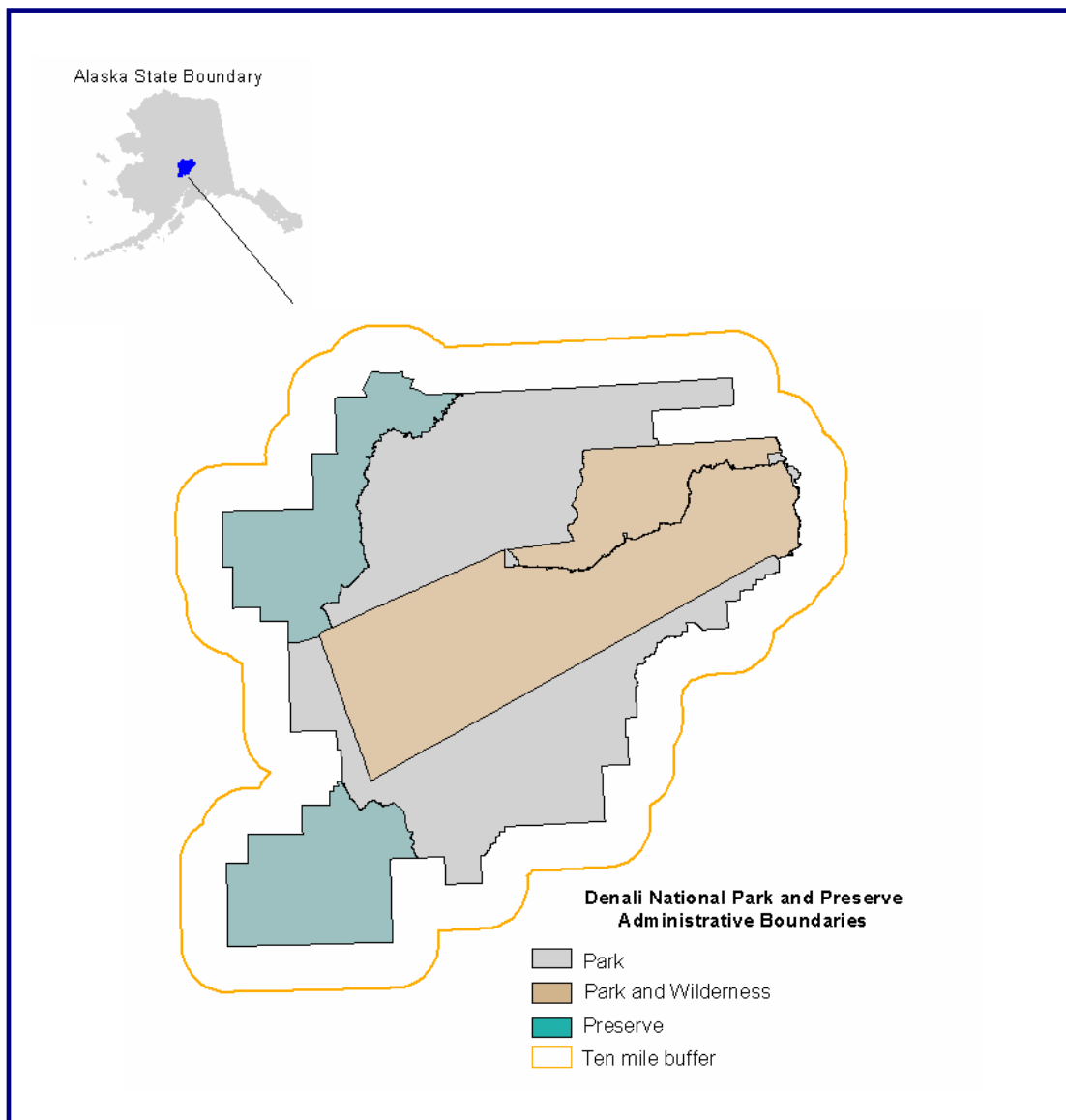


Figure 1. Location of the Denali NP&P study area

CHAPTER TWO

2.0 METHODS and MATERIALS

2.1 Overview of the Landcover Classification System

An initial list of over fifty Target Mapping Classes (Table 1) consisting of landcover types believed to potentially occur within the study area was developed. This list was developed from review of the Denali Fire Program (FirePro) vegetation data as well as from vegetation literature reviews of the study area (refer to Volume 2). The target mapping classes were used to help guide field collection efforts, and were later combined or dropped (based on ecological and/or spectral imagery considerations) to form the 25 endpoint mapping classes used in the final detailed landcover map (Table 2). A landcover class key and descriptions of the final 25 (detailed) landcover classes are provided in Appendices 5.1 and 5.2. For additional discussion on the process of combining the Target classes down to the 25 endpoint class level, refer to section 2.7 of this Volume. The detailed landcover map was further aggregated to create a general 16 landcover classes (Table 3) which may be useful for broad-scale summaries or analyses of the landcover types found in the study area .

Table 1. Post-Field Target Mapping Classes for Denali NP&P. Following the field season and review of existing data, there were 56 target landcover classes that were tested for ‘spectral map-ability’ . However, based on satellite imagery resolution issues and ecological considerations, this list was refined to the final detailed (25) mapping classes shown in Table 2.

Final Code	Target Mapping Class	Canopy Cover	Height of vegetation / site factor
1	Open White Spruce	25-59	
2	Open Black Spruce		
3	Open Stunted Spruce (~black spruce)	25-59	
4	Woodland White Spruce	10-24	> 15'
5	Woodland Stunted Spruce Ericaceous	10-24	<15', >25% Ericaceous
6	Woodland Stunted Spruce Sedge	10-24	< 15', >25% Sedge
7	Closed Birch	60-100	> 50% Birch
8	Closed Aspen	60-100	> 50% Aspen
9	Closed Balsam Poplar	60-100	> 50% B. Pop.
10	Closed Mixed Deciduous	60-100	-
11	Open Birch	25-59	> 50% Birch
12	Open Aspen	25-59	> 50% Aspen
13	Open Balsam Poplar	25-59	> 50% B. Pop.
14	Open Mixed Deciduous	25-59	-
15	Woodland Broadleaf		
16	Closed Mixed	60-100	-
17	Open Mixed	25-59	-
18	Woodland Mixed	10-24	-
19	Closed Tall Alder -Willow	75-100	> 1.5m (5'), >75% Alder
20	Closed Tall Alder	75-100	> 1.5m (5'), >75% Willow
21	Closed Tall Willow	75-100	> 25-75% of each
22	Open Tall Alder	25-74	> 1.5m (5')
23	Open Tall Willow	25-74	> 1.5m (5')

Final Code	Target Mapping Class	Canopy Cover	Height of vegetation / site factor
24	Closed Low Alder-Willow	75-100	8"-5'(1.5m)
25	Closed Low Shrub Birch-Willow		
26	Closed Low Willow		
27	Closed Low Shrub Birch-Ericaceous Shrub	75-100	8"-5'(1.5m)
28	Closed Low Shrub Birch	75-100	8"-5'(1.5m)
29	Open Low Alder-Willow	25-74	8"-5'(1.5m)
30	Open Low Alder	25-74	8"-5'(1.5m)
31	Open Low Shrub Birch/Ericaceous Shrub-Willow	25-74	8"-5'(1.5m)
32	Open Low Willow	25-74	8"-5'(1.5m)
33	Open Low Mixed Shrub-Tussock	25-74	8"-5'(1.5m), >25% tuss
34	Open Low Shrub Bog		
35	Open Low Shrub Birch-Ericaceous Shrub	25-74	8"-5'(1.5m)
36	Dryas Dwarf Shrub		>50% Dryas, <8", >25% Rock
37	Mixed Dwarf Shrub		>50%MixDwfShrb, <25% Sedge, <25% Rock
38	Mixed Dwarf Shrub-Sedge		>50%MixDwfShrb, >25% Sedge, <25% Rock
39	Mixed Dwarf Shrub-Lichen		>50%MixDwfShrb, >25% Tussock, <25% Rock
40	Mixed Dwarf Shrub-Rock		>50%MixDwfShrb, <25% Tussock or sedge, >25%Rock
41	Dry/Mesic Grass		>25% Herb, <25% Shrub, <25% Tussock
42	Dry/Mesic Grass-Forb		>25% Herb, >25% Grass, 50% Forb, <25% Tussock
43	Dry/Mesic Sedge-Forb		>25% Herb, >25% Sedge, 50% Forb, <25% Tussock
44	Tussock		Mesic, >25%
45	Wet Herbaceous		Emergent Vegetation., No Tussock
46	Aquatic		
47	Sparse Vegetation		15-25% Total Vegetation Cover
48	Mosaic/Patterned Ground		< 15% Vegetation Cover
49	Bare Ground		
50	Snow/Ice		
51	Shadow/Indeterminate		
52	Silty Water		
53	Clear Water		
54	Human Development		
55	Burn Site		
56	Cloud		

Table 1 cont. Post-Field Target Mapping Classes for Denali NP&P.

Table 2. Target mapping classes (right) were combined to form the final 25 landcover classes (left).

Endpoint Class	Final Mapping Class Name	Target Class*	Target Mapping Class Name
1	Dense Open Spruce	1	Open White Spruce
2	Open-Woodland Spruce	2	Open Black Spruce
3	Stunted Spruce	3 5 6	Open Stunted Spruce (~black spruce) Stunted Spruce Ericaceous Stunted Spruce Sedge
4	Broadleaf	7 11 8 12 10 14 9 13	Closed Birch Open Birch Closed Aspen Open Aspen Closed Mixed Deciduous Open Mixed Deciduous Closed Balsam Poplar Open Balsam Poplar
5	Spruce-Broadleaf	16 17	Closed Mixed Open Mixed
6	Alder	19 20 22 30 24 29	Closed Tall Alder -Willow Closed Tall Alder Open Tall Alder Open Low Alder Closed Low Alder-Willow Open Low Alder-Willow
7	Willow	21 23 26	Closed Tall Willow Open Tall Willow Closed Low Willow
8	Closed Low Birch Shrub	28	Closed Low Shrub Birch
9	Low Shrub Birch / Ericaceous / Willow	25 27 31 35 32	Closed Low Shrub Birch-Willow Closed Low Shrub Birch-Ericaceous Shrub Open Low Shrub Birch/Eric Shrub-Willow Open Low Shrub Birch-Ericaceous Shrub Open Low Willow
10	Low Shrub-Sedge	33	Open Low Mixed Shrub-Tussock
11	Peatland (Southside only)	34	Open Low Shrub Bog
12	Herbaceous-Shrub (Southside only)		**
13	Mixed Dwarf Shrub	37 38 36 39	Mixed Dwarf Shrub Mixed Dwarf Shrub-Sedge Dryas Dwarf Shrub Mixed Dwarf Shrub-Lichen
14	Mixed Dwarf Shrub-Rock	40	Mixed Dwarf Shrub-Rock
15	Dry- Mesic Herb	41 42 43 44	Dry-Mesic Grass Dry-Mesic Grass-Forb Dry-Mesic Sedge-Forb Tussock

Endpoint Class	Final Mapping Class Name	Target Class*	Target Mapping Class Name
16	Wet Herb	45	Wet Herbaceous
17	Aquatic	46	Aquatic
18	Sparse	47	Sparse Vegetation
19	Bare	49	Bare Ground
20	Snow-Ice	50	Snow-Ice
21	Shadow	51	Shadow-Indeterminate
22	Silty	52	Silty Water
23	Clear	53	Clear Water
24	Burn	55	Burn site
25	Cloud	56	Cloud

*Target classes listed in Table 1 that were not verified either during the 1999 field season or in the NPS FirePro vegetation database were not included (ex., *Target Class #4 Woodland White Spruce*).

** The Herbaceous-Shrub class was not defined until the later stages of classification and map development. Refer to section 2.84, “Defining and Delimiting the Southside Herbaceous-Shrub Class”.

Table 3. The detailed 25 mapping classes were aggregated to create the general (16 class) landcover map product.

	General Mapping Class Name
1.	Needleleaf (Dense-Open Spruce, Open–Woodland Spruce)
2.	Stunted Spruce
3.	Broadleaf
4.	Spruce-Broadleaf
5.	Tall shrub (Alder, Willow)
6.	Low Shrub (Closed Low Shrub Birch, Low Shrub Birch Ericaceous Willow)
7.	Lowland Low Shrub (Low Shrub-Sedge, Peatland)
8.	Mixed Dwarf Shrubs
9.	Dry-Mesic Herbaceous and Herbaceous-Shrub
10.	Wet Herbaceous
11.	Sparse Vegetation and Barren Ground
12.	Snow-Ice
13.	Silty and Clear Water and Aquatic Herbaceous
14.	Burn
15.	Clouds
16.	Indeterminate - Shadow (Cloud and Terrain Shadow)

2.2 Preprocessing of Satellite Imagery (Selection Criteria, Issues, Pre-Processing)

Both Landsat TM and SPOT XS imagery were used to derive the Landcover map. Although there were advantages and disadvantages to both image data sources, Landsat TM imagery was ultimately selected to serve as the base imagery, and the SPOT XS imagery was used to supplement or enhance the Landsat TM derived classification where appropriate. Tables 4 and 5 outline some of the spectral and spatial differences between Landsat TM and SPOT XS data.

Table 4. Key Spectral and Spatial Differences between Landsat TM and SPOT XS Imagery

	Landsat TM	SPOT XS
Spatial Resolution	28.5 m	20 m
Number of Spectral Bands	6	3
Average Spatial (Geographic) Extent	600 sq km	60 sq km

Table 5. Spectral ranges (per band) of Landsat TM and SPOT XS Imagery. Units are in micrometers. (Jensen, 1996)

	Landsat TM *	SPOT XS**
Band 1 (Blue)	0.45 – 0.52	0.50 - 0.59
Band 2 (Green)	0.52 – 0.60	0.61 - 0.68
Band 3 (Red)	0.63 – 0.69	0.79 - 0.89
Band 4 (Reflective Infrared)	0.76 – 0.90	Not Applicable
Band 5 (Mid Infrared)	1.55 – 1.75	Not Applicable
Band 7 (Mid Infrared)	2.08 – 2.35	Not Applicable

* Landsat TM data also has a thermal band (Band 6) that was not used in the mapping effort

** SPOT data also contains a Panchromatic Band, which was not acquired or integrated into the mapping effort

2.2.1 Scene Selection

The selection criteria for both the Landsat TM and the SPOT XS data were similar, and generally were based on consideration of image date, atmospheric quality and radiometric quality:

Image Date (i.e., the date of image acquisition) was critical to the mapping effort. Only scenes that were acquired during peak vegetation season (late June to early September) were considered. Additionally, more recently acquired scenes were given preference over older image date scenes.

Once a scene met the image date criteria, it was evaluated for atmospheric quality. Generally, acceptable scene quality was related to a low cloud occurrence and/or low to zero atmospheric haze. Cloud cover and associated cloud shadows obstruct the spectral reflectance of the vegetation beneath it, while atmospheric haze may distort or diminish the observed spectral values.

Scene selection was also based on its radiometric quality. However, radiometric quality could not always be easily or accurately ascertained when selecting and ordering the imagery remotely. Both the Landsat TM and the SPOT XS data were affected with a radiometric quality issue known as “striping” or “banding”. Section 2.21a provides additional information on the radiometric quality issue of striping.

The Denali NP&P Landcover Project Area could have potentially been covered with just four Landsat TM scenes (assuming they were cloud free) or approximately 15+ SPOT XS scenes. However, the limited availability of cloud-free imagery for the study area during the summer seasons necessitated the integration of multiple TM scenes. Imagery searches of the U.S. Geological Survey Earth Resources Observation Systems (EROS) Data Center (for Landsat TM data), the SPOT DALI browser and NPS-AKSO archives resulted in the selection of six Landsat TM scenes (Figures 2-7) and 16 SPOT XS scenes (Figures 8 & 9) to be used for map development. A list of all the Landsat TM and SPOT XS satellite imagery that were used to develop the land cover map is provided in Table 6.

Table 6. List of all Landsat TM and SPOT XS used to develop the Denali NP&P landcover map. Six Landsat TM scenes formed the primary image base for the classification, while the remaining scenes were used to update the classification where appropriate (i.e., as cloud and snow fill-in areas).

Status	Data Type	Acquisition Date	Path	Row
Primary	Landsat TM 5	8/15/88	70	15
Primary	Landsat TM 5	8/15/88	70	16
Primary	Landsat TM 5	7/21/85	71	15
Primary	Landsat TM 5	6/20/91	71	16
Primary	Landsat TM 5	6/29/91	70	16
Primary	Landsat TM 7	9/08/99	69	16
Alternate	Landsat TM 7	9/08/99	69	15
Alternate	SPOT-XS	9/04/96	445	218
Alternate	SPOT-XS	9/04/96	445	219
Alternate	SPOT-XS	9/04/96	445	220
Alternate	SPOT-XS	9/04/96	445	221
Alternate	SPOT-XS	9/04/96	446	218
Alternate	SPOT-XS	9/04/96	446	219
Alternate	SPOT-XS	9/04/96	446	220
Alternate	SPOT-XS	9/04/96	449	221
Alternate	SPOT-XS	9/06/94	442	218
Alternate	SPOT-XS	9/06/94	442	219
Alternate	SPOT-XS	9/06/94	442	220
Alternate	SPOT-XS	9/06/94	442	221
Alternate	SPOT-XS	9/06/94	445	218
Alternate	SPOT-XS	9/06/94	445	219
Alternate	SPOT-XS	9/06/94	445	220
Alternate	SPOT-XS	9/06/94	445	221
Alternate	SPOT-XS	9/06/94	445	222

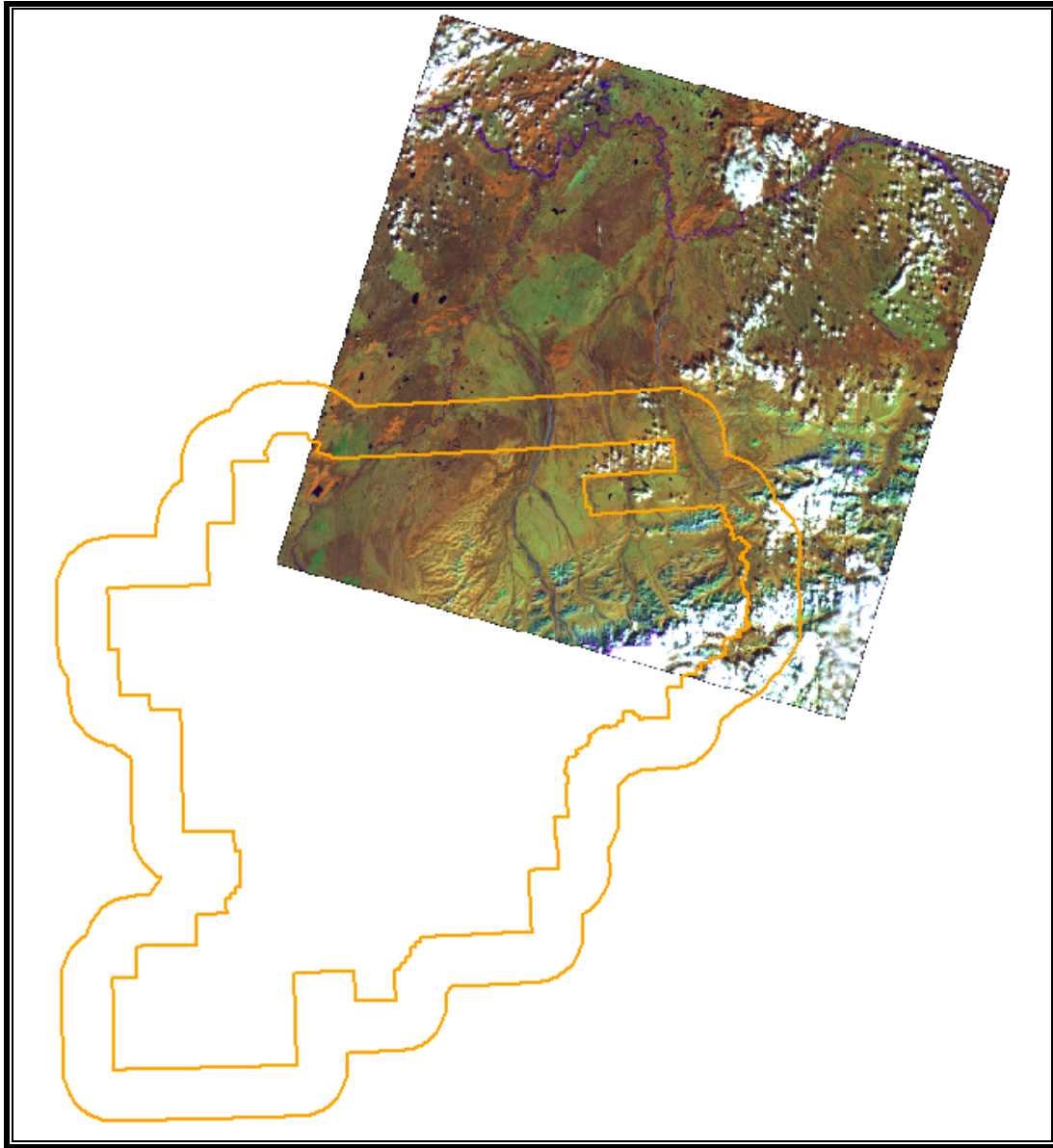


Figure 2. Primary Landsat TM Scene Path 70 Row 15 – August 15, 1988. The scene is displayed in band combination 4,5,3.

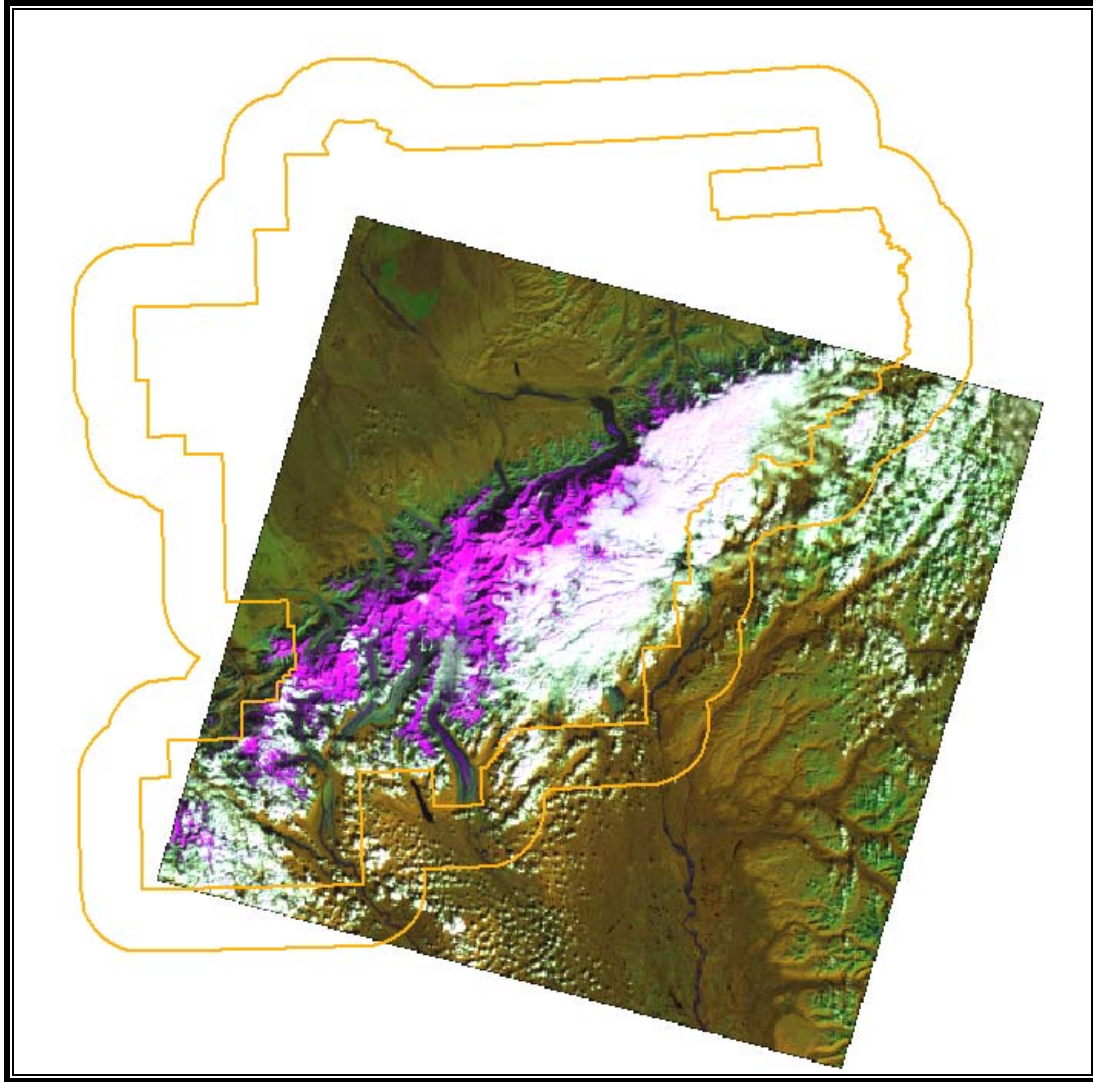


Figure 3. Primary Landsat TM Scene Path 70 Row 16 – August 15, 1988. The scene is displayed in band combination 4,5,3.

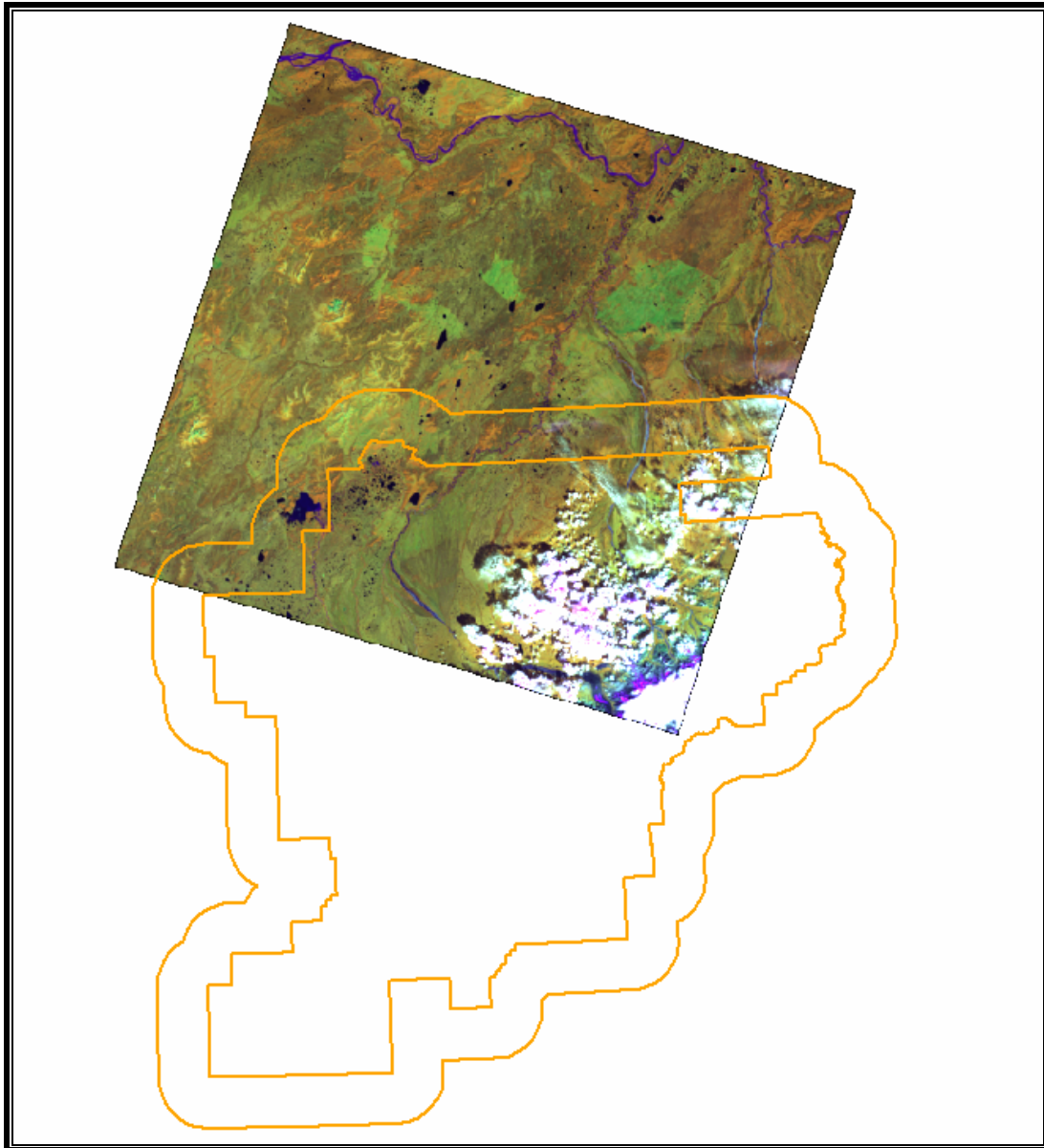


Figure 4. Primary Landsat TM Scene Path 71 Row 15 – July 21, 1985. The scene is displayed in band combination 4,5,3.

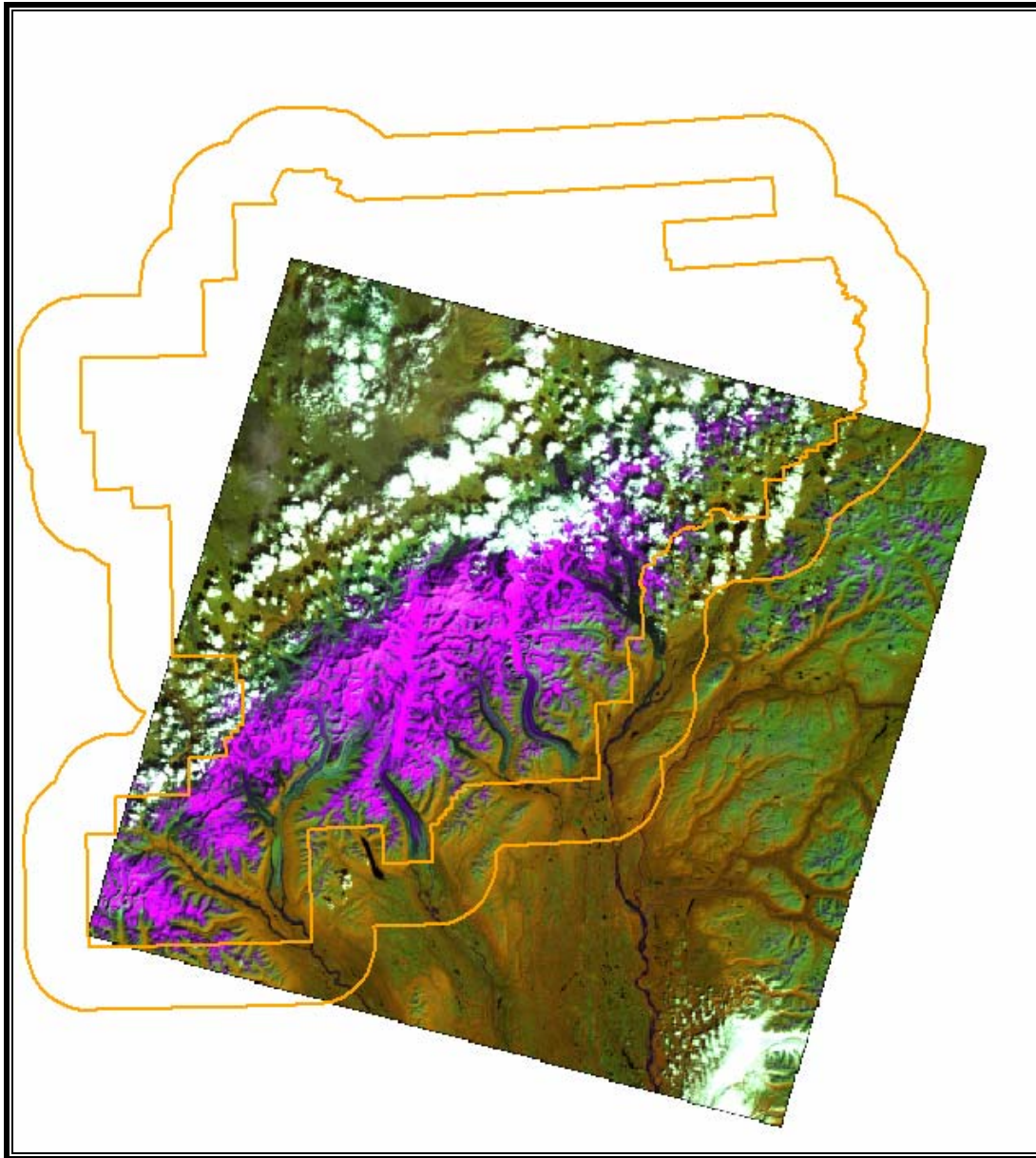


Figure 5. Primary Landsat TM Scene Path 70 Row 16 – June 29, 1991. The scene is displayed in band combination 4,5,3.

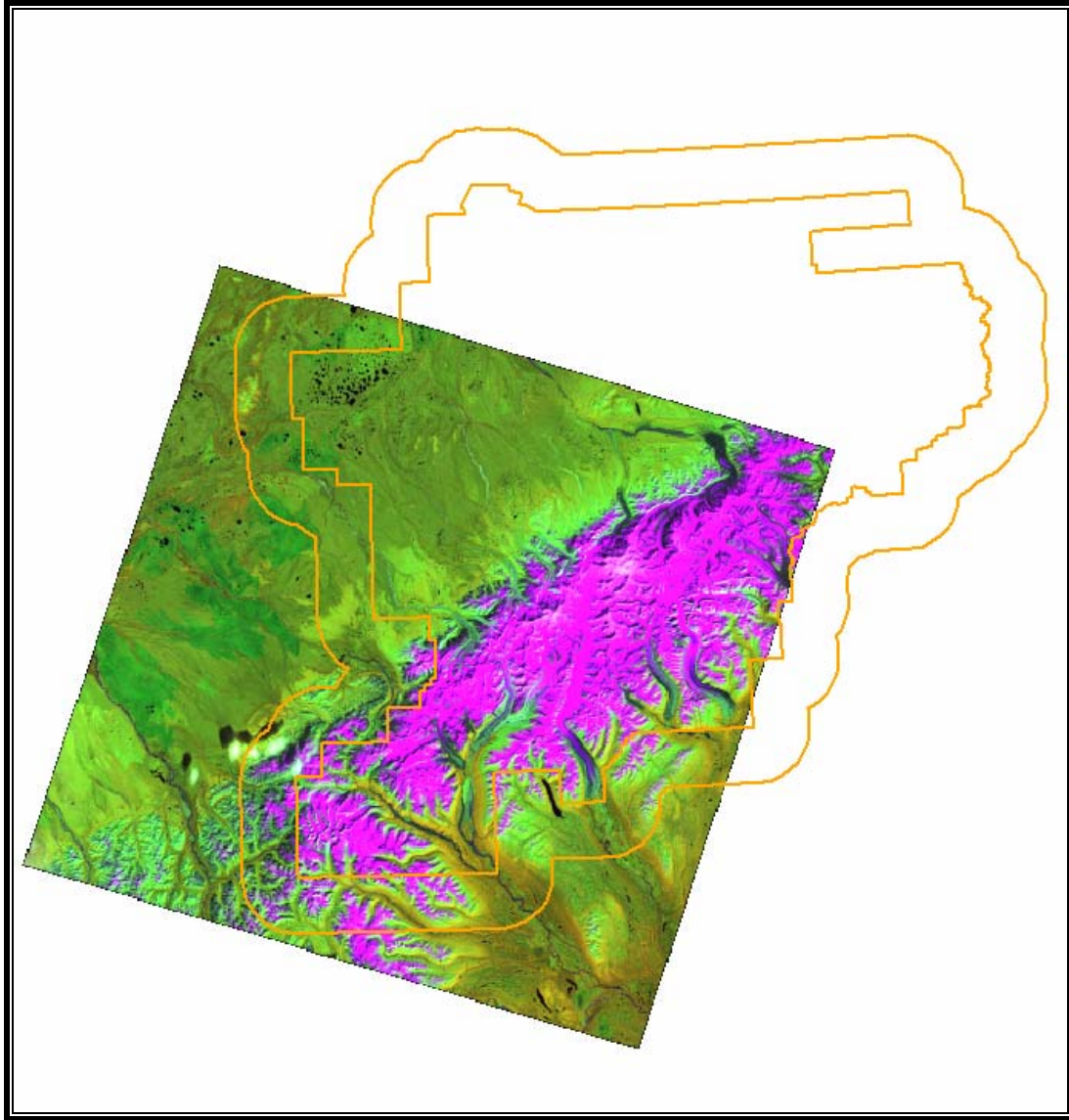


Figure 6. Primary Landsat TM Scene Path 71 Row 16 – June 20, 1991. The scene is displayed in band combination 4,5,3.

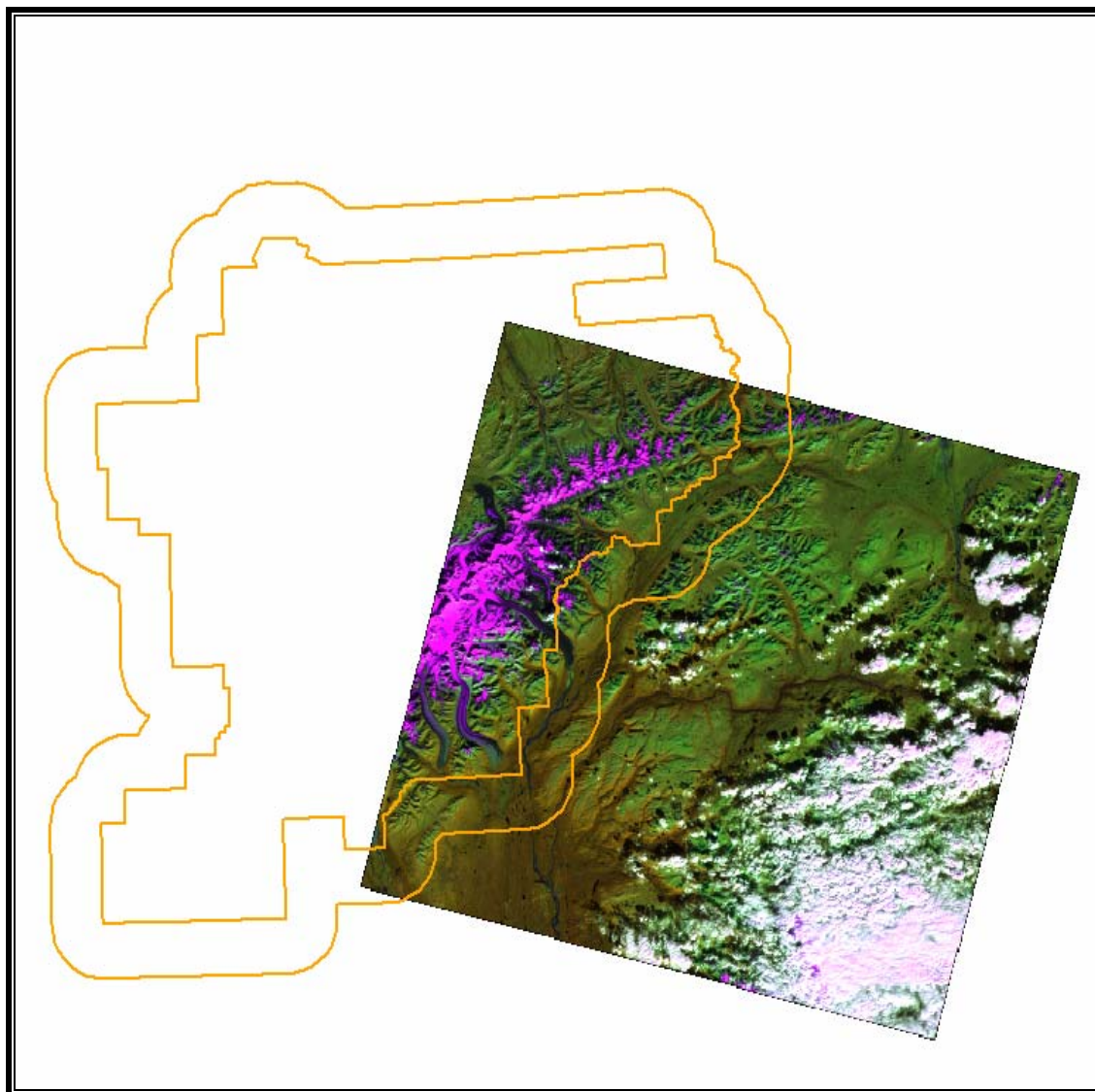


Figure 7. Primary Landsat TM Scene Path 69 Row 16 – September 08, 1999. The scene is displayed in band combination 4,5,3.

