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Ducks Unlimited, Inc.

Northern Innoko Earth Cover Classification

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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 the Nogahabara Sand Dunes located in the northeastern portion of the Northern Innoko Project Area. It depicts the remoteness of the area and the need to use helicopters for data collection.

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Northern Innoko
Earth Cover Classification

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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 extent of Landsat Thematic Mapper scene Path 77/Row 14 covering portions of the Innoko National Wildlife Refuge and the Koyukuk National Wildlife Refuge, and associated uplands. Portions of two Landsat TM satellite scenes (Paths 77, Row 14, acquired August 28, 1995) and Path 76, Rows 14 (acquired June 23, 2000) were used to classify the project area into 43 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 343 field sites during a 14-day field season from 7/12/99 through 7/27/99. Approximately 20% (63) 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 90.5% at the +/-5% level of variation in interpretation of the accuracy assessment reference sites.

Introduction

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 Northern Innoko Earth Cover Mapping project area contained diverse landscapes and was deemed important for its wildlife and recreational values. The project area extends from the Yukon River in the southeast, to Selawik Lake in the northwest, to the Koyukuk River in the east, and west to Granite Mountain. The project area was essentially roadless and supported limited recreational use with the exception of fishing along the Yukon River and an occasional boating/canoeing trip on the Koyukuk River. The project area included abundant moose and tundra swan populations. 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 Northern Innoko study region, 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 Northern Innoko mapping project (Figure 1) consisted of 8.4 million acres centered roughly on the area framed by a square connecting Selawik Lake, Purcell Mountain, Koyukuk River, and Granite Mountain. The project area falls in the center of the Kateel River and Candle 1:250,000 scale quadrangles. The Koyukuk River runs along the eastern boundary of the study area. It included portions of the following USGS 1:250 scale quadrangles: Selawik, Melozitna, Nulato, Kateel River, Norton Bay, and Shungnak. The village of Galena fell just outside the southeastern boundary of the project along the Yukon River.

While this project area encompassed a wide variety of environments ranging from glaciated mountains to lowland black spruce muskeg, much of the study area (45%+) included habitats composed of some form of shrub/graminoid/tussock cover. Large regions of open and woodland black spruce accounted for over one-quarter of the study area. Minimal non-forested uplands and associated habitats were present within the study area and were found only along the extreme northern edge of the mapping area. While moose abounded throughout most of the project area, evidence of frequent bear use was not noted. Small lakes and ponds supported the pond lilies and other aquatic vegetation that make up an important summer food source for breeding tundra swans. These lakes were limited in extent in the study area to the region east and south of Selawik Lake and northeast of the Nogahabara Sand Dunes. Several wildfires that had burned over the study area were indicated on the 1995 and 1999 satellite imagery.

