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Ducks Unlimited, Inc.

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# Kvichak Earth Cover Classification



## **Mission Statement**

The Bureau of Land Management (BLM) sustains the health, diversity and productivity of the public lands for the use and enjoyment of present and future generations.

## **Partners**

The Department of the Interior's Bureau of Land Management and Ducks Unlimited, Inc. completed this project under a cooperative agreement.

## **Cover**

The cover photo shows a portion of the Kvichak Project Area. It depicts the remoteness of the area and the need to use helicopters for data collection.

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# **Kvichak Earth Cover Classification**

Technical Report  
October 2002

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# Abstract

The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) have been cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and GIS technologies since 1988. The goal of this project was to continue the mapping effort by mapping the Kvichak project area, which contains Lake Iliamna and the lower portions of the Nushagak and Kvichak Rivers. Portions of four Landsat TM satellite scenes (Path 71, Rows 18, and 19, acquired 09/99; and Path 72, Rows 18 and 19, acquired 09/00) were used to classify the project area into 30 earth cover categories. An unsupervised clustering technique was used to determine the location of field sites and a custom field data collection form and digital database were used to record field information. A helicopter was utilized to gain access to field sites throughout the project area. Global positioning system (GPS) technology was used both to navigate to pre-selected sites and record locations of new sites selected in the field. Data were collected on 296 field sites during a 9-day field season from 7/1/00 through 7/9/00. Approximately 25% (64) of these field sites were set aside for accuracy assessment. A modified supervised/unsupervised classification technique was performed to classify the satellite imagery. The classification scheme for the earth cover inventory was based on Viereck et al. (1992) and revised through a series of meetings coordinated by the BLM – Alaska and DU. The overall accuracy of the mapping categories was 79.7% at the +/-5% level of variation in interpretation of the accuracy assessment reference sites.

# Introduction

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The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) began cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and GIS technologies in 1988 (Ritter et al. 1989). Early mapping projects focused exclusively on wetlands (Ritter et al. 1989) but it was apparent that mapping the entire landscape was more cost effective and ultimately more useful to land managers. The BLM is creating a satellite-based earth cover inventory of all BLM managed lands in Alaska. Many other agencies in Alaska (e.g., National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, Alaska Department of Natural Resources, Alaska Department of Fish and Game) are also using similar techniques, and cooperating on these mapping projects. This earth cover mapping effort provides an inventory of Alaska's land base that can be used for regional management of land and wildlife. Earth cover databases allow researchers, biologists, and managers to define and map crucial areas for wildlife; perform analysis of related habitats; detect changes in the landscape; plot movement patterns for large ungulates; generate risk assessments for proposed projects; and provide baseline data to which wildlife and sociological data can be related.

Landsat Enhanced Thematic Mapper (ETM) satellite imagery was chosen as the primary source for the BLM/DU earth cover mapping effort. Satellite imagery offered a number of advantages for region-wide projects. TM data was cost effective, processed using automated mapping techniques, and collected on a cyclical basis, providing a standardized data source for future database updates or change detection

studies (Kempka et al. 1993). In addition, TM imagery included a mid-infrared band, which was sensitive to both vegetation and soil moisture content and was useful in identifying earth cover types. When combined with other GIS data sets, (e.g., elevation, slope, aspect, shaded relief, and hydrology), Landsat TM data produced highly accurate classifications with a moderately detailed classification scheme.

The Kvichak Earth Cover Mapping project area contained diverse landscapes and was deemed important for its wildlife and recreational values. The project area extended from the upper Chulitna River in the north, to the Naknek River and town of King Salmon in the south, to the Iniskin Peninsula and Chinitna Bay in the east, and west to Kvichak Bay. The project area entirely encompasses Lake Iliamna.

The project area was essentially un-roaded and supported remote recreational use with many hunting and fishing camps scattered throughout the area. These camps were accessed primarily via boat or plane. The project area included an abundant moose and tundra swan population, and large herds of caribou. The earth cover data aid in the critical process of resource planning in this valuable and diverse area.

## Project Objective

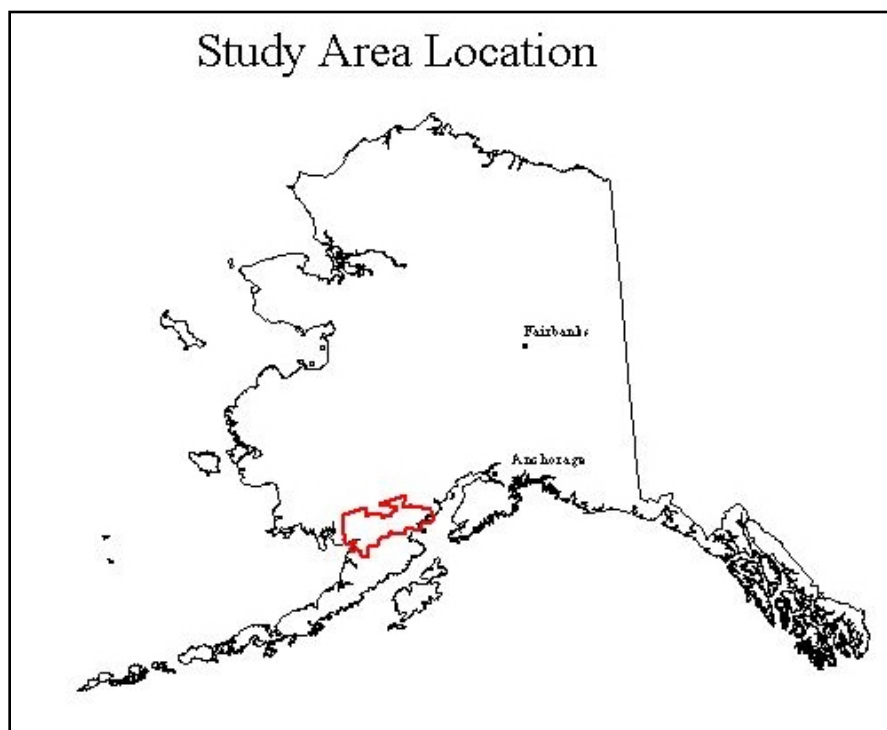
The objective of this project was to develop a baseline earth cover inventory using Landsat TM imagery for the Kvichak and associated areas. More specifically, this project purchased, classified, field verified, and produced high quality, high resolution

digital and hard copy resource base maps. The result of this project was an integrated GIS database that can be used for improved natural resources planning.

## Project Area

The Kvichak mapping project consisted of 6.5 million acres centered roughly on Lake Iliamna, the largest freshwater lake in Alaska. The Kvichak River drains Lake Iliamna to the west into Kvichak Bay. The project area includes small portions of the Katmai and Lake Clark National Parks and it is contained on the following USGS 1:250 scale quadrangles: Dillingham, Naknek, Iliamna, and Lake Clark. The community of King Salmon is on the Naknek River in the southwest portion of the project area.

The project area encompassed a wide variety of environments ranging from glaciated mountains to lowland shrub-tundra complexes and tidal flats. Steep mountainous terrain with broad valleys comprised mostly of shrub and deciduous cover types were located to the east and north of Lake Iliamna. The eastern portion of the project area was comprised mostly of small shrub and lichen cover types. Many caribou and moose were observed in this area. Innumerable small lakes and ponds supported the pond lilies and other aquatic vegetation that make up an important summer food source for breeding tundra swans. Brown bears were observed primarily in the western portion of the study area, particularly on the tidal marshes. With the imagery acquisition dates of July 1999, and July 2000 most all wildfires that had burned over the study area were indicated on the 1999 satellite imagery.



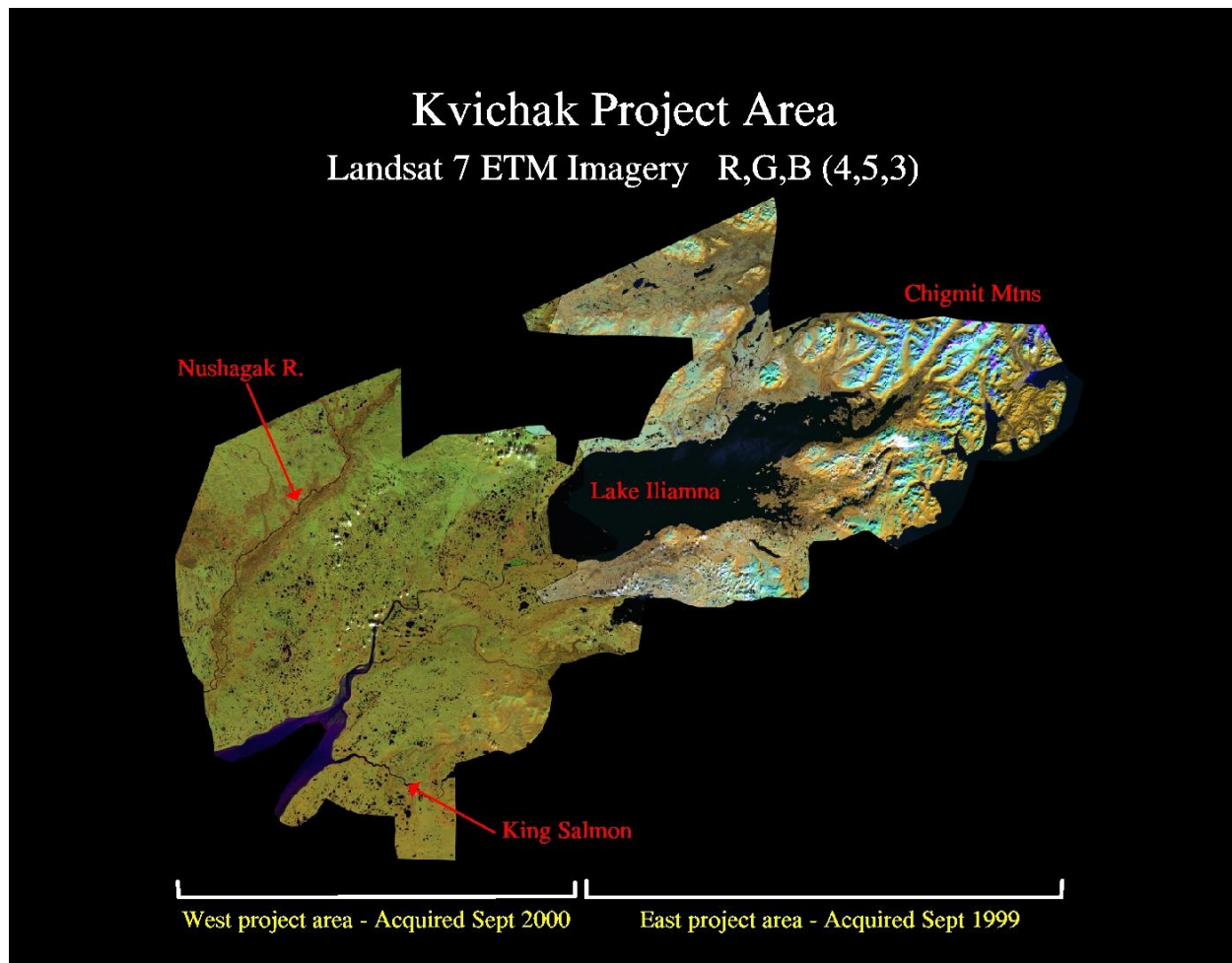
**Figure 1.** Kvichak project location.

## Data Acquisition

Four Landsat-7 ETM scenes were obtained to cover the project area. Imagery from Sept, 1999 were acquired from the BLM (Path 71 Rows 18 and 19) and two scenes were purchased from EROS Data Center in Albers Equal Area projection and were terrain corrected by ImageLinks, Inc., Melbourne, FL (Path 72 Rows 18 and 19 – Sept 2000). The image data contained moderate cloud cover in two or three general

locations in the project area. The imagery shows abundant snow and ice in the northeast part of the project area, despite the late summer acquisition date.

Field data were collected on 296 field sites during an 8-day field season from 7/1/01 through 7/9/01. The ancillary data used in this project included: 1:60,000 aerial photographs (color infrared transparencies from 1978-94, USGS 1:250,000 scale Digital Elevation Models (DEM), and training site data from a land classification effort in 1992.



**Figure 2.** Satellite imagery used for the Kvichak earth cover mapping project.





# Methods

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## Classification Scheme

The classification system categorized the features to be mapped. The system was derived from the anticipated uses of the map information and the features of the earth that could be discerned by TM data. The classification system had two critical components: (1) a set of labels (e.g., forest, shrub, water); and (2) a set of rules, or a system for assigning labels. The set of rules for assigning labels was mutually exclusive and totally exhaustive (Congalton 1991). Any given area fell into only one category and every area was to be included in the classification.

Until recently, the BLM/DU classification systems were project specific. As projects expanded in size and as other cooperators began mapping and sharing data across Alaska, the necessity for a standardized classification system became apparent. At the BLM Earth Cover Workshop in Anchorage on 3-6 March 1997, a classification system based on the existing Alaska Vegetation Classification (Vioreck et al. 1992) (Table 3) was designed to address this need. The goal of this meeting was to (1) develop an earth cover classification system for the state of Alaska that can be used in large regional mapping efforts, and (2) build consensus for the system among multiple land management agencies. The classification system has been slightly improved since the last meeting.

The classification scheme consisted of 10 major categories and 27 subcategories. A classification decision tree and written description (Appendices A and B) was

developed in order to clarify the classification. Though based largely on Level III of the Vioreck et al. (1992) classification, some classes have been modified, added or omitted for these mapping projects: e.g., rock, water, ice, cloud and shadow classes were added. Other classes that could not reliably be discerned from satellite imagery had to be collapsed, such as open and closed low shrub classes, or dryas, ericaceous, willow, and dwarf shrub classes. Because of the importance of lichen for site characterization and wildlife, and because the presence of lichen can be detected by satellite imagery, shrub and forested classes with and without a component of lichen were distinguished. A few classes from Level IV of the Vioreck et al. (1992) classification were also mapped because of their identifiable satellite signature and their importance for wildlife management. These Level IV classes included tussock tundra, low shrub tussock tundra and low shrub willow/alder.