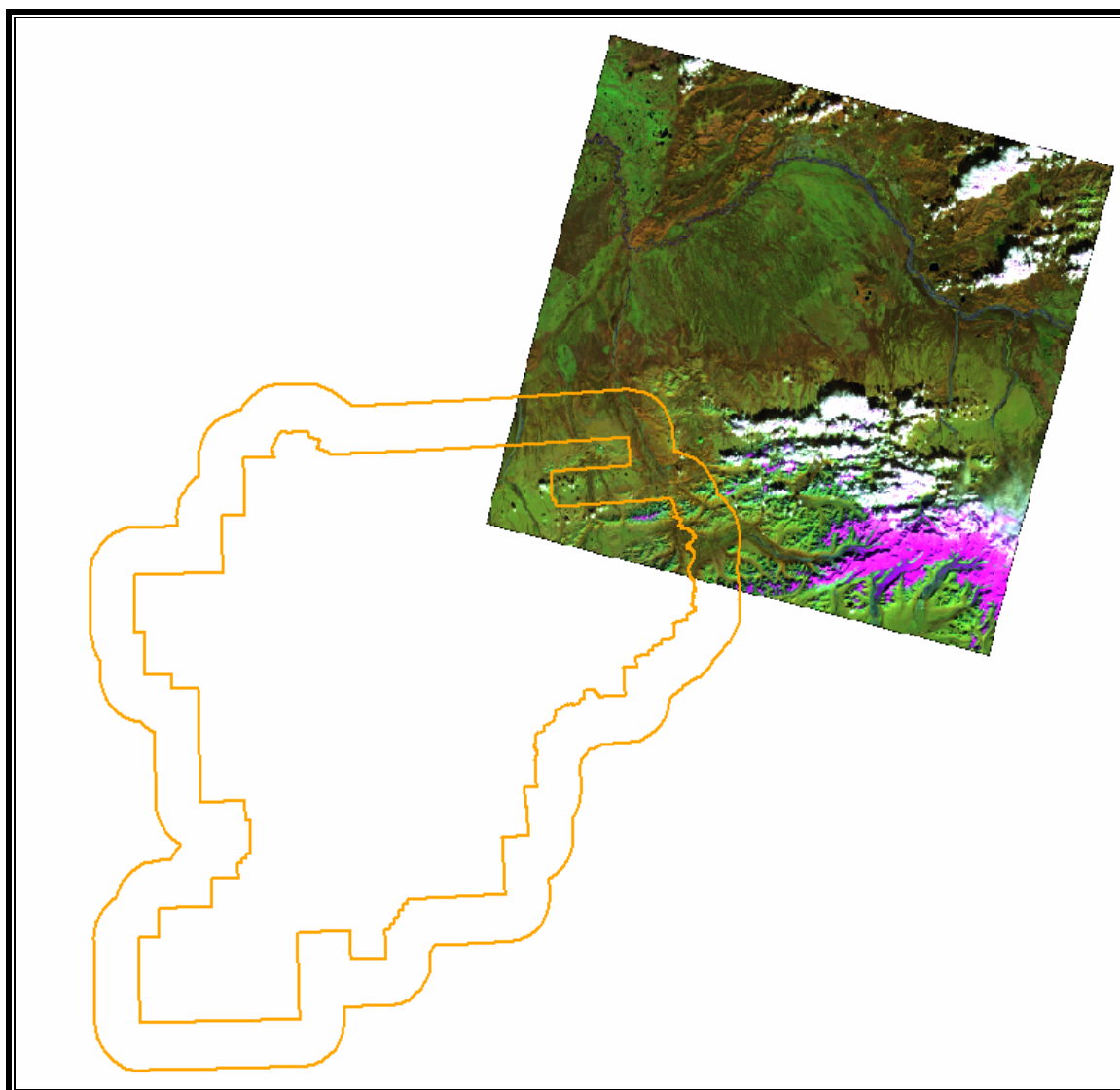


Figure 8. Alternate Landsat TM Scene Path 69 Row 15 – September 08, 1999. The scene is displayed in band combination 4,5,3.

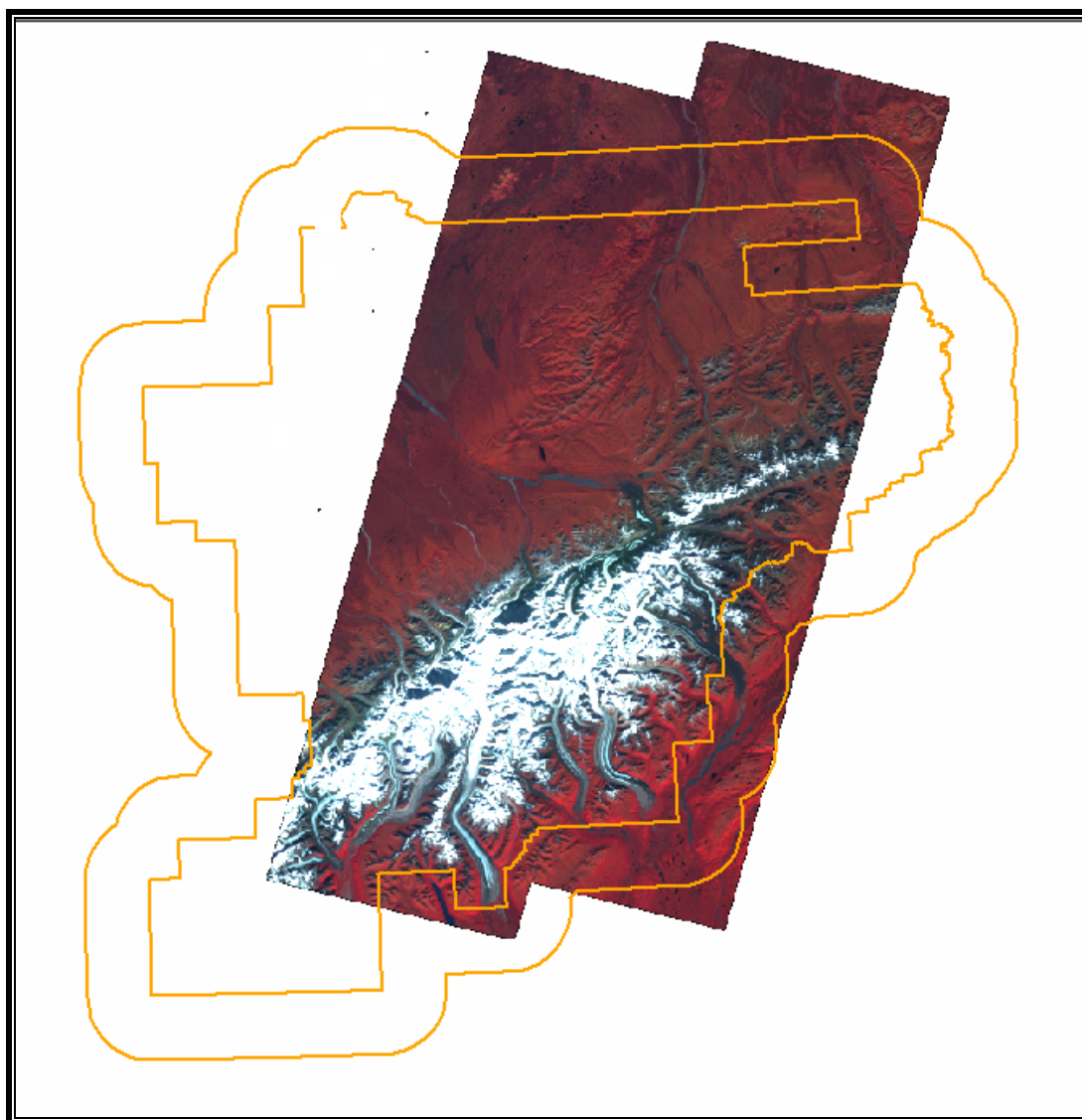


Figure 9. Alternate SPOT XS Mosaic– September 04, 1996 (Mosaic is comprised of the eight 1996 SPOT scenes listed in Table 6). The mosaic is displayed in band combination 3,2,1.

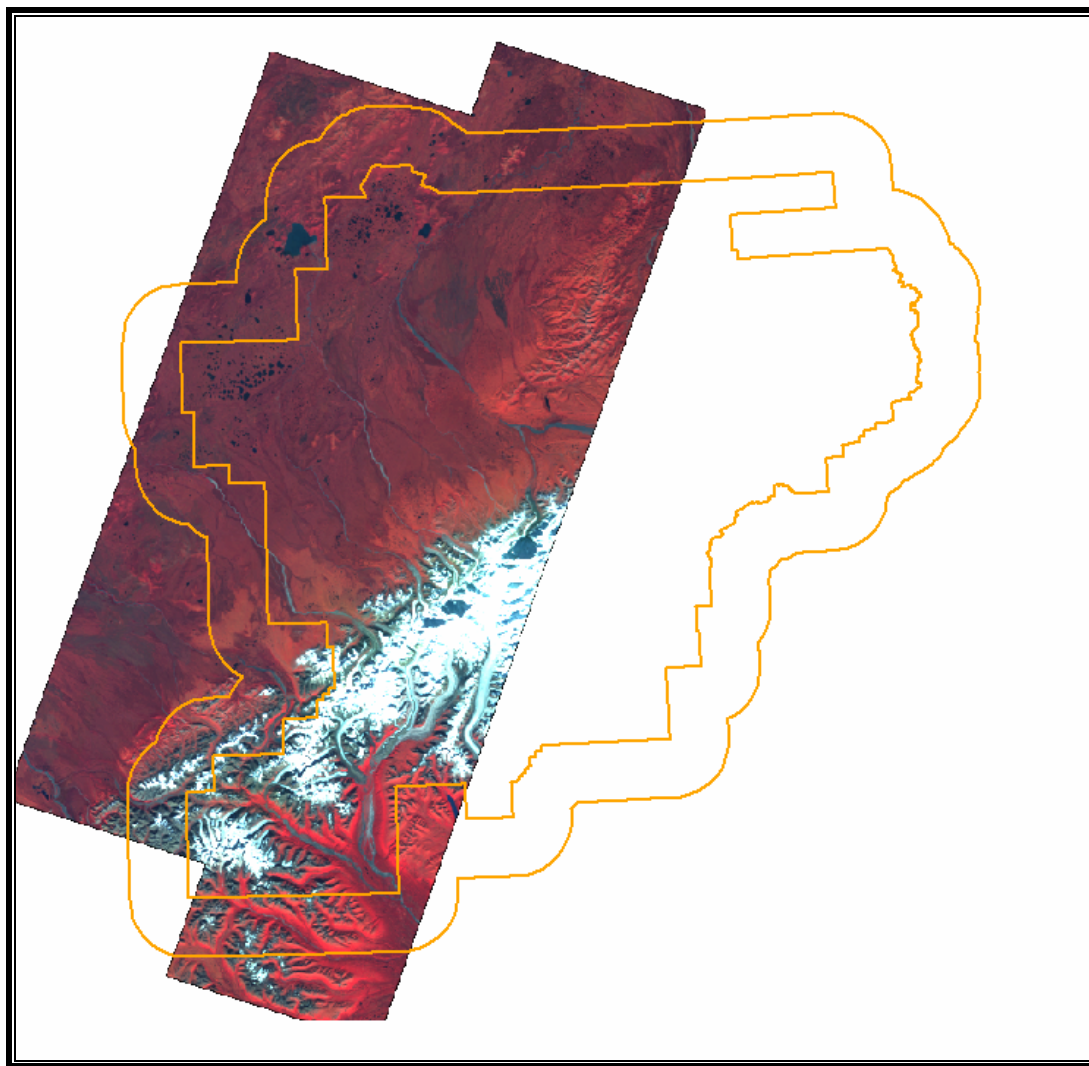


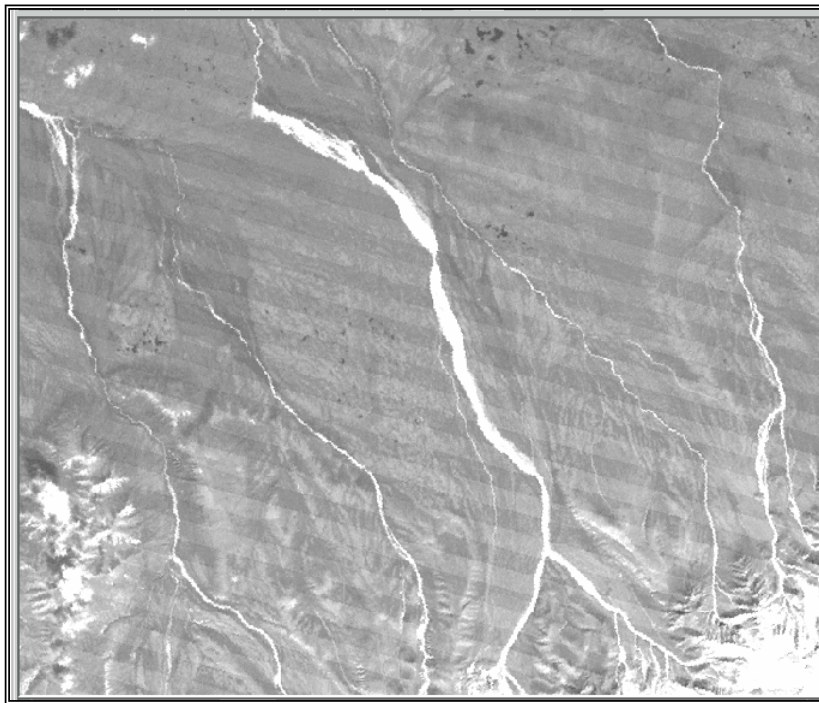
Figure 10. Alternate SPOT XS Mosaic– September 06, 1994 (Mosaic is comprised of the nine 1994 SPOT scenes listed in Table 6). The mosaic is displayed in band combination 3,2,1.

2.21a. Radiometric quality (Striping) issues:

Landcover types found in the Denali NP&P study area (and in many areas of Alaska) make images acquired there more susceptible to a radiometric anomaly known as ‘striping’ or ‘banding’. “Striping” in satellite imagery appears as stripes in the images that have a lighter or darker tone than in adjacent stripes. Data striping is related to a slight malfunctioning of the sensor’s scanning instruments. It typically occurs after the scanners ‘sweep’ from a large expanse of very bright radiance values (such as snow, ice or desert sand) to immediate adjacent areas of significantly lower radiance values (such as water or vegetation). In effect, there is a delayed calibration in one or more of the detectors, which slightly alters the observed spectral values for that that sweep, and causes a noticeable striping effect in the imagery.

Data striping occurred in both the Landsat TM and SPOT XS data available for the Denali NP&P Project Area. Unfortunately, its impact on the 1994 SPOT XS data was significant enough to preclude its use in the spectral analysis. Although many of the Landsat TM scenes also had some areas of striping, their enhanced spectral resolution helped mitigate the phenomenon. Typically only TM Bands 1 – 3 were affected by striping, thus leaving Bands 4, 5 and 7 available for spectral analysis. An example of a ‘data- striping’ area in one of the Landsat TM scenes is shown in Figure 11.

Figure 11. Example of ‘Striping’ or ‘Banding’ affecting Landsat TM imagery (p70r 15 and 16- August 1988). The raw pixel values were affected. (Band2 shown here)



2.22 Orthorectification of the Satellite Data - Development of the Image Base

Prior to further processing, the TM and SPOT imagery were orthorectified to create a stable and geometrically accurate base map. USGS Digital 1:63,360 Elevation Models (DEM) of the project area were obtained and mosaicked to complete a parkwide DEM database. Horizontal controls were selected from a 1:63,360 USGS topographic digital raster graphic (DRG) file for the area. TM and SPOT imagery were co-registered so that information extracted from either could be accurately overlaid with the other. Ideally, in the interest of both accuracy and efficiency, this would have been best accomplished by processing all 23 individual scenes simultaneously. However, the imagery was received and processed piecemeal as project goals and objectives became better defined over time. First the eight September 4, 1996 SPOT XS scenes were orthorectified using the horizontal and vertical controls described above. Next the nine September 6, 1994 scenes were received and processed using the previously mentioned controls and were additionally tied into the 1996 SPOT mosaic. Finally, the Landsat TM images were received and were processed together in a single, photogrammetric block adjustment process using the previously mentioned controls as well as the 1996 SPOT mosaic. All in all, the image to image registration between all 23 scenes (total number of both TM and SPOT scenes) was quite good. Image co-registration between all the individual Landsat TM scenes and between the Landsat TM scenes and the 1996 SPOT Mosaic averaged two pixels (+/- 57.0 m). Image co-registration between the 1994 SPOT mosaic with the other image data sets was also approximately 2 pixels in the central section of the Park, however the co-registration between the 1994 SPOT XS mosaic and the Landsat TM images diminished to approximately 4+ pixels in the most western reaches of the study area. As previously stated, the poor radiometric quality of the 1994 SPOT XS imagery pre-empted its use for vegetation spectral analysis. It was used however to identify fire impacted areas. Qualitative evaluation of the resulting orthorectification TM image base with other layers such as the 1:63,360 derived hydrology vector coverage, were also very positive.

2.23 Imagery Processing Blocks and Mosaic Design

Once all of the images were orthorectified and co-registered with one another, 'Image Processing Blocks' and the study wide mosaic design were formed. Again, the Landsat TM imagery was selected to serve as the base imagery for classification, and the SPOT XS imagery was used to supplement or enhance the Landsat TM derived classification where appropriate. Satellite scenes from different sensors (Landsat 5, Landsat 7 and SPOT) and/or different dates were processed separately. Similarly, individual scenes from the same sensor and date were mosaicked and processed together as an 'Image Processing Block'. This resulted in a total of five TM processing blocks and two SPOT processing blocks. Table 7 identifies these image processing blocks.

Although the resulting landcover classifications from each of the Image Processing Blocks were not mosaicked together until after all of the appropriate spectral and modeling procedures were conducted on each of them, development of the Mosaic Design (i.e., how to piece the blocks together) was developed in conjunction with the formation of the Image Processing Blocks.

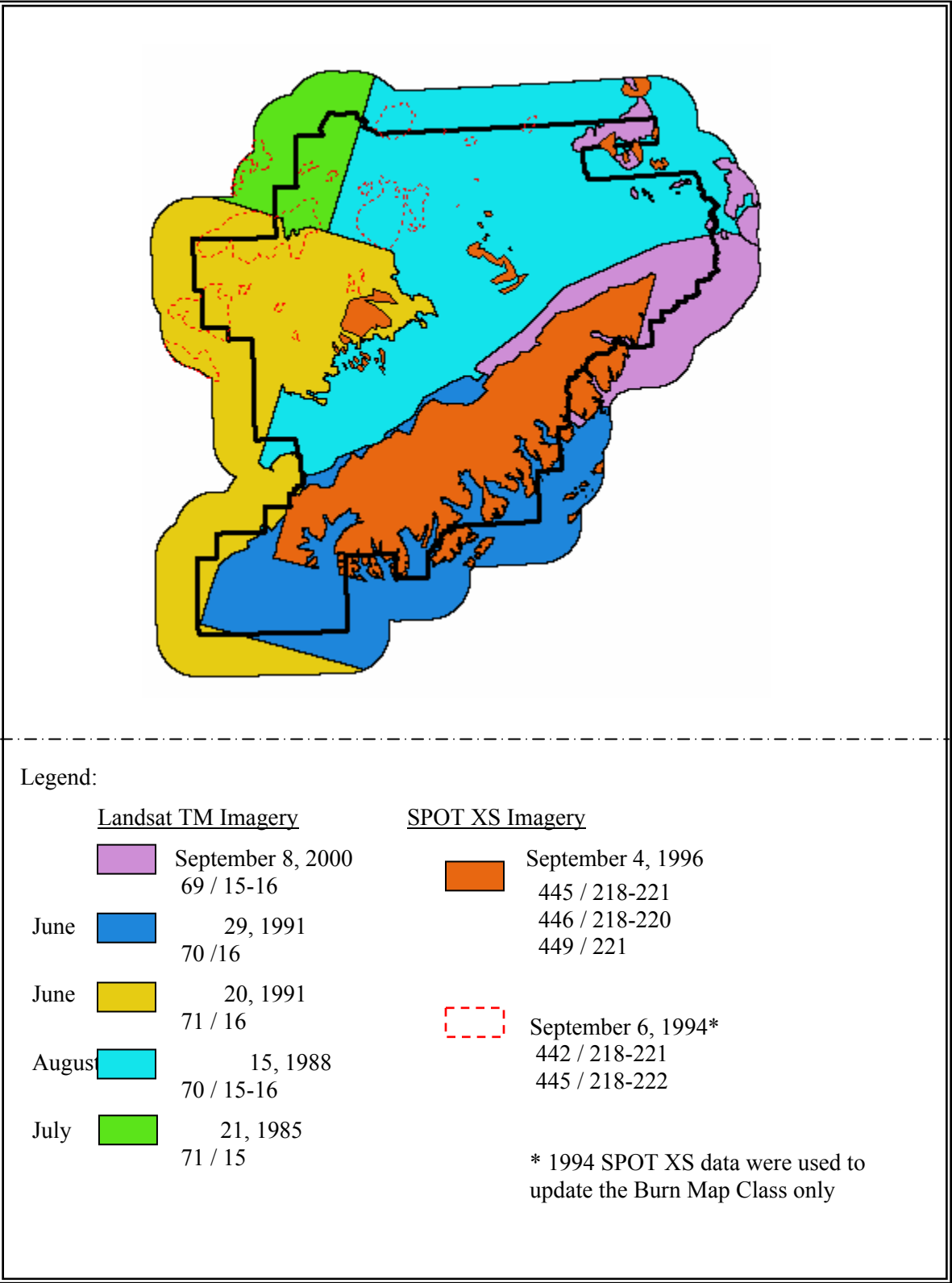
Mosaic design criteria were similar to the image selection criteria. Emphasis was placed on using the most recent and/or the image date with the best vegetation phenology as the top layer. Cloud obstructed areas were cut out and replaced with either alternate TM imagery or with the 1996 SPOT data.

Generally, most of the Landsat TM image dates (late June-August) corresponded to prime vegetation biomass and phenology (with the exception of path 69 row 16 - September 8, 2000). Although the early September Imagery (both SPOT and TM) were not as ideal for vegetation mapping, they did tend to have less cloud cover, and they provided useful information on some vegetation species (primarily birch and willow) that had already begun to senesce by early September. Additionally, the more recent SPOT datasets (1994 and 1996) were used to extract updated fire burn information, which was identified to be of significant interest to Park Staff. The early September 1996 SPOT data also had a higher snow line than the late June Landsat TM scene (path 70 row 16 – June 29, 1991). Therefore, mapping class information for elevations greater than 784 m on the Park's southside was extracted from the SPOT spectral classification in order to update areas still covered in snow and ice in the late June Landsat TM scene. The final image mosaic design for the Denali NP&P landcover map is shown in Figure 12.

Table 7. Imagery Processing Blocks used to develop the Denali NP&P Landcover Map.

<i>Landsat TM data was the Primary Image Base for the Landcover Map</i>		
Block Name	Composed of: Path/Row - Date	Comments / Issues
Landsat TM Block 1	P70 / R15 – August 15, 1988 P70 / R16 – August 15, 1988	Block was clipped to exclude clouds occurring on and south of the Alaska Mountain Range. Block had desirable vegetation phenology / spectral reflectance . Some ‘striping effects’ in the Wonder Lake area
Landsat TM Block 2	P71 / R15 – July 21, 1985	Individual scene was clipped to remove clouds and haze occurring on the Eastern section of the image.
Landsat TM Block 3	P70 / 16 – June 29, 1991	Vegetation phenology earlier than ideal. Snow line still fairly low. Some areas effected by striping
Landsat TM Block 4	P71/ R16 – June 20, 1991	Vegetation phenology thought to be earlier than ideal, however spectral classification results were positive.
Landsat TM Block 5	P69 / R16 – Sept. 8, 1999	Acquired from the Landsat 7 sensor. Vegetation phenology later than ideal. Snow line fairly low.
<i>SPOT XS data was used to augment the Base Landsat TM Classification</i>		
1996 SPOT Mosaic Block	All eight September 4, 1996 scenes listed in Table 4 were used to make the 1996 SPOT Mosaic Block	Mosaic was later split along the Alaska Range to form Northside and Southside SPOT spectral processing blocks. The Northside SPOT classification was used to fill in scattered clouds occurring on TM Block1, and the Southside SPOT classification was used to fill in the low snow line on TM Blocks 3 and 5
1994 SPOT Mosaic Block	All nine September 6, 1994 scenes listed in Table 4 were used to make the 1994 SPOT Mosaic Block	Due to poor radiometric quality, the 1994 SPOT data was <i>not</i> used for spectral analysis. It was however used to identify fire scars, senesced birch and willow and other landcover types during the 1999 field season

Figure 12. The Imagery Mosaic Design for the Denali NP&P Study area.



2.24 CIR Photography

A set of color infrared-stereo pair aerial photography was also available for the Park. These 1:63,360 scale photographs were acquired through Alaska's High Altitude Program in the early 1980's (1979-1984). Although these photographs provided better spatial detail, the prints were of variable quality. Where they were of good quality, these prints were useful for identifying and delineating different vegetation / mapping class types (broadleaf versus needleleaf, etc.), and were used to help classify and edit the satellite imagery classification.

2.25 FirePro Database

Over the past 15 years NPS AKSO had collected an extensive database in support of fire history and succession studies, landcover mapping and fire fuel modeling. Under the AKSO Landcover Mapping program, the spatial coordinates or locations of the Fire Program (FirePro) data points were digitized, and the tabular data were automated for use in landcover mapping projects. The FirePro database represent(ed) the best available Park-wide vegetation or landcover information within the Denali NP&P project area at the inception of this mapping project. However, it is worth noting that a field data collection effort currently in progress by the Natural Resources Conservation Service (NRCS) will also become a valuable ecological data resource for the Park. The NRCS database, when completed in the next few years, will contain species level information that will be used to develop soil and seral stage associations. The NRCS database could potentially provide a powerful means to link and/or further refine the mapping classes derived from this Landcover mapping effort to a more detailed, localized scale.

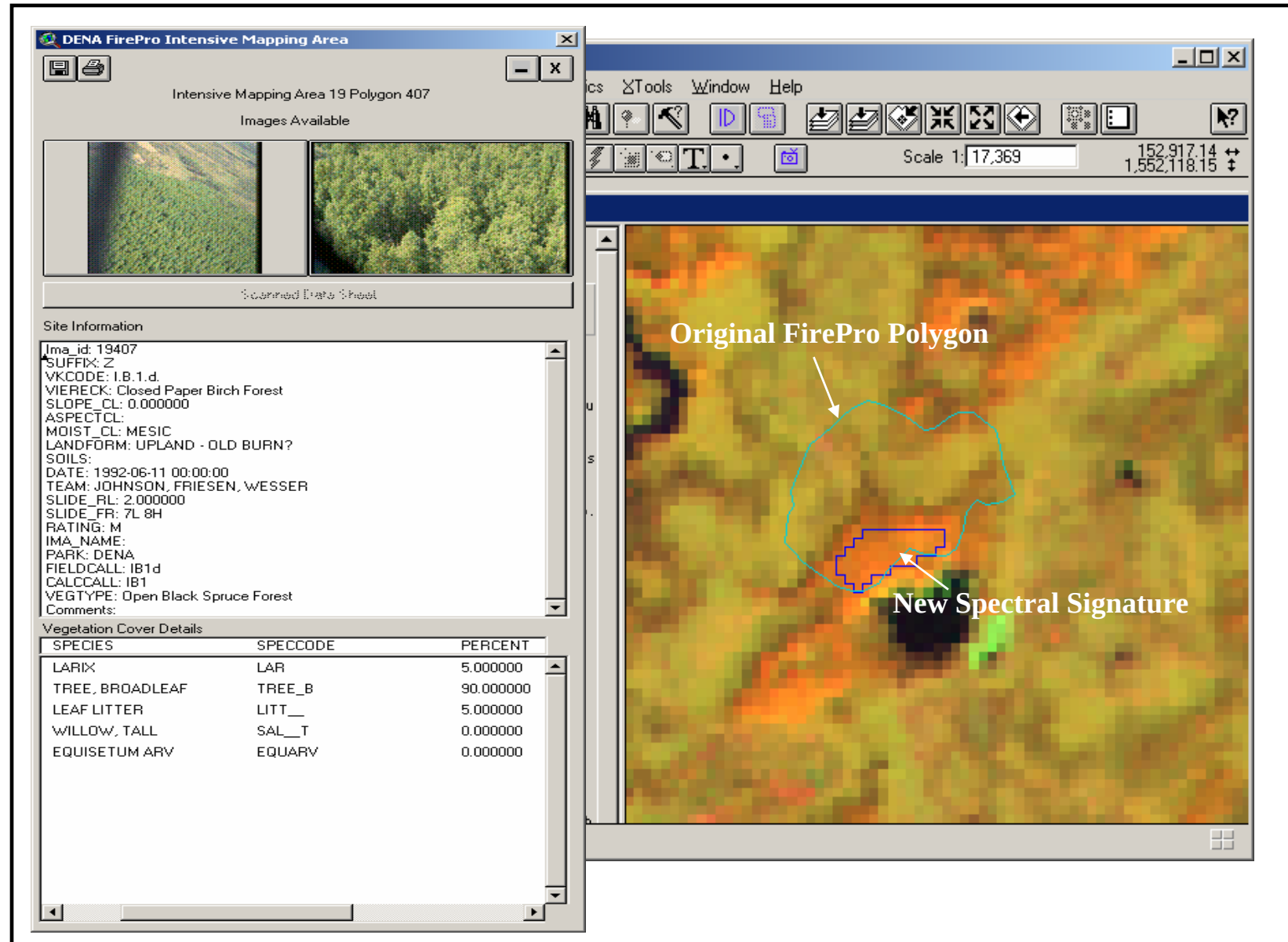
The Denali NP&P FirePro database however, was used extensively in this landcover mapping project. This database was comprised of two ARC/INFO coverages (with approximately 840 georeferenced features), 1:60,000 high altitude aerial photos, 35-mm photo slides, and field forms. The FirePro data included detailed vegetation composition and information on dominant plant communities in sampled sites, and tree cores and cross sections to aid in determining when the site burned. Since 1987, remote sensing specialists in the AKSO GIS office have delineated polygons of homogeneous signature and representative vegetation types on aerial photos, which the FirePro crews then sampled. The sampled areas were qualitatively selected so as to approximate the full range of spectral and vegetative variation in the park. Summaries of the FirePro database were utilized during development of the classification system for the Denali NP&P landcover project.

2.3 Spectral Database Development : Modifying the FIREPRO Database

In order to directly integrate the FirePro database into the landcover project, it was necessary to generate a spectral signature for each FirePro site. To accomplish this, all available data for each FirePro site (species composition, percent cover, aerial photos, site photographs, and field forms) were integrated into an ESRI ArcView project that had enhanced data integration and display features. The enhanced ArcView Project, known as the Field Data Viewer, was specifically developed by NPS and EarthSat to accommodate the FirePro and other field-related data sets. All available information for a particular FirePro site was displayed in an ArcView Dialog Box

(Figure 13). All FirePro data were then reviewed by an image analyst and botanist to determine the appropriate mapping class. A new spectral signature polygon was then screen digitized onto the Landsat TM image base (to capture only the spectrally relevant (homogenous) portion of the polygon), and assigned the appropriate mapping class label. FirePro sites that showed inconsistencies in the database, photos, or field-forms were generally not used as spectral signatures. The FirePro derived signature database went through multiple revisions and refinements. In general, the FirePro Intensive Mapping Area (IMA) polygon coverage was more useful for deriving signatures than the FirePro Ground Truth (GT) point coverages. The point coverages however did provide useful reference information for general map development and editing. In all, about 535 FirePro IMA polygons were evaluated, resulting in the development of approximately 400+ spectral signatures distributed throughout the Denali NP&P project area. These signatures were then supplemented with field data collected during the 1999 field season to create the final spectral database used for both classifying and evaluating the Landcover Map.

Figure 13. The Dialog Box to the left displays the photos and the tabular data for the original FirePro polygon (light blue). A new spectral signature polygon (dark blue) that better reflects the site data and the Landsat TM imagery was delineated.



2.4 Goals and Preparation for the 1999 Field Season

The primary goals of the 1999 fieldwork were to allow the Project Team to better familiarize themselves with the distribution of vegetation and landcover types within the Park, and to collect samples (in addition to those derived from the FirePro database) required to create the landcover map products. Image maps and a Sampling Design were developed for the 1999 field season to assist with the placement of field verification transect areas (FVAs). Field verification transect areas were similar in concept to FirePro Intensive Mapping Areas, and represented general locations targeted for 1999 field season sampling.

2.41 Image Map Production for Sampling Design and FVA Transect Placement

From the onset of the Project in the Spring of 1999, a decision was made by the Project Team to try and integrate the best available imagery into the landcover map. This meant remaining open and flexible to integrating any new satellite scenes (either SPOT or Landsat) acquired of the study area during the 1999 summer growing season. This effectively meant that the imagery that would serve as the base image map was not known at the time of the 1999 field season. So although Landsat TM data later served as the primary image base for the Landcover Map, the SPOT imagery was used for the sampling design (FVA transect placement) and 1999 fieldwork. While this was disadvantageous from a project design and imagery processing point of view (ideally the Project Team should have had the final TM image base map to work with in the field), it helped prevent delaying map production for another season (year) while waiting for new 1999 satellite acquisitions.

To begin with, a 1:125000 scale SPOT image mosaic (both the 1994 and 1996 datasets) of Denali NP&P was produced and used as the base map for the placement of the FVA transects. Next, ecoregions as defined by the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (US EPA) (Gallant et al., 1995) that occurred within Denali NP&P were overlaid on the SPOT mosaic for coarse scale stratification purposes. Other relevant vector coverages, such as Park boundary and the FirePro points and polygons were also included. Finally, a systematic sampling scheme was developed by overlaying a grid on top of the SPOT mosaic. The grid was large enough (10 mile spaced intervals) to ensure placement of more than 30 FVAs across the vegetated portion of Denali NP&P, with slight overlap into the bareground and glacier landcover classes.

Within each FVA, a transect or discontinuous transect was laid out on the SPOT mosaic to encompass the FVA's full variation of environmental factors. These environmental variables included ecoregion, aspect, slope and distinct SPOT spectral signatures. In the mountains, each transect spanned an entire valley, from ridgetop to ridgetop. In the remaining regions, transects that encompassed the environmental variability were often too long to fully sample.

Movement of some of the FVA transects was based upon having area-weighted representative examples of FVAs within each ecoregion. FVAs that overlaid Firepro locations were moved to an edge of the Firepro IMA. All aspects (north, south, east, west) on mountain slopes were included. Both large and small valleys within the Alaska Range were sampled. Private in-holdings were avoided whenever possible.

Again, the intent of this transect-polygon sampling approach was to target areas for sample collection to be used in spectral training signature generation during automated image classification and for ecological characterization of mapping types). This approach provided a complete picture of the occurrences of mapping classes for areas over all slope/aspect /ecoregion positions in the FVA. This transect “snapshot” was important for establishing realistic parameters in the environmental and spectral models used to refine the landcover map. Locations of the 1999 FVA transects are shown in Figure 14.

2.42 Image Map Production for the 1999 Field work

Following development and delineation of the sampling design (section 2.41), image maps (tiles) of the SPOT data at 1:63,360 inch to a mile (ITM) scale were produced to support field data collection and subsequent processing. (The TM images used to derive the LC map were not acquired until after the 1999 field season). Histogram equalization stretches were applied to the SPOT data sets to enhance vegetation discrimination. Image maps had the appropriate layers for fieldwork (sampling design, Denali NP&P boundary and buffered boundary, private lands, ITM and QM quad boundaries and latitude/longitude graticules). FirePro samples were also included as annotation on these working field maps to improve their interpretability during fieldwork. In addition, available CIR prints (9” x 9”) of select FVA transect areas were also identified, scanned and enlarged to 1:~21,000 in order to fully exploit all available resources during the field season.

2.5 1999 Field Data Collection Procedures

The field season was from approximately July 13, 1999 to August 6, 1999. Personnel from EarthSat, AKNHP and NPS participated in the field season. The primary purpose of field data collection was specifically to provide additional training signatures for the automated image processing required to develop the landcover map. Similarly, it was also important to obtain more specific site information that could be used to describe landcover types and plant associations. To support these objectives, field data were collected at three levels of detail: FVA ‘fly over’ polygons, ground site descriptions, and incidental observations.

2.51 FVA ‘Fly Over’ Polygons

The image analyst and botanist arrived at the target FVA transect area by helicopter, and then flew a reconnaissance of the transect. After landing at one end of the FVA transect (typically on a high vantage point), the image analyst and the botanist surveyed the potential sample sites and compared it to the CIR enlargements and SPOT image map of the area. Polygons that were sufficiently large (>10 acres) and distinct/recognizable on the CIR photo and SPOT image were delineated on both the CIR photo field map (when available) and the SPOT imagery. On average, the crew delineated approximately 20 polygons within the FVA vicinity for sampling. These polygons were then sampled by hovering and/or slow fly-by in the helicopter. Again, between 15-25 polygons were visited at each FVA for a total of approximately 330 samples

(Figure 14). Great care was taken to minimize helicopter impacts (i.e., hover height and duration were minimized), and wildlife were avoided throughout the entire Project Area.

Information collected at ‘Fly-Over’ polygons was recorded on field forms (Appendix 5.3) and included the minimum data required to assign one of the 55 Target Mapping class calls for each sampled polygon. This included total cover % for the various landcover classes, dominant species % cover, and photo records. Canopy cover was ocularly estimated (Brown 1954) for the dominant species, and defined as the percent of the ground in the polygon covered by the gross outline of an individual plant's foliage (canopy), or the outline collectively covered by all individuals of a species or life-form within the polygon (Daubenmire 1959). Total cover for each sample area was expected to sum to 100%.

2.52 Ground Site Descriptions

The purpose for this level of data collection was to support classification system refinement, to provide a more thorough understanding of the mapping classes (and therefore improve class descriptions), and to provide the required information for linking the landcover map to plant communities. Landcover class descriptions were initially derived from literature descriptions, Firepro data and the Viereck et al. (1992) classification. Ground site descriptions collected during the 1999 field season provided additional species information for the landcover class descriptions (vegetation structure, plant dominance type, site moisture level, and soil characteristics).

To gather this information, The Project Team’s ecologist was dropped off at each FVA, and sampled as many distinct landcover class types/polygons (on foot) as possible in the time allowed on the ground. Ground time was largely dictated by the time it took for the fly-over crew to delineate and then sample an FVA’s polygons. Selection of ground sites to sample within a polygon were made similar to the approach termed "subjective sampling without preconceived bias" as described by Mueller-Dombois and Ellenberg (1974). Site selection was based on homogeneous vegetation. Sample sites (homogeneous land cover units) were chosen with regard to their position in any classification, extant or envisioned, or by applicability to specific management considerations.

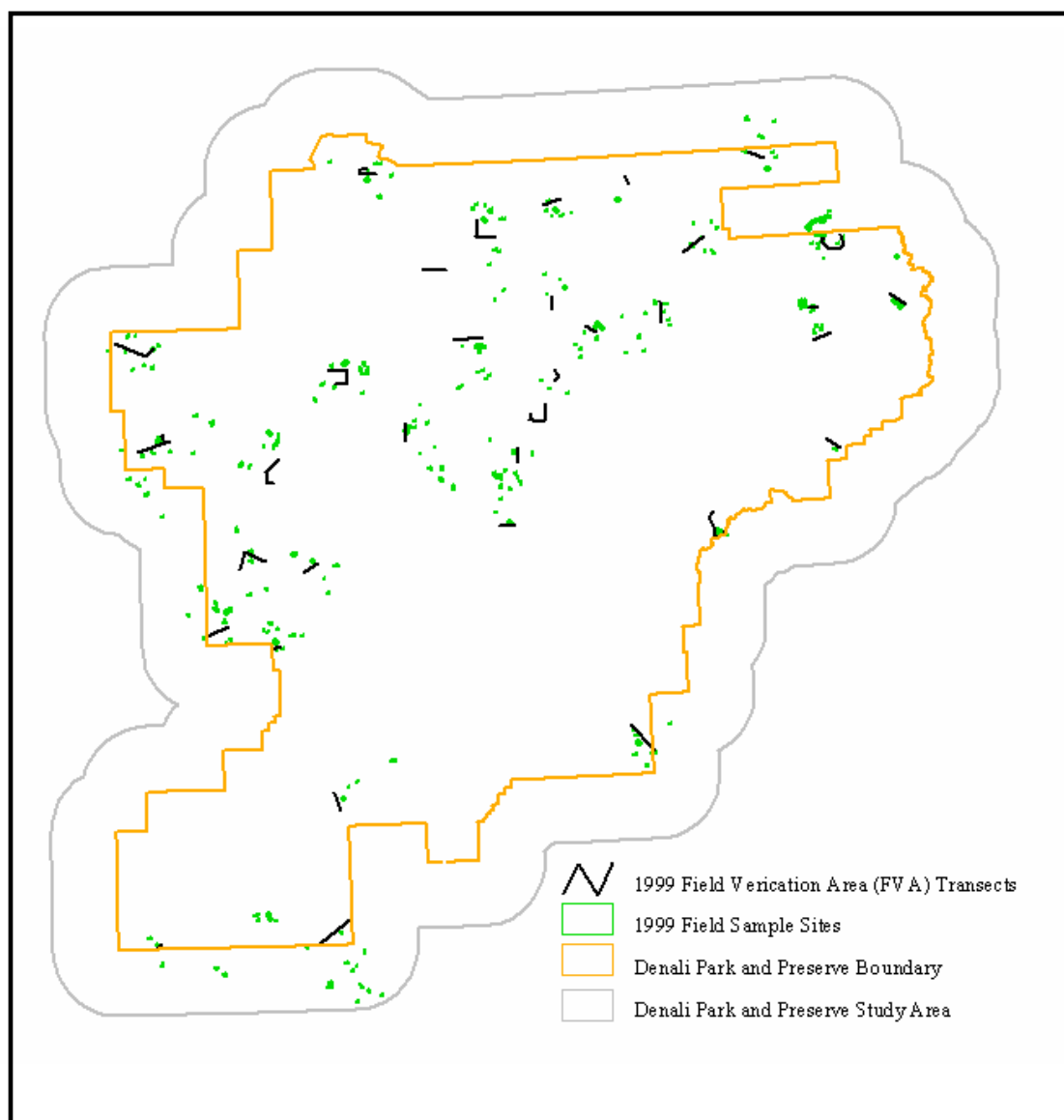
A GPS point and photo record were taken at each Ground Site area. Additionally, the following site variables were also recorded: slope, aspect, landform, surficial geology, hydrologic regime (dry, mesic, wet, aquatic), depth of soil peat, A, B and C horizons, depth to permafrost, and depth to water. A sample Ground site form is available in Appendix 5.3. Other recorded variables included air photo number, polygon code, landcover class name, landcover class code, date, surveyors, photos, latitude and longitude, environmental comments and disturbance comments. Although Ground Site Description areas could not be used to generate training signatures for the automated map development, they did provide useful information for map modeling and editing purposes, in addition to the value they added to the landcover and mapping class descriptions.