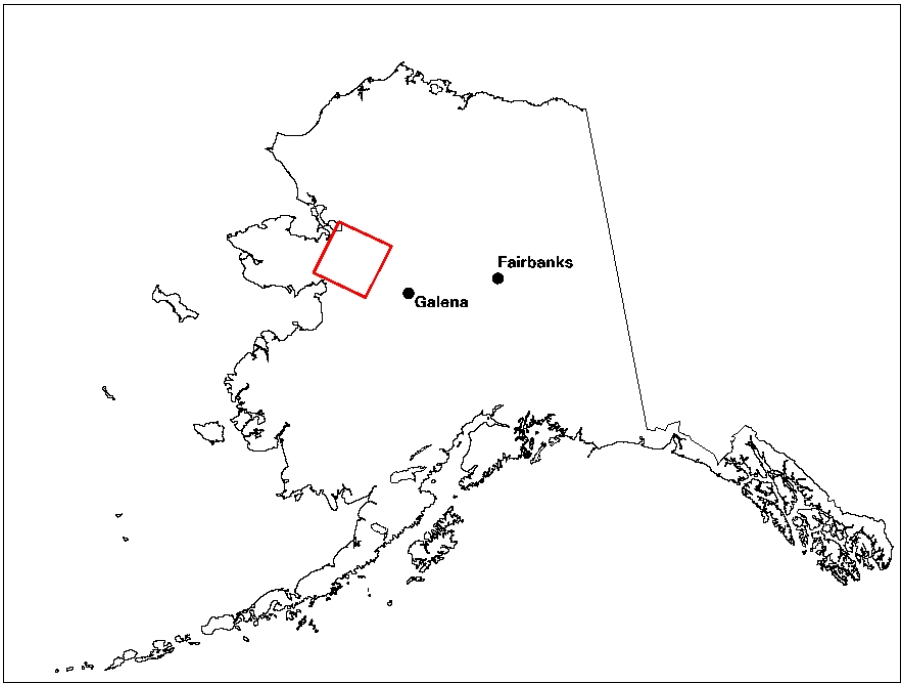


Figure 1. Northern Innoko project location.

Data Acquisition

Although the study area was delineated according to the boundary of a single scene of Landsat imagery (Path 77/Row 14) two separate Landsat scenes were utilized to cover the project area (Figure 2). Imagery from June 2000 was acquired (Paths 76/Row 14) to cover the eastern 3/5 of the study area. This scene was utilized in the recently completed earth cover mapping project for the eastern portion of the Koyukuk National Wildlife Refuge and the Melozitna River drainage area. Employing this scene in the Northern Innoko mapping project assured a seamless classification across the boundaries of the two mapping study areas. For the remaining 2/5 of the study area lying to the west and south of Landsat TM scene P76/R14, a Landsat TM scene captured in August, 1995 was acquired. The scenes were purchased from EROS Data Center. The two scenes were projected into a UTM projection to match the ancillary spatial data accompanying the project. No cloud cover was present in the June, 2000 image (P76/R14). The August, 1995 (P77/R14) image contained a bank of significant cloud cover along the southeastern edge of the study area just west of the Koyukuk River. A small region of cloud cover was evident immediately north of Inland Lake and northeast of Selawik Lake. Due to the relatively low mean elevation of the study area and the mid-summer date of the imagery, no snow or ice covered any portion of the study area.

Field data were collected on 343 field sites during a 14-day field season from July 12 through July 27, 1999. The ancillary data used in this project included: 1:60,000 aerial photographs (color infrared transparencies from 1980-82, 1984, and 1986-87 and USGS1:250,000 scale Digital Elevation Models (DEM).