## Image preprocessing

Each image was examined for quality and consistency. Each band was examined visually and statistically by reviewing histograms. Combinations of bands were displayed to check for band-to-band registration and for clouds, shadows, and haze. Positional accuracy was checked by comparing the image to available ancillary data such as adjacent imagery, hydrography, and DEMs. The images of the same date and path were mosaiced together and clipped

**Table 1.** Classification scheme developed at the BLM Earth Cover Workshop.

Level II	Level III	Level IV
1.0 Forest	1.1 Closed Needleleaf 1.2 Open Needleleaf 1.3 Woodland Needleleaf  1.4 Closed Deciduous  1.5 Open Deciduous  1.6 Closed Mixed Needleleaf/Deciduous 1.7 Open Mixed Needleleaf/Deciduous	1.21 Open Needleleaf Lichen 1.31 Woodland Needleleaf Lichen  1.41 Closed Paper Birch 1.42 Closed Aspen 1.43 Closed Balsam Poplar/Cottonwood 1.44 Closed Mixed Deciduous 1.51 Open Paper Birch 1.52 Open Aspen 1.53 Open Balsam Poplar/Cottonwood 1.54 Open Mixed Deciduous
2.0 Shrub	2.1 Tall Shrub 2.2 Low Shrub  2.3 Dwarf Shrub	2.21 Low Shrub Willow/Alder 2.22 Low Shrub Tussock Tundra 2.23 Low Shrub Lichen 2.24 Low Shrub Other  2.31 Dwarf Shrub Lichen 2.32 Dwarf Shrub Other
3.0 Herbaceous	3.1 Bryoid  3.2 Wet Herbaceous  3.3 Mesic/Dry Herbaceous	3.11 Lichen 3.12 Moss  3.21 Wet Graminoid 3.22 Wet Forb  3.31 Tussock Tundra 3.32 Mesic/Dry Sedge Meadow 3.33 Mesic/Dry Grass Meadow 3.34 Mesic/Dry Graminoid 3.35 Mesic/Dry Forb
4.0 Aquatic Vegetation	4.1 Aquatic Bed 4.2 Emergent Vegetation	
5.0 Water	5.1 Snow 5.2 Ice 5.3 Clear Water 5.4 Turbid Water	
6.0 Barren	6.1 Sparsely Vegetated 6.2 Rock/Gravel 6.3 Mud/Silt/Sand	
7.0 Urban		
8.0 Agriculture		
9.0 Cloud/Shadow	9.1 Cloud 9.2 Shadow	
10.0 Other		

to the project boundary. Due to differences in target and sensor conditions, it is not recommended to mosaic and process imagery acquired on different dates. Because we used imagery from Sept 99 for the east part of the project area, and imagery from Sept 2000 for the west part of the project area, we had two separate classification efforts to cover the project area - east and west. A boundary line between the east and west areas was carefully digitized to maximize use of cloud free parts of each raw image.

In order to optimize helicopter efficiency, field sites were identified and plotted on field maps before fieldwork began. Sufficient samples for each mapped class were selected to span the variation of spectral responses within that class throughout the entire image. For example, a shrub class in the southern part of an image may have a different spectral response than the same shrub class in the northern part of that image. Many factors contribute to such variation, including aspect, terrain shadow, or small differences in soil moisture. In addition, each earth cover type encompassed a variety of subtypes; e.g., the open needleleaf class included forested areas with 25%-60% crown closure, trees of varying height, and a diverse understory composition.

An unsupervised classification was used to identify spectrally unique areas within the study area. The image analyst individually selected training sites from these spectrally unique areas. Whenever possible, training sites were grouped in clusters to reduce the amount of travel time between sites. The image analyst also placed training sites near landmarks that were easily recognizable in the field, such as lakes or streams. The coordinates of the center points of the field sites were then uploaded into a Y-code Rockwell Precision Lightweight GPL

receiver (PLGR) for navigational purposes. Training sites were overlain with the satellite imagery and plotted at 1 inch = 1 mile scale. These field maps were used for recording field notes, placing additional field sample sites, and navigating to field sites.

## Field Verification

The purpose of field data collection was to assess, measure, and document the on-the-ground vegetation variation within the project area. This variation was correlated with the spectral variation in the satellite imagery during the image classification process. Low-level helicopter surveys were a very effective method of field data collection since a much broader area was covered with an orthogonal view from above, similar to a satellite sensor. In addition, aerial surveys were often the only alternative in Alaska due to the large amount of roadless areas.

In order to obtain a reliable and consistent field sample, a custom field data collection form (Kempka et al. 1994) was developed and used to record field information (Figure 3). A four-person helicopter crew performed the field assessment. Each crew consisted of a pilot, biologist, recorder, and navigator.. The navigator operated the GPS equipment and interpreted the satellite image derived field maps to guide the biologist to the pre-defined field site. It was valuable for the image processor to gain first-hand knowledge of the project area, so therefore the image processor had the navigator role. The biologist identified plant species, estimated the percent cover of each cover type, estimated the overall earth cover class, and photographed the site. The recorder wrote species percentages and other data on

### Sample Field Form

Rev 7/15/97

1997-XXXX		1 - XXX		DEISHILF		Obs. Date: 8/13/97		1/3 3 4		Obs. Time: 16:27	
Yr	Project	Crew	Site Number	Observers		Mo Day Year		Obs. Level		Hr Min	

Digital Photo 2 12, 13		LAT (GPS) _____		LONG (GPS) _____	
Session # Photo #		Decimal Degrees		Decimal Degrees	

%Slope (Avg) 45	Elev	Aspect: N NE E SE S SW W NW Flat
-----------------	------	----------------------------------

Average Distance Between Stems: 10-15' 15-20' 20-25' 25-30' 30-35' 35-40' (Open or Woodland Needleaf Only)					
--	--	--	--	--	--

(Circle Lichen where present)							
Forest	Forest	Shrub	Herbaceous	Herbaceous	Aquatic Veg/Water	Barren	Other
Closed Needleaf	Open Deciduous	Tall	Lichen	Dry Sedge	Aquatic Bed	Sparse Veg	Other
Open Needleaf	Closed Mixed	SA/AL Low	Moss	Dry Graminoid	Emergent	Rock/Gravel	
Woodland Needleaf	Open Mixed	Tussock Low	Wet Sedge/Gr	Dry Sedge/Gr	Snow/Ice	Mud/Silt/Sand	
Wldnd Ndlf-Lichen		Other Low-Lichen	Wet Forb	Dry Forb	Turbid Water		
Closed Deciduous		Dwarf-Lichen	Tussock-Lichen		Clear Water		

%Cov	Height	TREES	
50	14	White Spruce	Picea glauca
		Black Spruce	Picea mariana
30	15	Aspen	Populus tremuloides
	15	Birch	Betula papyrifera
		Balsam Poplar	Populus balsamifera
		Larch, Tamarack	Larix laricina

%Cov	Height	SHRUBS	
	1.5	Willow	Salix spp.
		Alder	Alnus crispa
		Dwarf Arctic Birch	Betula nana/glandulosa
		Blueberry	Vaccinium uliginosum
		Low Bush Cranberry	Vaccinium vitis-idaea
		Bearberry	Arctostaphylos spp.
		Kinnikinnick	Arctostaphylos uva-ursi
		Crowberry	Empetrum nigrum
		Alpine Azalea	Loiseluria procumbens
		Mountain Avens	Dryas spp.
		Mountain Bell Heather	Cassiope tetragona
		Labrador Tea	Ledum palustre
5	0.4	Rose	Rosa acicularis
		Cinquefoil	Potentilla spp.
		Firquand	

%Cov	HERBACEOUS	
	Sedge/Graminoid	
	Grass	
	Poa	Poa spp.
	Cotton Grass	Eriophorum spp.
	Holy Grass	Hierochloa alpina
	Sedge	Carex spp.
85	Subtotal % Cover	

%Cov	HERBACEOUS cont.	
	Forbs	
	Sedfrage	Sedfrage spp.
	Vetch	Astragalus spp.
	Horsetails	Equisetum spp.
	Fireweed	Epilobium spp.
	Coltsfoot	Petasites frigidus
	Cinquefoil	Potentilla spp.
	Bistort	Polygonum spp.
	Rubus	Rubus spp.
5	Bryoid	
	Moss	
	Lichen	Color:

%Cov	AQUATIC	
	Water Lily	Nuphar polysepalum
	Pondweed	Potamogeton spp.
	Buttercup	Ranunculus spp.
	Mare's Tail	Hippuris spp.
	Buckbean	Menyanthes trifoliata
	Marsh Fivefinger	Potentilla palustris
	Horsetails	Equisetum spp.

%Cov	NON-VEGETATED	
	Clear/Turbid Water	(circle one)
	Snow/Ice	(circle one)
	Mud/Silt/Sand	(circle one)
	Gravel/Rock	(circle one)
	Litter	
10	Bare Ground	
15	Subtotal % Cover	
100	GRAND TOTAL % COVER	

C#	COMMENTS

CALL CLASS M.N.E.E.D. NPS SHH

Figure 3. Custom field data collection form.

the field form and generally assisted the biologist. An alternate person was responsible for crew check-ins, data entry, and substitution in case of sickness. This person remained at the base of operations. The majority of sites were observed without landing the helicopter. Ground verification was performed when identification of dominant vegetation was uncertain.

These DU/BLM procedures for collecting field data have evolved into a very efficient and effective means of data collection. The navigator used a GPS to locate the site and verified the location on the field map. As the helicopter approached the site at about 300 meters above ground level the navigator described the site and the biologist took a picture with a digital camera. The pilot then descended to approximately 5-10 meters above the vegetation and laterally moved across the site while the biologist called out the vegetation to the recorder. The biologist took another picture with the digital camera for a close-up view of the site. The pilot then ascended to approximately 100 meters so that the biologist could estimate the percentages of each species to the recorder. The navigator then directed the pilot to the next site. On average, it took approximately 4-6 minutes to collect all of the information for one site.

## **Field Data Analysis**

The collected field information was entered into a digital database using a custom data entry application (DUFF), designed jointly by the BLM and DU and programmed by GeoNorth. The relational database was powered by SQL Anywhere while the user interface was programmed in Visual Basic. The user interface was organized similarly to the field form to facilitate data entry (Figure 4). The application utilized pull down menus to minimize keystrokes and checked for data

integrity to minimize data entry errors. The database program also calculated an overall class name for each site based on the recorded species and its cover percentage. Digital images from each site were stored in the database and accessible from within the user interface. The number of field sites per earth cover class was tracked daily to ensure that adequate samples were being obtained within each class.

## **Classification**

Every image is unique and presents special problems in the classification process. The approach used in this project (Figure 5) has been proven successful over many years. The image processor was actively involved in the field data collection and had first hand knowledge of every training site. The image processor's site-specific experience and knowledge in combination with high quality ancillary data overcame image problems to produce a high quality, useful product.

ERDAS Imagine (vers. 8.5) was used to perform the classification as well as to manage the field site polygons. Various word processing and data analysis software packages were also used during the image classification including MS Word, Excel, Access, and ESRI ArcView 3.2a.

## **Generation of New Bands**

The Landsat TM imagery contained 7 bands of data: 3 visible bands, 1 near-infrared band, 2 mid-infrared bands, and 1 thermal band. One new band was generated for this project. This new band was created using a band-4/band-3 ratio, a band ratio that typically reduces the effect of shadows in the image and enhances the differences between

## Sample Field Site – Closed Mixed Needleleaf/Deciduous



High site photo



Low site photo

## DUFF INTERFACE

**Ducks Unlimited**  
File Tools Help

1997 XXXX 1 XXX  
Year Project Crew Site  
(click to search) Delete New

Observation Crew ☐ Check Flag (military)  
Nav Veg Rec Observ Date Obs Level Obs Time  
DF JH LF 03-Aug-97 2 16:27 Update

Session Photo  
2 -> 13  
2 -> 12

Lat (degrees, decimal min) Long % Slope Elev Aspect Avg Dist Btwn Stem  
00d00.00000 000d00.0000 45 0. SE

All Species ☒ Latin ☐ Common ☐ Show All Species  
Add ... Delete Edit ...