2.53 Incidental Observations

In addition to targeted FVA polygons, opportunistic or incidental polygon areas of homogeneous or known vegetation class types identified while in flight from one FVA to the next were also delineated and recorded. These incidental observations were used primarily for editing the map and qualitative assessment of its accuracy. These observations typically included a general vegetation call, such as “alder”, without providing any indication of height, canopy cover, understory, etc. They also often represented broad landscapes rather than particular sites. Photographs were often collected for these sites, and in some cases GPS points were recorded. The purpose of these sites was to provide a ‘reality check’ on the Landsat TM derived landcover map, and to provide additional general information for editing the map.

Additional information related to Sampling Design and Field Data Collection is also available in Volume 2: Landcover Classes and Plant Associations.

Figure 14. Locations of 1999 Field Transects and Sample Sites



2.6 Supplementing the Spectral Signature Database with the 1999 Field Data

Following the 1999 field season, collected data were entered into a Microsoft Access database, and the spatial extents of the polygons were digitized and attributed in an ArcView project. This process was similar to the process of modifying the FirePro polygons (recall section 2.3). Delineation of spectral signature polygons from the 1999 FVA data was based on field annotations made on the SPOT and CIR imagery and from the field collected GPS points. As with the FirePro derived signatures, signatures from the 1999 FVA data were reviewed by both an image analyst and botanist, and delineated on the appropriate (orthorectified) TM image base map. The FVA polygons were utilized to generate approximately 330 additional spectral signatures. A total of 426 signatures had been derived from the FirePro database. Thus making the total number of signatures defined for Denali NP&P, from both the FVA and the FirePro databases to be approximately 755. However, numerous and extensive review of these signatures (in simulated 4,5,3 (RGB) color) with regard to spectral homogeneity, size, appropriateness of assigned mapping class and output from preliminary spectral classifications resulted in the elimination of about 100 of these (Section 2.7). In the end, 656 signatures were eligible for use in the final automated map classification. The number of training signatures for each mapping class (by image processing block) can be found in Appendix 5.4.

2.7 Supervised Maximum Likelihood Classification, Signature Evaluation and Mapping Class Refinement

The spectral signature database derived from the field verified data had two potential uses; 1.) to be used as “training” data for the automated spectral classification and 2.) for evaluating the resulting classification (i.e., accuracy assessments). Originally it was hoped that there would be enough spectral signatures derived from the field databases to use a portion for training, while using the remaining portion for later accuracy assessments. However, the entire spectral database (650+ signatures) was used for training in order to obtain the best spectral classification possible.

Training signatures provide the statistical (spectral) criteria that the processing software (ERDAS, Imagine) uses to classify all of the pixels in a satellite scene. For every land cover mapping polygon delineated on the imagery, the spectral statistics (typically the mean and covariance matrix) for the pixels under that polygon were extracted.

These training signatures were then used as input into a supervised classification of the TM scenes using the Maximum Likelihood (ML) classifier. Based on the statistical spectral characteristics of the training signatures, the ML classifier assigned every pixel in the scene to one of the land cover mapping types.

ML classifications were run on the 5-band (bands 2,3,4,5,7) TM image datasets and on 3-band (bands 4,5,7) datasets for areas of the TM imagery that were affected by ‘striping’ (recall Section

2.21). Figure 15 shows the differences between a spectral classification of a 5-band imagery data set affected by striping versus a spectral classification run of the 3-band imagery data set. The channels most affected by striping (Bands 2 and 3) were eliminated from the data set prior to running the ML classifier.

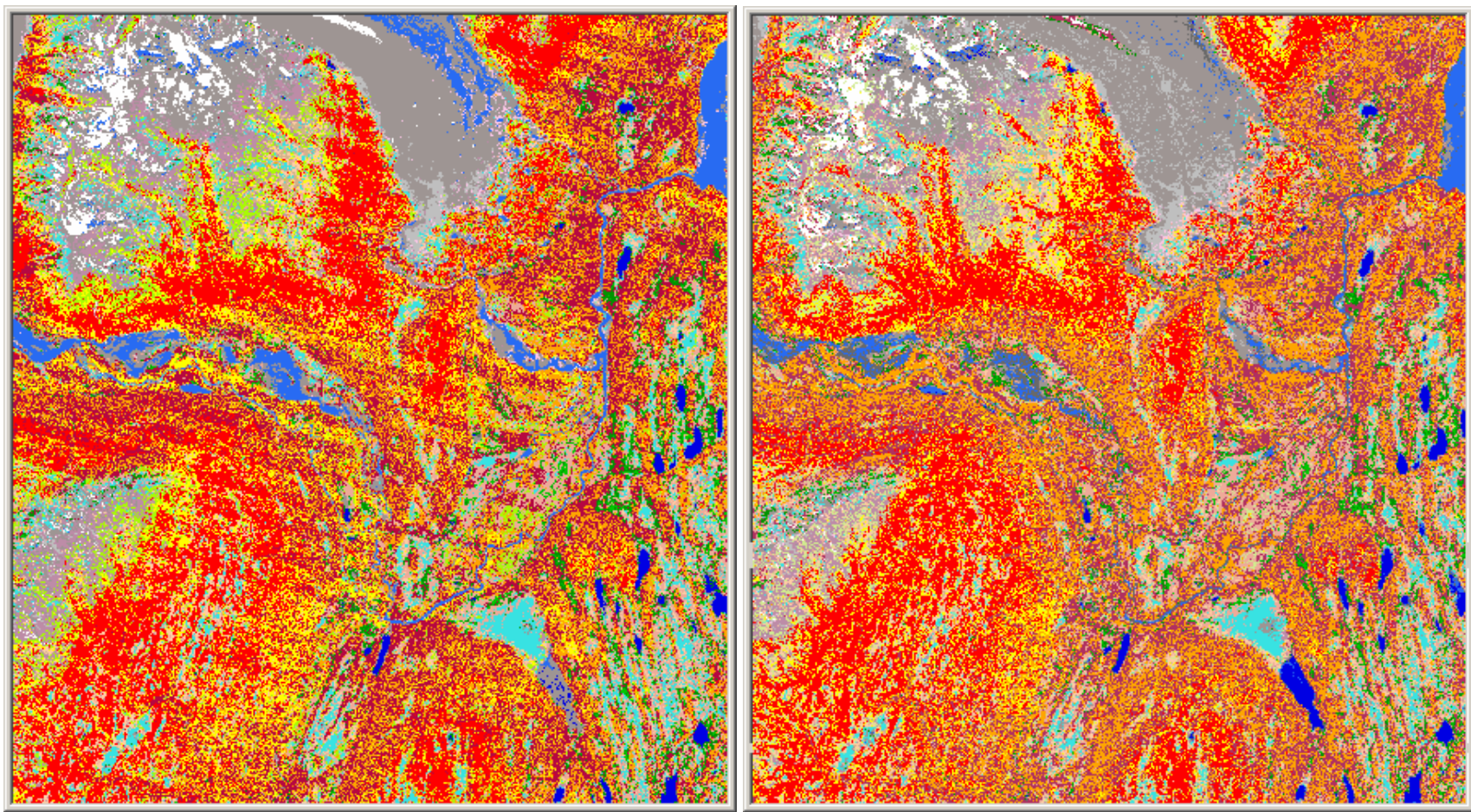


Figure 15. Spectral classification output from an area on TM block 3 that was affected by striping (left). The impacted channels (bands 2 and 3) were eliminated from the data set and the classification was re-run on bands 4, 5 and 7 (right).

Each image processing block was treated as a separate stratum for the automated image classification. This situation was ideal for maximizing vegetation discrimination within individual processing blocks. Mapping classes were generally evaluated with a confusion matrix between the supervised classification output and the training data for that block. This provided mapping class level information (i.e. how good the training data were at mapping themselves). Initially, the ML classifier was run on TM block 1 and the 1996 SPOT imagery block using the 55 Target Mapping Classes used in the field.

Confusion matrices for both the TM Block1 and the 1996 SPOT blocks were generated (Tables 8 and 9) and evaluated by NPS, EarthSat and AKNHP. Identifying which mapping classes were better captured in the respective data sources, as well as which classes were poorly represented in both data types helped guide the evolution to the final 25 endpoint classes. In general, mapping classes were combined or dropped if they lacked sufficient signatures (five signatures per processing block was considered the minimum number needed), or if there was too much spectral confusion with another (ecologically) similar class. For example, there was significant confusion between Open Low Alder and Open Low Alder Willow (i.e., neither the TM nor the SPOT spectral resolution was fine enough to reliably discern between the two classes, so they were combined to be included in the same mapping class). Mapping classes were evaluated and combined as necessary throughout the entire map development process. However, mapping classes that were unique (such as closed low shrub birch or peatland) or were considered important to wildlife (willow) were kept separate even if they consistently exhibited spectral confusion with other mapping classes.

Generally, before making the final decision to combine or discard a particular mapping class, the spectral signatures used to define that mapping class were first evaluated within an ArcView Project. Individual signatures were interactively reviewed and evaluated based on the imagery, the vegetation species information and zonal statistical criteria established by NPS and EarthSat. Signatures for each processing block were reviewed and used to classify the training data sets. In general, signatures for training sites where the assigned land cover *mapping class was not equal to the majority* occurring class based on the ML algorithm were either deleted or revised based on additional reviews of the site data, photos, and the imagery's spectral characteristics.

In addition, signatures from training sites whose assigned land cover *mapping class equaled the majority class, but had a majority percent lower than 50%* were either deleted, redrawn or relabeled based on additional reviews of the site data, photos, and the imagery's spectral characteristics.

Upon completion of each [ArcView] signature review process, the ML classification was rerun, and both the confusion matrices and the signatures were again evaluated in the same manner. This iterative review process was implemented a minimum of two-three times for every Landsat TM and the 1996 SPOT image processing block. Interim versions of the ML classifier output and training signatures for every TM image processing block were evaluated by NPS, enabling integration of their input and comments into the final supervised classification run. Only after multiple signature reviews and ML classifier runs (and after the classifier output had been reviewed by both NPS and EarthSat) did the output become final, and thus ready to move on to the modeling stage. Confusion matrices for the final ML spectral classification (for each of the

Imagery Processing Blocks) are provided in Appendix 5.5.

2.8 Spectral and Environmental Modeling

2.81 Model Development and Implementation

Upon iterative refinements and finalization of the supervised ML spectral classification, landcover characterization in each Landsat TM image processing block was further improved through modeling. Spectral and environmental data layers were specifically generated and utilized for improving the spectral classification. Modeling was conducted at the image processing block level and was implemented in multiple stages. The primary goal of the beginning stages was to first identify confused classes in the individual Landsat TM processing block spectral classifications, and then to determine what, if any ancillary data from the environmental/spectral modeling database could be used for consistently separating and accurately mapping the confused classes. Classes requiring modeling were selected based on their low class accuracy on the training data confusion matrices and/or were flagged during the multiple spectral classification evaluations and reviews. Once the spectral confusion between certain mapping classes were identified, the next steps involved formulating ecologically-based modeling rules appropriate to the specific image processing block (i.e., specific to that area of the Park) that could resolve the confusion.

An ecological/biophysical justification was required for every model implementation. For example, in many of the processing blocks, water, which generally has a low spectral reflectance (or a high absorbance) was often spectrally confused with terrain shadowed areas. Since the ML classifier was not able to always distinguish between water and shadow spectral values, there were instances where the shadow class was incorrectly mapped in place of water bodies, and instances of water being incorrectly mapped high in the Alaska Mountain Range. In order to correct the misclassification of water on shadowed hillsides, a simple ecological model based on the assumption that water does not generally occur in areas of significant slope was developed. In order to employ this model, the slope data layer was generated for the particular processing block, and then the appropriate slope thresholds were established. For a discussion of the various model layers that were generated, refer to Section 2.82. For a general discussion of mapping classes that were typically spectrally confused with one another (and therefore required modeling and/or editing), refer to Section 2.83.

The process of parameter-threshold testing was one of the final modeling steps. Initial modeling parameters were established based on interactive review of the spectral classification with each of the modeling data layers and the Landsat TM data. Field data and other available vegetation data were also referenced along with the image and modeling data in establishing and refining these parameters. After each model run, the results were reviewed and compared with the satellite imagery, the field data, and other available data for the project area. Based on these reviews, parameters were refined and the models re-run until the model outputs were determined to best represent the particular landcover class(es) being modeled. Once the model output passed this iterative evaluation process, the Landsat TM processing block was mosaicked into the thematic landcover database.

Table 9. Original Confusion Matrix for 96 SPOT block (North of the Alaska Range only) and the Target Mapping Classes. Landcover types that were ecologically similar, but exhibited poor spectral discrimination were combined. After comparing the matrices and mapped output for both the TM and SPOT data, the TM classification was ultimately selected to serve as the base classification map.

[illegible]

Since modeling was conducted at the image processing block level, the modeling layers/steps that were applied varied based on classification issues specific to the individual processing block. Terrain shadow modeling for example, was used extensively in the eastern and central portions of the study area, but not at all in the flat boreal forest areas found in the western section of the Park. In cases where the same ecological model / concept was applied to two different processing blocks, the final parameters used for the respective blocks often varied depending on the specifics of the imagery and the particular processing area.

Appendix 5.6 provides the final modeling reports for each of the five Landsat TM image processing blocks identified in Section 2.23. Section 2.82 identifies all spectral and environmental data layers that were produced and evaluated for use in the modeling process. Again, not all modeling layers were appropriate (and were therefore not implemented on all processing blocks).

2.82 Summary of Key Data Layers Used for Modeling and Editing

The key modeling layers identified as most useful were slope, illumination (shaded relief), elevation, Transformed Normalized Difference Vegetation Index (TNDVI), and Landsat TM Band 5.

The TNDVI (Transformed Normalized Difference Vegetation Index) was particularly useful for refining the *Dwarf Shrub* classes, *Sparsely Vegetated*, and *Bare Ground* classes since it is a measure of relative “greenness”.

Spectral reflectance of the TNDVI layer was less affected by terrain shadow, which was particularly important for discriminating these classes in alpine areas. NDVI was also utilized to identify and extract burn information from the SPOT and TM data layers.

Burn areas were identified and mapped by establishing thresholds within the NDVI layers created from the 1994 and 1996 SPOT imagery and from TM image processing blocks 1 and 4. The thresholds for the upper and lower NDVI values for each image block were defined through interactive review with the satellite imagery and the associated thematic NDVI layers. Once the range of NDVI values corresponding to burn areas (i.e., no or very low ‘greenness’) was established, a burn mask that was constrained by a Park provided fire polygon coverage, was extracted. Two map products were provided, one with the burn mask digitally overlaid on the landcover map (i.e. replacing the wet herbaceous with the burn category) and one that left the wet herbaceous as it was spectrally mapped by the ML classifier. The burn mask was also provided as a separate product layer. However users should take note, that in addition to legitimate burn areas, some areas of legitimate wet herbaceous (i.e., wet herbaceous that was not burned) as well as some areas of water and aquatic herbaceous areas fell into the thresholded range of NDVI values and were included in the burn mask. To help alleviate the misclassification of legitimate water (both silty and clear) and aquatic herbaceous to burn, an additional water and aquatic herbaceous mask was also generated. This water mask was digitally overlaid on top of the burn mask in order to restore the overrepresentation of burn area back to water and/or aquatic herbaceous.

Illumination/shaded relief was useful for refining upslope versus floodplain and aspect differences. This layer was generated from the ITM DEM (Albers), and the sensor-to-surface orientation parameters of sun elevation and solar azimuth for the Landsat TM image acquisition date and path/row. Because of the various illumination conditions dependent on local aspect, slope and neighboring terrain, and the limited direct relationship between illumination and vegetation, this layer was determined to best represent the modeling as a continuous variable (as opposed to discrete aspect categories such as S, SE, SW, etc.). Thresholds were established for identifying areas of Full Terrain Shadow and Partial Terrain Shadow. It was assumed that no reliable or consistent information could be extracted from areas of full terrain shadow. Ecological and modeling assumptions were only applied to areas of partial terrain shadow.

Band 5 - This was the 8-bit unsigned thematic image file for Landsat TM Band 5 (middle IR). Band 5 was useful for establishing thresholds for mapping classes based on moisture and/or the amount of standing water. Band 5 was also used extensively (with AOI delineations) to refine water classes.

Slope was useful for discriminating floodplain from upslope areas. It was particularly useful for water and shadow separation. The raw slope layer (based primarily on 1:63,360 level DEMs) contained too many contour line relics to be useful for modeling. Several different approaches and scales to eliminating relics were investigated, and it was determined that a 5x5 smoothing (low pass) filter removed most problems while preserving the essential detail for upslope/floodplain modeling.

Elevation from the DEM was used to limit the occurrence of many classes at higher elevations. It was used to model *Needleleaf*, *Broadleaf*, *Spruce–Broadleaf*, *Water* and *Wet Herbaceous* classes out of high elevation areas.

2.83 Models and edits to reduce spectral confusion between mapping classes

Models and parameters applied to each individual Landsat TM scene (block) are detailed in Table 10. The climatic conditions and ecological communities found in Denali NP&P study area north of the Alaska Range vary from the climatic conditions and ecological communities found south of the Alaska Range. The climatic condition in the lowlands north of the Alaska Range is subarctic-continental with short, warm summers and long, cold winters. While the climate of the lowlands south of the Alaska Range is affected by both maritime and subarctic-continental influences, being warmer and moister in winter and cooler and moister in summer than the northern half of the mountain range.

An ecological/biophysical justification was required for all model implementations. Typical examples of confusion between mapping classes, and some of the models and/or edits implemented to remedy that confusion are described below:

Spruce / Water confusion. *Spruce* (both *Dense Open Spruce* and *Open-Woodland Spruce*) and *Water* areas were confused, particularly along lake/pond edges. Many of the ponds south of the McKinley gravel bar (i.e. south of Wonder Lake) incorrectly had a *Dense Open Spruce* or *Open*

Spruce perimeter around them. This spectral confusion problem was corrected primarily through interactive editing with Landsat TM Band 5, the SPOT imagery and the CIRs (Figure 16).

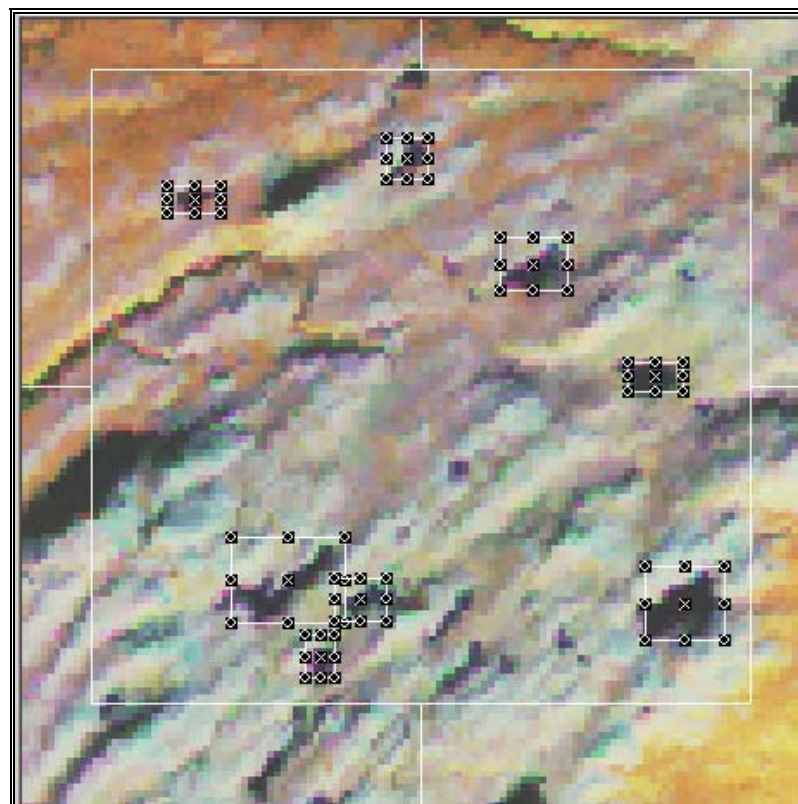
Spruce / Shadow confusion. *Shadow* and *Spruce*, particularly dense open spruce were sometimes spectrally confused. This problem, when it occurred, was more common on the east side, over to and including the Kantishna Hills (i.e, in areas of significant terrain relief). Areas of misclassified *Spruce* sometimes occurred at high elevations (well above the boreal extent). Similarly, shadow pixels were often mixed with needle-leaf mapped areas, particularly when they occurred on slopes with north or west aspects. Both *Dense-Open Spruce* and *Shadow* occurring on the hillsides of the northern Kantishna Hills were either modeled or edited to *Open-Woodland Spruce*. However, in other areas of the Park, it was necessary to consult ancillary data sources to determine whether it was *Open-Woodland Spruce*, *Alder* or *Broadleaf* occurring on the hillsides. In general, in the northeast section of the Study area (over towards Healy), it was often *Broadleaf* occurring on the shadowed hillside, while in the southern Kantishna Hills, it was *Alder*.

Dense Open Spruce / Open-Woodland Spruce / Stunted Spruce confusion. Confusion between the different needleleaf classes occurred when the percent of needleleaf canopy for an area approached the upper limit for that mapping class. For example, in the Western section of the Park (west of the Kantishna Hills), it was difficult to spectrally differentiate between *Open-Woodland Spruce* and *Stunted Spruce* when the percent composition of stunted spruce was 40% or greater, or when there was 15% or more *Larix spp.* mixed in with the *Stunted Spruce* areas. For the areas east of the Kantishna Hills, the needleleaf classes were sometimes confused with one another in areas of terrain shadow. The illumination layer was used to model *Dense Open Spruce* occurring in terrain shadow to either *Open-Woodland Spruce*, terrain shadow or to some other appropriate class.

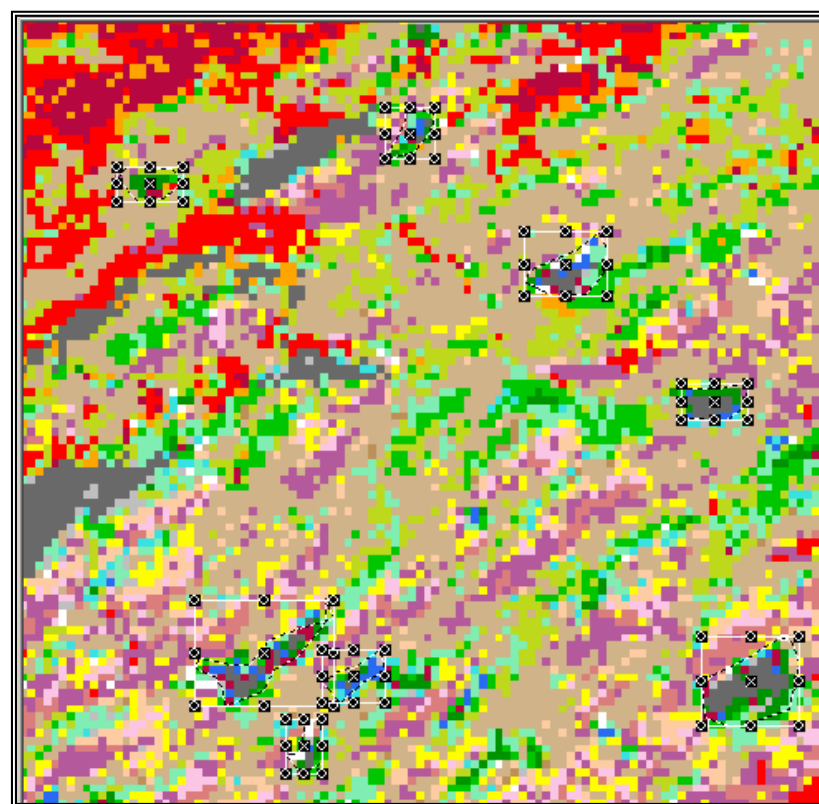
Stunted Spruce / Closed Low Shrub Birch / Low Shrub Birch-Ericaceous-Willow confusion. Throughout most of TM image processing block1, there were many instances, particularly in areas of low illumination (partial shadow), where *Closed Low Shrub Birch-Ericaceous-Willow* areas were spectrally misclassified as *Stunted Spruce* (or as closed low shrub birch to a lesser extent). The illumination model layer was used to remap areas of *Stunted Spruce* in partial terrain shadow areas to *Closed Low Shrub Birch-Ericaceous-Willow*. Areas of *Closed Low Shrub Birch* occurring in low illumination areas were remapped to *Low Shrub Birch-Ericaceous-Willow* via raster editing and review of available field data, the CIR photography and/or the examination of the mapping classes occurring in adjacent, but better illuminated areas. In other words, determination of the specific low shrub class was based on the context of the site (review of the mapping classes of surrounding areas).

Stunted Spruce / Wet Herbaceous confusion. Spectral confusion between *Wet Herbaceous* and *Stunted Spruce* occurred throughout the study area, usually within a drainage feature.

Figure 16. Selected box areas in both the Landsat TM imagery (left) and a draft version of the landcover classification (right) show areas where water, terrain shadow and spruce were misclassified (spectrally confused) with one another. Such areas were modeled or raster edited to the appropriate class.



Landsat TM Imagery (Bands 4,5,3)



Landcover Classification: Shadow =Black, Water = Blue, Spruce = Dark Green

If available CIRs indicated there were spruce present, then these areas were usually left as Open-woodland stunted spruce. There was no systematic way, other than visual inspection, to check for and remedy this confusion.

Spruce-Broadleaf and *Broadleaf* confusion. There was significant spectral confusion between *Broadleaf* and *Spruce-Broadleaf*, particularly on the Southside. *Spruce-Broadleaf* was fairly extensive on the southside, but many of those areas contained high percentages of *Broadleaf* (balsam poplar and/or paper birch). So although these areas technically keyed to the *Spruce-Broadleaf* class, they had significant spectral confusion with (i.e., similarities to) the *Broadleaf* class. Similarly, the *Spruce-Broadleaf* also had confusion with the *Open-Woodland Spruce* class in areas where the *Spruce-Broadleaf* contained high percentages of conifer. Unfortunately, although a surficial geology / floodplain layer may have been useful for separating Spruce-Balsam poplar from Spruce-Paper Birch, there was no such layer readily available. Additionally, the Project Team did not come up with any satisfactory models to better separate the Broadleaf from the Spruce-Broadleaf. Instead, separation relied on interactive editing with the imagery, field data and CIRs.

Broadleaf / Alder / Willow confusion. Spectral confusion between the *tall shrub* class (mainly *Alder*, but also *Willow* to a lesser extent) and the *Broadleaf* class was observed in the northern portions of the study area. In upslope or higher elevation areas (particularly the North east section of the study area) *Alder* was often spectrally confused with Paper Birch and/or Aspen Stands. In the area between the Toklat and Teklanita Rivers, willow was spectrally confused with the broadleaf forest mapping class. The confusion between the Tall Shrub and *Broadleaf* classes may have been exacerbated by the uneven ratio of Tall Shrub to Broadleaf signatures in the training database. Although there was a fair amount of Balsam poplar signatures, there were relatively few Paper Birch / Aspen signatures in the database. In contrast, there were often numerous *Alder* and/or *Willow* signatures available for each processing block. The 1994 and 1996 SPOT data were relied on to strengthen the broadleaf forest class. Both of these image data sets had an early September image date, and Paper Birch and Aspen had already begun to senesce in both of them. These senesced areas showed up as distinctly recognizable bleached out whitish or pinkish areas on both data sets (particularly on south and/or east aspect locations). A mask of these areas was made and overlaid on top of the existing mosaic. Additionally, elevation models were used in some areas to remap broadleaf forest occurring at high elevations to either *Alder* or *Willow*. Willow and young or open balsam poplar occurring on gravel bars also exhibited a significant degree of confusion.

Low Shrub Sedge / Dry-Mesic Herbaceous confusion. There was some confusion between *Dry-Mesic Herbaceous* and *Low Shrub-Sedge* on both the North and the South side of the Alaska Mountain Range. In general, these two classes had ecological, and therefore spectral similarities. Since there were significantly more *Low Shrub-Sedge* signatures than *Dry-Mesic Herbaceous* signatures on the Northside, and since the *Low Shrub-Sedge* Signatures tended to have larger spatial extents, the ML classifier mapped *Low Shrub-Sedge* much more aggressively than *Dry-Mesic Herbaceous* on the Northside processing blocks (particularly TM Processing Blocks 1 and 4). Arguably however, the lack of large or numerous *Dry-Mesic Herbaceous* signatures on the Northside may be indicative of that it does not have extensive occurrence there. Since no concerns were raised at any of the Draft Map reviews regarding the patterning of *Low Shrub-Sedge*

and / or *Dry-Mesic Herbaceous* classes on the Northside, no attempt was made to model or edit between these two classes. On the Southside however, there were concerns that both classes were over classified, particularly on hillsides. There were significantly more *Dry-Mesic Herbaceous* signatures available from the Ground truth data for the southside. Many of these occurred in TM Processing Block #5 (the Broad Pass area). The spectral classification was relied on heavily for discriminating between these two classes.

Dry-Mesic Herbaceous/Dwarf Shrub confusion. In the higher elevation valleys, *Dry-Mesic Herbaceous* areas were found adjacent to *Dwarf Shrub* areas. This confusion was particularly problematic when the herbaceous content of the *Dwarf Shrub* areas was close to the 25% upper threshold for this mapping class. The spectral classification was relied on heavily for discriminating these two classes. Other modeling layers (such as NDVI) were ineffective at separating the two classes, and image interpretation and review of CIR photos was also not very effective at reducing the confusion.

Dwarf Shrub/Dwarf Shrub-Rock/Sparse Vegetation/Bare Ground confusion. The “greenness” as indicated by NDVI was used to separate the *Dwarf Shrub/Dwarf Shrub-Rock/Sparse Vegetation/Bare Ground* classes. This layer was particularly useful because it enabled partial penetration of terrain shadow. NDVI thresholds were established and used to model (distinguish) these four mapping classes.

Wet Herbaceous/Sparse Vegetation/Bare Ground confusion. *Wet Herbaceous* tended to be misclassified along river channels and roads. *Wet Herbaceous* that occurred along river channels or roads was usually edited to either the *Sparse Vegetation* or the *Bare Ground* class based on imagery interpretation.

Wet Herbaceous/Shadow confusion. *Wet Herbaceous* was significantly overclassified in terrain shadow areas. The shaded relief and slope data layers were used to model erroneous *Wet Herbaceous* on ridge tops and hillsides to the *Sparse Vegetation* or *Shadow* classes, respectively.

Wet Herbaceous/Peatland confusion. *Wet Herbaceous* and *Peatland* confusion occurred on the valley bottoms of the Southside. Although it was hoped that TM Band 5 could be used for thresholding out the very wet sites within the *Peatland* mapping class, investigations found it to not be very effective. In general, Band 5 alone, was not enough to consistently and accurately distinguish between these two classes. Minimal modeling and editing were applied to the *Wet Herbaceous* and *Peatland* classes on the Southside (i.e., their distribution and occurrence is primarily the result from the ML classifier).

Wet Herbaceous/Burn confusion. Large areas of burn on the Park’s west side were spectrally mapped by the ML classifier as wet herbaceous. Since there were no burn samples collected or included as signatures, there was no possible way for the ML classifier to map the burn class. Interestingly, many of the more recent or the very intense burns (as indicated by the scarring on the raw imagery) were spectrally classified to *Wet Herbaceous*, while many of the older, or less intense burns were spectrally mapped to *Willow* or *Low Shrub-Sedge*. Moreover, many of the recent and/or more intense burns probably scorched the ground surface’s top organic layer, exposing the permafrost layer beneath it. This could conceivably create legitimate *Wet*

Herbaceous-like conditions, such as close to saturated conditions and the colonization of herbaceous emergent vegetation species.

Willow/Low Shrub-Sedge/Burn confusion. As described above, older or less intense burns (i.e., those that had regrowth) tended to be spectrally mapped as willow or low shrub sedge. These areas were not included as part of the burn mask because the NDVI layer indicated that there was some 'greenness' associated with them. Since there were no samples collected in the burn areas during the 1999 field season, it was difficult to say with any certainty which vegetation mapping class would be the most appropriate for these areas (in reality, different burn areas would be at different regrowth / successional stages and therefore have different site characteristics and plant associations). Unfortunately, the Project Team did not have the opportunity or resources to visit and/or sample burn areas following the spectral classification results. Thus, without the benefit of any empirical data in hand, both the *Willow* and *Low Shrub-Sedge* mapping classes spectrally mapped in obvious old burn areas seemed reasonable, and were not changed to the burn or any other mapping class. General or incidental observations made of various burn areas during the 1999 field season (i.e., before the spectral classification results were known) indicated that some (but not all) of the burn sites tended to be wet. Typical vegetation species included (but were not limited to) cotton grass, willow and/or young balsam poplar or aspen.

Herbaceous-Shrub/Dwarf Shrub /Dry-Mesic Herbaceous/Willow confusion. The *Herbaceous-Shrub* class (which is limited to the Park's southside) is a composition of three other mapping classes; *Dwarf Shrub*, *Dry-Mesic Herbaceous* and *Willow*. User's should therefore expect some confusion amongst all four classes on the hillslopes of the Park's southside. (Refer to section 2.84 and Appendix 5.2 for more information about the *Herbaceous-Shrub* class).

Water/Shadow confusion. In areas of high terrain and extensive terrain shadows, erroneous water often appeared in areas of shadow or partial shadow. A combination of illumination, slope, and the spectral classification was used to ensure that overclassified water areas were remapped to shadow based on the principal that water bodies only occur on low slope areas, and not in terrain shadow areas. The illumination and spectral classification were again used to enhance the *Shadow* class.

Cloud or Snow/Bare confusion. Scatterings of either snow or cloud pixels were spectrally mapped at higher elevations or on gravel bars. They were usually reclassified to the *Bare Ground* or *Sparse Vegetation* class.

Table 10. Models and modeling parameters applied to the Imagery Processing Blocks. Refer to Appendix 5.6 for additional modeling details

Image Processing Block 1 - Landsat TM p70r15/16 - August 15, 1988

Model Layer /Name	Confused Class(es)	Separable by ...	IF	Parameter 1	AND	Parameter 2	THEN	Output equals
Terrain Shadow	All classes	Illumination	IF	illum >= 69			THEN	Shadow /Indeterminate
Partial Terrain Shadow	Wet Herbaceous	Illumination		70 < illum <= 134			THEN	Mixed Dwarf Shrub
	Mixed Spruce-Deciduous	Illumination		70 < illum <= 134			THEN	Alder
	Dense Open Spruce	Illumination		70 < illum <= 134			THEN	Shadow /Indeterminate
	Open-Woodland Spruce	Illumination		70 < illum <= 134			THEN	Alder
	Open-Woodland Stunted Spruce	Illumination		70 < illum <= 134			THEN	Low Shrub Birch-Ericaceous-Willow
TNDVI to correct overclassification of floodplain dwf shrub rock and upslope bare								
	Dwarf Shrub Rock	Slope, TNDVI	IF	Slope <= 12	AND	TNDVI > = 124	THEN	Sparse Vegetation (18)
	Bare ground	Slope, TNDVI	IF	Slope >= 13	AND	TNDVI > = 124	THEN	Sparse Vegetation (18)
Correct overclassification of water on partially shadowed upslopes								
	Shadow/Indeterminate	Illumination, Slope	IF	illum < 135	AND	Slope > 16	THEN	Bare Ground
	Silty Water	Illumination, Slope	IF	illum < 135	AND	Slope > 16	THEN	Bare Ground
Correct overclassification of water and wet herb on upslopes								
	Clear Water	Slope		Slope > 11			THEN	Bare Ground
	Silty Water	Slope		Slope > 11			THEN	Bare Ground
	Wet Herbaceous	Slope		Slope > 11			THEN	Mixed Dwarf Shrub

Image Processing Block 2 - p71r15 - July 21, 1985

No models applied

Table 10 cont. Models and modeling parameters applied to the Imagery Processing Blocks. Refer to Appendix 5.7 for additional modeling details

Image Processing Block 3 - p70r16 - June 29, 1991 (and Upper Elevation SPOT - September 4, 1996)

Model Layer /Name	Confused Class(es)	Separable by ...	IF	Parameter 1	AND	Parameter 2	THEN	Output equals
Correction of overclassification of wet herb in upslope areas	Wet Herbaceous	Slope	IF	Slope >= 12			THEN	Mixed Dwarf Shrub
Corrects error in terrain shadow	Open-Woodland Spruce	Illumination	IF	80 < illum <= 157			THEN	Shadow/Indeterminate
	Open-Woodland Stunted Spruce	Illumination	IF	80 < illum <= 157			THEN	Low Shrub Birch-Ericaceous-Willow
	Mixed Spruce-Deciduous	Illumination	IF	80 < illum <= 157			THEN	Alder Shrub
	Balsam Poplar	Illumination	IF	80 < illum <= 157			THEN	Willow Shrub
	Open Low Shrub (Peatland)	Illumination	IF	80 < illum <= 157			THEN	Shadow/Indeterminate
Correction of terrain shadow and overclassification of water	Silty Water	Illumination, Slope	IF	80 < illum <= 136	AND	Slope >= 17	THEN	Shadow/Indeterminate
	Clear Water	Illumination, Slope	IF	80 < illum <= 136	AND	Slope >= 17	THEN	Shadow/Indeterminate
Subsets Alpine (upper elevation) SPOT Spectral Classification		Elevation	IF	DEM >= 784			THEN	Use Spot classification values (else use TM classificatin values)
Corrects shadow effects in SPOT alpine subset based on Slope	Dense Open Spruce		IF	Mapping Class = 1			THEN	Shadow/Indeterminate
	Open-Woodland Spruce		IF	Mapping Class = 2			THEN	Shadow/Indeterminate
	Open-Woodland Stunted Spruce		IF	Mapping Class = 3			THEN	Shadow/Indeterminate
	Silty Water	Slope	IF	Slope >= 16			THEN	Shadow/Indeterminate
	Clear Water	Slope	IF	Slope >= 16			THEN	Shadow/Indeterminate
	Wet Herbaceous	Slope	IF	Slope >= 16			THEN	Shadow/Indeterminate
Additional correction of upslope water	Silty Water	Slope	IF	Slope >= 17			THEN	Bare Ground
	Clear Water	Slope	IF	Slope >= 17			THEN	Bare Ground
Correct overclassification of wet herb on upslope areas	Wet Herbaceous	Slope	IF	Slope >= 12			THEN	Mixed Dwarf Shrub
Correct overclassification of low shrub sedge		elevation, AOI	IF	If Elev <~ 600			THEN	Herb Shrub

Table 10 cont. Models and modeling parameters applied to the Imagery Processing Blocks. Refer to Appendix 5.7 for additional modeling details

Image Processing Block 4 - p71r16 - June 21, 1991

Model Layer /Name	Confused Class(es)	Separable by ...	IF	Parameter 1	AND	Parameter 2	THEN	Output equals
Correct barren to ice, mixed dwf shrub, dwfshrub-rock or sparse based on TNDVI								
	Bare Ground	TNDVI	IF	TNDVI <= 109			THEN	Snow/Ice
	Bare Ground	TNDVI	IF	125 <=TNDVI <= 130			THEN	Sparse Vegetation
	Bare Ground	TNDVI	IF	131 <=TNDVI <= 143			THEN	Mixed Dwarf Shrub Rock
	Bare Ground	TNDVI	IF	144 <=TNDVI <= 200			THEN	Mixed Dwarf Shrub
Correct shadow and upslope water								
	Silty Water	Slope and Illumination	IF	Slope >= 17			THEN	Bare Ground
	Clear Water	Slope and Illumination	IF	Slope >= 17			THEN	Bare Ground
	All Classes			illum >= 130			THEN	Shadow/Indeterminate

Image Processing Block 5 - p69 r16 - Sept. 8, 1999

Model Layer /Name	Confused Class(es)	Separable by ...	IF	Parameter 1	AND	Parameter 2	THEN	Output equals
Identify terrain shadow/indeterminate								
	All classes	Illumination	IF	illum >= 87			THEN	Shadow/Indeterminate
Integrates bare& Ice from SPOTclassification andcorrects ice/snow shadowed areas in TM classification								
	Snow /ice	Bare Ground	IF	Tm map class = snow AND	SPOT map class =	THEN	Bare Ground	
			IF	Tm map class = Silty AND	SPOT map class =	THEN	Bare Ground	
			IF	Tm map class = Clea AND	SPOT map class =	THEN	Bare Ground	
			IF	SPOT map class = Snow		THEN	Snow/Ice	
Correct overclasification of water on upslopes								
	Silty Water	Slope	IF	Slope > 16			THEN	Shadow/Indeterminate
	Clear Water	Slope	IF	Slope > 16			THEN	Shadow/Indeterminate

2.84 Defining and delimiting the Southside Herbaceous-Shrub Class

The *Herbaceous-Shrub* class was not defined until the final phases of the mapping project. It was developed to correct extensive over classification of the *Low Shrub-Sedge* class on the hill slopes of the Southside. Since *Herbaceous-Shrub* was not identified as a potential target or endpoint mapping class during the 1999 fieldwork or during the review and attributing of the firepro vegetation database, there were no *Herbaceous-Shrub* training signatures in the spectral database for the ML Classifier to utilize for spectrally mapping the *Herbaceous-Shrub* class. Instead, the mapped extent of the *Herbaceous-Shrub* class was the result of reclassing the *Low Shrub-Sedge* class on the hill slopes (at or above the occurrence of dense alder) on the Southside through modeling and editing.

The extensive overclassification of the *Low Shrub-Sedge* class was the result of two issues:

1.) the mis-assignment of 3-4 polygons from the firepro database to the *Low Shrub-Sedge* class; and 2.) the poorer spectral resolution of the SPOT XS data. The firepro vegetation species list for the 3-4 mis-assigned signatures included a mix of species types, such as alder or willow (low and dwarf), ericaceous (low and dwarf), significant graminoid component (usually 35% or more) and some sedge. (Refer to Appendix 5.2 for a description of the *Herbaceous-Shrub* Class). The species composition for these sites did not neatly key into any of the previously defined mapping classes, but in lieu of tossing them from the spectral database (spectral training signatures based on actual field data are considered a valuable commodity!), they were assigned to the *Low Shrub-Sedge* class. In general the grass/forb component was significantly higher in the subalpine herbaceous and shrub types South of the Alaska range. Consequently a new mapping category was established.