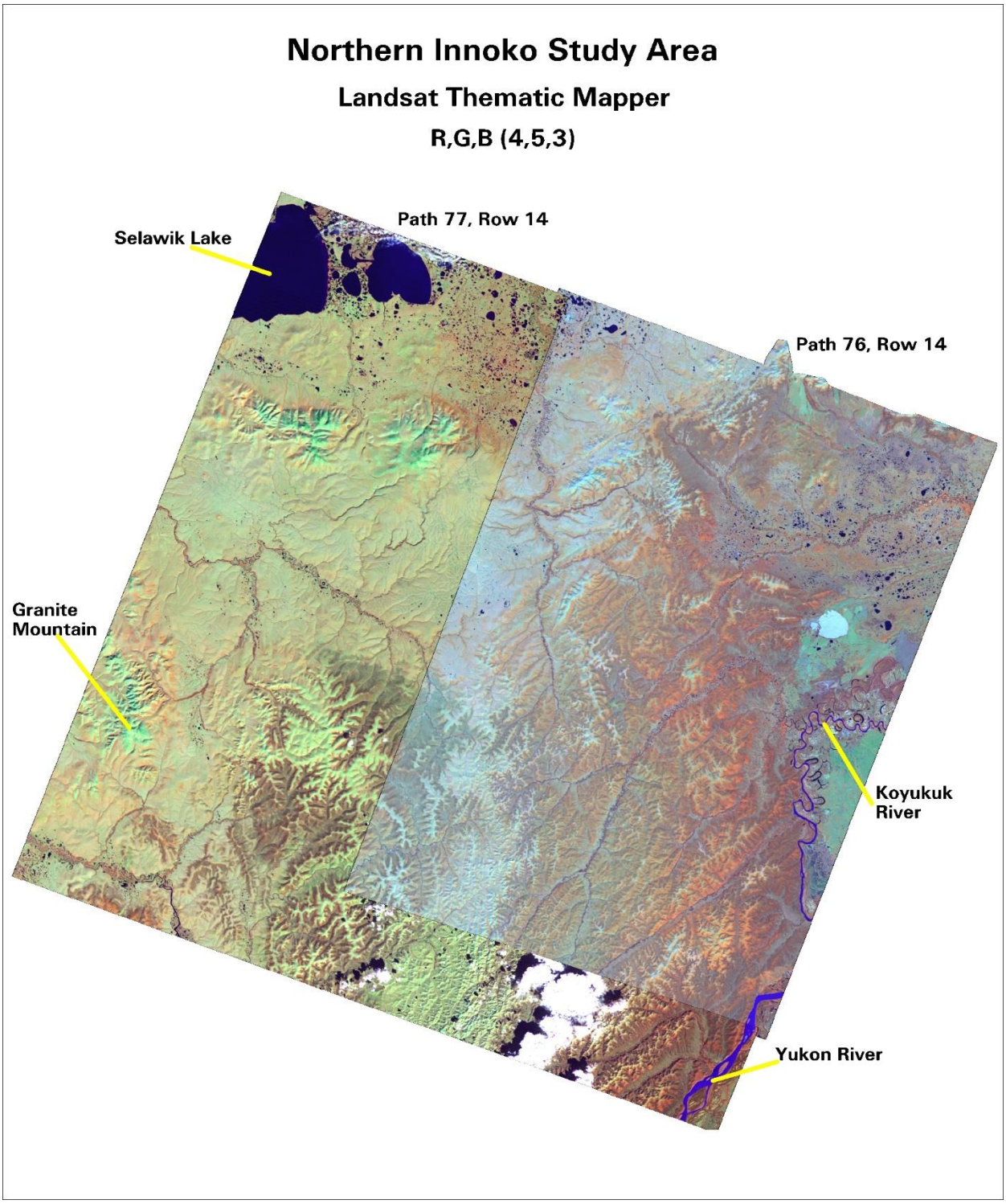


Figure 2. Satellite imagery used for the Northern Innoko earth cover mapping project.

Methods

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 (Viereck 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 Viereck 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 Viereck 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 DEM's.

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	1.21Open Needleleaf Lichen
	1.3 Woodland Needleleaf	1.31 Woodland Needleleaf Lichen
	1.4 Closed Deciduous	1.41 Closed Paper Birch
		1.42 Closed Aspen
		1.43 Closed Balsam Poplar/Cottonwood
		1.44 Closed Mixed Deciduous
	1.5 Open Deciduous	1.51 Open Paper Birch
		1.52 Open Aspen
		1.53 Open Balsam Poplar/Cottonwood
		1.54 Open Mixed Deciduous
	1.6 Closed Mixed Needleleaf/Deciduous	
	1.7 Open Mixed Needleleaf/Deciduous	
2.0 Shrub	2.1 Tall Shrub	
	2.2 Low Shrub	2.21 Low Shrub Willow/Alder
		2.22 Low Shrub Tussock Tundra
		2.23 Low Shrub Lichen
		2.24 Low Shrub Other
	2.3 Dwarf Shrub	2.31 Dwarf Shrub Lichen
		2.32 Dwarf Shrub Other
3.0 Herbaceous	3.1 Bryoid	3.11 Lichen
		3.12 Moss
	3.2 Wet Herbaceous	3.21Wet Graminoid
		3.22 Wet Forb
	3.3 Mesic/Dry Herbaceous	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		