**Observed Classes**

- ☐ FOREST- CLOSED NEEDLELEAF
- ☐ FOREST- OPEN NEEDLELEAF
- ☐ FOREST- OPEN NDLF-LICHEN
- ☐ FOREST- WOODLAND NEEDLELEAF
- ☐ FOREST- WOODLND NDLLF-LICHEN
- ☐ FOREST- CLOSED DECIDUOUS
- ☐ FOREST- OPEN DECIDUOUS
- ☒ FOREST- CLOSED MIXED
- ☐ FOREST- OPEN MIXED
- ☐ SHRUB- TALL
- ☐ SHRUB- SA/AL LOW
- ☐ SHRUB- TUSsock LOW
- ☐ SHRUB- OTHER LOW
- ☐ SHRUB- OTHER LOW-LICHEN
- ☐ SHRUB- DWARF
- ☐ SHRUB- DWARF-LICHEN
- ☐ HERBACEOUS- LICHEN
- ☐ HERBACEOUS- MOSS

**Observed Species**

Symbol	Latin	Common	% Cov	Height
POTR1C	POPULUS TREMULOIDES	ASPEN,QUAKING	30	15
ALCR6	ALNUS CRISPA	ALDER, GREEN	0	1.5
BEPA	BETULA PAPHYRIFERA	BIRCH,PAPER	0	15
ROAC	ROSA ACICULARIS	ROSE,PRICKLY	5	0.4
MOXX	MOSS	MOSS	5	0
BARE	BARE GROUND	BARE GROUND	10	0
PIGL	PICEA GLAUCA	SPRUCE,WHITE	50	14
GRASS	GRASS	GRASS	0	0

Comments Sum of % Covers : 100

Calculated Class 1.6 CLOSED MIXED NEEDLELEAF/DECIDUOUS

**Aerial Photos**

Flight Line	Photo #	Date	Source

**Quad**

Quad

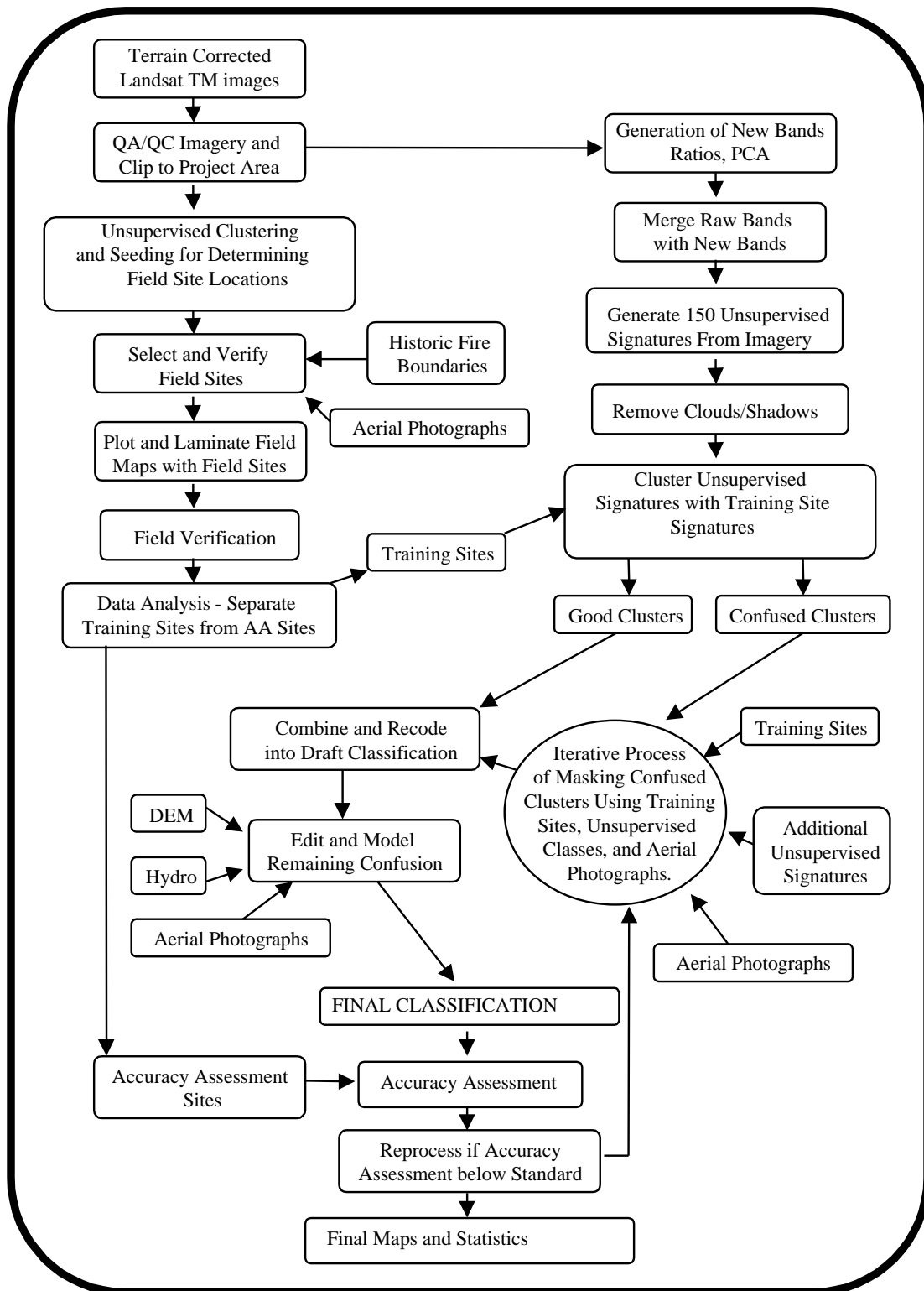
**Satellite Image**

Image #

**TRS**

Township	Range	Section

Figure 4. The customized database and user interface for field data entry (DUFF).





**Figure 5.** The image processing flow diagram. vegetation types (Kempka et al. 1995, Congalton et al. 1993). This 4/3 ratio band replaced thermal band (band 6) to retain a 7-band image for classification.

### Removal of Clouds and Shadows

The majority of clouds and cloud shadows that were present on the imagery were removed from before field sites were selected. This process eliminated any confusion between clouds, cloud shadows, and other vegetation types. They were removed using an unsupervised classification and manual on-screen editing. Clouds were separated from shadows and classes were recoded to their respective class number. The cloud/shadow layer is then combined with the rest of the classified image during the last step in the classification process.

### Seeding Process

Spectral signatures for the field sites to be used as training areas were extracted from the imagery using a “seeding” process in ERDAS Imagine. A pixel within each training area was chosen as a “seed” and adjoining pixels were evaluated for inclusion in each training site using a threshold value based on a spectral euclidean distance. The standard deviations of the seeded areas were kept close to or below 3 and all seeded areas were required to be over 15 pixels (approximately 3.75 acres) in size. Along with the field training areas, additional “seeds” were generated for clear water, turbid water, and snow classes. These classes were easily recognized on the imagery and aerial photography. The output of the seeding process in Imagine was a signature file that contains all of the statistics for the training areas. The signature file was then used in the modified supervised/unsupervised classification.

### Generation of Unsupervised Signatures

An unsupervised classification was generated using the six raw bands and the 4/3 ratio. One hundred and fifty signatures were derived from the unsupervised classification using the ISODATA program in Imagine. The output of this process was a signature file similar to that of the seeding process but containing the 150 unsupervised signatures. A maximum likelihood classification of the 150 unsupervised signatures was generated using the supervised classification program in Imagine.

### Modified Supervised/Unsupervised Classification

A modified supervised/unsupervised classification approach (Chuvieco and Congalton 1988) was used for the classification. This approach used a statistical program to group the spectrally unique signatures from the unsupervised classification with the signatures of the supervised training areas. In this way, the spectrally unique areas were labeled according to the supervised training areas. This classification approach provided three major benefits: (1) it aided in the labeling of the unsupervised classes by grouping them with known supervised training sites; (2) it helped to identify classes that possessed no spectral uniqueness (i.e., training sites that were spectrally inseparable); and (3) it identified areas of spectral reflectance present in the imagery that had not been represented by a training site. This approach was an iterative process because all of the supervised signatures do not cluster perfectly with the unsupervised signatures the first time. The unsupervised signatures that matched well with the supervised signatures were inspected, labeled with the appropriate class label, and removed from the classification process. The remaining confused clusters were grouped into general

categories (e.g., forest, shrub, non-vegetation) and re-run through the process. This process was repeated until all of the spectral classes were adequately matched and labeled, or until the remaining confused classes were spectrally inseparable. Throughout this iterative process, interim checks of classification accuracy were performed by intersecting the classified image with a coverage of the training sites to determine if the training sites were being accurately labeled by the classification. Areas with incorrectly classified training sites were run through further iterations of the supervised/unsupervised classification and further refined. The iterative process of interim accuracy assessments and refining classifications was terminated when the accuracy assessments indicated no improvements between one iteration and the next.

## Editing and Modeling

Models that incorporated ancillary data sets such as elevation, slope, aspect, shaded relief, etc. helped to separate confused classes. For instance, terrain shadow/water confusion was easily corrected by creating a model using a shaded relief layer derived from DEMs.

For this project, the final steps of the classification process were to model the confused classes remaining after the iterative supervised/unsupervised classification process and to make final edits in areas that still had classification errors. Editing of classification errors was a process of comparing the classified image to the raw satellite image, aerial photography, and notes on field maps to identify errors remaining in the classification. These errors were then corrected by manually changing the class value for the pixels that were classified in error to their correct class value.

## Accuracy Assessment

There were two primary motivations for accuracy assessment: (1) to understand the errors in the map (so they can be corrected), and (2) to provide an overall assessment of the reliability of the map (Gopal and Woodcock, 1992). Factors affecting accuracy included the number and location of test samples and the sampling scheme employed. Congalton (1991) suggested that 50 samples be selected for each map category as a rule of thumb. This value has been empirically derived over many projects. A second method of determining sample size includes using the multinomial distribution and specifying a given confidence in the estimate (Tortora 1978). The results of this calculation tend to favorably agree with Congalton's rule of thumb. Once a sample size is determined, it must be allocated among the categories in the map. A strictly proportional allocation is possible. However, the smaller categories in areal extent will have only a few samples that may severely hamper future analysis. The other extreme is to force a given number of samples from each category. Depending on the extent of each category, this approach can significantly bias the results. Finally, a sampling scheme must be selected. A purely random approach has excellent statistical properties, but is practically difficult and expensive to apply. A purely systematic approach is easy to apply, but could result in sampling from only limited areas of the map.

## Alaska Perspective

Obtaining adequate reference data for performing an accuracy assessment can be extremely expensive in remote areas. Aircraft is the only means of transportation throughout most of Alaska. Aerial photographs are available for most of Alaska, but most are at a scale that makes it difficult if not impossible to distinguish some vegetation classes.

Ideally, fieldwork would be performed during one summer, the classification would be performed during the winter, and the reference data would be collected the next summer. This procedure would allow a stratified random sample of the classification and ensure adequate sampling of all the classes. Unfortunately, this methodology is not typically feasible due to the cost of obtaining the field data in Alaska.

In this project, the fieldwork for obtaining the training sites for classifying the imagery and the reference data for the accuracy assessment was accomplished at the same time. Special care was taken during the preprocessing stage and in the field to make sure adequate samples were obtained. However, funding limitations did not allow for the number of samples suggested for each class ( $n=50$ ) for the accuracy assessment. Some earth cover classes were naturally limited in size and distribution, so that a statistically valid accuracy assessment sample could not be obtained without additional field time. For classes with low sample sizes few, if any, field sites were withheld for the accuracy assessment. This does not indicate that the classification for these types is inaccurate but rather that no statistically valid conclusions can be made about the accuracy of these classes. However, withholding even a small percentage of sites for the accuracy assessment provided some confidence in the classification and guided the image processor and end user in identifying areas of confusion in the classification.

### Selection of Accuracy Assessment Sites

Approximately 30% of the collected field sites were set aside for use in the assessment of map accuracy while the remaining sites were utilized in the classification process. Unfortunately, given time and budget constraints it was not always possible to obtain

enough sites per class to perform both the classification and a statistically valid accuracy assessment. A minimum of 15 sites in an individual class (5 for accuracy assessment, 10 for image processing training sites) was required before any attempt was made to assess the accuracy of that class. Classes with less than 15 field sites were still classified. However, much fewer, if any, field sites were utilized for accuracy assessment for these classes. Accuracy assessment sites were selected randomly across the project area to reduce bias.

### Some Considerations

While the accuracy assessment performed in this project is by no means a robust test of the classification, it does give the user some confidence in using the classification. It also provides enough detail for the end user to determine where discrepancies in the classification may cause a problem while using the data. It is also important to note the variations in the dates of the imagery, aerial photographs, and field data. For this project, the imagery was from September, 1999 and September 2000; the aerial photographs spanned a six year period from 1978 through 1984, the field data was collected in June/July 2000. Differences due to environmental changes from the different sources may have had a major impact on the accuracy assessment.

A major assumption of quantitative accuracy assessments is that the label from the reference information represents the “true” label of the site and that all differences between the remotely sensed map classification and the reference data are due to classification and/or delineation error (Congalton and Green 1993). Unfortunately, error matrices can be inadequate indicators of map error because they are often confused by non-map error differences. Some of the non-map errors that can cause confusion are:

registration differences between the reference data and the remotely sensed map classification, digitizing errors, data entry errors, changes in land cover between the date of the remotely sensed data and the date of the reference data, mistakes in interpretation of reference data, and variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation.

In an effort to account for some of the variation in human interpretation in the accuracy assessment process, overall classification accuracies were also generated assuming a  $\pm 5\%$  variation in estimation of vegetation compositions for each of the accuracy assessment sites. In other words, if a variation in interpretation of  $\pm 5\%$  would have resulted in the generation of a different reference site label, this new label was also considered an acceptable mapping label for the reference site.

## Error Matrix

The standard method for assessing the accuracy of a map was to build an error matrix, also known as a confusion matrix, or contingency table. The error matrix compares the reference data (field site or photo interpreted site) with the classification. The matrix was designed as a square array of numbers set out in rows and columns that expressed the number of sites assigned to a particular category in the reference data relative to the number of sites assigned to a particular category in the classification. The columns represented the reference data while the rows indicated the classification (Lillesand and Kiefer, 1994). An error matrix was an effective way to represent accuracy in that the individual accuracy of each category was plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present

in the classification. A commission error occurred when an area was included in a category it did not belong. An omission error was excluding that area from the category in which it did belong. Every error was an omission from the correct category and a commission to a wrong category. Note that the error matrix and accuracy assessment was based on the assumption that the reference data was 100% correct. This assumption was not always true.

In addition to clearly showing errors of omission and commission, the error matrix was used to compute overall accuracy, producer's accuracy, and user's accuracy (Story and Congalton 1986). Overall accuracy was allocated as the sum of the major diagonal (i.e., the correctly classified samples) divided by the total number of samples in the error matrix. This value is the most commonly reported accuracy assessment statistic. Producer's and user's accuracies are ways of representing individual category accuracy instead of just the overall classification accuracy. Producer's accuracy, or error of commission, is the probability that any given site has been correctly classified. User's accuracy, or error of omission, is regarded as the reliability of the map in representing actual ground conditions. Users accuracy is generally regarded as being more pertinent to land managers, who often use the data to represent ground conditions for various analyses (Story and Congalton, 1986).