Supervised ML classifications (using the spectral database that contained the 3-4 signatures described above) were run on both the Landsat TM and SPOT XS imagery available for the Park's Southside. In general, these areas were spectrally mapped in the TM data as a mix of *Dwarf Shrub*, *Dry-Mesic Herbaceous* and some *Low Shrub-Sedge*. These same areas were predominantly spectrally mapped as *Low Shrub-Sedge* in the SPOT XS data. So while the TM data results appeared to be more 'pixelated', the results indicated that the TM data were better able to discern the true variability of landcover types occurring in these areas. And although the SPOT classification results of uniformly classifying these areas as *Low Shrub-Sedge* appeared 'cleaner', it actually provided less insight into the heterogeneous nature of these areas. A complicating factor however was that poor herbaceous development was expected in the early (June 29, 1991) and late (September 8, 1999) TM image dates (as evidenced by their low snow lines).

As discussed in Section 2.23, the advantage of integrating the 1996 SPOT data set into the mosaic design was that the SPOT data had a higher snow line than the corresponding TM data. The SPOT classification was therefore incorporated in the study wide mosaic for elevations greater than 784 m on the Park's southside. While this alleviated concerns that vegetation hadn't 'greened' up by the late June TM date, it also introduced the SPOT's overclassification of the *Low Shrub-Sedge* into the landcover mosaic.

A proposed remedy for correcting the extensive *Low Shrub-Sedge* classification on the Southside hill slopes, was to expand the *Low Shrub-Sedge* mapping class description to include graminoids

and forbes. However, there was resistance to ‘diluting’ the *Low Shrub-Sedge* class to accommodate the Southside, especially since the *Low Shrub-Sedge* class appeared to be accurately defined and mapped on the Northside. In addition lower elevation valley bottoms on the Southside were typically sedge dominated.

In general, areas of *Low Shrub-Sedge* at or above the alder line (generally elevations of 600 m and higher) on the Park’s southside (below Broad Pass) were reclassified to the *Herbaceous-Shrub* mapping class (Figure 17).

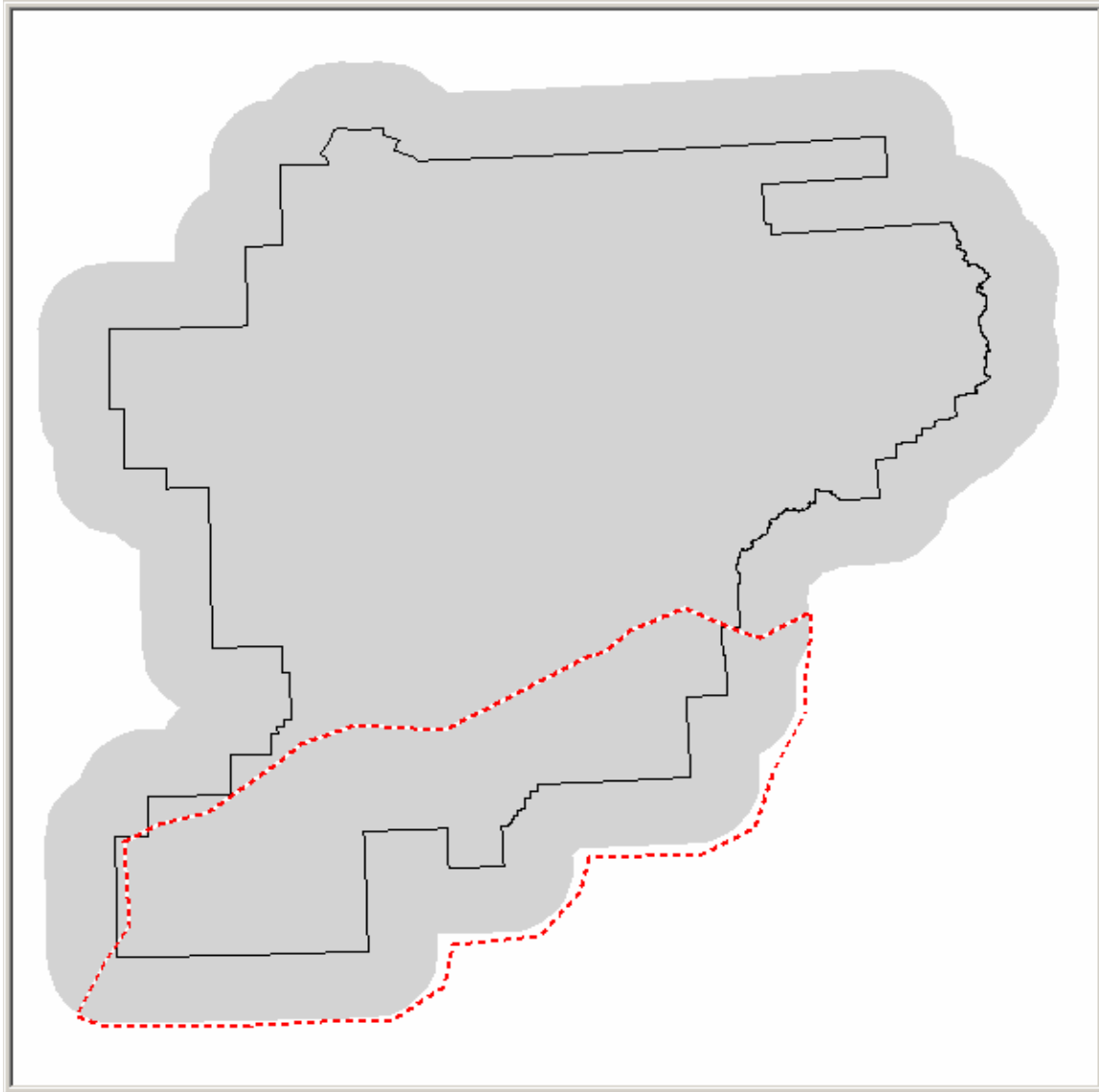


Figure 17. The red dashed area indicates where *Low Shrub-Sedge* was reclassified to *Herbaceous-Shrub* on the Southside of the study area.

2.9 Raster Editing and Filtering Approach

Raster editing is the process of changing, adding, or deleting raster attributes or data values of thematic and continuous raster data. Raster editing is used in image classification to correct bad or noisy data values by recoding or reassigning pixels to another class. In the Denali NP&P landcover project, raster editing was focused on classes that could not be separated effectively through models, but could be positively identified through image interpretation or CIR photography, and/or review of the Denali NP&P Landcover (spectral) Database (FirePro, 1999 field data, annotations/notes).

During preliminary product development, the landcover map was first reviewed at small and intermediate scales (1:250,000, and 1:100,000 respectively) to identify obvious problems. More detailed editing was conducted at approximately 1:63,360 or larger scale throughout the Denali NP&P project area. In most cases, areas requiring edits were analyzed to determine whether problems could be resolved through further modeling. Many edits were completed through this approach (further refinement of and application of models on a local or ecoregion basis).

Priority for raster editing was focused along mosaic scene boundaries, and within the park boundary (where virtually all ground reference data were located). Substantial editing was also required within the 10-mile park buffer. This editing was difficult due to the lack of field data for areas outside the park (other than incidental observations and image annotations collected during the 1999 field season).

Further edits were completed based on comments from NPS and AKNHP during an onsite review of the draft landcover classification map on August 21, 2000. This review focused on the evaluation of both the digital and hardcopy versions (1:100,000 scale plots of the NE, NW, SE and SW sections of the study area). NPS staff familiar with the Park or with particular areas within the Park reviewed and annotated recommendations on the draft plots. An overflight was conducted to visit areas of concern that were accessible. All requested edits, including refinements to existing models were implemented.

Following implementation of all requested edits, the unfiltered pixel map was filtered to two different levels of aggregation. The first level was referred to as the 'single pixel eliminated' version. All single "detached" pixels were identified and recoded to the mapping class of the majority occurring pixels surrounding the detached pixel. Single pixels were essentially regarded as noise, and their removal greatly increased the readability / interpretability of the unfiltered product. The second level of aggregation was approximately a 2 acre minimum mapping unit (MMU). This was accomplished by first running the unfiltered map through a clumping algorithm, which grouped connected pixels into millions of individual clusters of like mapping class pixels. Next, an elimination algorithm was applied to the clumped file so that all groups of less than approximately 2 acres (9 pixels) were automatically recoded to the majority occurring class surrounding the clump. Initially, NPS was given the draft map at a variety of aggregation levels, including an unfiltered level, a single pixel eliminated level, a .80 acre mmu level, a 2 acre mmu level and a 5 acre mmu level. Ultimately however, NPS decided that the single pixel eliminated and the ~2 ac. mmu aggregation levels best retained the detail for their level of interest.

The NPS-AKSO office was supplied with the digital version of the unfiltered LC database so additional levels of aggregation can be performed as required by users in the future.

2.10 QUALITY CONTROL AND EVALUATION

Throughout the project, from fieldwork to final product, the image analyst, botanists, and ecologist team members remained consistent. This ensured a high level of consistency in the landcover map, and provided the image analysts with much needed ecological and botanical local expertise. Several teleconference calls related to spectral classification output, classification development, and modeling and editing output resulted in discussions and involvement of the project team throughout map development. Additionally, the NPS-AKSO office was given versions of all key interim products for review and evaluation. This included preliminary and final spectral classification outputs of all image processing blocks, final model output from all image processing blocks and multiple mosaic wide draft versions. Draft landcover maps at 1:250,000 and 1:100,000 scale (along with prints of the associated imagery) were presented to Denali NP&P staff August 23-25, 2000 for review. Comments and feedback received from either NPS or AKNHP on any of the interim products was integrated into the final versions of those datasets. Flexibility and customization by the contractor with regard to certain project specifications such as mapping classes, scale and layout of the hardcopy products, and multiple versions of the Landcover database (i.e., multiple mmu's, versions with and without burn areas, detailed and general mapping class levels) resulted in a more useable suite of products.

CHAPTER THREE

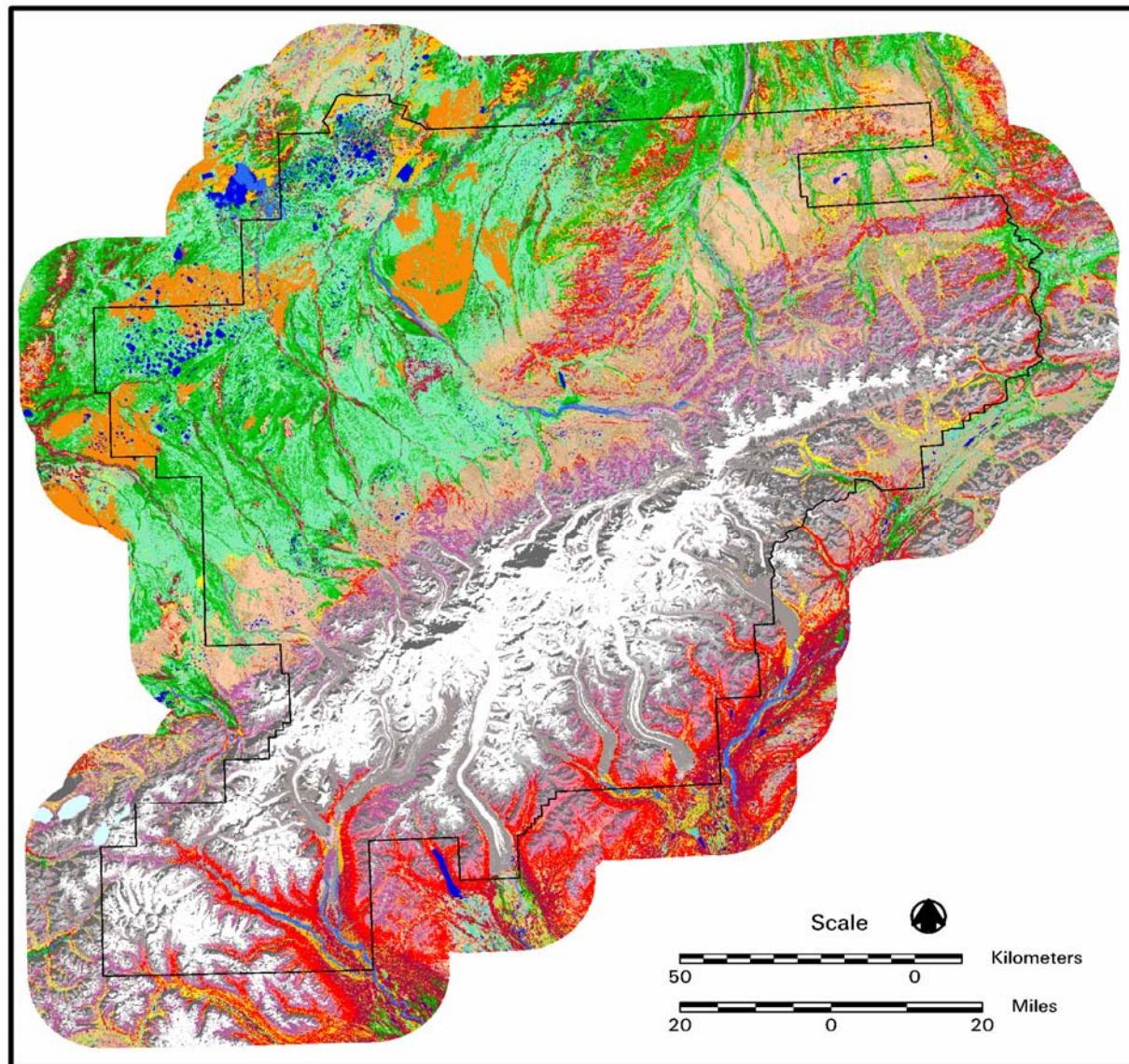
RESULTS AND DISCUSSION

3.1 Project Results (final maps, databases and files)

The following landcover databases were produced from this project:

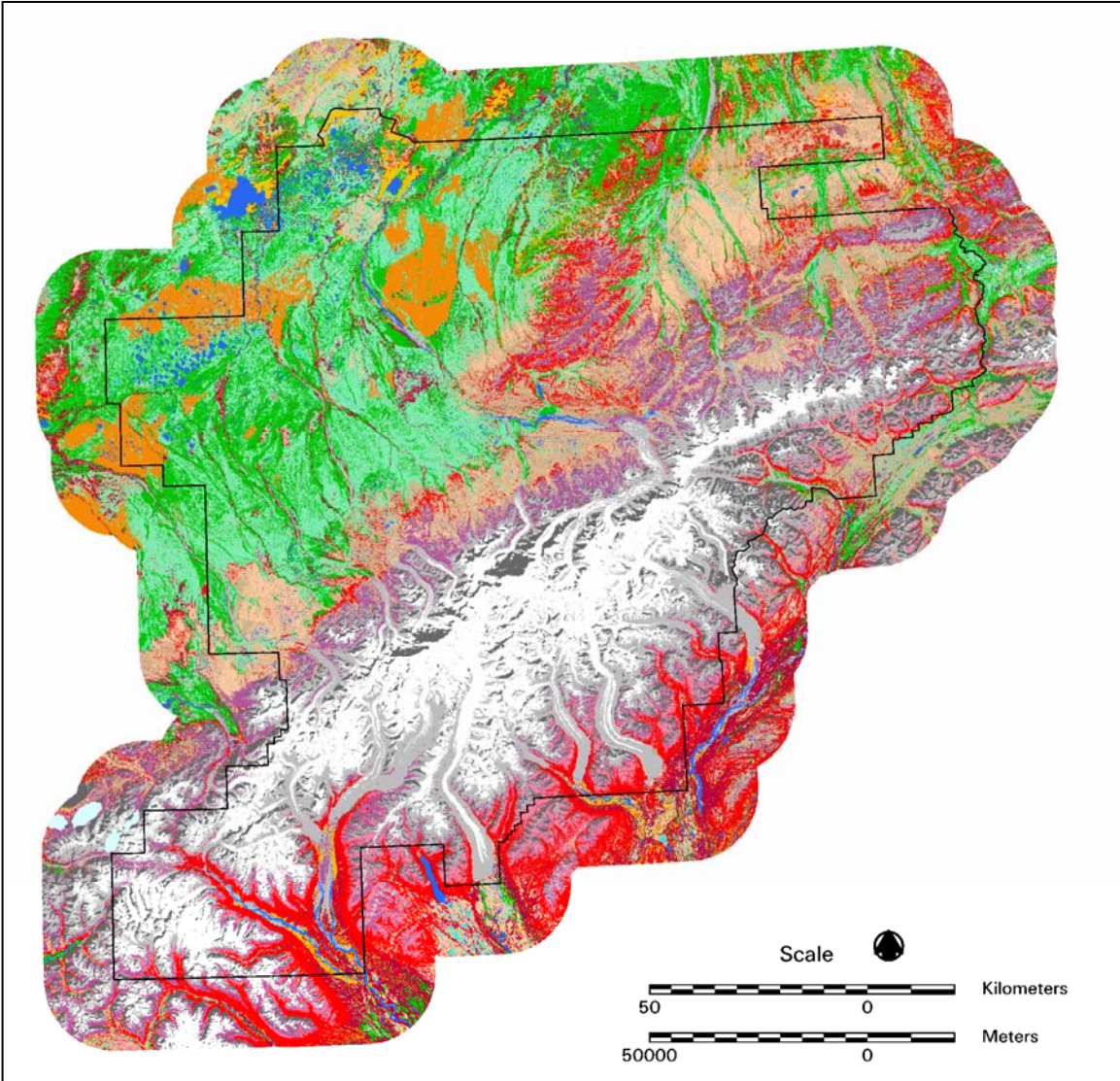
- Digital, unfiltered, 25 class (detailed) landcover database of the study area in ERDAS Imagine Format.
- Digital, single pixels eliminated, 25 class (detailed) landcover database of the study area in ERDAS Imagine Format
- Digital, 2 acre mmu, 25 class (detailed) landcover database of the study area in ERDAS Imagine Format (Figure 18).
- Digital, unfiltered, 16 class (general) landcover database of the study area in ERDAS Imagine Format
- Digital, single pixels eliminated, 16 class (general) landcover database of the study area in ERDAS Imagine Format
- Digital, 2 acre mmu, 16 class (general) landcover database of the study area in ERDAS Imagine Format (Figure 19).
- Digital, clumped file for the unfiltered, 25 class (detailed) landcover database of the study area in ERDAS Imagine Format. (This file allows users to produce the detailed landcover database at aggregation levels(mmu) other than those provided).
- Two hardcopy, 36” x 40” photographic quality maps of the 2 acre mmu, 25 class (detailed) landcover database of the study area. Includes Park Boundary, legend, and Project description.
- An enhanced Arcview 3.2 project file that includes Project related datalayers: the FirePro Vegetation field database, the 1999 fieldwork database, the final signature file, the final landcover database and the Park boundary vector layer.
- Two hardcopies of the Final Report (Volumes I and II) as well as digital versions (MS Word file for text files and MS Excel files for tables, if separate from the text file).

Figure 18. The detailed (25) mapping class Denali NP&P landcover map (2 ac mmu).



- | | |
|---|--|
| Dense-Open Spruce | Dwarf Shrub-Rock |
| Open-Woodland Spruce | Dry-Mesic Herbaceous |
| Stunted Spruce | Wet Herbaceous |
| Broadleaf | Aquatic Herbaceous |
| Spruce-Broadleaf | Sparse Vegetation |
| Alder | Bare Ground |
| Willow | Snow-Ice |
| Closed Low Shrub Birch | Shadow-Indeterminate |
| Low Shrub Birch-Ericaceous-Willow | Silty Water |
| Low Shrub-Sedge | Clear Water |
| Peatland | Burn |
| Herbaceous-Shrub | Cloud |
| Dwarf Shrub | |

Figure 19. The general (16) mapping class Denali NP&P landcover map (2 ac mmu).



Mapping Class Name	
 Needleleaf Forest	 Herbaceous / Shrub
 Stunted Spruce	 Wet Herbaceous
 Broadleaf Forest	 Sparse Vegetation / Bare Ground
 Spruce - Broadleaf	 Snow / Ice
 Tall Shrub	 Water
 Low Shrub (drier sites)	 Burn
 Low Shrub (lowland / moister sites)	 Cloud
 Dwarf Shrub	 Shadow / Indeterminate

3.2 DISTRIBUTION OF LANDCOVER WITHIN DENALI NP&P

The final mapping classes for both the 25 class (detailed) and the 16 class (general) landcover databases, as well as their distribution in the Denali NP&P Project Area are provided in Tables 11, 12a and 12b below.

The names of the final landcover classes used in the Detailed Denali Landcover Mapping Project are listed below. A class key and description (species, photos, physical site variables) for each of these classes can be found in Appendices 5.1 & 5.2.

Table 11. Area (ac) and percent distribution of the detailed (25) landcover mapping class for Denali NP&P.

Landcover Classes	PARK		Park and Buffer	
	Area (acres)	Percent Distribution	Area (Acres)	Percent Distribution
Dense-Open Spruce Forest	50,359.02	0.84	157,156.52	1.65
Open - Woodland Spruce	551,427.78	9.15	931,270.54	9.75
Stunted Spruce	853,984.85	14.16	1,283,661.22	13.44
Broadleaf	97,062.91	1.61	253,607.63	2.65
Spruce-Broadleaf	149,929.39	2.49	509,643.88	5.34
Alder	260,197.98	4.32	533,799.04	5.59
Willow	95,590.17	1.59	195,666.18	2.05
Closed Low Shrub Birch	54,033.90	0.90	87,201.42	0.91
Low Shrub Birch-Ericaceous-Willow	570,700.34	9.47	898,321.93	9.40
Low Shrub-Sedge	277,322.25	4.60	450,123.90	4.71
Peatland	2,303.66	0.04	34,475.01	0.36
Herbaceous-Shrub	68,871.56	1.14	132,299.29	1.38
Dwarf Shrub	346,846.88	5.75	517,563.60	5.42
Dwarf Shrub-Rock	73,894.04	1.23	107,685.76	1.13
Dry-Mesic Herbaceous	45,684.09	0.76	95,915.64	1.00
Wet Herbaceous	38,426.74	0.64	74,171.66	0.78
Aquatic Herbaceous	563.95	0.01	590.10	0.01
Sparse Vegetation	289,308.38	4.80	389,988.64	4.08
Bare Ground	592,298.24	9.82	710,194.02	7.43
Snow -Ice	932,789.58	15.47	1,049,705.66	10.99
Shadow-Indeterminate	413,259.80	6.85	657,181.47	6.88
Silty Water	30,765.06	0.51	67,957.35	0.71
Clear Water	60,764.31	1.01	100,879.80	1.06
Burn	172,528.50	2.86	296,213.54	3.10
Cloud	357.05	0.01	17,299.60	0.18
Total	6,029,270	100.0	9,552,573	100.0

Based on spectral and ecological similarities, the detailed landcover mapping class types were combined to create a general landcover map. This was to provide users with a more accurate and aggregated database if needed.

Table 12a. General mapping class list.

General Landcover Classes	Combined Detailed Landcover Classes
Needleleaf	Dense-Open Spruce Open-Woodland Spruce
Stunted Spruce	Stunted Spruce
Broadleaf	Broadleaf Forest
Spruce-Broadleaf	Spruce-Broadleaf
Tall Shrub	Alder Willow
Low Shrub (drier sites)	Closed Low Shrub Birch Low Shrub Birch-Ericaceous-Willow
Low Shrub (lowland / moister sites)	Low Shrub-Sedge Peatland (Southside only)
Dwarf Shrub	Dwarf Shrub Dwarf Shrub-Rock
Herbaceous-shrub	Dry-Mesic Herbaceous Herbaceous-Shrub (Southside only)
Wet herbaceous	Wet Herbaceous
Sparse Vegetation-Bare Ground	Sparse Vegetation Bare Ground
Snow-Ice	Snow-Ice
Water	Silty Water Clear Water Aquatic Herbaceous
Burn	Burn
Indeterminate	Cloud Shadow (terrain and cloud)

Table 12b. Area (ac) and percent distribution of the general (16) landcover mapping class for Denali NP&P.

General Landcover Classes	PARK		Park and Buffer	
	Area (acres)	Percent Distribution	Area (Acres)	Percent Distribution
Needleaf	601,787	10.0	1,088,427	11.4
Stunted Spruce	853,985	14.2	1,283,661	13.4
Broadleaf	97,063	1.6	253,608	2.7
Spruce-Broadleaf	149,929	2.5	509,644	5.3
Tall Shrub	355,788	5.9	729,465	7.6
Low Shrub (drier sites)	624,734	10.4	985,523	10.3
Low Shrub (moister sites)	279,626	4.6	484,599	5.1
Dwarf Shrub	420,741	7.0	625,249	6.5
Herbaceous-shrub	114,556	1.9	228,215	2.4
Wet herbaceous	38,427	0.6	74,172	0.8
Sparse Vegetation- Bare	881,607	14.6	1,100,183	11.5
Snow-Ice	932,790	15.5	1,049,706	11.0
Water	92,093	1.5	169,427	1.8
Burn	172,528	2.9	296,214	3.1
Cloud	357	0.0	17,300	0.2
Indeterminate (Shadow)	413,260	6.9	657,181	6.9
Totals	6,029,270	100.0	9,552,573	100.0

3.3 ACCURACY ASSESSMENT

Confusion matrices (also called error matrices) and associated statistics have been adopted by the remote sensing community as the standard technique for accuracy assessment (Campbell 1987, Congalton 1991, Jensen 1996).

A confusion matrix is a square array of numbers set out in rows and columns that represents the number of information classes or classification categories, used to compare (on a category-by-category basis) the relationship between known reference data and the corresponding results of a classification. The columns and rows of an error matrix show the number of sample units assigned to a particular landcover class (classification data) relative to the actual number of sample units that belong to the landcover class (reference data). The error of commission is computed as 100% minus the producer's accuracy and error of omission is 100% minus user's accuracy. From an error matrix the *overall accuracy* of the classification of a landcover map can be quantified along with both the *producer's accuracy* (or errors of omission or exclusion) and *user's accuracy* (or errors of commission or inclusion).

The overall accuracy is computed as the sum of all the main diagonal cells in the error matrix divided by the total number of sample units used in the error matrix. The overall accuracy shows the proportion of the classification that is correct but it does not indicate how the accuracy is distributed across the individual landcover classes. (Story and Congalton 1986).

The producer's accuracy is the sum of all correctly classified sample units in a landcover class divided by the total number of reference data in that landcover class. The producer's accuracy indicates how well members of a particular landcover were classified, or shows the ease or difficulty with which members of a particular landcover class were correctly identified, classified or mapped by the mapping methodology.

The user's accuracy indicates the probability that a particular landcover class (classification data) would represent that landcover class in the reference or ground truth data. The user's accuracy, computed as the sum of all correctly classified sample units in a landcover class divided by the total number of classification data in that landcover class, is termed a measure of reliability in specific map categories.

Both qualitative and quantitative evaluations of errors were made at various stages of developing the Denali NP&P landcover map for the purpose of improving or refining the mapping process. Accuracy assessments were performed on the endpoint (25 class) and general (16 class) final Denali NP&P landcover in order to quantitatively determine what proportion of the overall landcover map was correct, the probability that individual landcover classes were correctly mapped, which landcover classes were overestimated or underestimated, and the distribution of errors between mapping classes.

Ideally, the best way to assess the accuracy of the map would be to use an independent database, collected and processed similar to the manner in which the spectral training database was derived from the FirePro and 1999 Field data. In lieu of an additional field collection effort for accuracy assessment purposes, it was hoped that some of the ground reference data (i.e., the data collected for the supervised training database) could be reserved for accuracy assessment purposes. Unfortunately, all 650+ signatures in the supervised / signature training database were needed for spectral processing; precluding the reservation of a portion of them for later use. Therefore, the estimates of accuracy throughout this document are primarily based on the ~2 acre minimum mapping unit landcover database (prior to adding the burn mask) compared with the supervised training data set.

The results of this comparison were used to generate the confusion matrices used to quantitatively assess the landcover map. Admittedly, using the training database introduces some bias that would be avoided by using an independent database. Collecting an accuracy database would have required another field collection season, which was beyond the scope and resources of the project. Evaluating the landcover map with the training database is a measure of how well the training database was able to map itself. It is also an indication of the homogeneity ("spectral purity") of the training signatures. As discussed in Section 2.7, confusion matrices were generated during the iterative ML classification / signature evaluation process for each processing block. The confusion matrix generated for the final ML classification run of each block is available in Appendix 5.5. Again, these were for the individual processing blocks, prior to modeling and mosaicking. The per class accuracies for some of the mapping classes (dwarf shrub-rock, for example) were actually higher immediately following final spectral classification than they were after significant post processing (i.e. modeling and editing). This is primarily because the same post spectral processing procedures (mosaicking, modeling and editing) that were performed on the LC map were not

performed of the training database. Applying the same processing procedures to the training database would have introduced even greater bias to the dataset.

Although using the training database doesn't give an absolutely objective or reliable assessment of the map's accuracy, it does provide useful information regarding which mapping classes are generally confused, and what mapping classes caused the confusion. This information facilitates greater interpretability, and therefore understanding of the landcover database. Confusion matrices were generated for the 25 endpoint mapping classes and the 16 general mapping classes (at ~ 2 acre MMU). An estimate of the overall accuracy (with the approximately 650 training areas) for the detailed landcover class map was 81.6% (Table 13). Accuracies per mapping class are discussed in Section 3.31 below. The detailed landcovermap was then further grouped, based on ecological similarities to form the general landcover class map. The overall accuracy for the general landcover map was 84.8% (Table 14).

Since some of the classes (mixed spruce–broadleaf, willow, wet herbaceous, etc) exhibited a fairly significant amount of confusion, and since the Northside (which includes the Broad Pass area) and Southside areas of the Park are ecologically distinct, confusion matrices were also generated for the north and southsides of the Alaska Mountain Range (Figure 20, Tables 15 and 16).

Table 13. Confusion matrix for the Final Denali LC Mosaic (2 ac., no burn version) x training signature data (12/17/00):

		Reference / Training Data																													
		Dense Open Spruce Forest (White-like)	Open - Woodland Spruce Forest	Open - Woodland Stunted Spruce	Broadleaf Forest	Mixed Spruce-Broadleaf Forest	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Birch-Ericaceous-Willow	Peatland	Herbaceous / Shrub	Mixed Dwarf Shrub	Dry / Mesic Shrub-Rock	Wet Herbaceous	Aquatic Herbaceous	Sparse Vegetation	Bare Ground	Snow / Ice	Shadow	Silty Water	Clear Water	Burn	Cloud							
Theme		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Row Total	User %	Theme		
Image Classification	1	1092	475	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1574	69.4	1		
	2	119	4998	1131	9	15	2	0	0	3	5	0	0	4	0	4	9	0	0	0	0	0	0	0	0	0	6299	79.3	2		
	3	0	327	5833	7	118	0	9	168	60	104	0	0	1	0	0	29	0	0	0	0	0	0	0	0	0	6656	87.6	3		
	4	0	28	0	3798	2235	12	26	0	0	0	6	0	0	0	11	4	0	0	0	0	0	0	0	0	0	6120	62.1	4		
	5	8	154	70	153	3634	27	47	0	0	1	9	0	2	0	3	4	0	0	0	0	0	0	0	0	0	4112	88.4	5		
	6	0	16	11	44	57	6854	252	0	175	2	1	0	4	0	19	7	0	0	0	0	0	0	0	0	0	7442	92.1	6		
	7	0	0	20	305	0	203	681	0	67	25	0	0	21	0	15	19	0	7	0	0	0	0	0	0	0	1363	50.0	7		
	8	0	0	52	0	0	0	0	600	43	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	721	83.2	8		
	9	0	28	124	222	7	112	86	91	3877	425	0	0	75	1	56	41	0	1	0	0	0	0	0	0	0	0	5146	75.3	9	
	10	0	0	19	71	6	48	41	32	382	3308	28	0	71	1	55	58	0	0	0	0	0	0	0	0	0	0	4120	80.3	10	
	11	6	2	5	0	5	0	0	0	0	0	27	233	0	0	0	0	10	0	0	0	0	0	0	0	0	0	288	80.9	11	
	12	0	0	0	0	0	0	11	0	0	0	0	0	5	0	135	0	0	0	0	0	0	0	0	0	0	0	151	0.0	12	
	13	0	0	0	60	0	44	8	0	39	18	0	0	1039	32	44	0	0	0	12	0	0	0	0	0	0	0	1296	80.2	13	
	14	0	0	0	12	2	10	0	0	1	0	0	0	27	89	4	0	0	26	6	0	0	0	0	0	0	0	177	50.3	14	
	15	0	0	0	0	0	0	20	0	0	30	0	0	43	0	811	0	0	0	0	0	0	0	0	0	0	0	904	89.7	15	
	16	17	1	5	1	0	4	17	0	2	24	6	0	1	0	2	475	0	0	0	0	0	0	0	0	0	0	555	85.6	16	
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0	0	43	100.0	17	
	18	0	0	0	29	0	4	19	0	0	0	0	0	7	39	0	0	0	395	369	0	0	2	0	0	0	0	0	864	45.7	18
	19	0	0	0	15	0	1	0	0	0	0	0	0	5	0	0	1	0	22	1060	7	0	114	0	0	0	0	1225	86.5	19	
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	2376	0	0	0	0	0	0	0	2387	99.5	20	
	21	0	0	5	0	1	0	19	0	0	0	0	0	21	0	0	0	0	0	15	0	0	0	0	0	0	0	61	0.0	21	
	22	0	0	0	5	0	0	1	0	0	0	0	0	0	0	0	0	0	26	0	0	1388	0	0	0	0	0	1420	97.7	22	
	23	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	8	3599	0	0	0	3644	98.8	23	
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25
Col. Tot		1242	6029	7278	4731	6087	7321	1237	891	4649	3995	283	0	1326	162	1159	691	43	451	1499	2383	0	1512	3599	0	0	46183		Total correct		
Prod. %		87.9	82.9	80.1	80.3	59.7	93.6	55.1	67.3	83.4	82.8	82.3	NA	78.4	54.9	70.0	68.7	100.0	87.6	70.7	99.7	NA	91.8	100.0	NA	NA	56568		Total pixels		
Theme		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25		81.64		% Correct	

Table 14. Confusion matrix for the Final Denali LC Mosaic (General Classes) (2 ac., no burn version) x training signature data (12/18/00):

Image Classification	Reference / Training Data																Row Total	User %	Theme
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
1	6689	1138	9	25	3	3	9	4	6	18	0	0	0	0	0	0	7904	84.6	1
2	327	5827	7	118	9	200	103	1	0	24	0	0	0	0	0	0	6616	88.1	2
3	28	0	3777	2235	34	0	6	0	10	4	0	0	0	0	0	0	6094	62.0	3
4	158	70	150	3613	68	0	6	0	2	3	0	0	0	0	0	0	4070	88.8	4
5	18	33	370	74	8027	263	31	16	34	26	6	0	0	0	0	0	8898	90.2	5
6	26	174	220	7	193	4624	487	80	56	40	1	0	0	0	0	0	5908	78.3	6
7	7	24	71	12	84	408	3559	69	55	72	0	0	0	0	0	0	4361	81.6	7
8	0	1	77	2	54	40	18	1179	47	0	48	0	0	0	0	0	1466	80.4	8
9	0	0	0	0	35	0	30	65	947	0	0	0	0	0	0	0	1077	87.9	9
10	18	4	1	0	11	2	29	1	2	470	0	0	0	0	0	0	538	87.4	10
11	0	0	44	0	21	0	0	52	0	1	1845	7	125	0	0	0	2095	88.1	11
12	0	0	0	0	0	0	0	0	0	0	10	2376	0	0	0	0	2386	99.6	12
13	0	3	5	0	0	0	0	0	0	33	25	0	5029	0	0	0	5095	98.7	13
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	14
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	15
16	0	4	0	1	19	0	0	21	0	0	15	0	0	0	0	0	60	0.0	16
Col. Total	7271	7278	4731	6087	8558	5540	4278	1488	1159	691	1950	2383	5154	0	0	0	47962		Total correct
Prod. %	92.0	80.1	79.8	59.4	93.8	83.5	83.2	79.2	81.7	68.0	94.6	99.7	97.6	NA	NA	NA	56568		Total pixels
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		84.79	% Correct

Figure 20. The detailed (25) mapping class Denali NP&P landcover map (2 ac mmu), shown with the Northside – Southside divide.

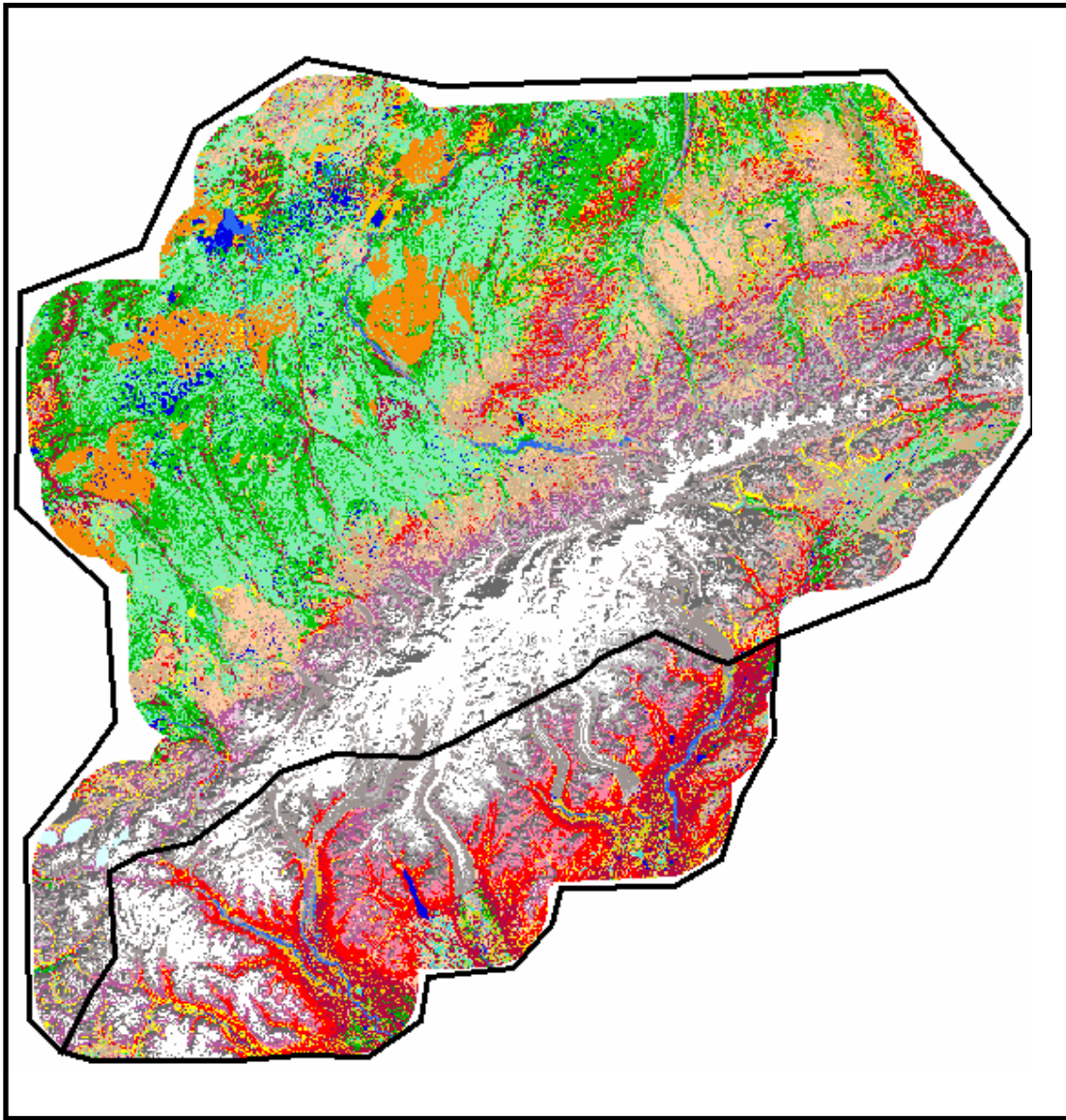


Table 15. Confusion matrix for the Final NORTHSIDE Denali LC Mosaic (2 ac., no burn version) x training signature data (12/18/00):

Image Classification	Reference / Training Data																												
	Dense Open Spruce Forest (white-like)	Open - Woodland Spruce Forest	Open - Woodland Stunted Spruce	Broadleaf Forest	Mixed Spruce-Broadleaf Forest	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Birch-Ericaceous-Willow	Low Shrub-Sedge	Peatland	Herbaceous / Shrub	Mixed Dwarf Shrub	Mixed Dwarf Shrub-Rock	Dry / Mesic Herbaceous	Wet Herbaceous	Aquatic Herbaceous	Sparse Vegetation	Bare Ground	Snow / Ice	Shadow	Silty Water	Clear Water	Burn	Cloud				
	Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Row Total	User %	Theme
	1	842	468	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1310	64.3	1
	2	117	4732	1131	9	15	2	0	0	0	5	0	0	4	0	4	9	0	0	0	0	0	0	0	0	0	6028	78.5	2
	3	0	327	5792	7	118	0	9	168	60	104	0	0	1	0	0	29	0	0	0	0	0	0	0	0	0	6615	87.6	3
	4	0	28	0	3206	113	12	26	0	0	0	0	0	0	0	11	4	0	0	0	0	0	0	0	0	0	3400	94.3	4
	5	1	146	70	126	992	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1357	73.1	5
	6	0	16	11	10	28	1235	15	0	175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1490	82.9	6
	7	0	0	20	282	0	27	474	0	67	7	0	0	21	0	9	19	0	0	0	0	0	0	0	0	0	926	51.2	7
	8	0	0	52	0	0	0	0	600	43	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	721	83.2	8
	9	0	28	124	222	7	96	86	91	3853	425	0	0	75	1	56	17	0	1	0	0	0	0	0	0	0	5082	75.8	9
	10	0	0	17	71	0	19	41	32	382	3269	0	0	67	0	3	51	0	0	0	0	0	0	0	0	0	3952	82.7	10
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	11
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	12
	13	0	0	0	58	0	44	8	0	39	18	0	0	654	32	29	0	0	0	9	0	0	0	0	0	0	891	73.4	13
	14	0	0	0	12	0	10	0	0	1	0	0	0	27	52	4	0	0	26	6	0	0	0	0	0	0	138	37.7	14
	15	0	0	0	0	0	0	4	0	0	29	0	0	28	0	595	0	0	0	0	0	0	0	0	0	0	656	90.7	15
	16	17	1	5	1	0	4	17	0	2	21	0	0	1	0	2	438	0	0	0	0	0	0	0	0	0	509	86.1	16
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0	0	43	100.0	17
	18	0	0	0	29	0	0	19	0	0	0	0	0	6	32	0	0	0	180	161	0	0	2	0	0	0	429	42.0	18
	19	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	18	964	0	0	114	0	0	0	1106	87.2	19
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2090	0	0	0	0	0	2090	100.0	20
	21	0	0	5	0	1	0	19	0	0	0	0	0	21	0	0	0	0	0	4	0	0	0	0	0	0	50	0.0	21
	22	0	0	0	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	26	0	0	1093	0	0	0	1125	97.2	22
	23	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	3072	0	0	3109	98.8	23
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25
	Col. Total	977	5746	7230	4048	1274	1449	741	891	4622	3904	0	0	905	117	713	601	43	225	1170	2090	0	1209	3072	0	0	34176		Total correct
Prod. %	86.2	82.4	80.1	79.2	77.9	85.2	64.0	67.3	83.4	83.7	NA	NA	72.3	44.4	83.5	72.9	100.0	80.0	82.4	100.0	NA	90.4	100.0	NA	NA	41027		Total pixels	
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25		83.30	% Correct	

Table 16. Confusion matrix for the Final Southside Denali LC Mosaic (2 ac., no burn version) x training signature data (12/18/00):

Image Classification	Reference / Training Data																												
	Dense Open Spruce Forest (White-like)	Open - Woodland Spruce Forest	Open - Woodland Spruce Forest	Broadleaf Forest	Mixed Spruce-Broadleaf Spruce	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Birch-Ericaceous-Willow	Peatland	Herbaceous / Shrub	Mixed Dwarf Shrub	Mixed Dwarf Shrub-Rock	Wet Herbaceous	Aquatic Herbaceous	Sparse Vegetation	Bare Ground	Snow / Ice	Shadow	Silty Water	Clear Water	Burn	Cloud						
	Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Row Tot	User %	Theme
	1	250	7	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	264	94.7	1	
	2	2	266	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	271	98.2	2	
	3	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	100.0	3	
	4	0	0	0	592	2122	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	2720	21.8	4	
	5	7	8	0	27	2642	27	25	0	0	1	9	0	2	0	3	4	0	0	0	0	0	0	0	0	2755	95.9	5	
	6	0	0	0	34	29	5619	237	0	0	2	1	0	4	0	19	7	0	0	0	0	0	0	0	0	5952	94.4	6	
	7	0	0	0	23	0	176	207	0	0	18	0	0	0	0	6	0	0	7	0	0	0	0	0	0	437	47.4	7	
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!	8	
	9	0	0	0	0	0	16	0	0	24	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	64	37.5	9	
	10	0	0	2	0	6	29	0	0	0	39	28	0	4	1	52	7	0	0	0	0	0	0	0	0	168	23.2	10	
	11	6	2	5	0	5	0	0	0	0	27	233	0	0	0	0	10	0	0	0	0	0	0	0	0	288	80.9	11	
	12	0	0	0	0	0	0	11	0	0	0	0	0	5	0	135	0	0	0	0	0	0	0	0	0	151	0.0	12	
	13	0	0	0	2	0	0	0	0	0	0	0	0	385	0	15	0	0	0	3	0	0	0	0	0	405	95.1	13	
	14	0	0	0	0	2	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	0	0	39	94.9	14	
	15	0	0	0	0	0	0	16	0	0	1	0	0	15	0	216	0	0	0	0	0	0	0	0	0	248	87.1	15	
	16	0	0	0	0	0	0	0	0	0	3	6	0	0	0	0	37	0	0	0	0	0	0	0	0	46	80.4	16	
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	17	
	18	0	0	0	0	0	4	0	0	0	0	0	0	1	7	0	0	0	215	208	0	0	0	0	0	435	49.4	18	
	19	0	0	0	5	0	1	0	0	0	0	0	0	5	0	0	1	0	4	96	7	0	0	0	0	119	80.7	19	
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	286	0	0	0	0	297	96.3	20	
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	11	0.0	21	
	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	295	0	0	0	295	100.0	22	
	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	527	0	0	535	98.5	23	
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24	
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25	
Col. Tot	265	283	48	683	4813	5872	496	0	27	91	283	0	421	45	446	90	0	226	329	293	0	303	527	0	0	12007	Total correct		
Prod. %	94.3	94.0	85.4	86.7	54.9	95.7	41.7	NA	88.9	42.9	82.3	NA	91.4	82.2	48.4	41.1	NA	95.1	29.2	97.6	NA	97.4	100.0	NA	NA	15541	Total pixels		
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	77.26	% Correct		

3.31 DISCUSSION OF ACCURACY OF LANDCOVER CLASSES

The estimated overall accuracy for the detailed class landcover data at 2 ac MMU when compared to the training database was 81.6%.