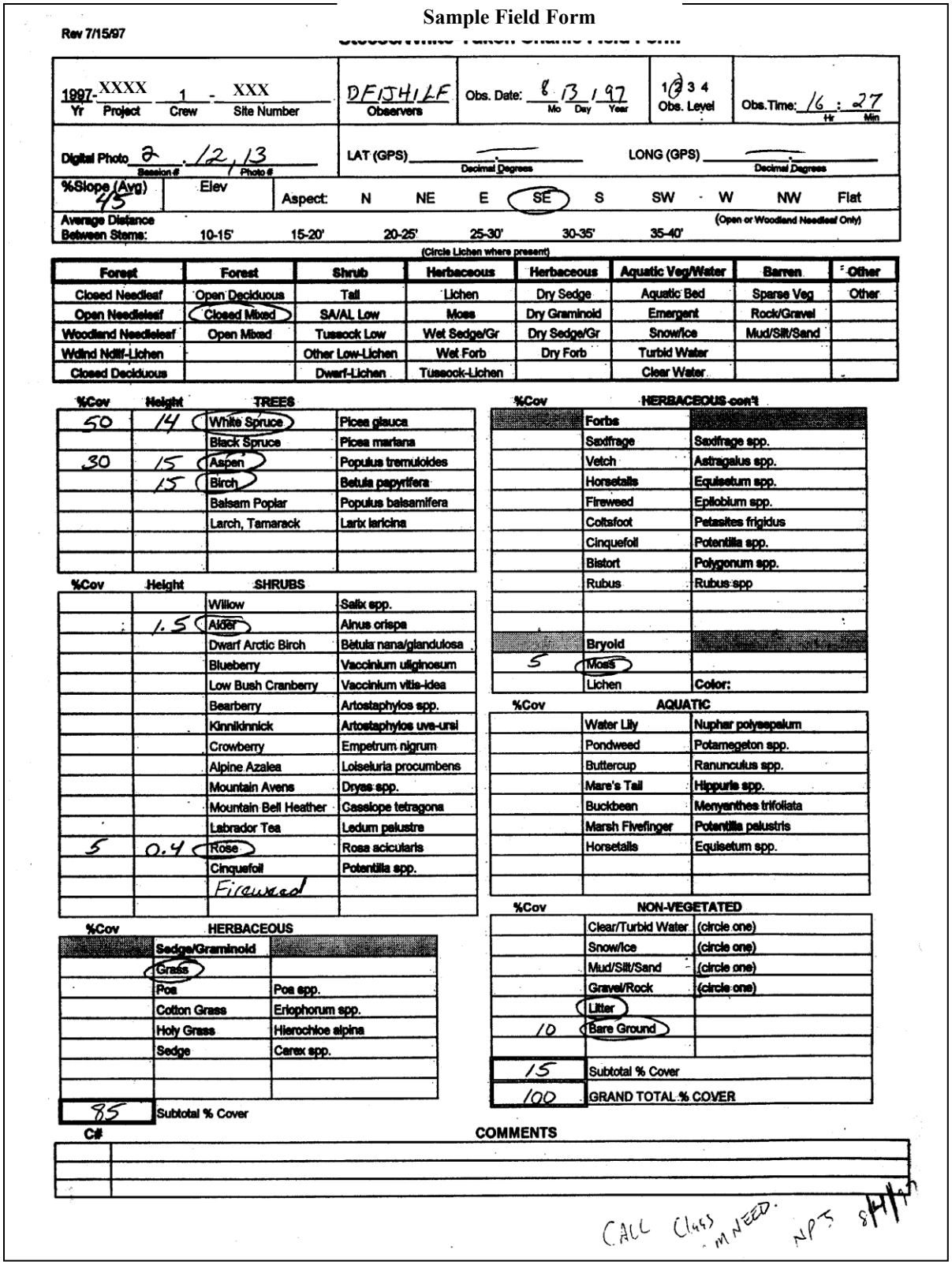
In order to optimize helicopter efficiency, field sites were identified and plotted on field maps before fieldwork began. Sufficient samples for each mapped class were selected to span the variation of spectral responses within that class throughout the entire image. For example, a shrub class in the 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 attempted to placed training sites near landmarks that were easily recognizable in the field, such as lakes or streams. A tally of the estimated number of field sites per class was kept until all of the target map classes were adequately sampled throughout the project area. 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 five-person helicopter crew performed the field assessment. Each crew consisted of a pilot, biologist, recorder, navigator, and alternate. 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, determined the overall earth cover class, and photographed the site. The recorder wrote species percentages and other data on the field form and generally assisted the biologist. The alternate was responsible for flight-following, data entry, and substitution in case of sickness. The majority of sites were observed without landing the helicopter. Ground verification was performed when identification of dominant vegetation was uncertain.