# Results

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## Field Verification

Data were collected on 296 field sites during a 9-day field season from 7/1/01 through 7/11/01, 132 sites in the east project area, and 164 sites in the west project area. We attempted to meet the 30% sample goal for selecting accuracy assessment sites, unfortunately many landcover classes contained too few sites. 22% (64 sites) were set aside for the accuracy assessment. The proportions of sites per class (Table 2) largely reflects the proportion of corresponding earth cover types within the project area, though proportionally more sites were collected for classes that exhibited greater variation in growth form and/or spectral response on the satellite imagery.

A French A-Star helicopter was used to gain access to the field sites. Two field camp locations were utilized during the field data collection of this project. A bed and breakfast in the village of Iliamna served as the staging area for the field crew, helicopter, field equipment during field work for the east project area. Fuel was obtained from the local vendor at the Iliamna airport. The field camp location for the west project area was the USFWS bunkhouse in King Salmon. Fuel was obtained at the King Salmon airport. Flight following was carried out by the alternate via satellite phone from both field camp locations.

## Classification

The three most extensive vegetated classes within the final classification were: dwarf shrub (698,483 acres or 10.76% of total area), low shrub (625,079 acres or 9.63% of total area), and tall shrub (542,102 acres or 8.35% of total area). In addition, extensive areas of low shrub lichen (467,074 acres or 7.20% of total area) and dwarf shrub lichen (341,063 acres or 5.25% of total area) were present throughout the study area. Large expanses of low shrub/dwarf shrub/grass complexes interspersed with open needleleaf were typical of the west project area. Tall shrub/mixed deciduous cover types with the occasional pure needleleaf stand characterize the east project area. In the mountainous northeast part of the project area, the valley bottoms contained primarily tall shrub. With increasing elevation, low shrub and dwarf shrub become the dominant cover types followed by sparse vegetation and rock of the ridge tops. The distribution of these types is characterized in Table 4 and Figure 7. Stands of closed needleleaf were found on low to mid elevation north facing slopes in the east project area. Closed birch and poplar were found throughout the project area but only formed extensive stands in riparian areas. No stands of aspen were mapped in the project area. Unfortunately, no consistent, reliable spectral signature could be derived for these often scattered and smaller stands of aspen. Cover types that contained at least 20% lichen were widespread throughout the project area, with the exception of the northeast corner where they occurred at upper elevations only.

**Table 2.** Field sites per mapped class

Class Name	Total Field Sites per Class	Sites Withheld for Accuracy Assessment
WOODLAND NEEDLELEAF – LICHEN	13	3
WOODLAND NEEDLELEAF	7	0
WET SEDGE / GRAMINOID	14	3
TUSsock TUNDRA	8	2
TALL SHRUB	38	10
SPARSE VEGETATION	6	1
ROCK GRAVEL	2	0
OTHER	1	0
OPEN POPLAR	1	0
OPEN NEEDLELEAF – LICHEN	4	0
OPEN NEEDLELEAF	13	4
OPEN MIXED NEEDLELEAF / DECIDUOUS	17	2
OPEN DECIDUOUS	5	0
NON-VEGETATED SOIL	2	0
MOSS	6	1
MESIC/DRY SEDGE MEADOW	6	1
MESIC/DRY GRASS MEADOW	8	2
MESIC / DRY GRAMINOID	3	0
MESIC / DRY FORB	1	0
LOW SHRUB WILLOW/ALDER	1	0
LOW SHRUB – TUSsock TUNDRA	7	2
LOW SHRUB – OTHER	26	7
LOW SHRUB – LICHEN	12	4
LICHEN	2	0
EMERGENT VEGETATION	1	0
DWARF SHRUB – OTHER	30	7
DWARF SHRUB – LICHEN	27	7
CLOSED POPLAR	1	0
CLOSED MIXED NEEDLELEAF / DECIDUOUS	11	5
CLOSED DECIDUOUS	10	2
CLOSED BIRCH	7	1
OPEN BIRCH	6	0
<b>TOTAL</b>	<b>296</b>	<b>64</b>

**Table 3.** List of field data collection participants.

Participant	Role	Agency
Scott Guyer	Biologist/Vegetation Expert	BLM
Jeff Denton	Biologist/Vegetation Expert	BLM
Alex Morton	Recorder/Alternate	DU
Dan Fehringer	Recorder/Alternate	DU
Becky Strauch	Recorder/Alternate	State of AK
Charlie Schrader-Patton	Navigator/Image Processor	DU – Spatial Solutions, Inc.

These lichen cover types accounted for over 13% of the project area. Differentiating between wet and dry graminoid proved to be difficult as the moisture and water level conditions visible on the satellite imagery and those observed in the field in 2001 in many of the forb/graminoid types appeared highly variable. Unfortunately, the class label for a given training site polygon is very sensitive to the presence of as little as 5% water. For instance, an area on the satellite imagery that appeared to contain 5-10% standing water was found to be almost dry during field reconnaissance. This discrepancy between the imagery and field conditions often resulted in a “dry” label for the polygon when the satellite image clearly portrayed the area as containing substantial amounts of water. As a result, there was initial confusion between forb/graminoid regions being classified as dry when there was obvious presence of standing water visible in the satellite imagery. There also was a tendency for these regions to be classified with lots of needleleaf, since needleleaf has relatively low reflectance values similar to water. Rock and sparse vegetation cover types were found mostly at the highest elevations, along stream and riverbanks and sandbars. Significant, mappable regions of snow and ice were found in the northeast part of the study area.. Snowfields were generally more extensive during field reconnaissance than on the imagery. Clouds were scattered in a number of locations throughout the project area; they accounted for .71% (206,427 acres) of the project area. These clouds and associated shadows were carefully edited to reduce committed errors caused by attenuated reflectance.

## Modeling

Modeling was performed using a shaded relief image and an elevation zone image

derived from USGS DEM at 1:250,000 scale. The shaded relief image was created in ERDAS Imagine using the solar azimuth and solar elevation listed in the header file for the TM image. The DEM was often used to help separate spectrally confused classes like terrain shadow and deep water. Elevation images were also used to model cover types that were slope, aspect or elevation limited. While these slope, aspect, and/or elevation limitations did provide good consistent measures for correcting misclassifications throughout the study area, they are not always to be trusted to represent actual vegetation occurrence 100% of the time. Therefore, careful manual confirmation of model results were performed and anomalies corrected following the execution of each spatial model.

Modeling was primarily used to identify misclassified areas. Since water, wet graminoid, needleleaf forest and shadow have similar spectral signatures these classes were often confused. Water obviously did not occur on a slope, but terrain shadows did, so a slope based model was used to search out shadowed areas that had been misclassified as water or wet graminoid. Tussock tundra signatures were confused with dwarf shrub, but unlike dwarf shrub, tussock tundra will not occur at higher elevations or on steep slopes. Modeling was also used to check for terrain shadow at higher elevations that had been misclassified as forest.

It is important to note that the modeling process was used primarily to identify *potentially* misclassified cover types throughout the study area. In order to maximize the reliability and classification accuracy in this mapping effort, manual review and editing techniques were utilized

to correct the misclassified pixels to their appropriate mapping classification.

## Editing

Editing was performed on all classes to various extents depending on how well the iterative classification process worked for each. The edits were verified with field sites, field photographs, aerial photography and field notes wherever possible. In addition, field site data from a classification effort in 1992 were also used. Some editing centered on ecological differences across the project area. For example, open needleleaf areas along the coast were being misclassified as low shrub. This was probably because there were no open needleleaf training sites in this particular part of the project area. Editing in this case consisted of correctly labeling and separating classes along ecological boundaries. Because the project area was very diverse, this kind of editing was often necessary; especially in the transitional areas created by topography and in the wetter east project area vs. the drier, colder, west project area.

Another kind of editing was needed to classify areas that fell in the middle of the gradient between one class and another, e.g., between woodland needleleaf and shrub. A woodland area of 10-15% trees was easily confused with a shrub area of 5-10% trees. This case was evident throughout the study area as occurrence of wetter low shrub/wet graminoid areas were surrounded by woodland needleleaf. The most prevalent example of the confusion within the gradient between classes was found between open- and woodland needleleaf. As evidenced by the field training sites, the majority of the open and woodland needleleaf classes exhibited a tree crown cover between 20% and 30%. Similarly, low shrub areas at a

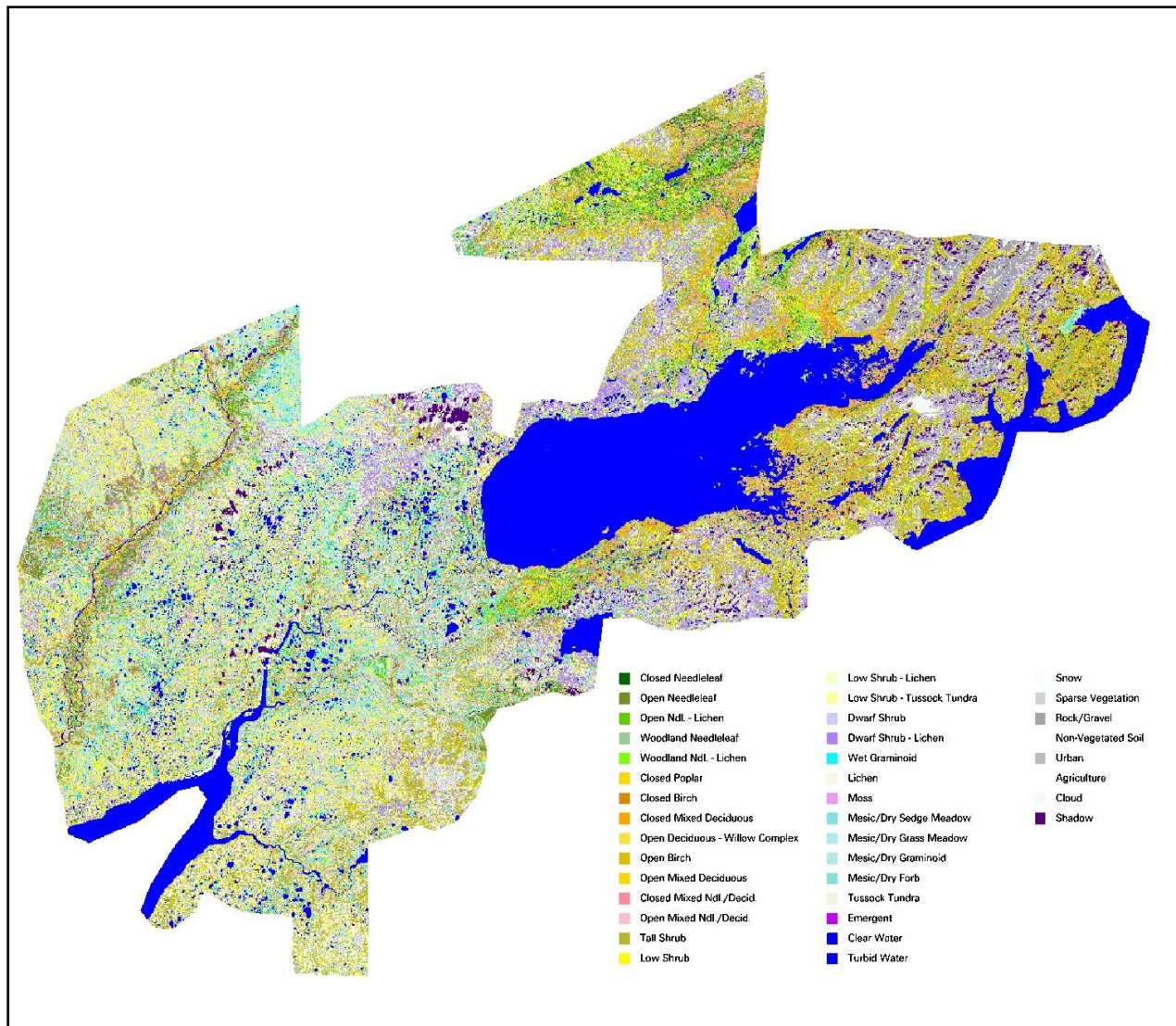
height of .3 meters were confused with dwarf shrub areas with a height of .2 meters. Also, low shrub areas at a height of 1 meter were confused with tall shrub areas of only 1.5 meters in height. These transitional areas and signatures had to be examined and a classification decision made based on the available data.

In some cases, a single pixel fell across two cover types, as when a pixel fell across the edge between a lake and the forested land surrounding it. These half-water, half-land signatures were often confused with emergent and needleleaf signatures. Editing was done to separate legitimate emergent, deciduous or mixed forest pixels based on aerial photography, field notes and topography.

Another set of landcover types that exhibited consistent spectral confusion was the combination of dwarf/low shrub types: low shrub-other, low shrub-lichen, dwarf shrub other and dwarf shrub-lichen. These types were compositionally and spectrally quite similar and many of the field sites were right on the breakpoints between the classes; i.e., shrub heights of .2-.3m and 15-20% lichen. Significant manual editing with the aid of ancillary data were used to separate these classes in the final map.

The needleleaf classes were also edited based on aerial photography and field notes; there was a tendency for pixels on the edges of water bodies to be misclassified as needleleaf instead of wet site types (wet graminoid, emergent, H20). These were probably mixed pixels, containing a both





**Figure 6.** Kvichak project area final classified map

vegetation and water in a combination that spectrally resembled needleleaf. These misclassified areas were often narrow strips along water bodies, mostly in the west project area.

As discussed earlier, variation in standing water level even from the time of satellite image acquisition (July, 1999 and 2000) to the time of field data collection (July, 2001) was evident. This discrepancy usually resulted in wet type sites (wet graminoid, tussock tundra, emergent vegetation) being misclassified as dry grass/graminoid and

dwarf/low shrub types. Therefore, the editing associated with this type of confusion focused on best representing conditions as they were at the time of satellite image capture.