The estimated overall accuracy for the general class landcover data at 2 acre MMU when compared to the training data was 84.8%.

Classes showing primary confusion are discussed below. All accuracies refer to the detailed class landcover data (prior to the digital integration of the burn mask) at a 2 acre mapping unit. Refer to Section 2.83 for other examples of confusion encountered during the map development process (and some of the modeling and editing steps employed to remedy them).

Mapping classes showing a particularly high degree of confusion (less than 65% producer's or user's accuracy) included *Spruce-Broadleaf*, *Broadleaf*, *Willow*, *Dwarf Shrub-Rock* and *Sparse Vegetation*. Mapping classes with a producer's accuracy between 65 and 70% included *Closed Low Shrub Birch* and *Wet Herbaceous*. Mapping classes with a User's accuracy between 65 and 70% included *Dense-Open Spruce*. All other mapping classes accuracies (both producer's and user's) were 70% or higher.

The producer's accuracy for the *Dense-Open Spruce* class was 87.9%, with a user's accuracy of 69.4%. Most of the errors of commission and omission were due to confusion with the *Open – Woodland Spruce* class. Error can generally be expected at the upper and lower canopy percent limits for similar types.

The producer's accuracy for the *Open–Woodland Spruce* class was 82.9%, with a user's accuracy of 79.3%. Most of the errors of commission were with the *Stunted Spruce* class while most of the errors of omission were with the *Dense-Open Spruce* class. There were also omission errors with the *Stunted Spruce* class and the *Spruce-Broadleaf* class. Woodland classes can be easily confused depending on understory species.

The producer's accuracy for the *Stunted Spruce* class was 80.1%, with a user's accuracy of 87.6%. Most of the errors of commission and omission were due to confusion with the *Open–Woodland Spruce* class.

The producer's accuracy for the *Broadleaf* class was 80.3%, with a user's accuracy of 62.1%. Most of the errors of commission were with the *Spruce-Broadleaf* class, while most of the omission errors were with *Willow* and *Low Shrub Birch-Ericaceous-Willow*. In general *Broadleaf* was confused with *Spruce-Broadleaf* South of the Alaska range and with *Willow* North of the Alaska Range.

The producer's accuracy for the *Spruce-Broadleaf* class was 59.7%, with a user's accuracy of 88.4%. Most of the errors of commission were with the *Open–Woodland Spruce class* and the *Broadleaf* class. Most of the error of omission was with the *Broadleaf* class. The *Spruce-Broadleaf* class by definition is spectrally mixed, and was very difficult to separate spectrally from open spruce forests with tall shrub understory (northside) or from mixed areas with a high

proportion of broadleaf (southside).

The producer's accuracy for the *Alder* class was 93.6%, with a user's accuracy of 92.1%. Most of the errors of commission and omission were with the *Willow* class.

The producer's accuracy for the *Willow* class was 55.1%, with a user's accuracy of 50.0%. Most of the errors of commission were with the *Broadleaf* and *Alder* classes. Most of the omission error was with *Alder*. Despite the significant spectral confusion with other classes, *Willow* was maintained as a class due to its ecological significance.

The producer's accuracy for the *Closed Low Shrub Birch* class was 67.3%, with a user's accuracy of 83.2%. Most of the errors of commission and omission were with *Stunted Spruce* and *Low Shrub Birch-Ericaceous-Willow*. Shrub birch vegetation types are highly variable and are frequently a component of woodland spruce communities.

The producer's accuracy for the and *Low Shrub Birch-Ericaceous-Willow* class was 83.4%, with a user's accuracy of 75.3%. Most of the errors of commission and omission were with *Low Shrub-Sedge*. In general the and *Low Shrub Birch-Ericaceous-Willow* contained more herbaceous vegetation than the *Closed Shrub Birch* class and would be expected to be similar in reflectance to *low shrub sedge*.

The producer's accuracy for the *Low Shrub-Sedge* class was 82.8%, with a user's accuracy of 80.3%. Most of the errors of commission and omission were with *Stunted Spruce* and and *Low Shrub Birch-Ericaceous-Willow*. The low shrub classes are broadly variable and some confusion among classes is expected.

The producer's accuracy for the *Peatland* class was 82.3%, with a user's accuracy of 80.9%. Most of the errors of commission and omission were with *Low Shrub-Sedge*.

Herbaceous-Shrub – There were no *Herbaceous-Shrub* signatures in the spectral database, and therefore no ready means to quantitatively access the accuracy of this class (refer to section 2.84 for a discussion on how this class was mapped).

The producer's accuracy for the *Dwarf Shrub* class was 78.4%, with a user's accuracy of 80.2%. Most of the errors of omission were with *Low Shrub Birch-Ericaceous-Willow* and *Low Shrub-Sedge*. Distribution of this class was enhanced through modeling in many of the processing blocks. Since the same modeling procedures were not applied to the training/accuracy dataset, accuracies for many of the significantly modeled classes tended to be lower than they were immediately following the spectral classification. Since reviews of the modeled out for this class were more favorable than the reviews of the spectral classification output for this class, the modeled output was used despite the higher accuracies associated with the spectral classification output.

The producer's accuracy for the *Dwarf Shrub-Rock* class was 54.9%, with a user's accuracy of 50.3%. Most of the errors of omission and commission were with *Dwarf Shrub* and the *Sparse Vegetation* class. The number of *Dwarf Shrub-Rock* signatures available for the classification

and/or the accuracy assessment was significantly less than preferred. Phenological development based on image date will influence classification of these types. Distribution of this class was enhanced through modeling in many of the processing blocks. Since the same modeling procedures were not also applied to the training/accuracy dataset, accuracies for many of the significantly modeled classes tended to be lower than they were immediately following the spectral classification. Since reviews of the modeled out for this class were more favorable than the reviews of the spectral classification output for this class, the modeled output was used despite the higher accuracies associated with the spectral classification output results.

The producer's accuracy for the *Dry-Mesic Herbaceous* class was 70.0%, with a user's accuracy of 85.6%. Most of the errors of omission and commission were with the low shrub, herbaceous shrub and dwarf shrub classes.

The producer's accuracy for the *Wet Herbaceous* class was 68.7%, with a user's accuracy of 9.7%. Errors of omission and commission were relatively small, but scattered with with a number of different mapping classes (*Stunted Spruce, Willow, Low Shrub* and *Water*).

The producer's accuracy for the *Aquatic Herbaceous* class was 100%, with a user's accuracy of 100%. The number of *Aquatic Herbaceous* signatures available for the classification and/or the accuracy assessment was significantly less than preferred.

The producer's accuracy for the *Sparse Vegetation* class was 87.6%, with a user's accuracy of 45.7%. Most of the errors of omission and commission were with the *Bare Ground* and *Dwarf Shrub-Rock* classes. Distribution of this class was enhanced through modeling in many of the processing blocks. Since the same modeling procedures were not also applied to the training/accuracy dataset, accuracies for many of the significantly modeled classes tended to be lower than they were immediately following the spectral classification. Since reviews of the modeled out for this class were more favorable than the reviews of the spectral classification output for this class, the modeled output was used despite the higher accuracies associated with the spectral classification output results.

The producer's accuracy for the *Bare Ground* class was 70.7%, with a user's accuracy of 86.5%. Most of the errors of omission and commission were with the *Sparse Vegetation* class. Distribution of this class was enhanced through modeling in many of the processing blocks. Since the same modeling procedures were not also applied to the training/accuracy dataset, accuracies for many of the significantly modeled classes tended to be lower than they were immediately following the spectral classification. Since reviews of the modeled out for this class were more favorable than the reviews of the spectral classification output for this class, the modeled output was used despite the higher accuracies associated with the spectral classification output results.

The producer's accuracy for the *Snow/Ice* class was 99.7%, with a user's accuracy of 99.5%. Most of the minor errors of omission and commission were with the *bare* class.

The producer's accuracy for the *Silty Water* class was 91.8%, with a user's accuracy of 97.7%. Most of the minor errors of omission and commission were with the *Bare Ground* class.

The producer's accuracy for the *Clear Water* class was 100%, with a user's accuracy of 98.8%. The minor error of commission was with the *Silty Water* class.

Accuracies were not reported for herbaceous shrub, shadow, burn or cloud mapping classes. This was either because there were no signatures available for the particular class (i.e, herbaceous shrub and burn), or because the class was so heavily modeled/edited (clouds, shadow) that the signatures were obsolete.

3.4 DISCUSSION OF STRENGTHS AND LIMITATIONS

To properly interpret and apply the landcover classes developed in the Denali NP&P mapping project, users must bear in mind the characteristics of the data used to derive the map, as well as the characteristics of the vegetation and other landcover types of interest. It is important to note that the Denali NP&P landcover project had the objectives to 1) map landcover characteristics that could be recognized by Landsat TM and SPOT XS imagery, and 2) delimit mapping classes that are flexible enough to describe potential new classes derived from Landsat imagery. Hence, although the mapping classes were derived from the Alaska Vegetation Classification (Viereck et al. 1992), they did not strictly adhere to this classification hierarchy. In the Denali NP&P project, the landcover classification system was customized so as to take advantage of the characteristics of the satellite data, while balancing the mapping detail needs of the end user. This classification system and the determination of final mapping classes remained open for discussion well into the final image processing phases of the project. Review of the Landcover Class Descriptions (Appendix 5.2) provides additional insight into the species composition of the mapping classes characterized by the Landsat TM and SPOT XS data.

In general, given the pixel size of the Landsat TM and SPOT XS satellite data (28.5 and 20 meters, respectively), the scale of derived maps should be no larger than 1:63,360. But at this large scale, very few landcover types can be consistently mapped without generating a great deal of "noise" or scattered pixels. A more appropriate mapping unit for Landsat TM derived landcover products is a 5 acre mmu (25 pixels). However, at this mapping unit size, many of the small linear features (streams, riparian shrub areas, ridge lines, pipelines) can be lost in the filtering process. In order to preserve more of the spatial detail found in the unfiltered landcover data, the final landcover database was filtered to approximately 2 ac (9 pixels). While this mapping unit resolution provides a good compromise for legibility (not pixilated), 5 ac may be a more appropriate minimum mapping unit for this landcover data.

In general, these landcover map products can be used to understand the distribution of the mapped units within the study area. Ground data were used to define plant associations in order to provide a hierarchical link between the relatively coarse scale landcover classes and the species information (Volume 2). Knowledge of plant associations occurring within the mapped units significantly adds to the database's usefulness. Other uses for these mapping products include broad scale wildlife habitat modeling and coarse scale analyses such as regional ecological planning and monitoring.

LITERATURE CITED

- Cambell, J. 1987. Introduction to Remote Sensing, New York: Guilid Press 551 p.
- Clark, M. 1998. Denali Park - Ecoregions and the National Hierarchical Framework of Ecological Units. Department of Agriculture, Natural Resources Conservation Service.
- Congalton, R.G. 1991. A Review of Assessing the Accuracy of Classifications of Remotely sensed data, Remote Sensing of Environment, Vol. 37, pp.35-46.
- Csejtey et al., 1992. Geology and Geochronology of the Healy Quadrangle, South-central Alaska.
- Densmore, R. 1992. Vegetation monitoring protocol development. Report for Denali National Park and Preserve.
- ECOMAP. 1993. National hierarchical framework of ecological units. ECOMAP, USDA Forest Service, Washington, DC. October 29, 1993. National hierarchical framework of ecological units.
- Grossman, D.H., D. Faber-Langendoen, A.S. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. The Nature Conservancy, Arlington, Virginia, USA.
- Hanson, Herbert C. 1950. Vegetation and soil profiles in some solifluction and mound areas in Alaska. Ecology. 31(4):606-630.
- Hanson, Herbert C. 1951. Charateristics of some grassland, marsh, and other plant communities in western Alaska. Ecological Monographs. 21(4):317-378.
- Heebner, Deborah K. 1982. The numerical analysis of vegetation plots in Denali National Park and Preserve. Fairbanks, AK: University of Alaska. 243 p. M.S. thesis.
- Jensen, J.R. 1996. Introductory Digital Image Processing, Prentice-Hall, Inc.
- Markon, Flemming, and Binnian Map derived from Hughes STX Corporation, EROS Alaska Field Office article-Characteristics of vegetation phenology over the Alaskan landscape using AVHRR time-series data by. In Polar Record 31 (177): 179-190 (1995).
- McNab, H.W. and Avers, P.E. 1994. Ecological Subregions of the United States: Section Descriptions. Publication WO-WSA-5. Department of Agriculture, Forest Service. Washington, D.C.
- Nowacki, G. and T. Brock. February 1995. ALASKA-ECOMAP version 2.0. United States Department of Agriculture-Forest Service.

Pratt, V.E. and F.G. Pratt. 1993. Wildflowers of Denali National Park. Alaskakrafts, Inc. Anchorage, AK. 166p.

Story, M. and R.G. Congalton 1986. Accuracy Assessment: A User's Perspective. Photogrammetric Engineering and Remote Sensing, Vol. 52, No. 3, pp. 397-399.

USDA-National Forest Service - National Hierarchical Framework of Ecological Units, 1993; and Ecoregions and Subregions of Alaska, ECOMAP version 2.0.

USDA-SCS Exploratory Soil Survey of Alaska, 1979.

USGS - Geologic Map of Alaska, compiled by Helen Beikman, 1980.

Viereck, L. A.; C.T. Dyrness, A.R. Batten, K.J. Wenzlick. 1992. The Alaska vegetation classification. Pacific Northwest Research Station, U. S. Forest Service, Portland, OR. Gen. Tech. Rep. PNW-GTR286. 278 p.

Viereck L.A., and E.L. Little, Jr. 1972. Alaska trees and shrubs. Agriculture Handbook No. 410 Forest Service, reprinted by the University of Alaska Press, Fairbanks, Alaska.

Wahrhaftig, C., and R. F. Black, 1958. Quaternary and Engineering Geology in the Central Part of the Alaska Range. USGS-Professional Paper 293A&B.

Appendix 5.1 Key to Landcover Classes

The herbaceous/shrub and peatland landcover classes are not included in the key.

GROWTH FORM GROUPS

1. Tree canopy cover is greater than or equal to 10% for needleleaf trees, deciduous trees, or deciduous-needleleaf mix 2
1. Tree canopy cover is less than 10% or absent..... 3
2. Needleleaf tree cover is greater than or equal to 75% of the total tree cover..... Needleleaf Forest Types
2. Needleleaf tree cover is less than 75% of the total tree cover..... Broadleaf and Mixed Forest Types
3. Shrub cover is greater than or equal to 25% Shrub Types
3. Shrub cover is less than 25%..... 4
4. Herbaceous cover is greater than or equal to 25% Herbaceous Types
4. Herbaceous cover is less than 25% 5
5. Total vegetation cover is 15-24%..... Sparse Vegetation
5. Total vegetation cover is less than 15% Bare Ground

NEEDLELEAF FOREST TYPES

1. Tree canopy cover is 45-70%..... Dense-Open Spruce
1. Tree canopy cover is 10-44%..... 2
2. Average tree height is greater than or equal to 7.5 meters Open-Woodland Spruce
2. Average tree height is less than 7.5 meters Stunted Spruce

BROADLEAF AND MIXED FOREST TYPES

1. Greater than or equal to 75% of the total tree cover is deciduous..... Broadleaf
1. Deciduous and needleleaf trees each contribute 25-75% of the total tree cover Spruce-Broadleaf

SHRUB TYPES

1. Willow greater than 20 centimeters tall contributes 75% or more of the total shrub cover..... Willow
1. Willow greater than 20 centimeters tall contributes less than 75% of the total shrub cover..... 2
2. Alder contributes 75% or more of total shrub cover Alder
2. Alder contributes less than 75% of total shrub cover..... 3
3. Shrub birch is greater than 75% of total shrub cover and total shrub cover is 75-100% Closed Low Shrub Birch
3. Shrub birch is less than 75% of total shrub cover 4

4. Willow, shrub birch or ericaceous shrubs—all greater than 20 centimeters tall—together contribute 25-75% of the total shrub cover and total shrub cover is 25-100% 5
4. Willow, shrub birch or ericaceous shrubs—all greater than 20 centimeters tall—together do not contribute 25-75% of the total shrub cover 6
5. Graminoids contribute 25-75% of the total cover; tussock formation is common.....
..... Low Shrub-Sedge
5. Less than 25% sedges present Low Shrub Birch-Ericaceous-Willow
6. Shrub height is less than 20 centimeters, and greater than 25% of the site contains rock
..... Dwarf Shrub-Rock
6. Shrub height is less than 20 centimeters, and less than 25% of the site contains rock Dwarf Shrub

HERBACEOUS TYPES

1. Vegetation is terrestrial; not submerged, floating, or growing in permanent water 2
1. Vegetation is submerged, floating, or growing in permanent water Aquatic Herbaceous
2. Site is dry to mesic; little to no standing water Dry-Mesic Herbaceous
2. Dominant vegetation is emergent; semi-permanent or standing water is present Wet Herbaceous

Appendix 5.2. Landcover Mapping Class Descriptions

The names and Viereck codes of the landcover classes in the Denali NP&P project area are listed below. Landcover class descriptions were derived from several sources including literature descriptions, Fireprodata, Natural Resources Conservation Service data, 1999 FVA fly-over data, and 1999 ground site descriptions. Plant association information can be found in Volume 2: Landcover Classes and Plant Associations.

DENSE-OPEN SPRUCE LANDCOVER CLASS 1

Classification—Tree canopy cover is between 45% to 70% with needleleaf tree cover greater than or equal to 75% of the total tree cover. The class is comparable to the Viereck et al. (1992) hierarchical levels closed needleleaf forest (IA1) and open needleleaf forest (IA2).



Distribution and Site Characteristics—The *Dense-Open Spruce* class occurs on low elevation (107 to 731 meters based on field data; Table 3) floodplains, toeslopes, and valley bottoms primarily north of the Alaska Range within Denali National Park and Preserve. It generally occurs as small to medium size patches on well-drained, loamy or sandy soils. These sites have little (5 to 10 degrees) to no slope, and generally occur on South and West aspects. Disturbance is typically from alluvial and fire processes. They are commonly found in the Toklat drainage, west of the Kantishna Hills, and the toeslopes of the Alaska Range in the west-central part of the park. Although it occurs in all ecoregions, it is more prevalent in the Kuskokwim-alluvial fans and flood plains ecoregion than other ecoregions (Tables 4a and 4b; Clark 1998). The *dense-open spruce* class covers 0.8% (50,359 acres) of Denali National Park and Preserve (Table 5).

Vegetation—*Picea glauca* or *Picea mariana* cover ranges from 45% to 70%. Tree height can reach greater than 20 meters. *Larix laricina*, alders (such as *Alnus crispa*) and willows (such as *Salix planifolia*) occur in canopy breaks along with ericaceous shrubs (such as *Arctostaphylos rubra*, *Vaccinium vitis-idaea*, and *V. uliginosum*). There frequently is a high graminoid component associated with these sites. Mosses are

common as well as small amounts of lichen. The *Dense-Open Spruce* class is typically interspersed with other spruce types such as the *Open-Woodland Spruce* and *Stunted Spruce* landcover classes.

Landcover Class Accuracy—The producer's accuracy for the *Dense-Open Spruce* class is 87.9%, with a user's accuracy of 69.4%. Most of the errors of commission and omission are due to confusion with the *Open-Woodland Spruce* class. All accuracies are based on the 25-class landcover map at a 2-acre mapping unit prior to the digital integration of the burn mask.

OPEN-WOODLAND SPRUCE LANDCOVER CLASS 2

Classification—Tree canopy cover is 10% to 44% with needleleaf cover greater than or equal to 75% of the total tree cover. Needleleaf tree height is greater than or equal to 7.5 meters. The class is comparable to the Viereck et al. (1992) hierarchical levels open needleleaf forest (IA2) and needleleaf woodland (IA3).



Distribution and Site Characteristics—The *Open-Woodland Spruce* class occurs primarily on lower elevation (80 to 912 meters based on field data; Table 3) landscapes north of the Alaska Range within Denali National Park and Preserve. The dominant landscapes are alluvial fans and outwash-floodplains. Site conditions range from strong sunlight and well-drained soils on gentle slopes and terraces to sites with poorly drained peat and silt soils. The latter is typically dominated by *Picea mariana*. Most sites have little to no slope although a few sites reached a slope of 40 degrees. When sloping sites occur they generally occupy east aspects. This class occurs in a region of high fire frequency. This landcover class is most common on the Kuskokwim-alluvial fans and floodplains ecoregion and is also common in the Kuskokwim-Minchumina Basin ecoregion (Tables 4a and 4b; Clark 1998); in addition it is the most common type in the Kuskokwim-low mountains and pediments ecoregion. The *Open-Woodland Spruce* landcover class covers 9.1% (551,428 acres) of Denali National Park and Preserve (Table 5).

Vegetation—The *Open-Woodland Spruce* class is dominated by *Picea mariana*, however *Picea glauca* also occurs. Average needleleaf cover is 40%, and tree height is typically greater than 7.5 meters. Ericaceous shrubs are commonly found in the understory including *Ledum decumbens*, *Vaccinium uliginosum*, *Cassiope tetragona*, and *Chamaedaphne calyculata*. Other shrubs include *Betula nana*, *Empetrum nigrum*, *Alnus* species, and *Salix* species. Mosses and lichens also occur. Some sites contain tussocks ranging up to 90% tussock cover, and average tussock cover in sites with high graminoid content is 35%. The class is typically interspersed with other spruce classes such as the *Dense-Open Spruce* and *Stunted Spruce* landcover classes.

Landcover Class Accuracy—The producer's accuracy for the *Open-Woodland Spruce* class is 82.9%, with a user's accuracy of 79.3%. Most of the errors of commission are with the *Stunted Spruce* class while most of the errors of omission are with the *dense-open spruce* class. There are also significant omission errors with the *Stunted Spruce* class and the *Spruce-Broadleaf* class.

STUNTED SPRUCE LANDCOVER CLASS 3

Classification—Tree canopy cover is 10% to 44% with needleleaf tree cover greater than or equal to 75% of the total tree cover. Needleleaf tree height is less than 7.5 meters. The class is comparable to the Viereck et al. (1992) hierarchical levels open needleleaf forest (IA2), needleleaf woodland (IA3), open dwarf tree scrub (IIA2), and dwarf tree scrub woodland (IIA3). The cutoff for stunted spruce in the Denali National Park and Preserve landcover classification is 7.5 meters whereas the cutoff for dwarf tree scrub is 3 meters in Viereck et al. (1992).



Distribution and Site Characteristics—The *Stunted Spruce* class is the most common vegetated class in Denali National Park and Preserve, covering 14.2% (853,985 acres) of its total area (Table 5). The class is primarily found on low to mid elevation (166 to 841 meters based on field data; Table 3) sites north of the Alaska Range. It occupies sites with poorly drained, cold soils with some peat formation, permafrost is common, and with little to no slope. This class occurs in a region of high fire frequency, although the sites have likely not recently been burned. It dominates the Kuskokwim-alluvial fans and floodplains ecoregion, the Kuskokwim-glaciated hills and pitted plains ecoregion, and the Kuskokwim-Minchumina basin ecoregion and is common in the Kuskokwim-low mountains and pediments ecoregion (Tables 4a and 4b; Clark 1998).

Vegetation—The forest canopy of the *Stunted Spruce* class is dominated by *Picea mariana* although *Picea glauca* may also occur. Average needleleaf cover is 30% and tree height averages 4 meters. These sites commonly have a high percent of ericaceous shrubs and a thick graminoid layer in the understory. Tussock formation is common and its cover reaches greater than 90% in some sites and averages 40% cover. Many sites are dominated by ericaceous shrubs, whereas others are a mix of low shrubs (such as *Salix* species and *Betula* species) and ericaceous shrubs. Shrub species include *Ledum decumbens*, *Vaccinium uliginosum*, *Chamaedaphne calyculata*, *Betula nana*, *Salix* species and occasionally *Alnus* species. *Larix laricina* has been found in trace amounts on many sites, and lichens and mosses are common.

Stunted Spruce stands are commonly found adjacent to the *Open-Woodland Spruce* and occasionally near the *dense-open spruce* map classes. Periodically, small patches of the *Dry-Mesic Herbaceous* class are found within large patches of *Stunted Spruce* often on lacustrine deposits.

Landcover Class Accuracy—The producer's accuracy for the *Stunted Spruce* class is 80.1%, with a user's accuracy of 87.6%. Most of the errors of commission and omission are due to confusion with the *Open-Woodland Spruce* class.

BROADLEAF LANDCOVER CLASS 4

Classification—*Betula papyrifera*, *Populus tremuloides* and *Populus balsamifera*, individually or combined, with a canopy cover of 10% to 100%, with needleleaf less than 25% of the total tree cover. The class is comparable to the Viereck et al. (1992) hierarchical levels closed broadleaf forest (IB1), open broadleaf forest (IB2), and broadleaf woodland (IB3).



Distribution and Site Characteristics—This class occurs at low elevations (93 to 774 meters based on field data; Table 3) primarily in the Lake Minchumina Basin, toeslopes of the Kantishna Hills, lower slope positions and rolling hills on the south side of the Alaska Range, and in localized patches on outwash plains and floodplains throughout Denali National Park and Preserve. The slope ranges from relatively level on floodplains, to moderate to steep on hillsides. The class is concentrated in the Kuskokwim-low mountains and pediments ecoregion and the Alaska Range-Kantishna Hills ecoregion (Tables 4a and 4b; Clark 1998). This class does not, however, dominate any one ecoregion. These deciduous forests cover 1.6% (97,063 acres) of Denali National Park and Preserve (Table 5).

Vegetation—Forest canopy closure for the *Broadleaf* class ranges from 10% to 100%, with an average cover of 75%. *Betula papyrifera* is the most common species dominating sites on both the north and south sides of the Alaska Range. *Populus tremuloides* often occurs as a sub-dominant to *Betula papyrifera*, but also occurs as the dominant deciduous tree species in the northeast portion of the Park. *Populus balsamifera* is typically restricted to floodplains occurring as small to mid size patches, but is also found in small patches on hillsides throughout the park. From an aerial perspective, understory shrubs are typically *Alnus* and *Salix* species. Small coverage of grasses and sedges also occur. Mosses and lichens are present in varying amounts. Adjacent landcover classes include *Open-Woodland Spruce* and, occasionally, *Dense-Open Spruce*. Small patches of *Dry-Mesic Herbaceous* or *Wet Herbaceous* often grow adjacent to this type on riparian areas.

Landcover Class Accuracy—The producer's accuracy for the *Broadleaf* class is 80.3%, with a user's accuracy of 62.1%. Most of the errors of commission are with the *Spruce-Broadleaf* class, while most of the omission errors are with the *Willow* and *Low Shrub Birch-Ericaceous-Willow* map class.

SPRUCE-BROADLEAF LANDCOVER CLASS 5

Classification—Tree canopy cover is 10% to 100%, with needleleaf and deciduous trees each contributing 25% to 75% of the total tree cover. The class is comparable to the Viereck et al. (1992) hierarchical levels closed mixed forest (IC1), open mixed forest (IC2), and mixed woodland (IC3).



Distribution and Site Characteristics—The *Spruce-Broadleaf* class is common on low elevation (91 to 721 meters based on field data; Table 3) foothills and floodplains south of the Alaska Range, and as scattered patches throughout the forested region—especially adjacent to floodplains—north of the Alaska Range. It is a dominant map class—along with *Low Shrub Birch-Ericaceous-Willow*—in the Cook inlet-glaciated hills and plains ecoregion (Tables 4a and 4b; Clark 1998). Slopes range from relatively level on floodplains, to moderate or steep on hillsides, and the soils are generally mesic with no peat development. This landcover class comprises 2.5% (149,929 acres) of Denali National Park and Preserve (Table 5).

Vegetation—The dominant tree species are typically either *Picea glauca* mixed with *Betula papyrifera* or *Picea glauca* mixed with *Populus balsamifera*. The white spruce-paper birch mix is generally found on sideslopes and toeslopes. *Populus tremuloides* and *Picea mariana* may also occur, sometimes as a strong codominant. Total tree cover ranges from 30% to 75%. When the white spruce-paper birch canopy is open, the trees tend to grow in a clumped distribution. Therefore, open patches in the canopy are common and allow for other species to take advantage of the available sunlight. Low and tall shrubs, such as *Salix* species, *Alnus* species, and *Vaccinium uliginosum* dominate these patches. Mosses or lichens also occur in minor amounts.

The white spruce-balsam poplar mix occurs on disturbed, sandy soils along riparian corridors with little to no slope. It is dominated by *Picea glauca* and *Populus balsamifera*, although *Betula papyrifera* is frequently, though not always, present. Canopy cover is often patchy and the open patches are typically dominated by *Alnus* species often growing over 3.6 meters tall.

The *Spruce-Broadleaf* landcover class occurs adjacent to needleleaf and deciduous classes, as well as small patches of tall shrub along riparian corridors.

Landcover Class Accuracy—The producer's accuracy for the *Spruce-Broadleaf* class is 59.7%, with a user's accuracy of 88.4%. Most of the errors of commission are with the *Open-Woodland Spruce* class and the *Broadleaf* class. Most of the error of omission is with the *Broadleaf* class. The *Spruce-Broadleaf* class by definition is spectrally mixed. It is very difficult to separate from stands of open-spruce forest with a tall shrub understory that typically occur on the north side of Denali, or from mixed areas with a high proportion of broadleaf that typically occur on the south side of the park. All accuracies are based on the 25-class landcover map at a 2-acre mapping unit prior to the digital integration of the burn mask.

ALDER LANDCOVER CLASS 6

Classification—Tree canopy cover is less than 10% (or absent). Total shrub cover is 25% to 100% and alder constitutes greater than 75% of the total shrub cover. The class is comparable to the Viereck et al. (1992) hierarchical levels closed tall alder (IIB1b), and open tall scrub alder (IIB2b).



Distribution and Site Characteristics—The *Alder* class dominates most steep slopes at low to mid elevations (191 to 1,124 meters based on field data; Table 3) on the south side of the Alaska Range and, to a lesser extent, the Kantishna Hills. It also occurs consistently in small patches on new alluvial deposits along floodplains. The steep slopes are typically colluvium and glacial drift, and slope values range from 0 to over 50% on all aspects. This class dominates the Alaska Range-south-central mountains and valleys ecoregion, and also is concentrated in the Alaska Range-interior mountains and valleys ecoregion and Alaska Range-Kantishna Hills ecoregion within Denali (Tables 4a and 4b; Clark 1998). The *Alder* landcover class covers 4.3% (260,198 acres) of Denali National Park and Preserve (Table 5).

Vegetation—*Alnus* species or a combination of alder and tall *Salix* species (>1.5 meters in height) dominate the landcover type. *Alnus crispa* is the most common species, however, *Alnus sinuata* and *Alnus tenuifolia* dominate some sites. Alder height ranges from less than 1.5 meters at higher elevations to 4.5 meters tall downslope. Alder cover or a combination of alder and willow is also variable, ranging from 25% to 95%. Sites with a more closed canopy are more common throughout Denali National Park and Preserve than the open sites. Large homogenous patches of open alder, however, do occur and typically grade into the closed alder patches.

Canopy cover of understory vegetation ranges from sparse to dense. Associated understory shrubs include *Salix* species, *Echinopanax horridus*, *Sorbus scopulina*, and *Spirea beauverdiana*. A significant herbaceous layer includes *Veratrum viride*, *Epilobium angustifolium*, *Heracleum lanatum*, and small amounts of *Iris setosa*, *Petasites* species, and *Boykinia richardsonii*. High graminoid content may be present typically dominated by *Calamagrostis canadensis*. Ferns are also common including *Dryopteris dilatata*.

The *Alder* class grows adjacent to *Broadleaf*, *Spruce*, *Willow*, *Low Shrub* and *Dwarf Shrub* classes. The pure alder sites often blend into sites with willow as a co-dominant species. Alder also commonly grades into the spruce classes at times forming extensive areas of high alder cover and low spruce cover. Sites dominated by both alder and willow occur as small discontinuous patches in narrow steep draws, the wetter depressions of sideslopes, and disturbed riparian corridors. Alder-willow dominated sites generally grade into the *Willow* class in the drainages and pure alder sites on the steep sideslopes.

Landcover Class Accuracy—The producer's accuracy for the *Alder* class is 93.6%, with a user's accuracy of 92.1%. Most of the errors of commission and omission are with the *Willow* class.

WILLOW LANDCOVER CLASS 7

Classification—Tree canopy cover is less than 10% (or absent). Total shrub cover is 25% to 100%, and willow greater than 20 centimeters tall comprises greater than 75% of the total shrub cover. The class is comparable to the Viereck et al. (1992) hierarchical levels closed tall willow (IIB1a), open tall willow (IIB2a), closed low willow (IIC1b), and open low scrub (11C2).



Distribution and Site Characteristics—The *Willow* class occurs on a variety of sites throughout the park. *Willow* dominated by low stature (20 centimeters to 1.5 meters in height) willow is common at mid elevations (range of 191 to 1,116 meters based on field data; Table 3) mixed with other low shrub classes on flat river drainages and the rolling foothills bordering the north side of the Alaska Range. When tall willow (>1.5 meters) dominates the class, it occurs primarily in small patches on new alluvial stream/river deposits, alluvial fans, colluvial sideslopes and bordering small mountain streams. Both tall and low willows occur on upper slope positions mixed in with or above the *Alder* class in the Alaska Range and Kantishna Hills.

The class does not dominate any ecoregion, but is concentrated in the Alaska Range-Kantishna Hills ecoregion and the Alaska Range-south-central mountains and valleys ecoregion of the park (Tables 4a and 4b; Clark 1998). It covers 1.6% (95,590 acres) of Denali National Park and Preserve (Table 5). On the landcover map, this class is underrepresented on the south side of the Alaska Range due to its partial inclusion in the *Herbaceous-Shrub* class.

Vegetation—This class includes all sites dominated by willows greater than 20 centimeters tall. Willow cover ranges from 25% to 95%, and its height ranges from 20 centimeters to 4.5 meters. Sites dominated by open tall willow and closed low willow are common in the park, whereas closed tall willow is uncommon. The dominant overstory species include *Salix alaxensis*, *S. barclayi*, *S. bebbiana*, *S. glauca*, *S. lanata*, and *S. planifolia*. Other overstory and understory shrubs include *Shepherdia canadensis*, *Vaccinium uliginosum*, *Betula nana*, and *Spirea beauverdiana*. Tall alder (*Alnus* species) may also be found in isolated locations within the landcover class. Grasses, sedges, and mosses are an important component in some sites

and include *Heracleum lanatum*, *Calamagrostis canadensis*, *C. inexpansa*, *Epilobium angustifolium*, *Streptopus* species and *Veratrum viride*.

The *Willow* class is most commonly found next to low shrub classes on gentle toeslopes, fans, floodplains and wide valleys. It is found near needleleaf classes in narrow drainages and also in wide valleys. The *Dry-Mesic Herbaceous* class occurs adjacent to the *Willow* class on sideslopes and saturated toeslopes.

Landcover Class Accuracy—The producer's accuracy for the *Willow* class is 55.1%, with a user's accuracy of 50.0%. Most of the errors of commission are with the *Broadleaf* and *Alder* classes. Most of the omission error is with *Alder*.

CLOSED LOW SHRUB BIRCH LANDCOVER CLASS 8

Classification—Tree canopy cover is less than 10% (or absent). Greater than 75% of the total shrub cover is shrub birch, and total shrub cover is 75% to 100%. The class is comparable to the Viereck et al. (1992) hierarchical level closed low shrub birch IIC1a.



Distribution and Site Characteristics—The *Closed Low Shrub Birch* landcover class is uncommon within Denali National Park and Preserve and is concentrated in the northeast portion of the park. It typically occurs at mid elevations (439 to 1,097 meters based on field data; Table 3) on gentle to moderate slopes within the foothills and broad valleys bordering the north side of the Alaska Range and the Kantishna Hills. It also occurs on floodplains. The class does not dominate any one ecoregion, but is concentrated in the Alaska Range-interior mountains and valleys ecoregion (Tables 4a and 4b; Clark 1998). It covers 0.9% (54,034 acres) of Denali National Park and Preserve (Table 5). The landcover class typically occurs adjacent to various needleleaf forest and low shrub classes.

Vegetation—*Betula glandulosa* or *B. nana* dominates this class. Average shrub cover is 75%. Tussocks are uncommon, but may be present. Associated species include low willow (*Salix* species), *Vaccinium uliginosum*, and various graminoid species. Small amounts of *Picea glauca*, *Ledum decumbens*, and moss also occur.

Landcover Class Accuracy—The producer's accuracy for the *Closed Low Shrub Birch* class is 67.3%, with a user's accuracy of 83.2%. Most of the errors of commission and omission are with the *Stunted Spruce* class and the *Low Shrub Birch-Ericaceous-Willow* class.

LOW SHRUB BIRCH-ERICACEOUS-WILLOW LANDCOVER CLASS 9

Classification—Tree canopy cover is less than 10% (or absent). Shrub birch, ericaceous shrubs and low willow (20 centimeters to 1.5 meters tall) individually contribute 25% to 75% of the total shrub cover; and total shrub cover is 25% to 100%. The class is comparable to the Viereck et al. (1992) hierarchical levels closed low scrub (IIC1), and open low scrub (IIC2).