Sample Field Form

Rev 7/15/97

1997-XXXX 1 - XXX (Yr Project Crew Site Number)	DFIJHILF (Observers)	Obs. Date: 8 13 / 97 (Mo Day Year)	1 (2) 3 4 Obs. Level	Obs.Time: 16 : 27 (Hr Min)
Digital Photo 2 . 12 , 13 (Session # / Photo #)	LAT (GPS) ___ (Decimal Degrees)	LONG (GPS) ___ (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 Needleleaf	(Closed Mixed)	SA/AL Low	Moss	Dry Graminoid	Emergent	Rock/Gravel	
Woodland Needleleaf	Open Mixed	Tussock Low	Wet Sedge/Gr	Dry Sedge/Gr	Snow/Ice	Mud/Silt/Sand	
Wdlnd Ndlf-Lichen		Other Low-Lichen	Wet Forb	Dry Forb	Turbid Water		
Closed Deciduous		Dwarf-Lichen	Tussock-Lichen		Clear Water		

TREES

%Cov	Height		
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

SHRUBS

%Cov	Height		
		Willow	Salix spp.
	1.5	(Alder)	Alnus crispa
		Dwarf Arctic Birch	Betula nana/glandulosa
		Blueberry	Vaccinium uliginosum
		Low Bush Cranberry	Vaccinium vitis-idea
		Bearberry	Artostaphylos spp.
		Kinnikinnick	Artostaphylos 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.
		Fireweed	

HERBACEOUS

%Cov		
	Sedge/Graminoid	
	(Grass)	
	Poa	Poa spp.
	Cotton Grass	Eriophorum spp.
	Holy Grass	Hierochloe alpina
	Sedge	Carex spp.
85	Subtotal % Cover	

HERBACEOUS con't

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

AQUATIC

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

NON-VEGETATED

%Cov		
	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 MNEED. NPS 8/4/97

Figure 3. Custom field data collection form.

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 Sybase 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 vegetation types (Kempka et al. 1995, Congalton et al. 1993). This 4/3 ratio band replaced the thermal band (band 6) to retain a 7-band image for classification.