A final case of spectral classification confusion involved the misclassification of tall shrub and low shrub pixels in the steep mountain valleys as closed deciduous types. The mix of the alder and willow tall shrubs that were distorted by heavy snow

**Table 4.** Acreage of earth cover classes within the project area.

CLASS NUMBER	CLASS NAME	ACRES	PERCENT COVER
1	Closed Needleleaf	17,001	0.26%
2	Open Needleleaf	304,527	4.69%
3	Open Ndl. - Lichen	48,450	0.75%
4	Woodland Needleleaf	164,007	2.53%
5	Woodland Ndl. - Lichen	138,019	2.13%
10	Closed Deciduous – Poplar	6,337	0.10%
11	Closed Deciduous – Birch	70,840	1.09%
12	Closed Mixed Deciduous	98,731	1.52%
13	Open Deciduous – Willow	0	0.00%
14	Open Deciduous – Birch	68,373	1.05%
15	Open Mixed Deciduous	97,403	1.50%
16	Closed Mixed Ndl./Decid.	91,388	1.41%
17	Open Mixed Ndl./Decid.	242,831	3.74%
20	Tall Shrub	542,102	8.35%
21	Low Shrub	625,079	9.63%
22	Low Shrub - Lichen	467,074	7.20%
23	Low Shrub - Tussock Tundra	86,666	1.34%
24	Dwarf Shrub	698,483	10.76%
25	Dwarf Shrub - Lichen	341,063	5.25%
32	Wet Graminoid	210,732	3.25%
33	Wet Forb	0	0.00%
34	Wet Sedge	0	0.00%
36	Lichen	60,535	0.93%
37	Moss	29,503	0.45%
41	Mesic / Dry Sedge Meadow	20,233	0.31%
42	Mesic / Dry Grass Meadow	121,113	1.87%
43	Mesic / Dry Graminoid	205,059	3.16%
44	Mesic / Dry Forb	0	0.00%
50	Tussock Tundra	189,679	2.92%
51	Tussock Tundra – Lichen	0	0.00%
60	Aquatic Bed	0	0.00%
61	Emergent Vegetation	7,753	0.12%
70	Clear Water	1,160,901	17.88%
71	Turbid Water	2,430	0.04%
72	Snow	12,016	0.19%
80	Sparse Vegetation	41,127	0.63%
81	Rock/Gravel	144,935	2.23%
82	Non-vegetated soil	28,283	0.44%
90	Urban	1,882	0.03%
92/93	Cloud / Shadow	146,987	2.98%
<b>Total</b>		<b>6,491,542</b>	<b>100%</b>

apparently mimicked the spectral signatures of closed deciduous. This confusion was corrected via manual editing utilizing photo-interpretation and review of specific field

notes and photos. Fortunately, the areas exhibiting this confusion were confined to the steep mountain valleys in the northeast part of the project area.

The classification of the east project area was challenging due to a lack of training sites for a large area southeast of King Salmon. Field reconnaissance was planned for this area, but inclement weather prevented travel by helicopter. Thus the initial analysis of the training sites and spectral variability in the image exhibited many classes that did not have a close spectral relationship with any training site. To adequately label these classes required close examination of cluster groupings, adjacent classes, field and training site data, and aerial photos. Often an iterative process was used and classes were relabeled based on a newer interpretation of the available information.

## Accuracy Assessment

Some earth cover classes were not adequately represented in the field data available for training and accuracy assessment, primarily because of their scarcity within the project area, e.g., moss, open mixed needleleaf deciduous, closed birch, closed poplar. In the past, classes with an inadequate sample size were collapsed into the next hierarchical cover type for accuracy assessment of the classification. This grouping often resulted in only 8-10 accuracy assessment classes vs. the 30+ classes present in the classification. In addition, this approach grouped classes based solely on their specific mapping class labels versus grouping individual sites based on their ecological composition or function. By grouping classes in this manner, one loses all ability to evaluate and measure the relationship between regions of the map that classify nicely into the “heart” of a mapping class and those regions that occur on the classification and ecological boundaries between the discrete mapping classes. For

example, a vegetation caller may have interpreted a site to contain 10% tree cover and 90% low shrubs. This site would be classified as a woodland conifer site. If this site is used to evaluate a site classified with a group of pixels indicating a presence of 5% tree cover and 95% low shrubs, the site would have been evaluated as incorrectly classified. Since the literature generally accepts the fact that even the most experienced visual estimates of earth cover consider a range of variation in interpretation of +/-10% to be acceptable, this particular accuracy assessment site containing 10% tree cover should also be considered acceptably classified as low shrub and tallied as such. Evaluating the earth cover classification in this manner provides the end user with a more realistic measure of reliability of the classified map as it relates to the actual continuum of vegetation composition as compared to simply lumping mapping classes for evaluation based on their discrete class name.

A more appropriate and informative representation of the reliability/accuracy of the earth cover classification is found in the error matrix provided in Appendix D. In this matrix, no lumping of mapping classes has occurred. Therefore, the user can evaluate the performance and interrelationships of *all* mapping classes represented in the final earth cover map. The error matrix presents values for user's accuracy, producer's accuracy, and the overall accuracy for +/- 0% and +/-5% variation in interpretation within the reference data. In the error matrix, numbers along the main diagonal of the matrix indicate an exact match between the reference data site and the map. A tally of these numbers indicates the overall accuracy of the map at the +/- 0% variation in interpretation level. If two numbers occupy

a non-diagonal cell, the left number indicates an acceptable match between the reference data site and the map assuming a  $\pm 5\%$  variation in reference data interpretation. The number on the right indicates the number of sites that are not acceptable matches. A tally of the numbers within the diagonal along with the acceptable numbers in the off-diagonal cells (left number(s)) indicates the overall accuracy of the map at the  $\pm 5\%$  variation in interpretation level.

A number of important analyses can be made regarding the relationship of the mapped data with the actual vegetation distributions throughout the study area using this method of accuracy assessment. Since the off-diagonal acceptable matches are presented, an indication of the number of field sites that represent vegetation compositions on the boundary of two or more mapping classes is given. The acceptance or unacceptance of each accuracy assessment site with an off-diagonal map class provides insight into the vegetation composition of that reference site. For instance, in the matrix in Appendix D (Total), of the seven reference sites characterized as dwarf shrub-lichen, two sites were an acceptable match with dwarf shrub-other and one site was an unacceptable match with sparse vegetation. The remainder of the sites (4) was diagonal matches with dwarf shrub-lichen. The off-diagonal matches indicate that two of those sites were just on the border between dwarf-shrub-lichen and dwarf shrub (15-20% lichen cover). Similarly, since the number of misclassified sites is still indicated in the matrix, a user can determine in which classes the map is least reliable and with which mapping classes the unreliable classes are confused. If lumping of classes is still desired, this can easily be accomplished through application of the techniques

utilized in previous projects. Although the matrix of lumped classes is not presented in this report, the classification accuracy of the grouped classes of open needleleaf, woodland needleleaf, deciduous, mixed needleleaf/deciduous, tall shrub, low shrub, dwarf shrub, forb/graminoid, and barren was computed to be 79.7%.

## Overall Accuracy Assessment

The difference in classification accuracy between the  $\pm 0\%$  variation in interpretation level (70%) and the  $\pm 5\%$  variation in interpretation level (80%) indicates that a substantial number of the reference data sites were characterized as being right on the boundary of two or more mapping classes. As stated earlier, it is generally accepted that variation in interpretation of  $\pm 10\%$  is common and accepted for human interpreters, either from aerial photography or on the ground. When this natural and accepted variation is measured and accounted for (as in the case of the error matrix in Appendix D), a more reliable and informative measure of accuracy and reliability is presented.

The results presented in Table 4 reflect the tremendous diversity in landcover types within the project area. Only one terrestrial land class accounts for more than 10% of the total project area (Dwarf shrub – 10.76%). Combining physiognomically similar classes shows that around 43% of the terrestrial land cover is in the dwarf/low shrub classes (23% low shrub, 20% dwarf). Terrestrial land cover is defined as the total landcover minus water and cloud/shadow acreage. Other classes and class groups that are present in relatively high percentages include tall shrub (10%), open needleleaf (6%), woodland needleleaf types (6%), and mixed needleleaf deciduous types (7%). Together these

classes account for over 70% of the project area.

The accuracy figures for the dwarf/low shrub classes are substantially higher at the  $\pm 5\%$  level, indicating that many of the sites were very close in structure and composition. This is evident when looking at the field data; many of the sites are near the .25m shrub height class break and/or the 20% lichen cover class break. Users accuracies ( $\pm 5\%$ ) for these classes range from 83-100%, indicating that the map reliably presents these classes. Producer's accuracies are somewhat lower (50-86%), indicating that some sites were incorrectly omitted from these classes. Two of these omitted sites were classed as wet graminoid and they most likely contained more water on the image date than during the field reconnaissance, thus they were identified as shrub sites but spectrally were classed as wet graminoid. This tendency to over map wet graminoid is of potential interest to the end user. Three other sites were placed in classes very similar to their reference classes, indicating the difficulty in distinguishing the subtle differences between the dwarf/low shrub tundra types. This is somewhat understandable when the patchy, heterogeneous nature of these sites is considered, as well as the compositional variation.

The tall shrub class was mapped with good accuracy (91% user's accuracy, 100% producer's accuracy), indicating that this class showed little confusion with other classes and that manual editing and modeling efforts to separate this class from some of the closed deciduous types were largely successful, with the exception of one site which was classed as closed mixed deciduous.

Open needleleaf was 6% of the total terrestrial landcover and was mapped with reasonable accuracies (75% user's and producer's accuracies). One closed birch site was classified as open needleleaf, indicating some confusion in the break between 75% majority needleleaf or deciduous. Further evidence of this is that another open needleleaf site was incorrectly classified as open mixed deciduous. Both of these sites were very heterogeneous mixes of mature needleleaf and deciduous trees and tall shrubs.

Woodland needleleaf types (Woodland needleleaf and woodland needleleaf lichen) also account for 6% of the total terrestrial landcover. Accuracy for woodland needleleaf lichen was 100%, indicating an outstanding correspondence between the map and ground for this class. The absence of any accuracy assessment sites for woodland needleleaf is worthy of mention, especially since woodland needleleaf is approximately 3% of the total terrestrial landcover. This is a good example of the larger problem of too few training sites. Seven woodland needleleaf sites were visited during field reconnaissance. Two were in the west project area, and four were in the east project area. Because the west and east project areas were separate classification efforts, no woodland needleleaf sites were set aside for accuracy assessment because to do so would severely limit the number of sites available for classification in both the east and west project areas. Qualitative Analysis of digitized field observations and data from the 1992 classification indicates that woodland needleleaf was mapped with good accuracy.

The open mixed needleleaf deciduous class shows low accuracies (50% users and producers accuracies), but these results are based on a very low number of accuracy

assessment sites – 2. Nevertheless, the error matrix results point out the difficulty in distinguishing the mature forested stands in the project area, many of which contain both needleleaf and deciduous trees. One open mixed needleleaf site was classified as closed birch; this site was classified with 18% open mixed needleleaf deciduous and 25% open needleleaf.

Lastly, the error matrix also shows some confusion between dwarf shrub classes and sparse vegetation. One dwarf shrub lichen site was erroneously classed as sparse vegetation, and a sparse vegetation site was classed as dwarf shrub. Both of these sites were at relatively high elevation rocky ridge crests; the confusion is not surprising as foliose lichens covering the rocks may spectrally mimic dwarf shrub and lichen.

In summary, based on the quantitative accuracy assessment, the earth cover classification map produced for the Kvichak is reliable. Over 70% of the accuracy assessment sites matched the full detailed 32 mapping classes directly; even when taking no variation in interpretation and no class lumping into account. When as little as +/- 5% variation in interpretation was accounted for, nearly eight out of ten (79.7%) of the reference sites were found to correspond correctly with the classified map.

## Discussion

As was stated earlier, the Kvichak Project Area is very diverse mix of landcover types. Only one class contained over 10% of the project area, three if the cloud/ shadow and water classes are subtracted from the acreage total. The majority of the landcover classes were between 1 and 5% of the total area mapped. There were a very low number of accuracy assessment sites available to estimate the accuracy of these landcover classes; only one class had 10 sites (Tall

shrub) and many had as few as two or three. Because of this, the reported accuracy assessment percentages must be viewed cautiously as one or two misclassified (or correctly classified) sites can have a great impact on the resulting percentage. Only 64 sites were used to assess an area of 5,328,211 acres comprised of 30+ landcover classes. This problem is directly related to the overall low number of training sites available for the classification (296 sites). While this number of sites may seem adequate for a project area of this size, these sites were divided for separate classifications for the east and west project areas (165 sites for the west project area and 131 for the east project area). When selecting accuracy assessment sites from the available field sites for each project area, the 15 site minimum rule discussed earlier was often ignored in order to have at least a handful of sites for accuracy assessment.

While the accuracy assessment performed in this project was not a robust test of the classification, it gives the user some confidence while using the classification. It provided enough detail for the end user to determine where discrepancies in the classification may cause a problem while using the data. It is also important to note the variations in the dates of the imagery, aerial photographs, and field data. For this project, the imagery was acquired on September 1999 and September 2000. The aerial photographs spanned a seven year period from 1978-84, and the field data was collected in July 2001. Differences due to environmental changes from the different sources may have affected the accuracy assessment. As discussed earlier, the significant differences in standing water on many of the wetter sites between the image date and the field collection date contributed to inconsistencies in correctly identifying sites. Depending on the standing water

present at any given time, each of these class labels may have been appropriate.