Distribution and Site Characteristics—The *Low Shrub Birch-Ericaceous-Willow* landcover class is an ecologically broad class ranging from sites dominated by open willow to *Betula nana* and ericaceous shrubs. The class is a dominant type above the boreal forest region and below alpine on gentle to moderate slopes within the foothills and broad valleys bordering the Kantishna Hills, the north side of the Alaska Range, and within Broad Pass. The elevation ranges from 204 to 1,068 meters based on field data (Table 3). It dominates several ecoregions including the Cook Inlet-glaciated hills and plains, Alaska Range-front range, Alaska Range-Kantishna Hills and Alaska Range-Teklanika mountains and plateaus ecoregions (Tables 4a and 4b; Clark 1998). It covers 9.5% (570,700 acres) of Denali National Park and Preserve (Table 5). Because this class covers a wide range of site conditions across the park, it is found adjacent to numerous landcover classes. However, it is most commonly found elevationally above needleleaf classes and mixed in with other shrub classes.

Vegetation—Species composition and cover often fluctuate within and between sites. The dominant species are *Betula nana*, *Chamaedaphne calyculata*, *Salix barrattiana*, *S. glauca*, *S. planifolia*, *Ledum decumbens*, *Vaccinium uliginosum*, and *Empetrum nigrum*. Herbaceous species include *Achillea* species, *Calamagrostis lapponica*, *Epilobium angustifolium*, and *Rumex* species. Mosses are common on some sites and lichens are rare.

Landcover Class Accuracy—The producer's accuracy for the *Low Shrub Birch-Ericaceous-Willow* class is 83.4%, with a user's accuracy of 75.3%. Most of the errors of commission and omission are with the *Low Shrub-Sedge* class.

LOW SHRUB-SEDGE LANDCOVER CLASS 10

Classification—Tree canopy cover is less than 10% (or absent). Low (20 centimeters to 1.5 meters tall) mixed shrubs and graminoids each contribute 25% to 75% of the total cover, and tussock formation is common. The class is comparable to the Viereck et al. (1992) hierarchical level open low scrub (IIC2).



Distribution and Site Characteristics—The *Low Shrub-Sedge* class is a common class occurring elevationally above the boreal forest and below alpine (168 to 1,052 meters based on field data; Table 3). It occurs on gentle to moderate slopes of foothills and broad valleys bordering the Kantishna Hills and the north side of the Alaska Range, and also on the hills north of Lake Minchumina. The soils are mesic with organic tussocks over top of mineral soil. Small seasonal pools of water often occur between tussocks. The class dominates the Alaska Range-Toklat Basin ecoregion and is common in other ecoregions including the Alaska Range-Teklanika mountains and plateaus and Kuskokwim-alluvial fans and flood plains ecoregions (Tables 4a and 4b; Clark 1998). It covers 4.6% (277,322 acres) of Denali National Park and Preserve (Table 5).

The *LowShrub-Sedge* class commonly forms a mosaic with the *Stunted Spruce* and *Low Shrub Birch-Ericaceous-Willow* landcover classes.

Vegetation—Low shrubs over a lush sedge/graminoid layer that typically form tussocks characterize this class. The dominant species are *Salix* species, *Betula nana*, *Chamaedaphne calyculata*, *Ledum decumbens*, *Carex aquatilis*, *Eriophorum brachyantherum*, *E. vaginatum* and other graminoids. The combined shrub cover ranges from 25% to 74%. *Picea mariana* occurs sporadically, and *Sphagnum* species are a frequent associate along with other mosses.

Landcover Class Accuracy—The producer's accuracy for the *Low Shrub-Sedge* class is 82.8%, with a user's accuracy of 80.3%. Most of the errors of commission and omission are with *Stunted Spruce* and *Low Shrub Birch-Ericaceous-Willow* map classes.

PEATLAND LANDCOVER CLASS 11

Classification—The *Peatland* landcover class occurs on peatlands (bogs and fens) south of the Alaska Range. The peatlands north of the Alaska Range are not included in this class. The *Peatland* landcover class is comprised of a variety of already defined landcover classes that occur on peat deposits including *Stunted Spruce*, *Willow*, *Dry-Mesic Herbaceous* and *Wet Herbaceous*. In addition, the *Myrica gale* plant association occurs in this landcover class. This combination class is defined because it is spectrally distinct on the south side of the Alaska Range, and the individual classes could not be spectrally separated reliably on peat deposits. The class is comparable to the Viereck et al. (1992) hierarchical levels open needleleaf forest (IA2), needleleaf woodland (IA3), open dwarf tree scrub (IIA2), dwarf tree scrub woodland (IIA3), closed tall willow (IIB1a), open tall willow (IIB2a), closed low willow (IIC1b), open low scrub (IIC2), dry graminoid herbaceous (IIIA1), mesic graminoid herbaceous (IIIA2), dry forb herbaceous (IIIB1), mesic forb herbaceous (IIIB2), wet graminoid herbaceous (IIIA3) and wet forb herbaceous (IIIB3).



Distribution and Site Characteristics—The *Peatland* landcover class is found only in the lowlands (74 to 315 meters based on field data; Table 3) south of the Alaska Range. Peat deposits (i.e., peatlands, muskeg, bogs, fens) are composed of >0.5 meters of accumulated peat in areas of restricted drainage with water tables at or close to the peat surface. They occupy former lake basins and other closed depressions, alluvium along some valley floors, and are abundant on older glacial drift deposits within the boreal forest. The class covers 0.04% (2,304 acres) of Denali National Park and Preserve (Table 5). Peatlands are generally found adjacent to forested areas in Denali.

The gradient of nutrient availability and water sources in peatlands is typically divided into nutrient rich (fen) and nutrient poor (bog) peatlands. Fens are wetlands with wet organic soils, dominated by aquatic, emergent, and dwarf shrubs, or raised peat dominated by shrubs and trees. Ground water, the primary water source in a fen, is nutrient rich because of its contact with mineral soils. Waters may be acidic or basic, but

typically with a pH above 4.7. Water is lost through evapotranspiration, seepage (infiltration through the soil), and surface outflow.

Bogs are wetlands with organic soils, typically dominated by *Sphagnum* (peat moss) species, sedges, grasses, or reeds. Bogs require depressions (ponds) in level areas where precipitation exceeds evapotranspiration. Precipitation is the primary water source in a bog, with little or no ground-water flow. Consequently the sites are nutrient-poor and acidic, commonly with a pH less than 4.7. The water table is at or close to the surface most of the year. Because of the continuum of site and vegetation change within a peatland, it is often difficult to clearly separate a fen from a bog in the field.

Vegetation—In level areas, peatlands generally exhibit recognizable and consistent vegetation zonation patterns that are directly associated with different water depths. The vegetation, on a wet to dry moisture gradient, changes from aquatic (pond), to emergent and mesic herbaceous (*Calamagrostis canadensis*, *Carex rostrata*, *C. aquatilis* and *Eleocharis quinqueflora*), to shrub-dominated wetland (*Myrica gale* and *Betula nana*), to dwarf tree (*Picea mariana*). *Sphagnum* species occur in most dominance types. Not all the vegetation zones are always expressed, and the zonation may change abruptly, such as from a pond to a shrubland. Fens on ground with a slight gradient and with heavy subsurface and surface waterflow often develop a patterned ground of vegetated ridges, and vegetated or unvegetated hollows filled with water.

Landcover Class Accuracy—The producer's accuracy for the *Peatland* class is 82.3%, with a user's accuracy of 80.9%. Most of the errors of commission and omission are with the *Low Shrub-Sedge* class.

HERBACEOUS-SHRUB LANDCOVER CLASS 12

Classification—The *Herbaceous-Shrub* landcover class is a mixture of three already defined landcover classes: *Willow*, *Dwarf Shrub* and *Dry-Mesic Herbaceous*. This combination class was created because of extensive over-classification of the *Low Shrub-Sedge* class on the upper slopes on the south side of the Alaska Range. The *Low Shrub-Sedge* class at this slope position was actually a combination of the *Willow*, *Dwarf Shrub* and *Dry-Mesic Herbaceous* classes. We were unable, however, to split the *Low Shrub-Sedge* class into its proper components—*Willow*, *Dwarf Shrub* and *Dry-Mesic Herbaceous*. The *Low Shrub-Sedge* class, consequently, was reclassified to a new class—*Herbaceous-Shrub*—at or above alder line (generally elevations of 600 m or greater) on the park's south side. For a complete description of the methods used to define this class see Stevens et al. (2001). The class is comparable to the Viereck et al. (1992) hierarchical levels closed tall willow (IIB1a), open tall willow (IIB2a), closed low willow (IIC1b), open low scrub (IIC2), dwarf scrub (IID), dry graminoid herbaceous (IIIA1), mesic graminoid herbaceous (IIIA2), dry forb herbaceous (IIIB1) and mesic forb herbaceous (IIIB2).



Distribution and Site Characteristics—The *Herbaceous-Shrub* class is found on mountain ridges and slopes on the south side of the Alaska Range. It occurs both above the alder zone and mixed in with the alder class moving down slope. The *Willow* and *Dry-Mesic Herbaceous* classes occur adjacent to this class both up and down slope. The *Dwarf Shrub* class typically borders the *Herbaceous-Shrub* class upslope. The sites are typically moist, and occur below 1,500 meters elevation (Table 3). It is a major component of the Alaska Range-south-central mountains and valleys ecoregion (Tables 4a and 4b; Clark 1998), and covers 1.1% (68,872 acres) of Denali National Park and Preserve (Table 5).

Vegetation—For species and structural information please review the individual landcover classes that make up the *Herbaceous-Shrub* class: *Willow*, *Dwarf Shrub* and *Dry-Mesic Herbaceous*. Note that sites dominated by *Dryas octopetala* are uncommon in the *Herbaceous-Shrub* class. Instead, dwarf shrub species are mixed, including *Empetrum nigrum* and *Vaccinium uliginosum*, and have a strong graminoid component. The *Dry-Mesic Herbaceous* component is typically lush and includes *Calamagrostis canadensis*, *Athyrium filix-femina*, *Epilobium angustifolium*, *Geranium erianthum*, *Heracleum lanatum* and *Sanguisorba stipulata*.

Landcover Class Accuracy—The accuracy of the *Herbaceous-Shrub* class was not assessed because the class is a combination of other map classes.

DWARF SHRUB LANDCOVER CLASS 13

Classification—Tree canopy cover is less than 10% (or absent). Shrub cover is greater than 25%, shrub height is less than 20 centimeters, and less than 25% of the site contains rock. The class is comparable to the Viereck et al. (1992) hierarchical level dwarf scrub (IID).



Distribution and Site Characteristics— The *Dwarf Shrub* landcover class dominates alpine areas in the Alaska Range and the Kantishna Hills. It is found on unstable to stable surfaces such as gentle to steep mountain slopes, high mountain valley floors, and rounded mountain ridges (often exposed bedrock). Slopes range from 0 to >50%. The soils are a thin layer of dry to mesic sand, litter or organic matter. Its elevation ranges up to 1,335 meters based on field data (Table 3). This class dominates the Alaska Range-interior mountains and valleys ecoregion, and is common in the Alaska Range-front range and Alaska Range-south-central mountains and valleys ecoregions (Tables 4a and 4b; Clark 1998). It covers 5.8% (346,847 acres) of Denali National Park and Preserve (Table 5). On the landcover map, this class is underrepresented on the south side of the Alaska Range due to its partial inclusion in the *Herbaceous-Shrub* class.

The *Dwarf Shrub* landcover class often grades into the *bare ground*, *sparse vegetation* or *Dwarf Shrub-Rock* landcover classes and, on more stable sites, the *Alder* and *Willow* landcover classes.

Vegetation— The *Dwarf Shrub* class is comprised of vegetation that generally reaches a height of 20 centimeters or less. Most sites are a blend of dwarf shrubs with some sedge and lichen species often interspersed with exposed rock. The dominant dwarf shrubs include *Dryas octopetala*, *D. integrifolia*, *Salix reticulata*, *S. arctica*, *S. phlebophylla*, *Cassiope tetragona*, *Vaccinium uliginosum*, *Arctostaphylos rubra* and *A. alpina*. Forbs include *Epilobium angustifolium*, *Aster* species, *Heracleum lanatum*, *Veratrum viride*, *Anemone narcissiflora*, and *Campanula* species. Some sites, however, have a strong graminoid presence, or are dominated by *Dryas* species in the dwarf shrub layer.

Landcover Class Accuracy—The producer's accuracy for the *Dwarf Shrub* class is 78.4%, with a user's accuracy of 80.2%. Most of the errors of omission are with the *Low Shrub Birch-Ericaceous-Willow* and *Low Shrub-Sedge* map classes.

DWARF SHRUB-ROCK LANDCOVER CLASS 14

Classification—Tree canopy cover is less than 10% (or absent). Shrub cover is greater than 25%, shrub height is less than 20 centimeters, and rock cover is greater than 25%. The class is comparable to the Viereck et al. (1992) hierarchical level dwarf scrub (IID).



Distribution and Site Characteristics—The physical site characteristics of the *Dwarf Shrub-Rock* landcover class are similar to the *Dwarf Shrub* landcover class, however it has a much higher surface rock component. It is a minor class of alpine areas in the Alaska Range and the Kantishna Hills, and is found on unstable to stable surfaces such as gentle to steep mountain slopes, high mountain valley floors, and rounded mountain ridges. In addition, it occurs on sandbars and alluvial fans. The slope ranges up to >50%, and the elevation ranges up to 1,335 meters based on field data (Table 3). The soils are a thin layer of dry to mesic sand, litter or organic matter. Vegetation typically grows on the thin organic mat. This class is common in the Alaska Range-high mountains ecoregion and the Alaska Range-interior mountains and valleys ecoregion (Tables 4a and 4b; Clark 1998). It covers 1.2% (73,894 acres) of Denali National Park and Preserve (Table 5).

The *Dwarf Shrub-Rock* class often grades into the *Bare Ground*, *Sparse Vegetation* or *Dwarf Shrub* landcover classes. On more stable surfaces, it grades into the *Alder* and *Willow* classes.

Vegetation—This class is dominated by dwarf shrubs, primarily *Dryas octopetala* and *D. integrifolia*, interspersed with exposed rock. Few additional species are present. Other dwarf shrubs include *Salix reticulata*, *S. arctica*, *S. phlebophylla*, *Cassiope tetragona*, *Vaccinium uliginosum*, *Arctostaphylos rubra*, and *A. alpina*. Forbs include *Epilobium angustifolium*, *Aster* species, *Heracleum lanatum*, *Veratrum viride*, *Anemone narcissiflora*, and *Campanula* species. Fruticose lichen species are common.

Landcover Class Accuracy—The producer's accuracy for the *Dwarf Shrub-Rock* class is 54.9%, with a user's accuracy of 50.3%. Most of the errors of omission and commission are with the *Dwarf Shrub* and *Sparse Vegetation* classes. The number of *Dwarf Shrub-Rock* signatures available for the accuracy assessment is significantly less than preferred.

DRY-MESIC HERBACEOUS LANDCOVER CLASS 15

Classification—Tree canopy is less than 10% (or absent), shrub cover is less than 25%, and herbaceous cover is greater than 25%. Vegetation is terrestrial (not submerged, floating, or growing in permanent water). Site is dry to mesic with little to no standing water. The class is comparable to the Viereck et al. (1992) hierarchical levels dry graminoid herbaceous (IIIA1), mesic graminoid herbaceous (IIIA2), dry forb herbaceous (IIIB1), and mesic forb herbaceous (IIIB2). The photo on the left is from the south side of the Alaska Range, and the photo on the right is a moist depression in the northwest region of Denali National Park and Preserve.



Distribution and Site Characteristics— The *Dry-Mesic Herbaceous* class is a minor class that occurs throughout the park under a variety of site conditions. It primarily occurs as rich herbaceous meadows on mesic sideslopes ranging up to >50% slope and river terraces on the south side of the Alaska Range. The class occurs both above the alder zone up to 1,200 meters, and mixed in with alder moving down slope (Table 3). On the landcover map, it is underrepresented on the south side of the Alaska Range due to its partial inclusion in the *Herbaceous-Shrub* class.

It also occurs as grassy meadows, dominated by *Calamagrostis canadensis*, found on low elevation moist—and periodically wet—depressions within the boreal forest in the northwestern portion of the park. These sites are moist, however, standing water may be present in small amounts seasonally. Tussock tundra, dominated by *Eriophorum* species, also forms a portion of this class occurring as small patches on gentle to moderate slopes of foothills and broad valleys bordering the Kantishna Hills and the north side of the Alaska Range, and also on hills near Lake Minchumina. Tussock tundra soils are mesic with tussocks of organic matter and live vegetation over mineral soil. Small seasonal pools of water are often found between the tussocks. The *Dry-Mesic Herbaceous* class nearly always occurs as small patches within a mosaic of other classes. Most landcover classes occur adjacent to the class due to its wide geographic distribution and elevation range. It is uncommon in most ecoregions except the Alaska Range-south-central mountains and valleys ecoregion (Tables 4a and 4b; Clark 1998), and covers 0.8% (45,684 acres) of Denali National Park and Preserve (Table 5).

Vegetation—The *Dry-Mesic Herbaceous* class is a grouping of plant associations that encompasses dry or mesic sites as well as lush herbaceous meadows. Herbaceous meadows contain such forbs as *Veratrum viride*, *Ligusticum scoticum*, *Geranium erianthum*, *Cicuta douglasii*, *Iris setosa*, *Athyrium filix-femina*, *Calamagrostis canadensis*, *Epilobium angustifolium*, *Heracleum lanatum* and *Sanguisorba stipulata*. Total cover often exceeds 90%. Low shrubs may also occur including *Spiraea beauverdana* and *Salix planifolia*.

The grassy meadows in the boreal forest are dominated by *Calamagrostis canadensis* with cover values up to 95%. Other species present but uncommon are *Betula glandulosa*, *Vaccinium uliginosum*, *Athyrium filix-femina* and *Myrica gale*.

Sites that are dominated by tussocks have high levels of graminoids, predominantly *Eriophorum* species, and mosses. Surface water, *Betula nana*, and *Rubus chamaemorus* also occur. Tussock cover ranges up to 90% on sites sampled.

Landcover Class Accuracy—The producer's accuracy for the *Dry-Mesic Herbaceous* class is 70.0%, with a user's accuracy of 85.6%. Most of the errors of omission and commission are with the *Low Shrub Birch-Ericaceous-Willow*, *Herbaceous-Shrub* and *Dwarf Shrub* classes.

WET HERBACEOUS LANDCOVER CLASS 16

Classification—Tree canopy is less than 10% (or absent), shrub cover is less than 25%, and herbaceous cover is greater than 25%. The dominant vegetation is emergent; semi-permanent or standing water is present. The class is comparable to the Viereck et al. (1992) hierarchical levels wet graminoid herbaceous (IIIA3), and wet forb herbaceous (IIIB3).



Distribution and Site Characteristics—The *Wet Herbaceous* class occurs in small patches throughout the park's boreal forest zone and at higher elevations dominated by low shrubs. The sites have standing or semi-permanent water dominated by hydrophilic vegetation. It most frequently occurs on lake edges, but also on saturated river terraces, the edge of ponds, sloughs, fens, other patterned ground, and occasionally in pools of hillside streams. The sites have little to no slope. Relative to other classes, the *Wet Herbaceous* class is generally small in size and patchy in distribution throughout Denali National Park and Preserve. The highest elevation, based on field data, is 824 meters (Table 3). It is uncommon in all ecoregions except the Kuskokwim-alluvial fans and flood plains ecoregion and the Kuskokwim-Minchumina Basin ecoregion (Tables 4a and 4b; Clark 1998). The class covers 0.6% (38,427 acres) of Denali National Park and Preserve (Table 5).

Vegetation—Herbaceous composition is highly variable and includes *Menyanthes trifoliata*, *Potentilla palustris*, *Cnidium cnidiifolium*, *Eriophorum brachyantherum*, *E. vaginatum*, *Equisetum fluviatile*, *Carex rostrata*, *C. aquatilis* and *C. lasiocarpa*. Each species may dominate a site. Low shrubs associated with the wet herbaceous class include *Betula nana*, *Salix* species, *Potentilla fruticosa*, *Myrica gale*, and *Spirea beauverdiana*. *Sphagnum* species sometimes form a floating mat interspersed with the emergent vascular species.

Landcover Class Accuracy—The producer's accuracy for the *Wet Herbaceous* class is 68.7%, with a user's accuracy of 89.7%. Errors of omission and commission are relatively small, but scattered with a number of different mapping classes (*Stunted Spruce*, *Willow*, *Low Shrub-Sedge* and *Water*).

AQUATIC HERBACEOUS LANDCOVER CLASS 17

Classification—Tree canopy is less than 10% (or absent), shrub cover is less than 25%, and herbaceous cover is greater than 25%. Vegetation is submerged, floating, or growing in permanent water. The class is comparable to the Viereck et al. (1992) hierarchical level freshwater aquatic herbaceous (IIID1).



Distribution and Site Characteristics—The *Aquatic Herbaceous* class occurs in small patches of open water throughout the park's boreal forest zone and at higher elevations dominated by low shrubs. The sites are in open water of lakes, ponds, sloughs and fens. It is generally small in size and patchy in distribution throughout Denali. The *Aquatic Herbaceous* class is uncommon in all ecoregions (Tables 4a and 4b; Clark 1998), and covers less than 0.01% (564 acres) of Denali National Park and Preserve (Table 5).

Vegetation—A high cover of water is found in this class. Associated vegetation includes *Nymphaea tetragona*, *Nuphar polysepalum*, and a few graminoids. Other aquatic species occur but were not sampled during the field season.

Landcover Class Accuracy—The producer's accuracy for the *Aquatic Herbaceous* class is 100%, with a user's accuracy of 100%. The number of *Aquatic Herbaceous* signatures available for the accuracy assessment is significantly less than preferred. All accuracies are based on the 25-class landcover map at a 2-acre mapping unit prior to the digital integration of the burn mask.

SPARSE VEGETATION LANDCOVER CLASS 18

Classification—The *Sparse Vegetation* landcover class refers to sites with 15% to 24% total vegetation cover.



Distribution and Site Characteristics— The *Sparse Vegetation* class is common in alpine areas of the Alaska Range. It is generally found on unstable to stable upslope bedrock and unconsolidated rock in the mountains and high mountain valley floors. This class also occurs on sandbars, alluvial fans and the debris covered surfaces of glaciers. The physical site characteristics are similar to the *Dwarf Shrub-Rock* class however it has a much higher surface rock and mineral soil component. The slope ranges up to >50%, and the elevation ranges up to 1,142 meters based on field data, however, the spectral map places the maximum elevation at 4,527 meters (Table 3). The soils are a thin layer of dry to mesic sand, litter or organic matter. The sparse vegetation typically occurs as patches on the organic matter interspersed with exposed rock. This class is common in the Alaska Range-high mountains, Alaska Range-interior mountains and valleys, and Alaska Range-south-central mountains and valleys ecoregions (Tables 4a and 4b; Clark 1998). The *Sparse Vegetation* landcover class covers 4.8% (289,308 acres) of Denali National Park and Preserve (Table 5).

The class frequently occurs next to the *Bare Ground*, *Dwarf Shrub-Rock* and *Dwarf Shrub* classes.

Vegetation—The *Sparse Vegetation* class is dominated by dwarf shrubs—primarily *Dryas octopetala*—surface rock, and exposed mineral soil. Other dwarf shrubs include *Dryas integrifolia*, *Salix reticulata*, *S. arctica*, *S. phlebophylla*, *Cassiope tetragona*, *Vaccinium uliginosum*, *Arctostaphylos rubra*, and *A. alpina*. Forbs include *Epilobium angustifolium*, *Aster* species, *Heracleum lanatum*, *Veratrum viride*, *Anemone narcissiflora*, and *Campanula* species.

Landcover Class Accuracy—The producer's accuracy for the *Sparse Vegetation* class is 87.6%, with a user's accuracy of 45.7%. Most of the errors of omission and commission are with the *Bare Ground* and *Dwarf Shrub-Rock* map classes.

BARE GROUND LANDCOVER CLASS 19

Classification—*Bare Ground* represents areas with less than 15% vegetation cover.



Distribution and Site Characteristics— The *Bare Ground* class primarily occurs on steep upslope bedrock, unconsolidated rock, mountain peaks, jutting rock outcrops, and talus slopes. It also represents exposed alluvial deposits along rivers, especially those with wide outwash plains. In addition, it represents the debris-covered surfaces of glaciers, typically increasing in cover toward a glacier's terminus. *Bare Ground* is often found adjacent to the *Sparse Vegetation*, *Dwarf Shrub-Rock* and *Dwarf Shrub* landcover classes. Elevation for the class ranges up to 5,536 meters based on the spectral map (Table 3). It dominates the Alaska Range-high mountains ecoregion (Tables 4a and 4b; Clark 1998) and covers 9.8% (592,298 acres) of Denali National Park and Preserve (Table 5).

Landcover Class Accuracy—The producer's accuracy for the *Bare Ground* class is 70.7%, with a user's accuracy of 86.5%. Most of the errors of omission and commission are with the *Sparse Vegetation* class.

SNOW-ICE LANDCOVER CLASS 20

The *Snow-Ice* class refers to areas covered with snowfields, glaciers or late lying snow. Glacier surfaces have less exposed ice as one moves towards the terminus. The elevation ranges up to 6,188 meters based on the spectral map (Table 3). The *Snow-Ice* class dominates the Alaska Range-high mountains ecoregion, and is the most common class in Denali National Park and Preserve covering 15.5% (932,790 acres) of its total area (Table 5).



Landcover Class Accuracy—The producer's accuracy for the *Snow-Ice* class is 99.7%, with a user's accuracy of 99.5%. Most of the minor errors of omission and commission are with the *Bare Ground* class.

SHADOW-INDETERMINATE LANDCOVER CLASS 21

The *Shadow-Indeterminate* landcover class includes areas of severe terrain shadow where landcover could not be reliably identified. This class covers 6.9% (657,887 acres) of Denali National Park and Preserve.

Landcover Class Accuracy—Accuracies were not reported for the *Shadow-Indeterminate* mapping class because the class was so heavily edited that the signatures were obsolete.

SILTY WATER LANDCOVER CLASS 22

Silty Water refers to water containing moderate to high levels of glacial silt and debris. The major rivers and portions of some lakes—such as Lake Minchumina—are mapped as silty water. The *Silty Water* class is common in the Cook Inlet-braided flood plains and stream terrace ecoregion. The *Silty Water* class covers 0.5% (30,765 acres) of Denali National Park and Preserve (Table 5).



Landcover Class Accuracy—The producer’s accuracy for the *Silty Water* class was 91.8%, with a user’s accuracy of 97.7%. Most of the minor errors of omission and commission were with the *Bare Ground* class.

CLEAR WATER LANDCOVER CLASS 23

Clear water indicates water with little to no sediment or glacial silt. Most lakes and ponds are mapped as *Clear Water* in the park. The class covers 1.0% (60,764 acres) of Denali National Park and Preserve (Table 5).



Landcover Class Accuracy—The producer’s accuracy for the *Clear Water* class is 100%, with a user’s accuracy of 98.8%. The minor error of commission is with the *Silty Water* class.

BURN LANDCOVER CLASS 24

Description—The *Burn* landcover class represents large areas that have recently been scarred by wildfires. The class occurs predominantly in the northwest region of the park on level landscapes and rolling hills. The burns were dominated, pre-fire, by the various spruce dominated landcover classes.



Because limited air and ground information was collected within burn scars, it was not possible to accurately map the class. However, many of the more recent or very intense burns (as indicated by the scarring on the raw imagery) on the park's west side were spectrally classified as *Wet Herbaceous*. Many of the older, or less intense burns were spectrally mapped to the *Willow* or *Low Shrub-Sedge* classes. See the description for the plant association *Larix laricina*, *Betula papyrifera*, *Picea mariana*, *Ledum palustre*, *B. nana*, *Rubus chamaemorus*, *Eriophorum vaginatum*, *Oxycoccus microcarpos* for a description of a post-fire community. The *Burn* class is common in the Kuskokwim-alluvial fans and floodplains ecoregion (Tables 4a and 4b), and covers 2.9% (172,528 acres) of Denali National Park and Preserve (Table 5).

Burn areas were identified and mapped by establishing thresholds within the NDVI layers created from the 1994 and 1996 SPOT imagery and from the TM imagery. The thresholds for the upper and lower NDVI values for each image block were defined through an interactive review with the satellite imagery and the associated thematic NDVI layers. Once the range of NDVI values corresponding to burn areas (i.e., no or very low 'greenness') were established, a burn mask was developed that was constrained by the fire polygon coverage provided by the Park. However, users should take note that in addition to legitimate burn areas, some areas of legitimate wet herbaceous (i.e., wet herbaceous that was not burned) as well as some areas of water and aquatic herbaceous areas fell into the threshold range of NDVI values and were included in the burn mask. To help alleviate the misclassification of legitimate water (both silty and clear) and *Aquatic Herbaceous* to *Burn*, an additional water and aquatic herbaceous mask was also provided. See Volume 1 (Stevens et al. 2001) for a complete description of the methods used to develop the *Burn* landcover class.

Landcover Class Accuracy—Accuracies were not reported for the *Burn* landcover class.

CLOUD LANDCOVER CLASS 25

The *Cloud* landcover class designates areas masked by cloud cover on the satellite imagery. Due to the lack of spectral data, vegetation classes could not be assigned to these sites. The *Cloud* landcover class covers 0.01% (357 acres) of Denali National Park and Preserve (Table 5).

Landcover Class Accuracy—Accuracies were not reported for the *Cloud* landcover class because the class was so heavily edited that the signatures were obsolete.

Appendix 5.3. Fly-Over (Polygon) and Ground Site (Point) Field Forms

1999 DENALI LANDCOVER MAPPING PROJECT: EVA "FLY-OVER" DATA FORM

Air Photo Number:		Polygon code:		Lat/Long:	
Landcover class name:		Landcover class code:			
Date:		Surveyors:		A. Garibaldi, J. Stevens	
Photos: Roll number:		Frame Number:		Azimuth:	
Video: tape #:		Footage:		Dig photo: ses. #: photo #: azimuth:	
Slope (0-100 degrees):		Aspect (0-360 degrees):			
Modifier: Riparian Alpine Subalpine Boreal Tussock Bog Meadow					
Landform:				Spruce	
Hydrologic Regime (circle one): Dry - Mesic - Wet - Aquatic				Closed White Spruce	
% Tussocks:				Closed Black Spruce	
Dominant Species:	% Canopy Cover	Height (ft)	% Total Cover	Open White Spruce	Low shrub
				Open Black Spruce	Closed Low Willow
				Woodland Spruce (Eric)	Closed Low Alder-Willow
				Woodland Spruce (Lichen)	Open Low Willow
				Woodland Spruce (Sedge)	Open Low Mix Shrub-Sedge Tussock
				Deciduous forest	Open Low Shrub Birch-Ericaceous
				Closed Birch	Open Low Shrub Birch-Willow
				Closed Aspen	Dwarf shrub
				Closed Balsam Poplar	Dryas Dwarf Shrub
				Closed Mixed Deciduous	Willow Dwarf Shrub
				Open Birch	Eric. Bearberry/Vaccinium Dw. Shrub
				Open Aspen	Eric. Cassiope Dwarf Shrub
				Open Balsam Poplar	Herbaceous
				Open Mixed Deciduous	Dry/Mesic Grass-Forb
				Woodland Birch	Dry/Mesic Sedge-Forb
				Woodland Balsam Poplar	Tussock Tundra
				Woodland Deciduous	Wet graminoid/forb
				Mixed forest	Other
				Closed Mixed	Lichen
				Open Mixed	Sparse Vegetation
				Woodland Mixed	Aquatic
				Tall shrub	Bare Ground
				Closed Tall Alder	Snow/Ice
				Closed Tall Willow	
Moss				Closed Tall Alder-Willow	
Lichen				Closed Tall Shrub Birch	
Bare ground				Open Tall Alder	Open Tall Shrub Birch
Water				Open Tall Willow	Open Tall Alder-Willow

	Total cover:	Height (feet)	Comments:
Tree			
Needleleaf			
Broadleaf			
Shrub			
Tall (> 5 ft.)			
Low (8 inches to 5 ft.)			
Dwarf (< 8 inches)			
Herbaceous			
Lichen/Moss			
Bareground			
Water			

Inclusion: Clumped vs. random distribution (circle one)	
---	--

Air Photo Number:		Polygon code:		Landcover class name:			
Date:	Surveyors:	Photos:	Roll number:	Frame Number:			
Lat:	Long: W	P:	Error±	Elevation:			
Slope (0-100 degrees):		Aspect (0-360 degrees):		Landform:			
Hydrologic Regime: Dry Mesic Wet Aquatic		Biome: Alpine Subalpine Boreal Bog		Herb meadow Tussock Rip			
Unvegetated Surface:		___% Water		___% Bare soil		___% Bedrock	
___% Wood (> 1 cm)		___% Large rocks (cobbles, boulders > 10 cm)		___% Small rocks (gravel, 0.2-10 cm)			
___% Sand (0.1-2 mm)		___% Other (describe):					

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Appendix 5.4 The number of Mapping Class Signatures per Image Processing Block

The number and spatial extents of a particular landcover type's spectral signatures directly effects how well that type will be mapped by the ML classifier. For this reason, the number of signatures (as well as location and size) of each potential landcover type was tracked. The number of original signatures derived from either the FirePro or 1999 field data for each of the target mapping classes is shown to the right. The final number of signatures used for generating the base spectral classification map (i.e., the 25 endpoint classes) is shown to the left. Although the table shows how the Target classes were generally combined to form the endpoint class, the number of signatures for each endpoint class may not necessarily equal the total number of combined Target Class signatures. This is because signatures were keyed, deleted or added as appropriate.

(Note: Balsam Poplar signatures were later added to the Birch / Aspen /Mixed Deciduous signatures to create the Broadleaf Forest Class. The Herbaceous-Shrub and Burn Classes did not have any signatures and are not listed in these tables).

Denali LC Endpoint Mapping Classes - October 12, 2000

TM Processing Block 1 70/15&16

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
1	Dense Open Spruce Forest (white like)	8	1	Open White Spruce	25
2	Open Spruce Forest (black or white)	30	2	Open Black Spruce	18
3	Stunted Spruce	39	3	Open Stunted Spruce (~black spruce)	15
			5	Stunted Spruce Ericaceous	13
			6	Stunted Spruce Sedge	6
4	Birch / Aspen / Mixed Deciduous	19	7	Closed Birch	12
			11	Open Birch	2
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	5
5	Balsam Poplar	11	14	Open Mixed Deciduous	0
			9	Closed Balsam Poplar	0
6	Spruce-Broadleaf	8	13	Open Balsam Poplar	11
			16	Closed Mixed	3
7	Alder	22	17	Open Mixed	10
			19	Closed Tall Alder -Willow	4
			20	Closed Tall Alder	6
			22	Open Tall Alder	10
			30	Open Low Alder	1
8	Willow	13	24	Closed Low Alder-Willow	1
			29	Open Low Alder-Willow	1
			21	Closed Tall Willow	4
9	Closed Low Shrub Birch	11	23	Open Tall Willow	4
			26	Closed Low Willow	4
			28	Closed Low Shrub Birch	9
10	Low Shrub Birch-Ericaceous-Willow		25	Closed Low Shrub Birch-Willow	6
				Closed Low Shrub Birch-Ericaceous Shrub	6

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 1 70/15&16

Endpoint			Target		
Class	Proposed Endpoint Class Name	# of sigs	Class	Target Class Name	# of sigs
			31	Open Low Shrub Birch-Eric-Willow	5
			35	Open Low Shrub Birch-Ericaceous Shrub	18
		36	32	Open Low Willow	2
11	Open Low Shrub-Sedge		33	Open Low Mixed Shrub-Tussock	30
		33	44	Tussock *	5
12	Open Low Shrub Bog-Like	0	34	Open Low Shrub Bog	0
13	Mixed Dwarf Shrub		37	Mixed Dwarf Shrub	8
			38	Mixed Dwarf Shrub-Sedge	1
			36	Dryas Dwarf Shrub	2
		12	39	Mixed Dwarf Shrub-Lichen	1
14	Mixed Dwarf Shrub-Rock	2	40	Mixed Dwarf Shrub-Rock	2
15	Dry-Mesic Herb		41	Dry/Mesic Grass	3
			42	Dry/Mesic Grass-Forb	2
			43	Dry/Mesic Sedge-Forb	0
		6	44	Tussock *	5
16	Wet Herb	13	45	Wet Herbaceous	14
17	Aquatic	0	46	Aquatic	0
18	Sparse	2	47	Sparse Vegetation	2
19	Bare	12	49	Bare Ground	12
20	Snow-Ice	4	50	Snow/Ice	4
21	Shadow	4	51	Shadow/Indeterminate	4
22	Silty	5	52	Silty Water	5
23	Clear	3	53	Clear Water	3
24	Burn	0	55	Burn site	0
25	Cloud	4	56	Cloud	4

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 2 71/15

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
1	Dense-Open Spruce	3	1	Open White Spruce	3
2	Open Spruce	9	2	Open Black Spruce	9
3	Stunted Spruce	18	3	Open Stunted Spruce (~black spruce)	5
			5	Stunted Spruce Ericaceous	7
			6	Stunted Spruce Sedge	6
4	Birch / Aspen / Mixed Deciduous	25	7	Closed Birch	15
			11	Open Birch	5
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	5
			14	Open Mixed Deciduous	0
5	Balsam Poplar	2	9	Closed Balsam Poplar	0
			13	Open Balsam Poplar	2
6	Spruce-Broadleaf	4	16	Closed Mixed	2
			17	Open Mixed	3
7	Alder	3	19	Closed Tall Alder -Willow	2
			20	Closed Tall Alder	0
			22	Open Tall Alder	1
			30	Open Low Alder	0
			24	Closed Low Alder-Willow	0
			29	Open Low Alder-Willow	0
8	Willow	2	21	Closed Tall Willow	1
			23	Open Tall Willow	1
			26	Closed Low Willow	0
9	Closed Low Shrub Birch	0	28	Closed Low Shrub Birch	0
10	Low Shrub Birch-Ericaceous-Willow	6	25	Closed Low Shrub Birch-Willow	0
			27	Closed Low Shrub Birch-Ericaceous Shrub	3
			31	Open Low Shrub Birch/Eric/Willow	1
			35	Open Low Shrub Birch-Ericaceous Shrub 2	
			32	Open Low Willow	1
11	Open Low Shrub-Sedge	13	33	Open Low Mixed Shrub-Tussock	9
			44	Tussock *	1
12	Open Low Shrub Bog-Like	0	34	Open Low Shrub Bog	0
13	Mixed Dwarf Shrub	1	37	Mixed Dwarf Shrub	1
			38	Mixed Dwarf Shrub-Sedge	0
			36	Dryas Dwarf Shrub	0
			39	Mixed Dwarf Shrub-Lichen	0
14	Mixed Dwarf Shrub-Rock	0	40	Mixed Dwarf Shrub-Rock	0
15	Dry / Mesic Herb		41	Dry/Mesic Grass	1
			42	Dry/Mesic Grass-Forb	1
			43	Dry/Mesic Sedge-Forb	1

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 2 71/15

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
		3	44	Tussock *	1
16	Wet Herb	7	45	Wet Herbaceous	7
17	Aquatic	0	46	Aquatic	0
18	Sparse	1	47	Sparse Vegetation	1
19	Bare	1	49	Bare Ground	1
20 Sn	ow-Ice	0	50	Snow-Ice	0
21 Sha	dow	5	51	Shadow-Indeterminate	5
22	Silty	7	52	Silty Water	7
23	Clear	6	53	Clear Water	6
24 Hum	an	0	54	Human development	0
25	Burn	0	55	Burn site	1
26	Cloud	5	56	Cloud	5

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 3 70/16

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
1	Dense-Open Spruce	3	1	Open White Spruce	2
2	Open Spruce	2	2	Open Black Spruce	1
3	Stunted Spruce	2	3	Open Stunted Spruce (~black spruce)	1
			5	Stunted Spruce Ericaceous	1
			6	Stunted Spruce Sedge	1
4	Birch / Aspen / Mixed Deciduous	0	7	Closed Birch	0
			11	Open Birch	0
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	0
		0	14	Open Mixed Deciduous	0
5	Balsam Poplar	14	9	Closed Balsam Poplar	6
			13	Open Balsam Poplar	8
6	Spruce-Broadleaf	18	16	Closed Mixed	1
			17	Open Mixed	16
7	Alder	35	19	Closed Tall Alder -Willow	6
			20	Closed Tall Alder	19
			22	Open Tall Alder	7
			30	Open Low Alder	2
			24	Closed Low Alder-Willow	1
			29	Open Low Alder-Willow	1
8	Willow	11	21	Closed Tall Willow	1
			23	Open Tall Willow	4
			26	Closed Low Willow	2
9	Closed Low Shrub Birch	0	28	Closed Low Shrub Birch	0
10	Low Shrub Birch-Ericaceous-Willow	8	25	Closed Low Shrub Birch-Willow	0
			27	Closed Low Shrub Birch-Ericaceous Shrub 1	
			31	Open Low Shrub Birch/Eric Shrub-Willow	4
			35	Open Low Shrub Birch-Ericaceous Shrub	9
			32	Open Low Willow	3
11	Open Low Shrub-Sedge	12	33	Open Low Mixed Shrub-Tussock	4
			44	Tussock *	0
12	Open Low Shrub Bog-Like	10	34	Open Low Shrub Bog	12
13	Mixed Dwarf Shrub	19	37	Mixed Dwarf Shrub	4
			38	Mixed Dwarf Shrub-Sedge	1
			36	Dryas Dwarf Shrub	8
			39	Mixed Dwarf Shrub-Lichen	4
14	Mixed Dwarf Shrub-Rock	1	40	Mixed Dwarf Shrub-Rock	5
15	Dry-Mesic Herb		41	Dry/Mesic Grass	1
			42	Dry/Mesic Grass-Forb	5
			43	Dry/Mesic Sedge-Forb	5