Sample Field Site – Closed Mixed Needleleaf/Deciduous

High site photo

Low site photo

DUFF INTERFACE

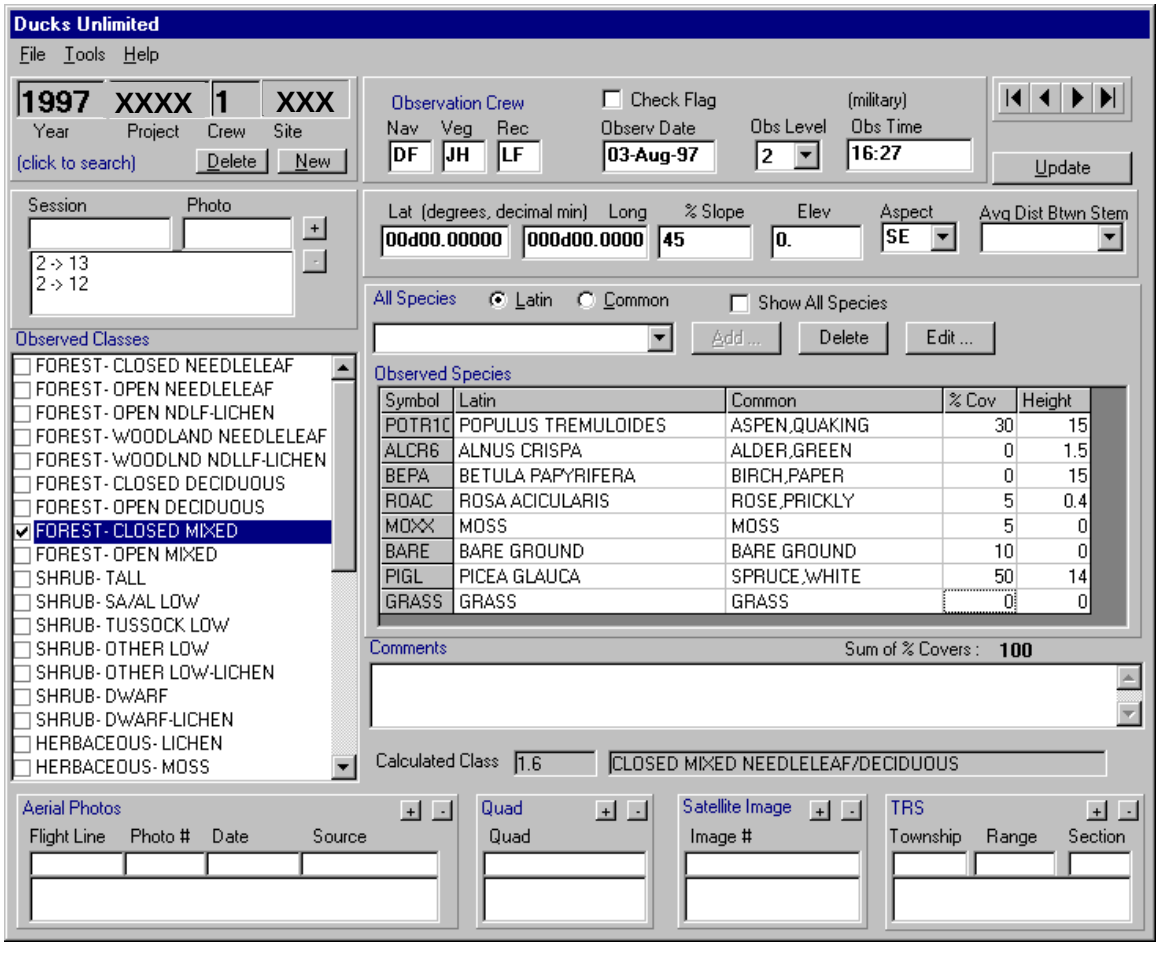


Figure 4. The customized database and user interface for field data entry (DUFF).