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

Unfortunately, error matrices can be inadequate indicators of map error because they are often confused by non-map error differences. Some of the non-map errors that can cause confusion are: (1) registration differences between the reference data and the remotely sensed map classification, (2) digitizing errors, (3) data entry errors, (4) changes in land cover between the date of the remotely sensed data and the date of the reference data, (5) mistakes in interpretation of reference data, and perhaps most significant (6) variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation. The error matrix developed and presented in this report attempts to capture, measure, and account for likely the most significant of these sources of inconsistency and error in the development of the

reference data set: variation in human interpretation. The results presented and discussed in this report provide the end user with valuable information regarding the accuracy and reliability of the earth cover data mapped for the Kvichak project area. Separate error matrices for the east and west project areas are provided to give the end user more detailed information about these areas.

## **Final Products**

The project final product included a digital classification, map, and database of 30 earth cover classes within the Kvichak project area as well as a map of wildlife sighting locations observed during the collection of field data. The digital classification map was delivered in Arc Info Grid and ERDAS Imagine format. The unclassified Landsat TM images used to create the cover map were also delivered. The field site database, a species list and earth cover acreage tables were stored as digital tables in Microsoft Excel and Access format. The wildlife sightings map was delivered as Arc Info shapefile point and polygon coverages. Digital photos of the field sites are stored as jpeg's





## Summary

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The Bureau of Land Management (BLM) – Alaska and Ducks Unlimited, Inc. (DU) have been cooperatively mapping wetlands and associated uplands in Alaska using remote sensing and GIS technologies since 1988. This project continued with the mapping effort for the Kvichak project using Landsat TM satellite scenes, Path 71, Rows 18, and 19, acquired 09/99; and Path 72, Rows 18 and 19, acquired 09/00. The project area was classified into 30 earth

cover categories with an overall accuracy of 79.7% at the +/- 5% level of variation in interpretation. The digital database and map of the classification were the primary products of this project along with hard copy maps of the classification, digital Arc Info shapefile point and polygon coverages of wildlife sightings locations observed during the collection of field data, and a complete field database including digital site photos.

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# Appendices

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## Appendix A. Alaska Earth Cover Classification Class Descriptions

### 1.0 Forest

#### Needleleaf and Deciduous Trees-

The needleleaf species generally found were white spruce (*Picea glauca*) and black spruce (*P. mariana*). White spruce tended to occur on warmer sites with better drainage, while black spruce dominated poorly drained sites, and was more common in the interior of Alaska. The needleleaf classes included both white and black spruce.

The deciduous tree species generally found were paper birch (*Betula papyfera*), aspen (*Populus tremuloides*) and cottonwood (*P. balsamifera* and *P. trichocarpa*). Black cottonwoods (*P. trichocarpa*) were generally found only in river valleys and on alluvial flats. Under some conditions willow (*Salix* spp.) and alder (*Alnus rubra*) formed a significant part of the tree canopy. Deciduous stands were found in major river valleys, on alluvial flats, surrounding lakes, or most commonly, on the steep slopes of small hills. Mixed deciduous/coniferous stands were present in the same areas as pure deciduous stands. While needleleaf stands were extremely extensive, deciduous and mixed deciduous/coniferous stands were generally limited in size. The only exception to this rule was near major rivers, where relatively extensive stands of pure deciduous trees occur on floodplains and in ancient oxbows.

### 1.1 Closed Needleleaf

At least 60% of the cover was trees, and  $\geq 75\%$  of the trees were needleleaf trees. Closed needleleaf sites were rare because even where stem densities were high, the crown closure remained low. Generally, closed needleleaf sites were found only along major rivers.

### 1.2 Open Needleleaf

From 25-59% of the cover was trees, and  $\geq 75\%$  of the trees were needleleaf. This class was very common throughout the interior of Alaska. A wide variety of understory plant groups were present, including low and tall shrubs, forbs, grasses, sedges, horsetails, mosses and lichens.

### 1.21 Open Needleleaf Lichen

From 25-59% of the cover was trees,  $\geq 75\%$  of the trees were needleleaf, and  $\geq 20\%$  of the understory was lichen.

### 1.3 Woodland Needleleaf

From 10-24% of the cover was trees, and  $\geq 75\%$  of the trees were needleleaf. Woodland understory was extremely varied and included most of the shrub, herbaceous, or graminoid types present in the study area.

### 1.31 Woodland Needleleaf Lichen

From 10-24% of the cover was trees,  $\geq 75\%$  of the trees were needleleaf, and  $\geq 20\%$  of the understory was lichen. The lichen often occurred in small round patches between trees. Within the study area, this class was generally found along ridgetops or on riparian benches.

#### **1.4 Closed Deciduous (Mixed Deciduous Species 1.45)**

At least 60% of the cover was trees, and  $\geq 75\%$  of the trees were deciduous.

Occurred in stands of limited size, generally on the floodplains of major rivers, but occasionally on hillsides, riparian gravel bars, or bordering small lakes. This class included Paper Birch, Aspen, or Cottonwood.

##### **1.41 Closed Birch**

At least 60% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Paper Birch (*Betula Papyfera*). This class was very rare.

##### **1.42 Closed Aspen**

At least 60% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Aspen. Stands of pure aspen occurred, but were generally no larger than a few acres. They were found on steep slopes, with particular soil conditions, and on river floodplains.

##### **1.43 Closed Poplar**

At least 60% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Cottonwood. Stands of pure cottonwood were occasionally found on riparian gravel bars.

#### **1.5 Open Deciduous (Mixed Deciduous Species 1.54)**

From 25-59% of the cover was trees, and  $\geq 75\%$  of the trees were deciduous. There was generally a needleleaf component to this class though it was less than 25%. This was a relatively uncommon class.

##### **1.51 Open Birch**

From 25-59% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Paper Birch. This

class was very rare. No examples of this class were found in the study area.

##### **1.52 Open Aspen**

From 25-59% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Aspen.

##### **1.53 Open Cottonwood**

From 25-59% of the cover was trees,  $\geq 75\%$  of the trees were deciduous, and  $\geq 75\%$  of the deciduous trees were Cottonwood.

#### **1.6 Closed Mixed Needleleaf/Deciduous**

At least 60% of the cover was trees, but neither needleleaf nor deciduous trees made up  $\geq 75\%$  of the tree cover. This class was uncommon and found mainly along the meanders of major rivers.

#### **1.7 Open Mixed Needleleaf/Deciduous**

From 25-59% of the cover was trees, but neither needleleaf nor deciduous trees made up  $\geq 75\%$  of the tree cover. This class occurred in regenerating burns, on hill slopes, or bordering lakes.

### **2.0 Shrub**

The tall and low shrub classes were dominated by willow species, dwarf birch (*Betula nana* and *Betula glandulosa*) and *Vaccinium* species, with alder being somewhat less common. However, the proportions of willow to birch and the relative heights of the shrub species varied widely, which created difficulties in determining whether a site was made up of tall or low shrub. As a result, the height of the shrub species making up the largest proportion of the site dictated whether the site was called a low or tall shrub. The shrub heights were averaged within a genus, as in the case of a site with both tall and low willow shrubs. Dwarf shrub was usually composed of dwarf ericaceous shrubs and *Dryas* species, but often included a variety

of forbs and graminoids. The species composition of this class varied widely from site to site and included rare plant species. It is nearly always found on hill tops or mountain plateaus, and may have included some rock.

## **2.1 Tall Shrub**

Shrubs made up 40-100% of the cover and shrub height was  $\geq 1.3$  meters. This class generally had a major willow component that was mixed with dwarf birch and/or alder, but could also have been dominated by nearly pure stands of alder. It was found most often in wet drainages, at the head of streams, or on slopes.

### **2.21 Willow/Alder Low Shrub**

Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and  $\geq 75\%$  of the shrub cover was willow and/or alder.

### **2.22 Other Low Shrub/Tussock Tundra**

Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and  $\geq 35\%$  of the cover was made up of tussock forming cotton grass (*Eriophorum vaginatum*). This class was found in extensive patches in flat, poorly drained areas. It was generally made up of cotton grass, ericaceous shrubs, willow and/or alder shrubs, other graminoids, and an occasional black spruce.

### **2.23 Other Low Shrub/Lichen**

Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters, and  $\geq 20\%$  of the cover was made up of lichen. This class was found at mid-high elevations. The shrub species in this class were nearly always dwarf birch.

## **2.24 Other Low Shrub**

Shrubs made up 40-100% of the cover, shrub height was .25-1.3 meters. This was the most common low shrub class. It was generally composed of dwarf birch, willow species, *Vaccinium* species, and ledum species.

### **2.31 Dwarf Shrub/Lichen**

Shrubs made up 40-100% of the cover, shrub height was  $\leq .25$  meters, and  $\geq 20\%$  of the cover was made up of lichen. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids. It was nearly always found at higher elevations on hilltops, mountain slopes and plateaus. This class may be more open than the Other Dwarf Shrub class.

### **2.31 Other Dwarf Shrub**

Shrubs made up 40-100% of the cover, the shrub height is  $\leq .25$  meters. This class was generally made up of dwarf ericaceous shrubs and *Dryas* species, but often included a variety of forbs and graminoids, and some rock. It was nearly always found at higher elevations on hilltops, mountain slopes, and plateaus.

## **3.0 Herbaceous**

The classes in this category included bryoids, forbs, and graminoids. Bryoids and forbs were present as a component of most of the other classes but rarely appeared in pure stands. Graminoids such as *Carex* spp., *Eriophorum* spp., or bluejoint grass (*Calamagrostis canadensis*) may have dominated a community.

### **3.11 Lichen**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 25\%$  water, and  $\geq 60\%$  lichen species.

### **3.12 Moss**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 25\%$  water, and  $\geq 60\%$  moss species.

### **3.21 Wet Graminoid**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 25\%$  water, and where  $\geq 60\%$  of the herbaceous cover was graminoid, and  $\geq 20\%$  of the graminoid cover was made up of *Carex aquatilis*. This class represented wet or seasonally flooded sites. It was often present in stands too small to be mapped at the current scale.

### **3.31 Tussock Tundra**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 25\%$  water, where  $\geq 50\%$  of the herbaceous cover was graminoid, and  $\geq 35\%$  of the graminoid cover was made up of tussock forming cotton grass. Tussock tundra often included ericaceous shrubs, willow and/or alder shrubs, forbs, bryoids, and other graminoids, and was usually found at lower elevations in flat, poorly drained areas.

### **3.311 Tussock Tundra/Lichen**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 25\%$  water, where  $\geq 50\%$  of the herbaceous cover was graminoid, and  $\geq 20\%$  of the cover was lichen, and  $\geq 35\%$  of the graminoid cover was made up of tussock forming cotton grass. Tussock tundra often included ericaceous shrubs, willow and/or alder shrubs, forbs and other graminoids, and was usually found at lower elevations in flat, poorly drained areas. This class included a major component of lichen.

### **3.34 Mesic/Dry Graminoid**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 5\%$  water, with  $\geq 50\%$  graminoids excluding tussock forming cotton grass and *Carex aquatilis*. This class was not common and was found generally only at high elevations.

### **3.35 Mesic/Dry Forb**

Composed of  $\geq 40\%$  herbaceous species,  $\leq 5\%$  water, with  $< 50\%$  graminoids. Regenerating burn areas dominated by fireweed (*Epilobium angustifolium*) fell into the mesic/dry forb category. However, forb communities without significant graminoid or shrub components were generally rare in the interior of Alaska.

## **4.0 Aquatic Vegetation**

The aquatic vegetation was divided into Aquatic Bed and Emergent classes. The Aquatic Bed class was dominated by plants with leaves that float on the water surface, generally pond lilies (*Nuphar polysepalum*). The Emergent Vegetation class was composed of species that were partially submerged in the water, and included freshwater herbs such as Horsetails (*Equisetum* spp.), Maretail (*Hippuris* spp.), and Buckbean (*Menyanthes trifoliata*).

### **4.1 Aquatic Bed**

Aquatic vegetation made up  $\geq 20\%$  of the cover, and  $\geq 20\%$  of the vegetation was composed of plants with floating leaves. This class was generally dominated by pond lilies.

### **4.2 Emergent Vegetation**

Aquatic vegetation made up  $\geq 20\%$  of the cover, and  $\geq 20\%$  of the vegetation was composed of plants other than pond lilies. Generally included freshwater herbs such as Horsetails, Maretail, or Buckbean.

### **5.1 Clear Water**

Composed of  $\geq 80\%$  clear water.

### **5.2 Turbid Water**

Composed of  $\geq 80\%$  turbid water.

## **6.0 Barren**

This class included sparsely vegetated sites, e.g., abandoned gravel pits or riparian gravel bars, along with non-vegetated sites, e.g., barren mountaintops or glacial till.

### **6.1 Sparse Vegetation**

At least 50% of the area was barren, but vegetation made up  $\geq 20\%$  of the cover. This class was often found on riparian gravel bars, on rocky or very steep slopes and in abandoned gravel pits. The plant species were generally herbs, graminoids and bryoids.

### **6.2 Rock/Gravel**

At least 50% of the area was barren,  $\geq 50\%$  of the cover was composed of rock and/or gravel, and vegetation made up less than 20% of the cover. This class was most often made up of mountaintops or glaciers.

### **6.3 Non-vegetated Soil**

At least 50% of the area was barren,  $\geq 50\%$  of the cover was composed of mud, silt or sand, and vegetation made up less than 20% of the cover. This type was generally along shorelines or rivers.

## **7.0 Urban**

At least 50% of the area was urban. This class was only found in the study area in the within the village of Ruby.

## **8.0 Agriculture**

At least 50% of the area was agriculture. This class was not found in the study area.

## **9.0 Cloud/Shadow**

At least 50% of the cover was cloud or shadow.

### **9.1 Cloud**

At least 50% of the cover was made up of clouds.

### **9.2 Cloud Shadow**

At least 50% of the cover was made up of clouds shadows.