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 3 70/16

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
		11	44	Tussock *	0
16	Wet Herb	7	45	Wet Herbaceous	8
17	Aquatic	0	46	Aquatic	0
18	Sparse	7	47	Sparse Vegetation	2
19	Bare	7	49	Bare Ground	7
20 Sn	ow-Ice	6	50	Snow-Ice	6
21 Sha	dow	4	51	Shadow-Indeterminate	0
22	Silty	4	52	Silty Water	0
23	Clear	3	53	Clear Water	0
24 Hum	an	0	54	Human development	0
25	Burn	0	55	Burn site	0
26	Cloud	3	56	Cloud	0

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 4 71/16

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
1	Dense-Open Spruce	6	1	Open White Spruce	14
2	Open Spruce	14	2	Open Black Spruce	22
3	Stunted Spruce	14	3	Open Stunted Spruce (~black spruce)	21
			5	Stunted Spruce Ericaceous	18
			6	Stunted Spruce Sedge	5
4	Birch / Aspen / Mixed Deciduous	4	7	Closed Birch	2
			11	Open Birch	0
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	0
		4	14	Open Mixed Deciduous	0
5	Balsam Poplar	8	9	Closed Balsam Poplar	5
			13	Open Balsam Poplar	26
6	Spruce-Broadleaf	10	16	Closed Mixed	7
			17	Open Mixed	18
7	Alder	11	19	Closed Tall Alder -Willow	10
			20	Closed Tall Alder	24
			22	Open Tall Alder	17
			30	Open Low Alder	3
			24	Closed Low Alder-Willow	0
			29	Open Low Alder-Willow	2
8	Willow	11	21	Closed Tall Willow	1
			23	Open Tall Willow	6
			26	Closed Low Willow	9
9	Closed Low Shrub Birch	2	28	Closed Low Shrub Birch	2
10	Low Shrub Birch-Ericaceous-Willow	13	25	Closed Low Shrub Birch-Willow	7
				Closed Low Shrub Birch-Ericaceous Shrub 8	
			31	Open Low Shrub Birch/Eric Shrub-Willow	5
			35	Open Low Shrub Birch-Ericaceous Shrub 20	
			32	Open Low Willow	6
			33	Open Low Mixed Shrub-Tussock	16
11	Open Low Shrub-Sedge	12	44	Tussock *	3
12	Open Low Shrub Bog-Like	7	34	Open Low Shrub Bog	7
13	Mixed Dwarf Shrub	14	37	Mixed Dwarf Shrub	16
			38	Mixed Dwarf Shrub-Sedge	2
			36	Dryas Dwarf Shrub	9
			39	Mixed Dwarf Shrub-Lichen	3
14	Mixed Dwarf Shrub-Rock	3	40	Mixed Dwarf Shrub-Rock	5
15	Dry-Mesic Herbaceous		41	Dry/Mesic Grass	6
			42	Dry/Mesic Grass-Forb	7

Denali LC Endpoint Mapping Classes - October 12, 2000
 TM Processing Block 4 71/16

Endpoint Class	Proposed Endpoint Class Name	# of sigs	Target Class	Target Class Name	# of sigs
		9	43	Dry-Mesic Sedge-Forb	3
			44	Tussock *	3
16	Wet Herb	5	45	Wet Herbaceous	15
17	Aquatic	1	46	Aquatic	2
18	Sparse	3	47	Sparse Vegetation	4
19	Bare	7	49	Bare Ground	20
20	Snow-Ice	5	50	Snow/Ice	7
21 Shadow		2	51	Shadow-Indeterminate	1
22	Silty	3	52	Silty Water	0
23 Clear		7	53	Clear Water	1
24	Human	0	54	Human development	0
25	Burn	0	55	Burn site	2
26	Cloud	3	56	Cloud	1

Denali LC Endpoint Mapping Classes
 TM Processing Block 5 - 69/16

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
1	Dense-Open Spruce	4	1	Open White Spruce	11
2	Open Spruce	3	2	Open Black Spruce	1
3	Stunted Spruce	2	3	Open Stunted Spruce (~black spruce)	0
			5	Stunted Spruce Ericaceous	1
			6	Stunted Spruce Sedge	1
4	Birch / Aspen / Mixed Deciduous	0	7	Closed Birch	0
			11	Open Birch	0
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	0
		0	14	Open Mixed Deciduous	0
5	Balsam Poplar	4	9	Closed Balsam Poplar	4
			13	Open Balsam Poplar	4
6	Spruce-Broadleaf	4	16	Closed Mixed	0
			17	Open Mixed	9
7	Alder	6	19	Closed Tall Alder -Willow	4
			20	Closed Tall Alder	4
			22	Open Tall Alder	7
			30	Open Low Alder	2
			24	Closed Low Alder-Willow	2
			29	Open Low Alder-Willow	1
8	Willow	5	21	Closed Tall Willow	0
			23	Open Tall Willow	8
			26	Closed Low Willow	1
9	Closed Low Shrub Birch	2	28	Closed Low Shrub Birch	5
10	Low Shrub Birch-Ericaceous-Willow	13	25	Closed Low Shrub Birch-Willow	5
			27	Closed Low Shrub Birch-Ericaceous Shrub 3	
			31	Open Low Shrub Birch/Eric Shrub-Willow	10
			35	Open Low Shrub Birch-Ericaceous Shrub	16
			32	Open Low Willow	10
			33	Open Low Mixed Shrub-Tussock	10
11	Open Low Shrub-Sedge	3	44	Tussock *	2
12	Open Low Shrub Bog-Like	8	34	Open Low Shrub Bog	11
13	Mixed Dwarf Shrub	7	37	Mixed Dwarf Shrub	10
			38	Mixed Dwarf Shrub-Sedge	5
			36	Dryas Dwarf Shrub	6
			39	Mixed Dwarf Shrub-Lichen	4
14	Mixed Dwarf Shrub-Rock	1	40	Mixed Dwarf Shrub-Rock	3
15	Dry / Mesic Herb		41	Dry/Mesic Grass	0
			42	Dry/Mesic Grass-Forb	7
			43	Dry/Mesic Sedge-Forb	4

Denali LC Endpoint Mapping Classes
 TM Processing Block 5 - 69/16

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
		5	44	Tussock *	2
16	Wet Herb	2	45	Wet Herbaceous	8
17	Aquatic	0	46	Aquatic	0
18	Sparse	2	47	Sparse Vegetation	3
19	Bare	1	49	Bare Ground	16
20	Snow-Ice	3	50	Snow-Ice	4
21	Shadow	3	51	Shadow-Indeterminate	1
22	Silty	1	52	Silty Water	3
23 C	lear	2	53	Clear Water	0
24 Hum an		0	54	Human development	0
25 B	urn	0	55	Burn site	0
26 C	loud	3	56	Cloud	1

Denali LC Endpoint Mapping Classes
1996 SPOT XS Processing Block Northside

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
1	Dense-Open Spruce	5	1	Open White Spruce	5
2	Open Spruce	24	2	Open Black Spruce	24
3	Stunted Spruce	26	3	Open Stunted Spruce (~black spruce)	6
			5	Stunted Spruce Ericaceous	13
			6	Stunted Spruce Sedge	7
4	Birch / Aspen / Mixed Deciduous	9	7	Closed Birch	4
			11	Open Birch	0
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	5
			14	Open Mixed Deciduous	0
5	Balsam Poplar	5	9	Closed Balsam Poplar	0
			13	Open Balsam Poplar	5
6	Spruce-Broadleaf	13	16	Closed Mixed	1
			17	Open Mixed	12
7	Alder	22	19	Closed Tall Alder -Willow	5
			20	Closed Tall Alder	7
			22	Open Tall Alder	9
			30	Open Low Alder	1
			24	Closed Low Alder-Willow	5
			29	Open Low Alder-Willow	3
8	Willow	6	21	Closed Tall Willow	1
			23	Open Tall Willow	5
			26	Closed Low Willow	6
9	Closed Low Shrub Birch	6	28	Closed Low Shrub Birch	5
10	Low Shrub Birch-Ericaceous-Willow	5	25	Closed Low Shrub Birch-Willow	8
			27	Closed Low Shrub Birch-Ericaceous Shrub 9	
			31	Open Low Shrub Birch/Eric Shrub-Willow	5
			35	Open Low Shrub Birch-Ericaceous Shrub	10
			32	Open Low Willow	4
11	Open Low Shrub-Sedge	8	33	Open Low Mixed Shrub-Tussock	19
			44	Tussock *	7
12	Open Low Shrub Bog-Like	14	34	Open Low Shrub Bog	0
13	Mixed Dwarf Shrub	7	37	Mixed Dwarf Shrub	10
			38	Mixed Dwarf Shrub-Sedge	3
			36	Dryas Dwarf Shrub	5
			39	Mixed Dwarf Shrub-Lichen	2
14	Mixed Dwarf Shrub-Rock	15	40	Mixed Dwarf Shrub-Rock	3
15	Dry-Mesic Herb		41	Dry/Mesic Grass	3
			42	Dry/Mesic Grass-Forb	3
			43	Dry/Mesic Sedge-Forb	0

Denali LC Endpoint Mapping Classes
1996 SPOT XS Processing Block Northside

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
		19	44	Tussock *	7
16	Wet Herb	0	45	Wet Herbaceous	6
17	Aquatic	5	46	Aquatic	1
18	Sparse	13	47	Sparse Vegetation	2
19	Bare	2	49	Bare Ground	7
20	Snow-Ice	3	50	Snow-Ice	4
21	Shadow	13	51	Shadow-Indeterminate	4
22	Silty	6	52	Silty Water	6
23	Clear	1	53	Clear Water	5
24	Human	2	54	Human development	0
25	Burn	7	55	Burn site	0
26	Cloud	4	56	Cloud	0

Denali LC Endpoint Mapping Classes
1996 SPOT XS Processing Block - Southside

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
1	Dense-Open Spruce	0	1	Open White Spruce	0
2	Open Spruce	4	2	Open Black Spruce	4
3	Stunted Spruce	3	3	Open Stunted Spruce (~black spruce)	2
			5	Stunted Spruce Ericaceous	1
			6	Stunted Spruce Sedge	3
4	Birch / Aspen / Mixed Deciduous	0	7	Closed Birch	0
			11	Open Birch	0
			8	Closed Aspen	0
			12	Open Aspen	0
			10	Closed Mixed Deciduous	0
			14	Open Mixed Deciduous	0
5	Balsam Poplar	11	9	Closed Balsam Poplar	4
			13	Open Balsam Poplar	7
6	Spruce-Broadleaf	8	16	Closed Mixed	0
			17	Open Mixed	10
7	Alder	17	19	Closed Tall Alder -Willow	3
			20	Closed Tall Alder	4
			22	Open Tall Alder	8
			30	Open Low Alder	2
			24	Closed Low Alder-Willow	0
			29	Open Low Alder-Willow	0
8	Willow	3	21	Closed Tall Willow	0
			23	Open Tall Willow	3
			26	Closed Low Willow	3
9	Closed Low Shrub Birch	3	28	Closed Low Shrub Birch	0
10	Low Shrub Birch-Ericaceous-Willow	12	25	Closed Low Shrub Birch-Willow	0
			27	Closed Low Shrub Birch-Ericaceous Shrub 0	
			31	Open Low Shrub Birch/Eric Shrub-Willow	5
			35	Open Low Shrub Birch-Ericaceous Shrub	3
			32	Open Low Willow	1
11	Open Low Shrub-Sedge	10	33	Open Low Mixed Shrub-Tussock	1
			44	Tussock *	0
12	Open Low Shrub Bog-Like	7	34	Open Low Shrub Bog	0
13	Mixed Dwarf Shrub	10	37	Mixed Dwarf Shrub	6
			38	Mixed Dwarf Shrub-Sedge	1
			36	Dryas Dwarf Shrub	4
			39	Mixed Dwarf Shrub-Lichen	2
14	Mixed Dwarf Shrub-Rock	1	40	Mixed Dwarf Shrub-Rock	1
15	Dry-Mesic Herb		41	Dry/Mesic Grass	0
			42	Dry/Mesic Grass-Forb	9
			43	Dry/Mesic Sedge-Forb	2

Denali LC Endpoint Mapping Classes
1996 SPOT XS Processing Block - Southside

Endpoint Class	Proposed Endpoint Class Name	#of sigs	Target Class	Target Class Name	#of sigs
		10	44	Tussock *	0
16	Wet Herb	5	45	Wet Herbaceous	0
17 Aquatic		2	46	Aquatic	0
18 Sparse		5	47	Sparse Vegetation	0
19 Bare		8	49	Bare Ground	0
20 Snow-Ice		5	50	Snow-Ice	0
21 Shadow		0	51	Shadow-Indeterminate	0
22 Silty		1	52	Silty Water	1
23 Clear		3	53	Clear Water	3
24 Human		0	54	Human development	0
25 Burn		0	55	Burn site	0
26 Cloud		0	56	Cloud	0

Appendix 5.5

Following the implementation of the spectral classification for each Image Processing Block, a confusion matrix was generated and submitted to NPS for review. Results from the spectral classification were used to refine the spectral signatures, which were then used to generate a new and better spectral classification. The final confusion matrices from this iterative process are presented on the following pages.

Confusion matrix for TM Block 2 Spectral Classification (ver. 4) x training signature data (5/19/00):

	Reference / Training Data																										Row Total	User %	Theme
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			
Image Classification	Dense Open Spruce Forest (white-like)	Open (Tall) Spruce Forest (black or white)	Stunted Spruce	Aspen / Birch / Mixed Deciduous	Balsam Poplar	Mixed Spruce-Broadleaf	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Bir-Eric-Willow	Open Low Shrub-Sedge	Mixed Dwarf Shrub	Mixed Dwarf Shrub-Rock	Dry / Mesic Herbaceous	Wet Herbaceous	Aquatic	Sparse Vegetation	Bare	Snow / Ice	Shadow	Silty Water	Clear Water	Human Development	Burn	Cloud				
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			
1	145	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	151	96.0	1
2	3	776	5	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	789	98.4	2
3	0	2	1973	0	0	3	0	0	0	13	30	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2023	97.5	3
4	0	0	0	1917	6	15	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1949	98.4	4
5	0	0	0	22	28	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	N/A	5
6	0	0	2	9	0	233	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	245	95.1	6
7	0	0	0	30	1	0	87	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	71.9	7
8	0	0	0	29	2	0	4	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	40.7	8
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	9
10	0	0	5	2	0	0	0	0	0	878	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	914	96.1	10
11	0	0	54	0	0	0	0	0	0	142	637	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	834	76.4	11
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	12
13	0	0	0	0	0	0	0	0	0	1	2	0	12	0	0	0	0	0	0	0	0	0	0	0	2	0	17	70.6	13
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	14
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0	35	100.0	15
16	0	7	13	0	0	1	0	0	0	0	0	0	0	0	209	0	0	0	0	0	0	0	0	0	0	0	230	90.9	16
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	17
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	23	0	0	0	0	0	0	0	0	0	24	95.8	18
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	34	100.0	19
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	20
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	352	0	0	0	0	0	0	352	100.0	21
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	562	0	0	0	0	0	562	N/A	22
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2592	0	0	0	0	2592	100.0	23
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	800	800	100.0	26	
Col. Total	148	791	2052	2009	37	256	99	35	0	1035	698	0	12	0	38	211	0	23	34	0	352	562	2592	0	0	802	11317		Total correct
Prod. %	98.0	98.1	96.2	95.4	75.7	91.0	87.9	68.6	NA	84.8	91.3	NA	100.0	NA	92.1	99.1	NA	100.0	100.0	NA	100.0	100.0	100.0	NA	NA	99.8	11786.0		Total pixels
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		96.02	% Correct

Note: There were 26 proposed endpoint mapping classes at the completion of Block 2. These were later refined to the 25 mapping classes detailed in this report.

Confusion matrix for TM Block 3 Spectral Classification (ver. 3) x training signature data (6/12/00):

Image Classification	Reference / Training Data																													
	Dense Open Spruce Forest (white-like)	Open (Tall) Spruce Forest (black or white)	Stunted Spruce	Aspen / Birch / Mixed Deciduous	Balsam Poplar	Mixed Spruce-Broadleaf	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Bir-Eric-Willow	Open Low Shrub-Sedge	Mixed Dwarf Shrub (bog-like)	Mixed Dwarf Shrub	Dry / Mesic Shrub-Rock	Wet Herbaceous	Aquatic	Sparse Vegetation	Bare	Snow / Ice	Shadow	Silty Water	Clear Water	Human Development	Burn	Cloud					
	Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Row Total	User %	Theme
	1	170	39	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	213	79.8	1	
	2	6	240	0	0	0	6	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	254	94.5	2	
	3	0	0	42	0	2	0	0	0	0	0	2	0	0	0	0	8	0	0	0	0	0	0	0	0	0	54	77.8	3	
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	na	4	
	5	0	0	0	0	581	2271	33	21	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2908	N/A	5	
	6	5	1	0	0	66	2266	21	3	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	2368	95.7	6	
	7	0	0	0	0	19	60	5496	64	0	0	4	0	3	0	42	0	0	0	0	0	0	0	0	0	0	5688	96.6	7	
	8	0	0	0	0	2	19	100	492	0	0	14	0	4	0	49	1	0	0	0	0	0	0	0	0	0	681	72.2	8	
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	na	9	
	10	0	0	0	0	0	0	1	0	0	352	7	0	7	0	7	6	0	0	0	0	0	0	0	0	0	380	92.6	10	
	11	0	0	3	0	0	0	6	12	0	5	292	25	13	0	16	11	0	0	0	0	0	0	0	0	0	383	76.2	11	
	12	1	3	0	0	5	38	0	1	0	0	25	245	0	0	6	4	0	0	0	0	0	0	0	0	0	328	74.7	12	
	13	0	0	0	0	0	0	15	1	0	1	1	0	608	0	38	0	0	2	1	0	0	0	0	0	0	667	91.2	13	
	14	0	0	0	0	0	0	0	0	0	0	0	0	2	42	0	0	3	0	0	0	0	0	0	0	0	47	N/A	14	
	15	0	0	0	0	4	2	44	5	0	3	5	3	17	0	427	0	0	0	0	0	0	0	0	0	0	510	83.7	15	
	16	0	0	3	0	1	0	0	0	0	7	5	2	0	0	0	105	0	0	0	0	0	0	0	0	0	123	85.4	16	
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	na	17	
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	218	0	0	0	0	0	0	0	222	98.2	18	
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	374	0	0	0	0	0	0	2	376	99.5	19	
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	433	0	0	0	0	0	0	433	100.0	20	
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	785	0	0	0	0	0	785	100.0	21	
	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	314	0	0	0	0	314	N/A	22	
	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1199	0	0	0	1199	100.0	23	
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	na	24	
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	na	25	
	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5021	5021	100.0	26
Col. Tot	182	283	48	0	680	4666	5716	599	0	368	355	283	654	45	587	136	0	223	375	433	785	314	1199	0	0	5023	19702	Total correct		
Prod. %	93.4	84.8	87.5	na	85.4	48.6	96.2	82.1	na	95.7	82.3	86.6	93.0	93.3	72.7	77.2	na	97.8	99.7	100.0	100.0	100.0	100.0	na	na	100.0	22954.0	Total pixels		
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	85.83	% Correct		

Note: There were 26 mapping classes proposed at the completion of TM Block3, this was later refined to the 25 mapping classes defined in this report.

Confusion matrix for TM Block 4 Spectral Classification (ver. 4)x training signature data (6/07/00):

	Reference / Training Data																										Row Total	User %	Theme	
	Dense Open Spruce Forest (white-like)	Open (Tall) Spruce Forest (black or white)	Stunted Spruce	Aspen / Birch / Mixed Deciduous	Balsam Poplar	Mixed Spruce-Broadleaf	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Bir-Eric-Willow	Open Low Shrub-Sedge	Mixed Dwarf Shrub (bog-like)	Mixed Dwarf Shrub	Dry / Mesic Herbaceous	Wet Herbaceous	Aquatic	Sparse Vegetation	Bare	Snow / Ice	Shadow	Silty Water	Clear Water	Human Development	Burn	Cloud					
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26				
Image Classification	1	594	90	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	696	85.3	1	
	2	42	2307	166	0	0	0	0	0	5	0	5	0	0	2	1	0	0	0	0	0	0	0	0	0	0	2528	91.3	2	
	3	0	244	1955	0	0	3	0	4	0	18	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2228	87.7	3	
	4	0	0	0	69	31	6	5	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	118	58.5	4	
	5	0	0	0	9	466	30	7	12	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	526	N/A	5	
	6	10	6	1	2	29	447	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	498	89.8	6	
	7	0	0	0	6	8	4	1973	10	0	32	2	0	0	0	7	0	0	0	0	0	0	0	0	0	0	2042	96.6	7	
	8	0	0	2	5	8	0	26	445	4	48	8	0	49	0	20	2	0	0	0	0	0	0	0	0	0	617	72.1	8	
	9	0	0	0	0	0	0	0	3	194	44	4	0	6	0	0	0	0	0	0	0	0	0	0	0	0	251	77.3	9	
	10	0	10	34	0	1	0	20	9	11	1240	85	0	13	0	21	3	0	0	0	0	0	0	0	0	0	1447	85.7	10	
	11	0	0	0	0	7	0	1	1	10	118	796	0	6	0	20	0	0	0	0	0	0	0	0	0	0	959	83.0	11	
	12	0	12	15	0	0	0	0	0	0	1	0	387	0	1	1	1	0	0	0	0	0	0	0	0	0	418	92.6	12	
	13	0	0	0	0	1	0	0	28	10	20	18	0	673	0	29	0	0	0	0	0	0	0	0	0	0	779	86.4	13	
	14	0	0	0	0	0	0	0	0	0	0	0	0	2	107	0	0	0	1	0	0	0	0	0	0	0	110	N/A	14	
	15	0	9	3	1	0	0	14	23	0	59	28	6	16	0	689	0	0	0	0	0	0	0	0	0	0	848	81.3	15	
	16	1	4	16	0	4	7	0	4	0	8	0	1	0	0	0	195	0	0	0	0	0	0	0	4	0	244	79.9	16	
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0	10	0	0	0	0	53	81.1	17	
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	1	0	0	0	0	0	0	0	86	98.8	18	
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	458	0	0	23	0	0	0	0	481	95.2	19	
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	584	0	0	0	0	0	0	584	100.0	20	
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1997	0	0	0	0	0	1997	100.0	21	
	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	770	0	0	0	0	774	N/A	22	
	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5192	0	0	0	0	5192	100.0	23	
	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	79	0	86	91.9	25	
	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17417	17417	100.0	26	
Col. Total	647	2682	2192	92	555	499	2046	545	229	1593	943	399	765	108	791	215	43	86	463	584	2017	793	5192	0	83	17417	39162	Total correct		
Prod. %	91.8	86.0	89.2	75.0	84.0	89.6	96.4	81.7	84.7	77.8	84.4	97.0	88.0	99.1	87.1	90.7	100.0	98.8	98.9	100.0	99.0	97.1	100.0	NA	95.2	100.0	40979.0	Total pixels		
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	95.57	% Correct		

Note: There were 26 proposed endpoint mapping classes at the completion of Block 4. These were later refined to the 25 mapping classes detailed in this report.

Confusion matrix for TM Block 5 Spectral Classification (ver. 1) x training signature data (6/08/00):

	Reference / Training Data																										Row Total	User %	Theme
	Dense Open Spruce Forest (white-like)	Open (Tall) Spruce Forest (black or white)	Stunted Spruce	Aspen / Birch / Mixed Deciduous	Balsam Poplar	Mixed Spruce-Broadleaf	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Bir-Eric-Willow	Open Low Shrub-Sedge	Mixed Dwarf Shrub (bog-like)	Mixed Dwarf Shrub-Rock	Dry / Mesic Herbaceous	Wet Herbaceous	Aquatic	Sparse Vegetation	Bare	Snow / Ice	Shadow	Silty Water	Clear Water	Human Development	Burn	Cloud				
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26			
1	246	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	246	100.0	1
2	3	261	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	267	97.8	2
3	0	2	68	0	1	0	0	0	0	0	0	13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	85	80.0	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	4
5	0	0	1	0	211	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	266	N/A	5
6	1	2	0	0	14	237	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	257	92.2	6
7	0	0	0	0	0	15	269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	284	94.7	7
8	0	0	0	0	0	0	0	147	0	4	0	0	1	0	13	0	0	0	0	0	0	0	0	0	0	0	165	89.1	8
9	0	0	0	0	0	0	0	0	119	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	124	96.0	9
10	0	1	0	0	0	0	0	1	6	582	12	0	7	0	1	0	0	0	0	0	0	0	0	0	0	0	610	95.4	10
11	0	0	0	0	0	0	0	0	0	19	133	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	156	85.3	11
12	0	1	12	0	0	0	0	0	0	1	0	254	0	0	0	2	0	0	0	0	0	0	0	0	0	0	270	94.1	12
13	0	0	0	0	0	0	0	2	0	19	7	0	194	0	20	0	0	0	0	0	0	0	0	0	0	0	242	80.2	13
14	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	0	0	0	0	37	N/A	14
15	0	0	0	0	0	0	0	5	0	3	0	0	4	0	236	0	0	0	0	0	0	0	0	0	0	0	248	95.2	15
16	0	0	2	0	0	0	0	0	0	0	0	5	0	0	0	39	0	0	0	0	0	0	0	0	0	0	46	84.8	16
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	17
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113	0	0	0	0	0	0	0	0	0	113	100.0	18
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	23	100.0	19
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1558	0	0	0	0	0	0	1558	100.0	20
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	964	0	361	0	0	0	1325	72.8	21
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	513	0	0	0	0	0	513	N/A	22
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	632	0	1011	0	0	0	1643	61.5	23
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35413	35413	100.0	26
Col. Total	250	267	84	0	226	307	272	155	125	633	152	273	210	37	270	42	0	113	23	1558	1596	513	1372	0	0	35413	42628		Total correct
Prod. %	98.4	97.8	81.0	NA	93.4	77.2	98.9	94.8	95.2	91.9	87.5	93.0	92.4	100.0	87.4	92.9	NA	100.0	100.0	100.0	60.4	100.0	73.7	NA	NA	100.0	43891.0		Total pixels
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		97.12	% Correct

Note: There were 26 proposed endpoint mapping classes at the completion of Block 5. These were later refined to the 25 mapping classes detailed in this report.

Confusion matrix for Southside SPOT Spectral Classification (ver. 3) x training signature data (6/08/00):

	Reference / Training Data																										Row Total	User %	Theme	
	Dense Open Spruce Forest (white-like)	Open (Tall) Spruce Forest (black or white)	Stunted Spruce	Aspen / Birch / Mixed Deciduous	Balsam Poplar	Mixed Spruce-Broadleaf	Alder Shrub	Willow Shrub	Closed Low Birch Shrub	Low Shrub Bir-Eric-Willow	Open Low Shrub-Sedge	Mixed Dwarf Shrub (hog-like)	Mixed Dwarf Shrub	Dry / Mesic Shrub-Rock	Wet Herbaceous	Aquatic	Sparse Vegetation	Bare	Snow / Ice	Shadow	Silty Water	Clear Water	Human Development	Burn	Cloud					
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26				
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	1	
2	0	574	0	0	1	4	0	0	0	2	0	3	0	0	0	10	0	0	0	0	0	0	0	0	0	0	594	96.6	2	
3	0	0	176	0	37	0	0	0	0	0	3	9	0	0	0	21	0	0	0	0	0	0	0	0	0	0	246	71.5	3	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	4	
5	0	1	9	0	3717	95	35	0	13	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	3875	N/A	5	
6	0	10	0	0	55	803	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	868	92.5	6	
7	0	0	0	0	93	0	2722	0	0	0	5	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	2824	96.4	7	
8	0	0	0	0	0	0	0	203	0	0	3	0	9	0	22	0	0	2	0	0	0	0	0	0	0	0	239	84.9	8	
9	0	0	0	0	46	0	7	5	346	0	28	0	1	0	28	0	0	0	0	0	0	0	0	0	0	0	461	75.1	9	
10	0	0	0	0	0	0	0	0	0	952	12	0	10	0	1	1	0	0	0	0	0	0	0	0	0	0	976	97.5	10	
11	0	0	7	0	7	0	37	1	13	0	688	0	14	0	25	2	0	0	0	0	0	0	0	0	0	0	794	86.6	11	
12	0	7	18	0	0	2	1	0	0	8	0	317	0	0	0	31	0	0	0	0	0	0	0	0	0	0	384	82.6	12	
13	0	0	0	0	0	0	3	34	6	6	64	0	1767	4	52	0	0	14	0	0	0	0	0	0	0	0	1950	90.6	13	
14	0	0	0	0	0	0	0	0	0	0	0	0	48	90	0	0	0	0	0	0	0	0	0	0	0	0	138	N/A	14	
15	0	0	0	0	0	0	4	55	6	2	29	0	79	0	612	0	0	24	0	0	0	0	0	0	0	0	811	75.5	15	
16	0	42	14	0	22	0	0	0	0	3	1	8	0	0	0	189	0	0	0	0	0	0	0	0	0	0	279	67.7	16	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	17	
18	0	1	0	0	0	0	0	0	0	0	0	0	9	0	9	0	0	711	27	0	0	0	0	0	0	0	757	93.9	18	
19	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	20	2676	0	0	0	0	0	0	0	2699	99.1	19	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1783	0	0	0	0	0	0	1783	100.0	20	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	21	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7843	0	0	0	0	0	7843	N/A	22	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2100	0	0	0	0	2100	100.0	23	
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	24	
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	25	
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35413	35413	100.0	26
Col. Total	0	635	224	0	3978	904	2809	298	384	973	833	337	1941	94	752	259	0	771	2703	1783	0	7843	2100	0	0	35413	63682	Total correct		
Prod. %	NA	90.4	78.6	NA	93.4	88.8	96.9	68.1	90.1	97.8	82.6	94.1	91.0	95.7	81.4	73.0	NA	92.2	99.0	100.0	NA	100.0	100.0	NA	NA	100.0	65034.0	Total pixels		
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		97.92	% Correct	

Note: There were 26 proposed endpoint mapping classes at the completion of the Southside SPOT block. These were later refined to the 25 mapping classes detailed in this report.

Confusion matrix for proposed endpoint (32 class) SPOT96 (North)Spectral Classification x training signature data (3/2/00):

Reference / Training Data

Image Classification

	Dense Open Spruce Forest (white-like)																																Open (Tall) Spruce Forest (black or white)																																Stunted Spruce (black)																																Closed / Open Aspen and/or Birch																																Closed / Open Balsam Poplar																																Closed / Open Mixed Spruce-Broadleaf																																Closed Low Willow																																Closed Low Alder-Willow																																Closed Low Shrub Birch-Eric-Willow																																Open Low Shrub Birch-Eric																																Open Low Willow Shrub																																Open Low Shrub Birch-Eric-Willow																																Dryas Dwarf Tussock																																Mixed Dwarf Shrub																																Mixed Dwarf Shrub/Sedge																																Mixed Dwarf Shrub-Lichen																																Dry / Mesic Herb																																Wet Herb																																Aquatic																																Sparse																																Bare																																Snow / Ice																																Shadow																																Silty																																Clear																																Human																																Burn																																Cloud																															
Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Row T	User %	Theme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Row T	User %	Theme																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
1	309	177	3	0	0	104	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	7	0	0	0	0	1	0	0	0	0	0	594	52.0	1	44	4031	895	0	0	1565	1	3	1	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6558	61.5	2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
2	0	447	6051	4	18	229	15	7	3	5	0	340	19	221	137	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	7498	80.7	3	0	0	25	313	1	8	44	0	0	2	0	18	0	0	2	0	3	39	7	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	464	67.5	4																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
3	0	0	49	4	1144	42	4	0	2	6	0	34	12	0	0	0	8	29	2	2	0	2	0	0	0	0	0	0	0	0	0	0	1340	85.4	5	0	0	25	4	1144	42	4	0	2	6	0	34	12	0	0	0	8	29	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1340	85.4	5																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
4	32	376	138	21	25	2741	27	0	0	0	0	14	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	3379	81.1	6	7	0	3	13	15	13	54	1605	0	0	173	0	0	60	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																		

Note: There were 32 proposed endpoint mapping classes at the completion of the Northside SPOT block. These were later refined to the 25 mapping classes detailed in this report

This dataset was not used for the base classification, and thus did not undergo multiple signature review evaluations and refinements.

Appendix 5.6 Modeling Reports for Landsat TM Blocks 1-5

Following the implementation of the appropriate models for each Image Processing Block, a report documenting the results and any remaining classification (confusion) issues was generated and submitted (along with the resulting digital model files) to NPS for review.

Modeling Report for Processing Block 1 - May 19, 2000

Upon finalizing the supervised Maximum Likelihood (ML) spectral classification for Landsat TM Processing Block 1, ten sequential modeling steps were implemented to improve landcover characterization. Modeling specifics are described in each of the steps below. Initial modeling parameters were established based on interactive review of the spectral classification with each of the modeling data layers and the Landsat TM and SPOT image data. Field data and other available vegetation data were also referenced along with the image and modeling data in establishing and refining these parameters. After each model run, the results were reviewed and compared with the TM and SPOT imagery, field data, and other available data for the project area. Based on these reviews, parameters were refined and the models re-run until the model outputs were determined to best represent the particular landcover class(es) being modeled. Model parameters can be found in the ERDAS Imagine model files (*.gmd), as well as the discussion of each model presented below. The order in which the models are applied (as detailed in the steps below) is significant as several of the models operate on the output of a previous model.

Phase I. Development of the Spectral/Environmental Data Layers

Shaded Relief (p7088_shd_them.img) – This layer was generated from the ITM DEM (Albers), and the sensor-to-surface orientation parameters sun elevation and solar azimuth for the Landsat TM image acquisition date and path/row. The file was recoded to an unsigned 8-bit file for modeling purposes.

TNDVI (p7088_tndvi_them.img) – This layer is essentially an NDVI layer that has been rescaled to an 8-bit unsigned file ranging from 0-255 for modeling purposes (as opposed to a more cumbersome floating point -1 to +1 range).

Slope (p7088_slp_5low.img) – “Raw” slope as calculated from the ITM DEM included too many contour line relicts to be effectively integrated in modeling. Therefore, a smoothed slope layer was generated by a 5x5 low pass filtering of the DEM prior to creation of the slope layer. These slope values should therefore be considered as relative values, rather than absolute percentages.

Isodata (cluster) 5-band TM data (p7088_iso_cls.img) – This layer was developed through a strict parameter ISODATA clustering process to generate a set of approximately 240 spectral signatures, which were then used as input into a supervised ML classification of the 5-band Landsat TM data (Bands 2,3,4,5,7). The resulting single band, 8-bit thematic image is a compact and interpretable representation of the spectral variability found in the 5-band TM image.

ML classification (p7088_mlcls_26_sub.img) – This is the 8-bit unsigned thematic image file of the final ML classification iteration to be used as the starting point for modeling and future processing.

Band 5 TM data (p7088_bnd5_them.img) – This is the 8-bit unsigned thematic image file for Landsat TM Band 5 (middle IR). This layer is to be used for limited modeling during the manual editing process to improve definition of the water and open low shrub (bog-like) classes.

Phase II. Develop models to correct problems in the supervised ML classification

1. Objective: Correct striping patterns in the supervised ML spectral classifications.

Rationale/Assumptions: TM Bands 4, 5, and 7 were determined to be free of striping in the source data. The supervised ML classification process was therefore repeated using only these three bands of data. The output from this ML spectral classification (effectively “destriped”) was then interactively reviewed with the field data, SPOT and TM image data, the output from the 5-band supervised ML classification (“striped”), and NPS comments from review of the 5-band ML classification, to identify the ideal combination of classes from each of the two ML classification outputs. Although the striping was eliminated in the Bands 4,5,7 ML classification, the *mixed forest* and *dry/mesic herbaceous* mapping classes were determined to be better represented in the 5-band (Band 2,3,4,5,7) ML classification. Therefore, these two classes from the 5-band classification were burned into the “destriped” ML classification.

Model: None (supervised ML classification and manual recode)

Output: p70r16_mlcls_26_destripe_sub.img
p7016_mlcls_5bnd_class6_15.img

2. Identify snow/ice mapping class clusters in ISODATA data layer, and recode to create ice mask (all other mapping classes zeroed out). Although the snow/ice class is well represented in the ML classification, the ISODATA derived snow/ice picks up some of the more lightly or partially covered snow/ice areas.

Model: None (manual recode)

Output: p7088_ice_sub.img

3. Objective: Identify terrain shadow/indeterminate mapping class by modeling with shaded relief (illumination).

Rationale/Assumptions: Interactive review of the shaded relief, and imagery revealed that the shadow/indeterminate class was typically found in those areas where shaded relief was less than or equal to 70. Because of the lower resolution and different source of the shaded relief layer (60m pixels, DEM) when compared with the Landsat TM source data (28.5m pixels, multispectral scanner), some degree of over classification of shadow occurred as the result of this model. However, we believe that this parameter (70) represents a good overall estimate of the upper end of the complete shadow class for Processing Block 1, and is therefore the most feasible approach to consistently characterizing the mapping class throughout Processing Block 1.

Results: Improved characterization of shadow class. Because of the resolution and source differences between the illumination and Landsat TM data, some manual edits will still be required.

Model: p7088_shadow.gmd

Output: p7088_shadow.img

4. Objective: Correct over classification of the water mapping classes on partially shadowed upslopes by modeling with shaded relief and slope.

Rationale/Assumptions: Because of the “casting” of partial terrain shadow across large areas where the *water* class is likely to occur (such as east-west oriented valleys), shaded relief is not as itself a

good layer for reducing over classification of water. Water typically occurs only on areas with little or no slope. Interactive review of the shaded relief, slope, and imagery revealed that the water class was not typically found in areas where shaded relief was less than 135 and slope greater than 16. Erroneous water areas that fell within these parameters were determined to more appropriately represent the *bare* mapping class.

Results: Corrected most of the water found on partially shadowed upslopes. There is still some speckling of erroneous upslope *water* that will have to be dealt with during manual editing.

Model: p7088_upslopeh2o_to_bare.gmd

Output: p7088_upslope_h2o_to_bare.img

5. Objective: Correct over classification of spruce forest, mixed forest, woodland, and wet herbaceous areas in partial terrain shadow areas based on shaded relief (illumination).

Rationale/Assumptions: Very significant misclassification of these classes was found on partially shadowed N-NW aspects, most obviously in the Kantishna Hills region. Fortunately, a vegetation map derived from photointerpretation was available for this area in the NPS GIS Browser. This “minveg” polygon coverage was reviewed along with the Landsat and SPOT imagery and field data to develop a modeling approach to resolving the problem. Other areas such as Jenny Creek were also reviewed in establishing the modeling approach. From this review, there was found to be a consistent relationship between the misclassification of certain mapping classes in partial terrain shadow, and the correct corresponding general vegetation type as indicated by the “minveg” database. “Partial terrain shadow” in this context was found to be those areas with illumination values between 70 and 134 (less than 70 was found to be legitimate shadow, while greater than 134 was generally found to be well characterized by the ML classification). Unfortunately, the “minveg” classification is quite general (8 mapping classes), which required that some assumptions be made based on field experience and limited field data available from the region. For example, those partially shadowed areas mapped as *open spruce forest* in the ML classification were consistently mapped as “*tall shrub*” in the “minveg” classification. Under the Denali landcover classification system, these areas could correspond to the *alder shrub* or *willow shrub* mapping classes. Based on our field data and limited experience in the area (and review of the SPOT and Landsat TM imagery), such “*tall shrub*” areas were modeled into our *alder shrub* mapping class. The shadow effected *mixed spruce-broadleaf forest* ML class was also found to correspond to a “*tall shrub*” type, and thought to be best represented as the *alder shrub* mapping class. The shadow effected *dense open spruce forest* ML class was found to correspond to the *shadow/indeterminate* mapping class. Shadow effected *stunted spruce/woodland* ML class was found to correspond to a “*short shrub*” type, and thought to be best represented by the *low shrub birch/ericaceous/willow* mapping class. Shadow effected *wet herbaceous* ML areas were found to correspond to the “*alpine tundra*” type, and thought to best represented by the *mixed dwarf shrub* mapping class. All of the above relationships are consistent with the principle of reduced surface reflectance of the respective landcover type based on reduced incoming solar radiation (illumination). The practical effect when reviewing the TM imagery or spectral signatures using a 4,5,3 (RGB) band combination is, of course, a “darker” signature. TNDVI was found to be inconclusive in improving this model beyond what could be done with just the ML classification and shaded relief. TNDVI was found to provide better “vision” through partial terrain shadow; However, the various combinations of slope, aspect, vegetation, and percent composition (various ratios of bare rock/talus, rock types/reflectance, snow/ice, dwarf shrubs, and other pseudo-veg cover (crustose lichen or moss) make the NDVI indicator very difficult to interpret beyond application as a general indicator of biomass in relation to exposed barren areas. This application of TNDVI is exploited in Step 8.

Results: Corrected most of the major problems found in partially shadow areas. Spot checking of field data throughout the processing block did not reveal any major problems or inconsistencies. The assumption as to which mapping class the model assigns the “*tall shrub*” or “*low shrub*” types may benefit from some further review by NPS staff based on local knowledge of areas within Processing Block 1. This local knowledge will need to be incorporated in the manual editing process.

Model: p7088_partial_terrain_shadow_correction.gmd

Output: p7088_spmixed_wdln_d_wetherb_to_shadow_alder_lowsh.img

6. Mosaic the output from Steps 1-4 into the ML classification output (p7088_mlcls_26_sub.img). This output becomes the input file for Step 6.

Model: p7088_mosaic_step1_4.mos

Output: p7088_mosaic_step1_4.img

7. Objective: Additional correction of overclassification of water and wet herbaceous classes on upslopes.

Rationale/Assumptions: Additional interactive review of the output of Steps 1-5, slope, imagery, and field data revealed that the mapping classes *clear water* and *silty water* on areas with slope values greater than or equal to 12 were most appropriately mapped as the *bare* class. *Wet herbaceous* areas on these fairly steep slopes appeared to be more appropriately mapped into one of the dwarf shrub classes. The decision was made to model these erroneous upslope wet herbaceous areas into the *mixed dwarf shrub* class after review of the TNDVI revealed that this layer could be used if necessary to improve separation of the *dwarf shrub rock* class from the *mixed dwarf shrub* class (the *dwarf shrub rock* class has a lower TNDVI than the *mixed dwarf shrub* class). However, based on reviewing the final model results (Step 9) with the imagery and field data, it appears that the dwarf shrub rock and mixed dwarf shrub classes are represented fairly well, and should require no further TNDVI modeling.