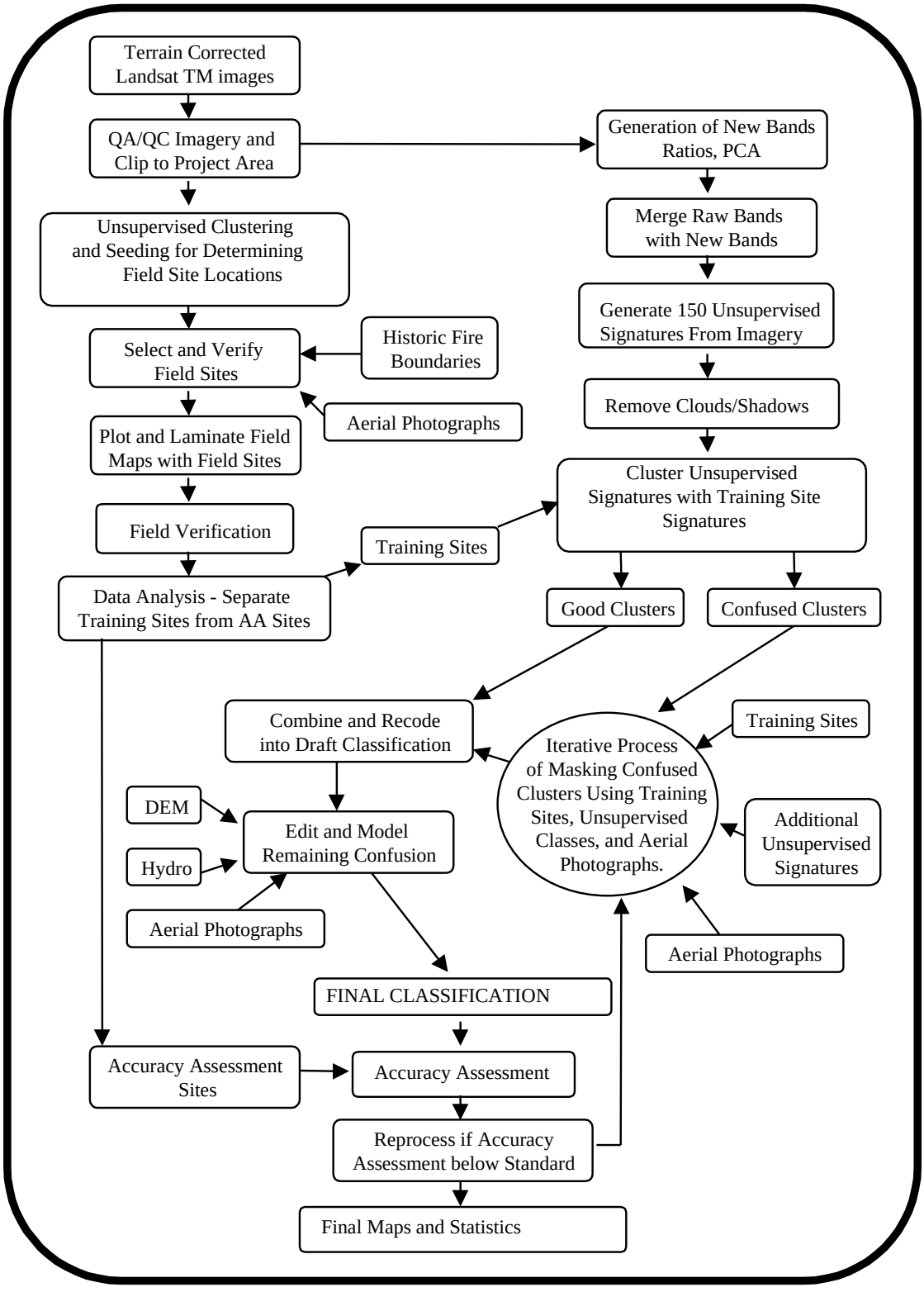


Figure 5. The image processing flow diagram.

Removal of Clouds and Shadows

Although the entire Northern Innoko study area can be captured on a single scene/date of Landsat TM imagery, the only available scene of imagery, of relatively recent vintage, that captured the entire study area contained significant cloud cover. Therefore, a decision was made to utilize a composite of two dates/scenes of TM imagery to create a base image data set that contained far fewer clouds and shadows. The remaining clouds in the August, 1995 imagery were removed using an unsupervised classification and manual on-screen editing. Clouds were separated from cloud shadows and these classes were recoded to their respective class number.

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 and turbid water. 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 20% 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. Generally, 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 June, 1999/2000; the aerial photographs spanned a seven year period from 1980 through 1987, the field data was collected in July 2001. 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 +/- 5% variation in estimation of vegetation compositions for each of the accuracy assessment sites. In other words, if a variation in interpretation of +/- 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.

Results

Field Verification

Data were collected on 343 field sites during a 14-day field season from 7/12/99 through 7/27/99. Approximately 20% (63) of these field sites were set aside for 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 Bell Jet Ranger helicopter was used to gain access to the field sites. Two field camp locations were utilized during the field data collection of this project. The Alaska Fire Service provided accommodations at Galena that served as a staging area for the helicopter, field equipment during field work for the east project area. The field camp location for the west project area was the USFWS bunkhouse east of Selawik. Fuel was obtained from several cache sites throughout the project area. Flight following was carried out by the alternate via satellite phone from both field camp locations.