### **9.3 Terrain Shadow**

At least 50% of the cover was made up of terrain shadows.

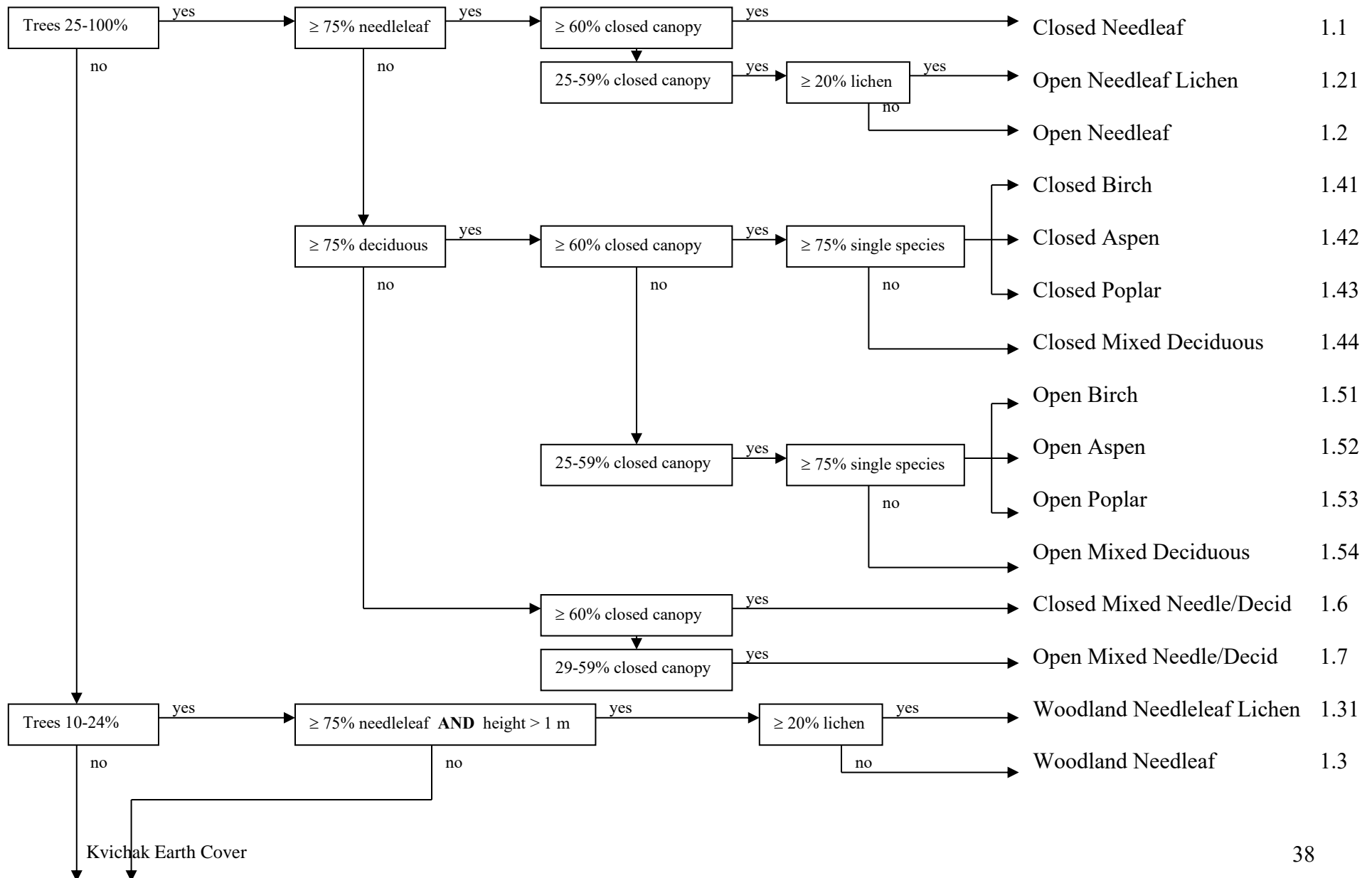
## **10.0 Other**

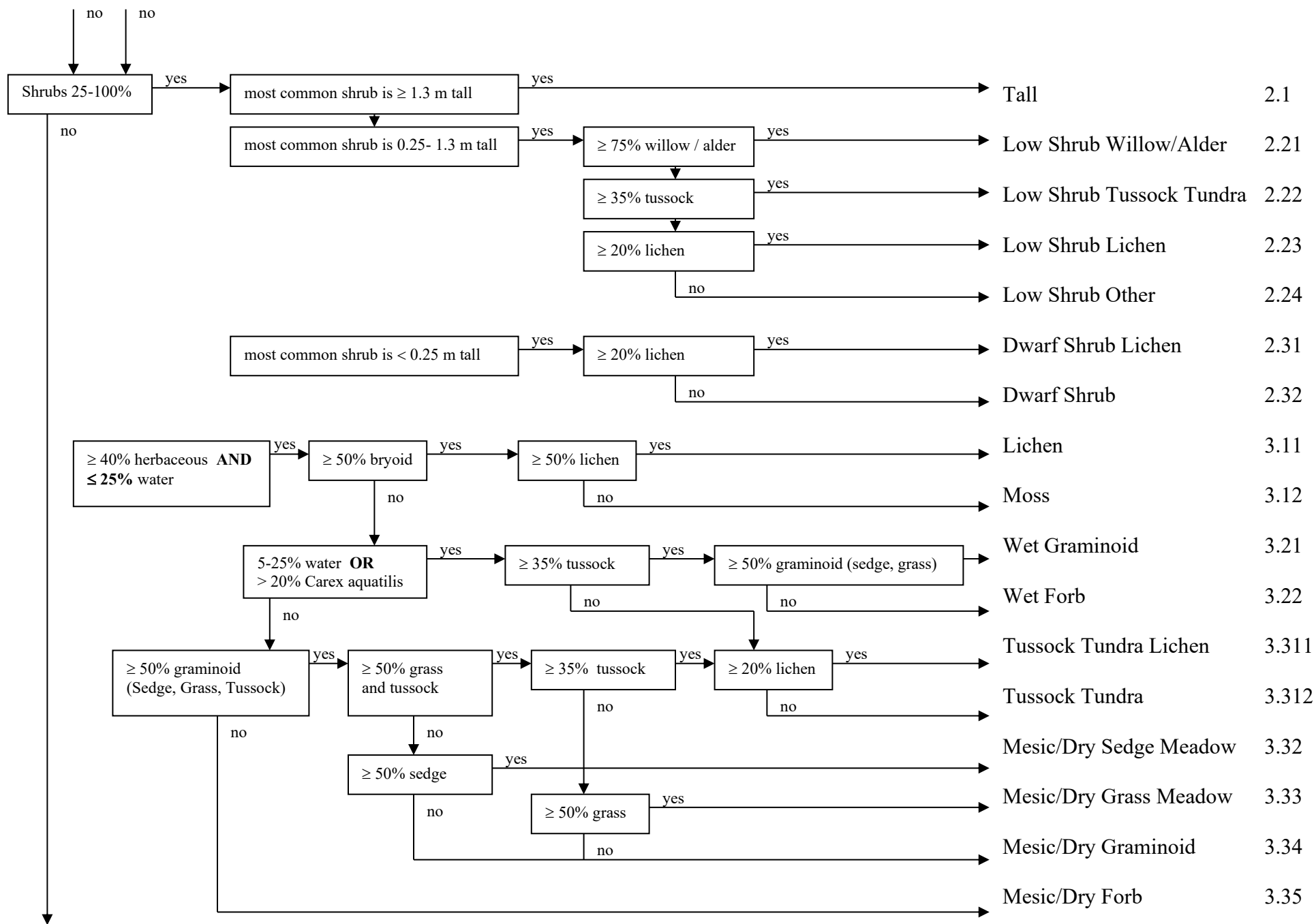
Sites that did not fall into any other category were assigned to Other. For example, sites containing 25%-80% water,  $< 25\%$  shrub and  $< 20\%$  aquatic vegetation were classed as Other. Sites classed as Other may have also included extensive areas of vegetative litter, such as downed wood.

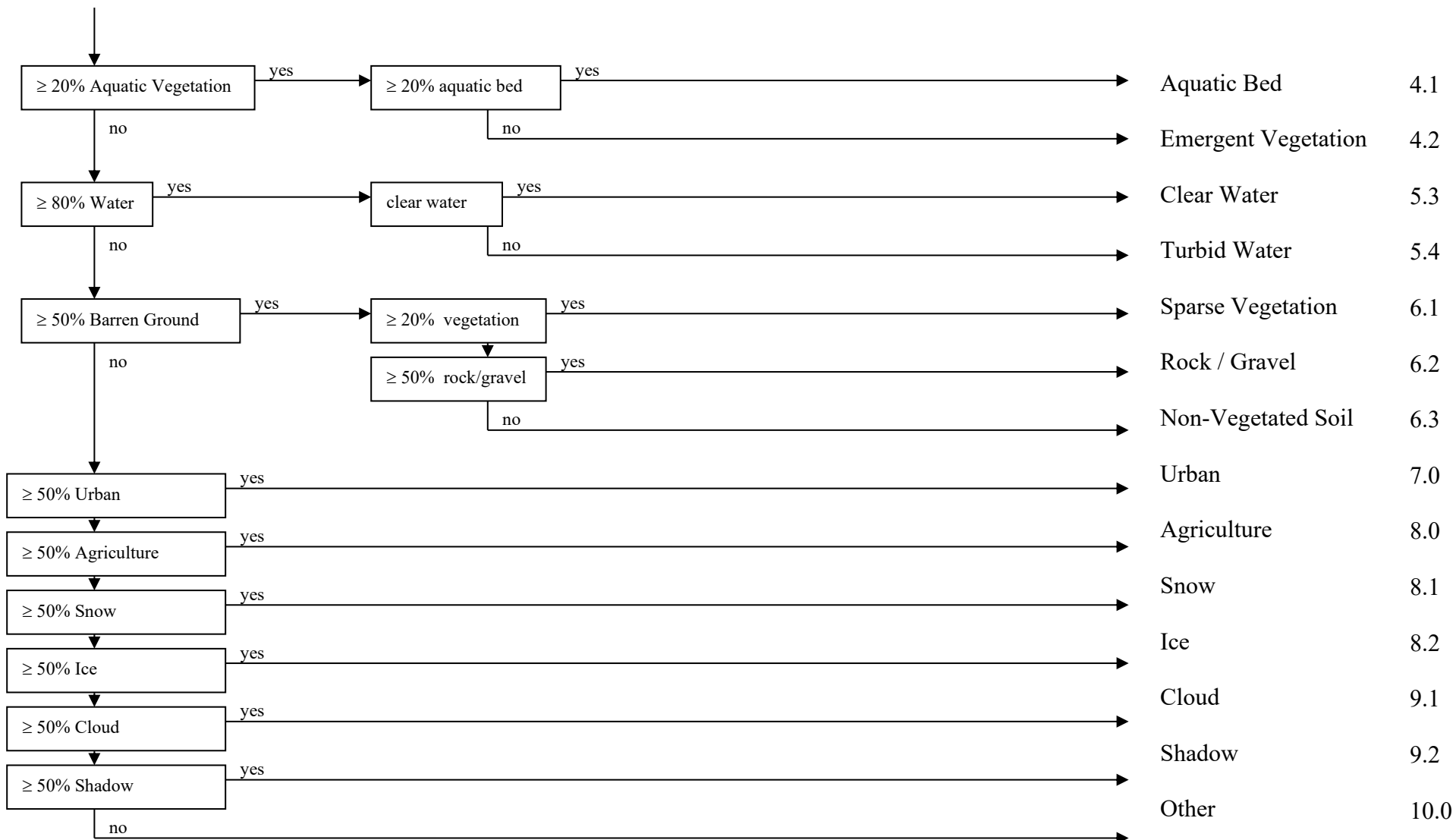




## Appendix B. Earth cover classification decision tree.







## Appendix C. Plant species and cover type list.

<u>Site Tally</u>	<u>Symbol</u>	<u>Species</u>	<u>Common Name</u>
237	LITT	LITTER	LITTER
160	LIXX	LICHEN	LICHEN
157	VAUL	VACCINIUM ULIGINOSUM	BLUEBERRY,BOG
150	MOXX	MOSS	MOSS
140	LEPA11	LEDUM PALUSTRE	LABRADOR TEA
136	CAXX	CAREX SPP	SEDGE SPP
134	SAX_	SALIX SPP	WILLOW
115	CACA4	CALAMAGROSTIS CANADENSIS	REEDGRASS,BLUE-JOINT
99	B EGL	BETULA GLANDULOSA	BIRCH,RESIN
82	EMNI	EMPETRUM NIGRUM	CROWBERRY,BLACK
80	BENA	BETULA NANA	BIRCH,DWARF
70	FEXX	FERN SPP	FERN SPP
70	PIGL	PICEA GLAUCA	SPRUCE,WHITE
57	BEPA	BETULA PAPYRIFERA	BIRCH,PAPER
55	SADW	SALIX DW.	WILLOW, DWARF
55	SPBE	SPIREA BEAUVERDIANA	SPIREA
49	EPAN2	EPILOBIUM ANGUSTIFOLIUM	FIREWEED
46	DEAD1	STANDING DEAD	STANDING DEAD
45	BARE	BARE GROUND	BARE GROUND
44	ALCR6	ALNUS CRISPA	ALDER,GREEN
41	ERXX	ERIOPHORUM SPP	COTTON-GRASS
41	PICEA	PICEA SPP.	SPRUCE, MIXED WHITE AND BLACK
40	ERVA4	ERIOPHORUM VAGINATUM	COTTON-GRASS,TUSsock
39	VAVI	VACCINIUM VITIS-IDAEA	CRANBERRY,LOWBUSH
35	CWATER	CLEAR WATER	CLEAR WATER
34	ALNU9	ALNUS SPP	ALDER SPP
33	ANPO	ANDROMEDA POLIFOLIA	ROSEMARY,BOG
33	EQXX	EQUISETUM SPP	HORSETAILS SPP
33	RUCH	RUBUS CHAMAEMORUS	CLOUDBERRY
30	LOPR	LOISELURIA PROCUMBENS	AZALEA, ALPINE
30	ROCK	ROCK	ROCK
27	POPA14	POTENTILLA PALUSTRIS	CINQUEFOIL,MARSH
25	MYGA	MYRICA GALE	SWEETGALE
23	CAAQ	CAREX AQUATILIS	SEDGE,WATER
18	ECHO2	ECHINOPANAX HORRIDUM	DEVIL'S CLUB
18	POBA2	POPULUS BALSAMIFERA	POPLAR,BALSAM
18	VEVI	VERATRUM VIRIDE	FALSE-HELLEBORE,AMERICAN
16	GRASS	GRASS	GRASS
16	SATRE	SALIX TREE	WILLOW TREE
15	LEGR	LEDUM GROENLANDICUM	LABRADOR-TEA,GREENLAND