Results: Corrected most of the erroneous *upslope wet herbaceous*, and the remaining erroneous *upslope water* class. Some wet herbaceous can still be found in upper elevation ridgeline and flatter areas. These areas will require further evaluation and correction (if determined to be in error) during the manual editing process.

Model: p7088_upslopeh20_wetherb_to_bare_dwfsch.gmd

Output: p7088_step3_upslopeh20_wetherb_to_bare_dwfsch.img

8. Mosaic the output from Steps 5-6 into the output from Step 4. This mosaic becomes the input file for Step 8.

Model: p7088_mosaic_step5_6.mos (Mosaic file; Note that paths will need to be edited to your local drive space if you want to run the mosaic process)

Output: p7088_mosaic_step5_6.img

9. Objective: Correct overclassification of floodplain *dwarf shrub rock* and upslope *bare* mapping class using TNDVI data layer.

Rationale/Assumptions: Additional interactive review of the output of Step 7, imagery, and field data revealed that the *dwarf shrub rock* class on areas with slope values less than or equal to 12 (flatter areas predominantly in valleys and floodplains) and TNDVI values between 124 and 173 (fairly low “greenness”) was more appropriately mapped as the *sparse* mapping class. This improves separation of the gravel bar sparsely vegetated sites (*sparse* class) from the upslope/alpine *dwarf shrub rock* class. The TNDVI range of 124-173 appears to be a good range for the *sparse* class in general. In upslope areas with slope values greater than 12, and within this “target” TNDVI range for the *sparse* class, the *bare* class was believed to more consistently mapped as the *sparse* class as well.

Model: p7088_lowlanddwfshrock_uplandbare_to_sparse.gmd

Output: p7088_step4_lowlanddwfshrock_uplandrock_to_sparse.img

10. Objective: Mosaic the output from Step 8 into the mosaic from Step 7. This mosaic is the final output from the modeling process.

Model: p7088_mosaic_step8_9.mos

Output: p7088_mosaic_step8_9.img This is the final model output which is identical to the p7088_md1_26.img file previously delivered.. (Mosaic file; Note that paths will need to be edited to your local drive space if you want to run the mosaic process)

Summary of known problems/limitations following modeling for Block 1:

- Some wet herb still on ridge tops (to be manually edited)
- Some water still on glacial outwash/moraines where rock or sparse is a more appropriate mapping class (to be manual edited)
- Still some overclassification of wet herbaceous on floodplains/along rivers (to be manual edited).
- Some striping/banding, which occurs in the source data is still problematic in some areas of this processing block. Striping/banding effects are most pronounced in Bands 2 and 3. ESC will investigate developing a new model data layer of a spectral classification of Bands 4, 5 and 7 (since these are stripe-free). Areas of striping in the original 5-band (bands 2-5, 7) ML spectral classification will be compared to the results of this 3-band (bands 4,5,7) ML classification. If ESC and NPS are still unable to consistently reconcile (model) misclassifications in the striped areas, then these areas will be manually edited prior to delivery of the Draft 1 Map.
- Willow shrub (perhaps overclassified where mapped outside of drainages, streams, floodplains. Can be manual edited, but will need guidance on how to handle/recode on a consistent basis).
- Band 5 modeling will also be incorporated into the manual editing process to improve spatial detail of water classes and the open low shrub (bog-like) class.
- Based on feedback from NPS, additional spectral processing and ML classification iterations were implemented, resulting in improved characterization of the closed low shrub birch class. Modeling efforts were therefore not focused on addressing this issue.
- The dense open spruce
- SPOT data does not appear to add significantly to the quality of the spectral classification or modeling, but is an excellent source of reference data during modeling and manual editing for those areas where the SPOT coverage is available.
- Burn areas will be handled during manual editing using the SPOT and TM imagery to capture the most current burn perimeters.

Modeling was not conducted on Processing Block 2

Modeling Report for Processing Block 3, Denali Landcover Mapping Project June 19, 2000

Upon finalizing the supervised Maximum Likelihood (ML) spectral classification for Landsat TM Processing Block 3, ten sequential modeling steps were implemented to improve landcover characterization. Modeling specifics are described in each of the steps below. Initial modeling parameters were established based on interactive review of the spectral classification with each of the modeling data layers and the Landsat TM and SPOT image data. Field data and other available vegetation data were also referenced along with the image and modeling data in establishing and refining these parameters. After each model run, the results were reviewed and compared with the TM and SPOT imagery, field data, and other available data for the project area. Based on these reviews, parameters were refined and the models re-run until the model outputs were determined to best represent the particular landcover class(es) being modeled. Model parameters can be found in the ERDAS Imagine model files (*.gmd), as well as the discussion of each model presented below. The order in which the models are applied (as detailed in the steps below) is significant as several of the models operate on the output of a previous model.

Phase I. Development of the Spectral/Environmental Data Layers

Shaded Relief (p70r16_shd_sub_them.img) – This layer was generated from the ITM DEM (Albers), and the sensor-to-surface orientation parameters sun elevation and solar azimuth for the Landsat TM image acquisition date and path/row. The file was recoded to an unsigned 8-bit file for modeling purposes.

TNDVI (p70r16_sub_tndvi_them.img) – This layer is essentially an NDVI layer that has been rescaled to an 8-bit unsigned file ranging from 0-255 for modeling purposes (as opposed to a more cumbersome floating point -1 to +1 range).

Slope (p70r16_slp_5low.img) – “Raw” slope as calculated from the ITM DEM included too many contour line relicts to be effectively integrated in modeling. Therefore, a smoothed slope layer was generated by a 5x5 low pass filtering of the DEM prior to creation of the slope layer. These slope values should therefore be considered as relative values, rather than absolute percentages.

Isodata (cluster) 5-band TM data (p70r16_sub_iso_cls.img) – This layer was developed through a strict parameter ISODATA clustering process to generate a set of approximately 240 spectral signatures, which were then used as input into a supervised ML classification of the 5-band Landsat TM data (Bands 2,3,4,5,7). The resulting single band, 8-bit thematic image is a compact and interpretable representation of the spectral variability found in the 5-band TM image.

ML classification (p7016_mlcls_26_sub.img) – This is the 8-bit unsigned thematic image file of the final ML classification iteration to be used as the starting point for modeling and future processing.

Band 5 TM data (p70r16_sub_bnd5_them.img) – This is the 8-bit unsigned thematic image file for Landsat TM Band 5 (middle IR). This layer is to be used for limited modeling during the manual editing process to improve definition of the water and open low shrub (bog-like) classes.

Supervised ML classification of TM Bands 4,5,7 (p7016_mlcls_26_destripe_sub.img) – The supervised ML classification was reprocessed using only bands 4, 5, and 7 as these were found to be relatively “stripeless” (no banding in the data).

Phase II. Develop models to correct problems in the supervised ML classification

1. Objective: Correct striping patterns in the supervised ML spectral classifications.

Rationale/Assumptions: TM Bands 4, 5, and 7 were determined to be free of striping in the source data. The supervised ML classification process was therefore repeated using only these three bands of data. The output from this ML spectral classification (effectively “destriped”) was then interactively reviewed with the field data, SPOT and TM image data, the output from the 5-band supervised ML classification (“striped”), and NPS comments from review of the 5-band ML classification, to identify the ideal combination of classes from each of the two ML classification outputs. Although the striping was eliminated in the Bands 4,5,7 ML classification, the *mixed forest* and *dry/mesic herbaceous* mapping classes were determined to be better represented in the 5-band (Band 2,3,4,5,7) ML classification. Therefore, these two classes from the 5-band classification were burned into the “destriped” ML classification.

Model: None (supervised ML classification and manual recode)

Output: p70r16_mlcls_26_destripe_sub.img
p7016_mlcls_5bnd_class6_15.img

2. Identify snow/ice mapping class clusters in ISODATA data layer, and recode to create ice mask (all other mapping classes zeroed out). Although the snow/ice class is well represented in the ML classification, the ISODATA derived snow/ice picks up some of the more lightly or partially covered snow/ice areas.

Model: None (manual recode)

Output: p7016_ice_sub.img

3. Objective: Identify terrain shadow/indeterminate mapping class by modeling with shaded relief (illumination).

Rationale/Assumptions: Interactive review of the shaded relief, and imagery revealed that the shadow/indeterminate class was typically found in those areas where shaded relief was less than or equal to 80. Because of the lower resolution and different source of the shaded relief layer (60m pixels, DEM) when compared with the Landsat TM source data (28.5m pixels, multispectral scanner), some degree of over classification of shadow occurred as the result of this model. However, we believe that this parameter (80) represents a good overall estimate of the upper end of the complete shadow class for Processing Block 3, and is therefore the most feasible approach to consistently characterizing the mapping class throughout Processing Block 3. Because of the “casting” of partial terrain shadow across large areas where the *water* class is likely to occur (such as east-west oriented valleys), shaded relief is not as itself a good layer for reducing over classification of water. Water typically occurs only on areas with little or no slope. Interactive review of the shaded relief, slope, and imagery revealed that the water class was not typically found in areas where shaded relief ranges between 80 and 136, and slope greater than 16. Erroneous water areas that fell within these parameters were determined to more appropriately represent the *shadow* mapping class.

Results: Improved characterization of shadow class, and reduced overclassification of water classes. Because of the resolution and source differences between the illumination and Landsat TM data, some manual edits will still be required. Corrected most of the water found on partially shadowed upslopes. There is still some speckling of erroneous upslope *water* that will have to be dealt with during manual editing.

Model: p7016_shadow.gmd

Output: p7016_shadow.img

4. Mosaic the output from Steps 1-3 into the “destriped” ML classification output (p7016_mlcls_26_destripe_sub.img). This output becomes the input file for Step 5.

Model: p7016_mosaic_step1_3.mos (mosaic file)

Output: p7016_mosaic_step1_3.img

5. Objective: Correct additional overclassification of the *water* mapping classes on upslopes by modeling with the slope layer.

Rationale/Assumptions : Additional upslope areas misclassified as water classes on upslopes, but not in terrain shadow effected areas, were reviewed with the TM and SPOT imagery to determine the most realistic class reassignment. These areas were found to be best represented by the *bare* class.

Results: Corrected most of the water found on partially shadowed upslopes. There is still some speckling of erroneous upslope *water* that will have to be dealt with during manual editing.

Model: p7016_upslope_h20_to_bare.gmd

Output: p7016_upslope_h2o_to_bare.img

6. Objective: Correct overclassification of dry/mesic herbaceous class on upslopes by modeling with TNDVI layer.

Results:

Model: p7016_herb_to_lowshsedge.gmd

Output: p7016_herb_to_lowshsedge.img

7. Objective: Correct overclassification of wet herbaceous on upslope areas

Results:

Model: p7016_wetherb_to_dwfsh.gmd

Output: p7016_wetherb_to_dwfsh.img

8. Mosaic the output from Steps 5-7 into the output from Step 4 (p7016_mosaic_step1_3.img) This output becomes the input file for Step 9.

Model: p7016_mosaic_step5_7.mos (mosaic file)

Output: p7016_mosaic_step5_7.img

9. Objective: Correct over classification of mixed forest, spruce forest, woodland, and in partial terrain shadow areas based on shaded relief (illumination).

Rationale/Assumptions: Significant overclassification of these classes was found on partially shadowed N-NW aspects. A similar phenomenon was observed in Block 1. Image interpretation of the Landsat and SPOT data, and review of the field data and samples of aerial photos were used to identify what mapping classes these partially shadowed areas actually represent. From this review, there appeared to be a fairly consistent relationship between the misclassification of certain mapping classes in partial terrain shadow, and the correct corresponding general vegetation type as indicated through image interpretation. "Partial terrain shadow" in this context was found to be those areas with illumination values between 80 and 157 (80 or less was found to be legitimate shadow, while greater than 157 was generally found to be well characterized by the ML classification). Assumptions similar to those applied in Block 1 were required, supplemented based on field experience and limited field data available from these N-NW aspects. However, unlike Block 1 where a photo-interpreted database (minveg) was available for verifying assumptions, in Block 3 there was no similar database. *Mixed forest* in partial terrain was found to correspond to the *alder shrub* class, while *balsam poplar* in these same shadow effected areas appears to be best represented by the *willow shrub* class. *Open spruce* and *dense open spruce* in partial shadow was believed to be best represented by the *shadow/indeterminate* mapping class. Shadowed *stunted spruce* (woodland) class was determined to correspond best with the *low shrub birch/ericaceous/willow* class. In addition, *open low shrub (bog)* mapped in partial terrain shadow was determined to be more appropriately mapped as the *shadow/indeterminate* class. All of the above relationships are consistent with the principle of reduced surface reflectance of the respective landcover type based on reduced incoming solar radiation (illumination). The practical effect when reviewing the TM imagery or spectral signatures using a 4,5,3 (RGB) band combination is, of course, a "darker" signature. TNDVI was found to be inconclusive in improving this model beyond what could be done with just the ML classification and shaded relief. TNDVI was found to provide better "vision" through partial terrain shadow; However, the various combinations of slope, aspect, vegetation, and percent composition (various ratios of bare rock/talus, rock types/reflectance, snow/ice, dwarf shrubs, and other pseudo-veg cover (crustose lichen or moss) make the NDVI indicator very difficult to interpret beyond application as a general indicator of biomass in relation to exposed barren areas. Because of the early date of the TM acquisition for this block (late-June), and the fact that most of the alpine areas where this type of TNDVI modeling is most effective are still covered with melting snow/ice, TNDVI modeling for the upper elevation/alpine areas is not practical.

Results: Corrected most of the problems found in partially shadow areas. Spot checking of field data throughout the processing block did not reveal any major problems or inconsistencies. However, particularly since there was not a "minveg-like" database available for model calibration (as was the case in Block 1), site specific observations and recommendations based on NPS field review of these N-NW aspect sites would be very helpful and could be incorporated during manual editing.

Model: p7016_partial_terrain_shadow_correction.gmd

Output: p7016_sp_mixed_poba_wdln_d_to_shadow_alder_willow_lowsh.img

10. Mosaic the output from Step 9 into the output from Step 8 (p7016_mosaic_step8_9.img) This output becomes the final output for the Block 3 modeling.

Model: p7016_mosaic_step8_9.mos (mosaic file)

Output: p7016_mosaic_step8_9.img

Summary of known problems/limitations following modeling for Block 3:

- Although much of the striping from the Band 2,3,4,5,7 spectral classification was significantly minimized by using the Band 4,5, 7 ML classification, some striping was re-introduced by burning the mixed spruce-broadleaf class from the Band 2-5, 7 classification into the Band 4,5,7 classification. Areas of open shrub-sedge occurring in the remaining striped areas will be manually edited to mixed spruce, balsam poplar or some other appropriate class as determined by imagery and field data interpretation.
- Some misclassified wet herb still occurs on ridge tops and in gently sloping areas (to be manual edited). These sites are probably more accurately described as mesic herbaceous or mixed dwarf shrub.
- Some water still on glacial outwash/moraines where rock or sparse is a more appropriate mapping class (to be manual edited)
- Still some overclassification of wet herbaceous on floodplains/along rivers (to be manual edited).
- Willow shrub (perhaps overclassified where mapped outside of drainages, streams, floodplains. Can be manual edited, but will need guidance on how to handle/recode on a consistent basis).
- Band 5 modeling will also be incorporated into the manual editing process to improve spatial detail of water, open low shrub (bog-like) class, wet herbaceous, and possibly open-low shrub-sedge classes. There are a few areas where water is inappropriately mapped as shadow, however, this corrections will be most efficiently implemented during this manual editing process.
- Balsam poplar appears to be overclassified in mixed forest areas. However, after reviewing the imagery and numerous field points, we found that these sites represent fairly well the dominant broadleaf forest and tall shrub composition, with relatively lower needleleaf components (one notable site is SIG_ID 829, which is only 10% spruce). We suggest modifying the balsam poplar forest class description as appropriate to describe this phenomena, and perhaps changing the name to allow for this mixture. We can use band 5 and/or NDVI to model more of these broadleaf dominant areas into the *mixed forest* class, but believe that the current *balsam poplar* class realistically represents broadleaf (forest and tall shrub) sites, as opposed to a more even mix or spruce dominated sites (which are mapped as the *mixed forest* class).
- The spectral classification from the SPOT data (September) will be investigated to see if improvement can be made in the alpine areas (hilltops/ridges) where the mid-June TM data typically is still covered or partially covered by seasonal snow/ice. The SPOT data is an excellent source of reference data during modeling and manual editing for those areas where the SPOT coverage is available.
- Burn areas will be handled during manual editing using the SPOT and TM imagery to capture the most current burn perimeters.

Summary of Modeling for Processing Blocks 3 – 5 (8/18/00)

Addendum to Modeling Report for Processing Block 3, Denali Landcover Mapping Project of 6/19/00

Integration of SPOT imagery

Due to the early acquisition dates of the landcover base-data Landsat TM imagery for Processing Block 3 (late-June), lingering snow cover and various stages of snowmelt and vegetation green-up were observed in the upper elevation (alpine/ridgelines) in this Landsat TM image. This created confusion in the supervised ML spectral classification of the TM data, particularly in those areas of partial snowmelt. As approximately

50% of Block 3 can be considered upper elevations (>750m), the scale of the problem was fairly significant. As such, this issue was identified as a known problem in the Block 3 Modeling Report of 06/19/00 (pg 6), and potential possible solution proposed was to investigate the SPOT data (acquired early Sept.) for improving the classification in the upper elevation TM data areas.

Interactive review of the field data, SPOT data, TM data, and their respective supervised ML classifications confirmed that the SPOT data could be integrated in the upper elevations. First, specific areas in the TM imagery, DEM, and slope data were reviewed to determine what values of these layers, if any, correlated to the TM image “problem” areas. Elevations above approximately 775 m were found to correspond fairly well with the snowmelt/snowcover areas of the TM imagery. Slope was typically a redundant factor at these elevations, and was therefore not used in the modeling process. Specific areas were then reviewed in the SPOT imagery, ML classification, and DEM data to determine what elevations were appropriate for usage of the SPOT ML classification for improving the Landsat TM-derived primary landcover classification. Elevations above 784 m were determined to be an improvement in the SPOT data over the TM-derived classification. Elevations above 784 m in the Landsat TM-derived landcover classification were then “zeroed-out,” and the SPOT ML classification substituted for these areas. The spectral ML classification for the prospective SPOT “fill-in” areas and field data were then reviewed to identify any major errors that could be handled through modeling. Spruce forest classes and water were found to occur in known shadow areas, and were corrected using models based on shaded relief and slope parameters. Errors were also found in the SPOT spectral classification in areas mapped as wet herbaceous. These areas were determined to correspond well with the tall alder shrub class in these upper elevations, and recoded as such. After reviewing the SPOT/TM boundary, and making appropriate boundary edits to ensure seamless integration of the two data sets, the upper elevation (>784 m) SPOT-derived landcover was burned into the primary TM-derived landcover data.

Known Problems with Block 3 related to SPOT data integration

The SPOT spectral classification used in the upper elevations introduces some erroneous “sparse vegetation” mapping class areas. These areas require manual recoding during final edits, and are actually either snow/ice or the shadow mapping class. Some upper elevation water also requires recoding during final edits to barren or shadow classes. *The SPOT classification also introduces significant overclassification of low shrub sedge and dry/mesic herbaceous to the upper elevation areas on the Southside. These should be discussed during the draft review.*

Summary of Processing Block 4 Modeling

The modeling process for Block 4 was similar to that of Block 3 and Block 1. Refer to the detailed Block 3 Modeling Report (6/19/00) and Block 1 Modeling Report (5/19/00) for specific order of processing and steps.

Prior to Block 3-like processing, an additional series of modeling steps were implemented to improve the classification for this early date imagery. First, all the training signatures were re-reviewed and re-evaluated to develop “tighter,” more precisely defined signatures, in the event that this may improve the separability of several of the classes (in particular the spruce classes and mixed forest classes). The supervised ML classification was then re-run, and the results reviewed in detail to refine the cut-lines along Processing Block boundaries so as to minimize the landcover differences between the Processing Blocks. Illumination was used to improve identification of terrain shadow areas. Erroneous upslope water was corrected to shadow or barren using slope and shaded relief models. TNDVI thresholds were used to breakout erroneous barren as either mixed dwarf shrub, dwarf shrub rock, or sparse.

Known Problems with Block 4

Although the vast majority of clouds have been removed from the landcover data, some cloud shadows in this processing block still require manual edits (currently not all the clouds have their shadows!). Also, the early acquisition of this scene (late June) resulted in a similar snowmelt problem in the upper elevations as occurred in Block 3. However, much of this processing block was not covered by the 1996 SPOT data, so a similar approach to integrating SPOT data to improve these upper elevation areas was not feasible (because of poor radiometric quality of the 1994 SPOT for this area, '94 SPOT spectral processing was eliminated early on in the project, and is beyond the scope of the current Task Order). This problem is fairly easy to find in the SE portion of Processing Block 4 along the Block 3 boundary. However, it does accurately represent the landcover during the late-June Landsat TM snapshot in time. The mapping class descriptions for snow/ice, barren and sparse mapping classes could be modified to include partial snowmelt as an included landcover type, or in some way this problem should be conveyed to the landcover map user.

Summary of Processing Block 5 Modeling

The modeling process for Block 5 was similar to that of Block 3 and Block 1. Refer to the detailed Block 3 Modeling Report (6/19/00) and Block 1 Modeling Report (5/19/00) for specific order of processing and steps. The primary difficulty with the Landsat TM spectral classification for Block 5 is relatively low solar angle during the early September acquisition, which results in a significantly larger shadow mapping class proportion. Barren and snow/ice classes 1996 SPOT spectral classification were integrated in a similar fashion as in Block 3 to improve the Landsat TM-derived classification.

Known problems with Block 5

The above-mentioned abundance of the shadow class is a difficult problem to solve. The shadow could be modeled to some extent with TNDVI, but modeled to what? We don't have the field data or detailed PI-derived vegetation dataset to test and establish realistic modeling parameters. In GAAR, Sara Wesser preferred that in such a situation, we not guess but instead simply maintain these areas as the shadow/indeterminate mapping class. Other known problems appear to be an abundance of tall willow shrub. These areas should be investigated by NPS and examined during the on-site review to determine what the appropriate class(es).

Summary of Cloud-Fill Processing Blocks

The general cloud-fill processing block from the Mosaic Plan (5/1/00) were fine-tuned by detailed delineation of all the cloud and cloud-shadow areas within the Cloud-fill Block. These areas were "zeroed-out" of the Landsat TM derived draft landcover classification, and the Cloud-fill Block spectral ML classifications were used to fill in. Block 1 and Block 3 modeling steps were generally followed based on the context (surrounding processing block) of the particular cloud area. Some manual edits of the Cloud-fill Block spectral ML classification were required to ensure a realistic and seamless "fit" into the larger draft landcover classification.

Some additional known problems throughout the draft landcover classification and general comments:

The following list of "final edits" could be made to the map following the draft review provided that detailed and location specific feedback in the form of annotations on the imagery, AOI's, or lat/lon's plus editing instructions are obtained from NPS during the review period.

Lakes/water bodies often include erroneous shadow or spruce, especially along the edges. These areas should be corrected in final edits through manual recoding and/or TM Band 5 modeling.

Wet herbaceous is overclassified throughout the project area. These areas should be corrected during final edits through manual recoding and/or TM Band 5 modeling.

Mesic herbaceous appears to be overclassified in the Block 3 and Block 5 areas. If this is determined to be the case during the draft review, we will need specific comments/annotations to make implementing these changes a possibility.

Tall willow shrub appears to be misclassified in many areas throughout the draft landcover. Recommend considering collapsing the tall alder and tall willow shrub, or the tall willow and low shrub birch-ericaceous-willow into a single class. Which collapsing scheme depends on NPS's feedback. These types are not spectrally separable on a consistent basis, and also do not appear to lend themselves to realistic modeling. A more time consuming alternative (for both NPS and ESC) is to have NPS provide annotations and detailed instructions on how to handle the tall willow shrub areas on a case-by-case basis. It is fairly easy to say leave those tall willow areas that occur in drainages alone (makes sense because much of the shrub in drainages is willow). However, how to handle those tall willow areas mapped outside the drainages is the real issue. *(Note: The issue of whether the tall willow was either over or misclassified was raised by ESC at the Draft Review. AKNHP and NPS reviewed its extent and distribution, and felt it appeared reasonable).*

Appendix 5.7 GLOSSARY

Most of the ecological terms below are from Hamilton (1999c), Gallant et al. (1995), Anderson et al. (1998), Viereck et al. (1992) and Gabriel and Talbot (1984).

Albedo—Same as reflectivity. The percentage of incoming radiation that is reflected by a natural surface such as a ground, ice, snow, water, clouds, or particulates in the atmosphere.

Alliance—A physiognomically uniform group of plant associations sharing one or more dominant or diagnostic species, which as a rule are found in the uppermost stratum of the vegetation (Grossman et al. 1998).

Alluvial fans—Erosional-depositional system in which rock and sediment are transported down-valley and deposited where it emerges from the confines of the valley into a larger valley or plain. They tend to be fan-shaped in plan view; a segment of a cone radiating away from a single point source.

Alluvial—Characterized by the deposition of sediment by a stream or other running water at any point along its course.

Alpine—The zone on mountain tops between permanent snow and the cold limits of trees.

Annual—Plant species that complete their life-cycle within a single growing season.

Aquatic—Refers to sites with vegetation that is submerged, floating, or growing in permanent water.

Bare-ground—Refers to (1) a landcover class with less than 15 percent vegetation cover, and (2) a soil surface devoid of vegetation.

Bedrock—Refers to exposed rock typically at higher elevations and includes all the jagged rocky ridges, peaks, cirque headwalls and cirque basins. It has little or no soil development.

Biennial—Plant species that complete their life-cycles within two growing seasons.

Boreal—Northern biogeographical region typically referring to subpolar and cold temperate areas.

Brackish—Tidal water with a salinity of 0.5-30 parts per thousand.

Broad-leaved—Describes a plant with leaves that have well-defined leaf blades and are relatively wide in outline (shape) as opposed to needle-like or linear; leaf area is typically greater than 500 square millimeters or 1 square inch.

Bryophyte—Nonvascular, terrestrial green plant, including mosses, hornworts, and liverworts.

Bunch grass—Multi-stemmed (Caespitose) life form of grasses characterized by clumps of erect shoots that slowly spread horizontally by tillers, generally creating distinct individual plants spaced across the ground; often applied to sedges and other graminoids with similar life forms.

Caespitose (cespitose)—Describes a low branching pattern from near the base that forms a multi-stemmed or a bunched appearance.

Canopy cover—The percent of the ground in the polygon covered by the gross outline of an individual plant's foliage (canopy), or the outline collectively covered by all individuals of a species or life-form within the polygon (Daubenmire 1959).

Classification—Process of assigning individual pixels of an image to categories, generally on the basis of spectral reflectance characteristics.

Cliff—Any high, very steep to perpendicular, or overhanging face of a rock outcrop.

Cold-deciduous—Describes a plant that sheds its leaves as a strategy to avoid seasonal periods of low temperature, often initiated by photoperiod; applied to vegetation adapted to seasonal cold season influences (temperate).

Colluvium—Unconsolidated surface materials that have been transported downslope and deposited on the lower slopes. Colluvium is moved by landslides, flow slides, talus rubble, rock-glaciers, solifluction and unconsolidated runoff.

Creeping—Describes the pattern of stems growing at or just beneath the surface of the ground and usually producing roots at nodes.

Crustose lichen—Lichen life form that grows in intimate contact with its substrate, lacks a lower cortex and rhizoids (root-like structures), and is impossible to separate from the substrate without destroying the thallus; lichen with an unlobed, flattened thallus, growing adnate to the substrate.

Cushion plant—A low, woody, plant life form so densely branched that it forms a compact canopy that is pad- or bolster-like in appearance; usually with microphyllous foliage; characteristic of alpine and tundra plants.

Deciduous—Describes a woody plant that seasonally loses all of its leaves and becomes temporarily bare-stemmed.

Digital image processing—computer manipulation of the digital-number values of an image.

Digital image—an image where the property being measured has been converted from a continuous range of analogue values to a range expressed by a finite number of integers, usually recorded as binary codes from 0 to 255, or as one byte.

Dominant—An organism, group of organisms, or taxon that by its size, abundance, or coverage exerts considerable influence upon an association's biotic (such as structure and function) and abiotic (such as shade and relative humidity) conditions.

Ecoregions—Landscape units defined based on similar patterns in potential natural communities, soils, hydrologic function, landform, topography, lithology, climate, and natural processes such as nutrient cycling, productivity, succession, and natural disturbance regimes associated with flooding, wind, or fire. Climate, as modified by topography, is the dominant criterion at the scale mapped for Denali.

Eolian—Wind blown sand and silt deposits.

Ephemeral forb vegetation—Annual vegetation that, during favorable periods, dominate areas that are usually sparsely vegetated or unvegetated for most of the year.

Epiphyte—Vascular plant that grows by germinating and rooting on other plants or other perched structures; sometimes called "air plants."

Evergreen—Describes a plant that has green leaves all year round.

Field verification area—An area sampled during the field season composed of multiple polygons.

Floodplain—A fluvial plain formed by non-glacial fed rivers. Along a meandering river—meandering rivers have one or two main channels—alluvium is deposited on convex curves in the river channel. The opposing concave bank is cut, providing sediment for deposition on convex curves downstream and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain.

Foliose lichen—Lichen life form that is leafy in appearance and loosely attached to its substrate; lichen with a lobed, flattened thallus growing loosely attached to the substrate, the lobes flattened or inflated with distinctly differentiated upper and lower surfaces; umbilicate lichens are included.

Forb—A broad-leaved herbaceous plant.

Fresh water—Water with a salinity of less than 0.5 parts per thousand.

Frost boils—These are areas of bare soil which are sufficiently disturbed by frost action to prevent plant colonization. On slopes, fine material in unsorted circles moves slowly downslope producing banked or "stepped" frost boils (from Gabriel and Talbot. 1984).

Frost Scar—These are exposed bare mineral soil formed by frost action in the soil.

Fruticose lichen—Lichen life form that is bunched, shrubby or "hairy" in appearance and loosely attached to its substrate; lichen with the thallus branched, the branches solid, or hollow and round, or flattened without distinctly differentiated upper and lower surfaces; squamulose lichens are included.

Geographic information system (GIS)—A data-handling and analysis system based on sets of data distributed spatially in two dimensions. The data sets may be map oriented, when they comprise qualitative attributes of an area recorded as lines, points, and areas often in vector format, or image oriented, when the data are quantitative attributes referring to cells in a rectangular grid usually in raster format. It is also known as a geobased or geocoded information system.

Geomorphic process—Refers to the mechanical transport of organic and inorganic material such as mass movement, surface erosion, the transport of material (silt) by water, and biogenic soil movement by root throw and animals.

Glacial drift—the material transported by a glacier and then deposited either directly from the ice or from the melt water. Numerous types of glacial drift occur including moraines, kettle-kame topography, eskers, drumlins, glacial till and outwash.

Glacial outwash—Fluvial plains formed when glacially fed rivers deposit their sediment in stream channels and the associated plain. Due to continual channel shifting the sediment is spread across an area called an outwash plain. Outwash plains typically have braided rivers consisting of multiple, wide, shallow channels characterized by rapid erosion, deposition and channel shifts.

Glacial till—A surface formed by sediment originating directly from glacial ice and typically has no discernible sediment stratification.

GPS—Global Positioning System—The GPS is a worldwide satellite navigation system that is funded and supervised by the U.S. Department of Defense. GPS satellites transmit specially coded signals. These signals are processed by a GPS receiver that computes extremely accurate measurements, including 3-dimensional position, velocity, and time on a continuous basis.

Graminoid—Grasses and grass-like plants, including sedges and rushes.

Grassland—Vegetation dominated by perennial graminoid plants.

Ground layer—Applies to the herbaceous layer.

Growth form—The shape or appearance of a plant; it primarily reflects the influence of growing conditions.

Herbaceous—A vascular plant without significant woody tissue above or at the ground; an annual, biennial, or perennial plant lacking significant thickening by secondary woody growth, with perennating buds borne at or below the ground surface (hemicryophytes, geophytes, helophytes, and therophytes of Raunkier).

Ice wedge polygons—Refers to patterned ground with polygons typically connected in a polygonal pattern that is similar to the pattern produced by mud cracks. They are formed by large masses of ice—called ice wedges—that grow in thermal contraction cracks in permafrost.

Image—pictorial representation of a scene recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired by non-photographic methods.

Interpretation—The process in which a person extracts information from an image.

IR color photograph—Color photograph in which the red-imaging layer is sensitive to photographic IR wavelengths, the green-imaging layer is sensitive to red light, and the blue-imaging layer is sensitive to green light. Also known as camouflage detection photographs and false-color photographs.

Krummholz—Growth form assumed by tree species at the upper treeline or in the alpine zone; characterized by a creeping and multi-stemmed growth pattern due to desiccation and physical damage caused by wind and blowing ice crystals near the upper treeline; the same species grows as an erect, single-stemmed tree at lower elevation.

Lacustrine deposits—derived from materials deposited in lake water and exposed when the water level is lowered or the land is raised.

Landsat (formerly ERTS)—The Landsat program, first known as the Earth Resources Technology Satellite (ERTS) Program, is a development of the National Aeronautics and Space Administration (NASA) in association with NOAA, USGS, and the Space Imaging. The activities of these combined groups led to the concept of dedicated Earth-orbiting satellites, the defining of spectral and spatial requirements for their instruments, and the fostering of research to determine the best means of extracting and using information from the data. The first satellite, ERTS 1, was launched on July 23, 1972. The second satellite was launched on January 22, 1975. Concurrently, the name of the satellites and program was changed to emphasize its prime area of interest (land resources). The first two satellites were designated as Landsats 1 and 2. Landsat

3 was launched on March 5, 1978. Landsat 4 was launched on July 16, 1982. Landsat 5 (launched March 1, 1984) is currently in service providing selected data to worldwide researchers.

Lichen—An organism generally recognized as a single plant that consists of a fungus and an alga or cyanobacterium living in symbiotic association.

Life form—The shape or appearance of a plant that mostly reflects inherited or genetic influences.

Low shrub—Low-growing shrub life form between 0.1 and 1 meter tall.

Matted—Describes a creeping plant that by reiterative growth has overlapping stems and forms a low, dense ground cover.

Mesic—Sites are moist and tussocks may dominate. Permanent standing water is not present.

Mixed forest—Describes vegetation in which evergreen and deciduous species each generally contribute 25-75% to the total canopy cover.

Montane—Describes the zone in mountainous regions where the influence of altitude (vertical relief) results in local climatic regimes that are sufficiently different from those in the adjacent lowlands as to cause a complex vertical climate-vegetation-soil zonation; includes vegetation at the base of a mountain when it is different from lowland vegetation.

Mosaic—Composite image or photograph made by piecing together individual images or photographs covering adjacent areas.

Nonvascular plant—A plant without specialized water or fluid conductive tissue (xylem and phloem); includes bryophytes, lichens, and algae.

Patterned ground—Refers to regions with perennially frozen ground that often have their surface materials arranged into distinct geometric shapes. The features, collectively known as patterned ground, include polygons, nets, circles and stripes.

Pavement—A relatively flat surface of consolidated material, generally exposed bedrock.

Perennial—Plant species with a life-cycle that characteristically lasts more than two growing seasons and persists for several years.

Pingo—These are ice-filled conical hills or mounds, 20 to 400 m in diameter and 10 to 70 m high.

Pixel—Contraction of picture element.

Plant association—The finest level of both the Viereck et al. (1992) and National Vegetation Classification System (Grossman et al. 1998) classifications. It is defined as "a plant community type of definite floristic composition, uniform habitat conditions, and uniform physiognomy" (Flahault and Schroter 1910).

Prostrate shrub—Shrub life form growing less than 0.1 meters tall.

Pulvinate mosses—Mosses growing in cushion-like mats or clumps.

Remote sensing—Collection and interpretation of information about an object without being in physical contact with the object.

Resolution—Ability to separate closely spaced objects on an image or photograph. Resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished. Also called spatial resolution.

Rock Glacier—Tongue-shaped or lobate masses of unsorted, angular frost-rived material with interstitial ice. They typically originate in cirques or in high, steep-walled recesses.

Saltwater—Water with a salinity of greater than 30 parts per thousand.

Satellite—An object in orbit around a celestial body.

Scene—Area on the ground that is covered by an image or photograph.

Scree—A sheet of coarse rock debris covering a mountain slope without an adjacent cliff.

Scrub—Vegetation dominated by shrubs, including thickets.

Seasonal—Showing periodicity related to the seasons; applied to vegetation exhibiting pronounced seasonal periodicity marked by conspicuous physiognomic changes.

Shrub—A perennial woody species with a life form that is usually less than 4 to 5 meters or 13 to 4.8 meters in height; typically, plants have several stems arising from or near the ground, but this term includes short tuft-tree, bamboo, and woody vine species; length of vine may exceed 5 meters; shrub species growth form may be taller than 5 meters or single-stemmed under certain environmental conditions.

Solifluction (or gelifluction)—The flow of soil in association with frozen ground. During the spring and summer thaw, water in the active layer cannot penetrate below the permafrost table. Soils are often saturated, and the loss of friction and cohesion causes them to behave like viscous fluids. The soil thus slowly ‘flows.’ The downslope fronts of the solifluction lobes are marked by near-vertical scarps as high as 2 m.

Sorted circles—Similar to sorted polygons but circular in outline.

Sorted polygons—Refers to patterned ground where sorting separates the coarse from the fine soil particles, and typically produces a surface feature of fine materials bordered by stones in a variety of geometric shapes; polygons, circles, nets and stripes.

Sorted stripes—Refers to patterned ground that consists of linear alignments of soil, vegetation and stones on slopes. They are strips of stone separated by broad zones of finer sediment and vegetation. The strips are up to several meters in width and 100 m in length.

Sparsely vegetated—Describes vegetation with low total plant cover (between 15 and 25%) that is scattered; areas with high cover of crustose lichen and no other vegetation are included here.

Spectral reflectance—Reflectance of electromagnetic energy at specified wavelength intervals.

Stomata—Pores or openings for gas exchange that are generally concentrated on leaf surfaces.

Subalpine—Upper mountain vegetation immediately below the cold limits of tree and tall shrub growth.

Supervised classification—Digital-information extraction technique in which the operator provides training-site information that the computer uses to assign pixels to categories.

Tall shrub—Tall-growing shrub life form greater than 1 meter tall.

Talus—A sloping accumulation of coarse rock fragments at the base of a cliff.

Temperate—Geographically, the region between the polar and tropical regions; climatically, the region is moderate with distinct seasons of alternating long, warm summers and short, cold winters.

Terraces—Floodplains and outwash plains removed from frequent flooding due to down-cutting of the river.

Texture—Frequency of change and arrangement of tones on an image.

Thematic Data—Thematic data layers in a data set are layers of information that deal with a particular theme. These layers are typically related information that logically go together. Examples of thematic data would include a data layer whose contents are roads, railways, and river navigation routes.

Thematic Mapper (TM)—A cross-track scanner deployed on Landsat that records seven bands of data from the visible through the thermal IR regions.

Thermokarst—Refers to the collapse of the soil surface due to the thawing of ice rich permafrost, resulting in ponds and hills.

TM—Thematic mapper.

Topographic Map—Map that presents the horizontal and vertical positions of the features represented; distinguished from a planimetric map by the addition of relief in measurable form.

Topography—Configuration (relief) of the land surface; the graphic delineation or portrayal of that configuration in map form, as by contour lines; in oceanography the term is applied to a surface such as the sea bottom or a surface of given characteristics within the water mass.

Training area—A sample of the Earth's surface with known properties; the statistics of the imaged data within the area are used to determine decision boundaries in classification.

Training site—Area of terrain with known properties or characteristics that is used in supervised classification.

Treeline—A zone where the normal growth of trees is limited; cold temperatures often combined with drought form the upper or arctic treeline, and drought combined with hot temperatures form lower or arid treeline.

Tundra—The treeless region north of the Arctic Circle (arctic tundra) or above the treeline of high mountains (alpine tundra) and on some sub-Antarctic islands; characterized by very low winter temperatures, short cool summers, permafrost below a surface layer subject to summer melt, short growing season, and low precipitation.

Tussock—Graminoid life form consisting of bunch-like tufts, sometimes more than 1 meter or 3 feet tall, in which the hard, old, withered leaves are intermingled with the fresh, young, green leaves.

Type—A general term used in place of "vegetation type" or "alliance". Plant associations are often referred to as "types", but the term generally is not applied to alliances, and needs to be corrected in descriptions where it's used.

Understory—General term that in these descriptions applies to the shrub and herbaceous layers of a vegetation type, as well as the tree regeneration layer. We have tried to use "shrub layer" or "herbaceous layer" in most cases, but understory is used in some places. "Undergrowth" is the more specific term used for shrub and herbaceous layers in forests or woodland vegetation types, and has been little used in these descriptions.

Unsupervised classification—Digital information extraction technique in which the computer assigns pixels to categories with no instructions from the operator.

Vascular plant—Plant with water and fluid conductive tissue (xylem and phloem); includes seed plants, ferns, and fern allies.

Wet—Refers to sites where the dominant vegetation is emergent—not submerged or floating—and semi-permanent or standing water is present.

Woody plant—Plant species life form with woody tissue and buds on that woody tissue near or at the ground surface or above; plants with limited to extensive thickening by secondary woody growth and with perennating buds; includes phanerophytes and chamaephytes of Raunkier.

Woody—Containing lignified plant tissue.

Xeromorphic—Describes plants with morphological and physiological characters that tolerate persistently low water availability, such as succulence, specialized leaf surfaces for light reflectance or water retention, opportunistic leaf growth, leaf-size reduction with increased thickness and sunken stomata, revolute margins, or stem and leaf modification to form thorns or spines.

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