13	HELA4	HERACLEUM LANATUM	COW-PARSNIP
12	CHCA2	CHAMAEDAPHNE CALYCVLATA	LEATHERLEAF
12	COCA13	CORNUS CANADENSIS	BUNCHBERRY,CANADA
11	DRXX	DRYAS SPP	MOUNTAIN-AVENS
10	ARXX	ARNICA SPP	ARNICA SPP
9	GRAV	GRAVEL	GRAVEL
9	METR3	MENYANTHES TRIFOLIATA	BUCKBEAN
8	ANNA	ANEMONE NARCISSIFLORA	ANEMONE,NARCISSUS
7	ALTRE	ALNUS SPP TREE	ALDER, TREE
7	ARRU	ARCTOSTAPHYLOS RUBRA	BEARBERRY,RED
6	BEPAK	BETULA PAPYRIFERA VAR. KENAICA	BIRCH,KENAI
6	GEPR4	GERANIUM PRATENSE	CRANE'S-BILL,MEADOW
6	MUDX	MUD	MUD
6	PIMA	PICEA MARIANA	SPRUCE,BLACK
5	ARUV	ARCTOSTAPHYLOS UVA-URSI	KINNEKINNICK
5	MIAR3	MINUARTIA ARCTICA	STITCHWORT, ARCTIC
5	SOSI2	SORBUS SITCHENSIS	MOUNTAIN ASH,WESTERN
4	LEDE5	LEDUM DECUMBENS	LABRADOR-TEA,NARROW-LEAF
4	SPRO	SPIRANTHES ROMANZOFFIANA	LADIES'-TRESSES,HOODED
3	ARCTO3	ARCTOSTAPHYLOS SPP	BEARBERRY
3	CASP5	CAREX SPECTABILIS	SEDGE,SHOWY
3	CATE11	CASSIOPE TETRAGONA	BELL-HEATHER,ARCTIC
3	DIAPÉ	DIAPENSIA LAPPONICA	DIAPENSIA
3	EQFL	EQUISETUM FLUVIATILE	HORSETAIL,WATER
3	LUPIN	LUPINUS SPP	LUPINE,SPP
3	PELA	PEDICULARIS LABRADORICA	LOUSEWORT,LABRADOR
3	POFR4	POTENTILLA FRUTICOSA	CINQUEFOIL,SHRUBBY
3	POTR15	POPULUS TRICHOCARPA	BLACK COTTONWOOD
3	RIBES	RIBES SPP	CURRENT,SPP
3	RUBUS	RUBUS SPP.	RUBUS SPP.
3	SAST11	SANGUISORBA STIPULATA	BURNET
3	SHCA	SHEPHERDIA CANADENSIS	SOAPBERRY
3	VAOX	VACCINIUM OXYCOCCOS	CRANBERRY,SMALL
3	VED	VIBURNUM EDULE	CRANBERRY,HIGHBUSH
2	ANLU	ANGELICA LUCIDA	ANGELICA,SEAWATCH
2	ARTEM	ARTEMISIA SPP	SAGE, SPP
2	CAMPA	CAMPANULA SPP	CAMPANULA SPP
2	CIMA	CICUTA MACKENZIANA	WATER-HEMLOCK,MACKENZIE
2	DROB	DROSERÁ X OBOVATA	SUNDEW
2	ELBE3	ELYNA BELLARDII	ALPINESEDGE,BELLARD
2	ERSP8	ERIOPHORUM SPISSUM	HARE'S-TAIL
2	IRSE	IRIS SETOSA	IRIS,BEACH-HEAD
2	LAPA4	LATHYRUS PALUSTRIS	PEAVINE,VETCHLING
2	LUNO	LUPINUS NOOTKATENSIS	LUPINE,NOOTKA

2	MINUA	MINUARTIA SPP.	STITCHWORT,SPP
2	PEDIC	PEDICULARIS SPP	LOUSEWORT,SPP
2	PEFR5	PETASITES FRIGIDUS	COLTSFOOT,ARCTIC SWEET
2	POAC	POLEMONIUM ACUTIFLORUM	JACOB'S-LADDER,STICKY TALL
2	PUNU	PUCCINELLIA NUTKAENSIS	GRASS,NOOTKA ALKALI
2	RUMEX	RUMEX SPP	DOCK,SPP
2	SASP2	SALIX SPHENOPHYLLA	WILLOW,WEDGE-LEAF
1	ANMO9	ANTENNARIA MONOCEPHALA	PUSSYTOE
1	ARAL2	ARCTOSTAPHYLOS ALPINA	MANZANITA,ALPINE
1	BEER2	BECKMANNIA ERUCIFORMIS	GRASS,BECKMANN'S
1	BEOC2	BETULA OCCIDENTALIS	BIRCH,SPRING
1	CAED	CAKILE EDENTULA	SEAROCKET,AMERICAN
1	DRIN4	DRYAS INTEGRIFOLIA	MOUNTAIN-AVENS,ENTIRE-LEAF
1	EPAN4	EPILOBIUM ANAGALLIDIFOLIUM	WILLOW-HERB,PIMPERNEL
1	EPXX	EPILOBIUM SPP	FIREWEED SPP
1	ERAN6	ERIOPHORUM ANGUSTIFOLIUM	COTTON-GRASS,NARROW-LEAF
1	GEER2	GERANIUM ERIANTHUM	GERANIUM,WOOLY
1	GRXX	GRAMINOID SPP	GRAMINOID SPP
1	LEDE	LEPIDIUM DENSIFLORUM	PEPPER-GRASS,DENSE-FLOWER
1	LEVI3	LEPIDIUM VIRGINICUM	PEPPER-GRASS,POOR-MAN'S
1	LICO5	LISTERA CONVALLARIOIDES	TWAYBLADE,BROAD-LEAF
1	LICO6	LISTERA CORDATA	TWAYBLADE,HEART-LEAF
1	LITT2	LITTER STANDING	LITTER STANDING
1	LYCOP2	LYCOPODIUM SPP	CLUBMOSS,SPP
1	MIOB2	MINUARTIA OBTUSILOBA	STITCHWORT,ALPINE
1	MIRU3	MINUARTIA RUBELLA	STITCHWORT,BOREAL
1	MOPA2	MONTIA PARVIFOLIA	MINER'S-LETTUCE,LITTLE-LEAF
1	NUPHA	NUPHAR SPP	PONDLILLY SPP
1	NUPO	NUPHAR POLYSEPALUM	WATER LILY
1	OXNIN	OXYTROPIS NIGRESCENS	OXYTROPE,BLACKISH
1	POAN5	POTENTILLA ANSERINA	SILVERWEED
1	POBI5	POLYGONUM BISTORTA	BISTORT,MEADOW
1	POLYG4	POLYGONUM SPP.	BISTORT
1	POTR10	POPULUS TREMULOIDES	ASPEN,QUAKING
1	RHLA2	RHODODENDRON LAPPONICUM	AZALEA,LAPLAND
1	SACA14	SANGUISORBA CANADENSIS	BURNET,CANADA
1	SAND	SAND	SAND
1	SASI2	SALIX SITCHENSIS	WILLOW,SITKA
1	SOSC2	SORBUS SCOPULINA	MOUNTAIN-ASH,GREENE'S
1	TRMA4	TRIGLOCHIN MARITIMUM	ARROW-GRASS,SEASIDE
1	TUWA	TURBID WATER	TURBID WATER





## Appendix D. Kvichak Accuracy Assessment Error Matrices

### KVICHAK

AA Matrix	REFERENCE																																					User's
	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	33	34	35	36	37	Accuracy (+/-5%)
1) Open NeedleLeaf	3			0,1																																		75
2) Closed NeedleLeaf																																						n/a
3) Open NeedleLeaf Lichen																																						n/a
4) Closed Birch										0,1																												0
5) Closed Poplar																																						n/a
6) Closed Mixed Deciduous							1																															100
7) Open Birch																																						n/a
8) Open Mixed Deciduous	0,1																																					0
9) Closed Mixed NL/Deciduous										5																												100
10) Open Mixed NL/Deciduous											1						0,1																					50
11) Woodland Needleleaf Lichen												3																										100
12) Woodland Needleleaf																																						N/A
13) Tall Shrub							0,1							10																								91
14) Low Shrub Tussock Tundra															1																							100
15) Low Shrub Lichen																3	2,0		0,1																			83
16) Low Shrub - Other																	2																					100
17) Dwarf Shrub Lichen																		4	1,0																			100
18) Dwarf Shrub - Other																0,1	2,0	4											1,0									88
19) Lichen																																						n/a
20) Moss																0,1				1																		50
21) Wet Graminoid														0,1	0,1						3																	60
22) Tussock Tundra																		0,1				2																67
23) Mesic Dry Sedge Meadow																							1	0,1														50
24) Mesic Dry Grass Meadow																								1														100
25) Aquatic Bed																																						n/a
26) Emergent Vegetation																																						n/a
27) Clear Water																																						n/a
28) Turbid Water																																						n/a
29) Sparse Vegetation																	0,1																					0
30) Rock/Gravel																																						n/a
31) Non-Vegetated Soil																																						n/a
32) Urban																																						n/a
33) Snow																																						n/a
34) Ice																																						n/a
35) Cloud																																						n/a
36) Shadow																																						n/a
37) Other																																						n/a
Reference Site Totals:	4	0	0	1	0	2	0	0	5	2	3	0	10	2	4	7	7	7	0	1	3	2	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	
Producer's Accuracy (+/-5%):	75%	n/a	n/a	0%	n/a	50%	n/a	n/a	100%	50%	100%	N/A	100%	50%	75%	57%	86%	72%	n/a	100%	100%	100%	100%	50%	N/A	n/a	n/a	n/a	0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	

Total = 64

Diagonal = 45

Off-Diagonal = 6

Overall Accuracy (0% var) = 70%

Overall Accuracy (+/- 5% var) = 80%



# KVICHAK WEST

## AA Matrix

## REFERENCE

	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	33	34	35	36	37	Accuracy (+/-5%)
1) Open NeedleLeaf	1			0,1																																		50
2) Closed NeedleLeaf		1																																				n/a
3) Open NeedleLeaf Lichen			1																																			n/a
4) Closed Birch				1						0,1																												0
5) Closed Poplar					1																																	n/a
6) Closed Mixed Deciduous						1																																n/a
7) Open Birch							1																															n/a
8) Open Mixed Deciduous								1																														n/a
9) Closed Mixed NL/Deciduous									1																													100
10) Open Mixed NL/Deciduous										1						0,1																					50	
11) Woodland Needleleaf Lichen											1																											n/a
12) Woodland Needleleaf												1																										n/a
13) Tall Shrub													1																									100
14) Low Shrub Tussock Tundra														1																								n/a
15) Low Shrub Lichen															2	2,0		0,1																			80	
16) Low Shrub - Other																1																						100
17) Dwarf Shrub Lichen																	3																					100
18) Dwarf Shrub - Other																0,1	2,0	3																				83
19) Lichen																		1																				n/a
20) Moss																0,1				1																	50	
21) Wet Graminoid																					3																	75
22) Tussock Tundra																		0,1				2																67
23) Mesic Dry Sedge Meadow																						1	0,1															50
24) Mesic Dry Grass Meadow																							1															100
25) Aquatic Bed																									1													n/a
26) Emergent Vegetation																										1												n/a
27) Clear Water																											1											n/a
28) Turbid Water																												1										n/a
29) Sparse Vegetation																													1									n/a
30) Rock/Gravel																														1								n/a
31) Non-Vegetated Soil																															1							n/a
32) Urban																																1						n/a
33) Snow																																	1					n/a
34) Ice																																		1				n/a
35) Cloud																																						n/a
36) Shadow																																						n/a
37) Other																																						n/a

Reference Site Totals: 1 0 0 1 0 0 0 0 1 2 0 0 1 0 3 6 5 5 5 0 1 3 2 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  
 Producer's Accuracy (+/-5%): 0% n/a n/a 0% n/a n/a n/a n/a 100% 50% n/a N/A 100% n/a 67% 50% 100% 75% n/a 100% 100% 100% 100% 50% N/A n/a n/a n/a n/a n/a n/a n/a n/a n/a n/a n/a n/a n/a n/a

Total = 34  
 Diagonal = 21  
 Off-Diagonal = 4  
 Overall Accuracy (0% var) = 62%  
 Overall Accuracy (+/- 5% var) = 74%



### AA Matrix

## REFERENCE

**Accuracy (+/-5%)**

[illegible]

Reference Site Totals:

Producer's Accuracy (+/-5%):

Total = 30

Diagonal = 24

Off-Diagonal = 2

Overall Accuracy (0% var) = 80%

Overall Accuracy (+/- 5% var) = 87%