Classification

Four vegetation classes dominated the Northern Innoko landscape as demonstrated by the final classification: Open Needleleaf (1,251,468 acres or 14.95% of total area), Tussock Tundra (1,206,516 acres or 14.41% of total area), Low Shrub – Tussock Tundra (1,203,394 acres or 14.37% of total area) and Low Shrub – Other (939,028 acres or 11.2% of total area). While the total of these three cover types accounted for well over 50% of the study area's vegetation, only two other vegetation types comprised more than 5% of the total earth cover (Woodland Needleleaf at 783,813 or 9.36% of the total area and Tall Shrub at 620,318 or 7.41% of the total area). The vast majority of the remainder of the study area's earth cover was comprised of various mosaics of: 1) regenerating fire scars containing dry/wet graminoids, low shrub, birch, bare ground, and occasional forbs; 2) wet lowlands of standing water, sedges, low shrubs and emergent vegetation; and 3) open and woodland needleleaf and open mixed needleleaf/deciduous forests. The bulk of the non-forest vegetation compositions were comprised of some form of tussock tundra. An even mix of low shrub – tussock tundra and herbaceous tussock tundra and tussock tundra - lichen dominated the central and western 1/3 of the study area. Upland spruce and mixed deciduous/spruce forests characterized the southern and eastern half of the study area. Non-woody vegetation apart from these classes accounted for less than 7% of the earth cover in the remainder of the study area. Most of the non-woody vegetation was contained in the Wet Sedge/Graminoid classes that were found surrounding much of the low lying, poorly drained areas surrounding the numerous small ponds and lakes found in two distinct areas north and east of Nogahabara sand dunes and east and south of Inland and Selawik Lakes. Forested stands of pure open and woodland spruce were far more "restricted" than those found on the adjacent Koyukuk/Melozitna and Nowitna NWR/ Galena MOA project areas. Open and woodland spruce stands were isolated in the

Table 2. Field sites per mapped class.

Class Name	Total Field Sites per Class	Sites Withheld for Accuracy Assessment
CLOSED NEEDLELEAF	5	0
OPEN NEEDLELEAF	43	13
OPEN NEEDLELEAF – LICHEN	12	0
WOODLAND NEEDLELEAF	12	0
WOODLAND NEEDLELEAF – LICHEN	1	0
CLOSED DECIDUOUS	20	5
OPEN DECIDUOUS	8	0
CLOSED MIXED NEEDLELEAF / DECIDUOUS	12	0
OPEN MIXED NEEDLELEAF / DECIDUOUS	5	0
TALL SHRUB	35	9
LOW SHRUB – OTHER	25	7
LOW SHRUB – LICHEN	2	0
LOW SHRUB – ALDER/WILLOW	0	0
LOW SHRUB – TUSSOCK TUNDRA	34	9
DWARF SHRUB – OTHER	28	5
DWARF SHRUB – LICHEN	5	0
WET SEDGE / GRAMINOID	28	7
WET FORB	2	0
MESIC/DRY SEDGE MEADOW	1	0
MESIC/DRY GRASS MEADOW	7	0
MESIC / DRY GRAMINOID	5	0
MESIC / DRY FORB	1	0
TUSSOCK TUNDRA	28	8
TUSSOCK TUNDRA – LICHEN	9	0
EMERGENT VEGETATION	2	0
AQUATIC BED	1	0
CLEAR WATER	0	0
TURBID WATER	0	0
SPARSE VEGETATION	3	0
ROCK GRAVEL	3	0
NON-VEGETATED SOIL	2	0
LICHEN	1	0
MOSS	2	0
OTHER	1	0
TOTAL	**343**	**63**

Table 3. List of field data collection participants.

Participant	Role	Agency
Randi Myers	Biologist/Vegetation Expert	Bureau of Land Management
Roxie Anderson	Recorder/Alternate	Ducks Unlimited Inc
Guy Hughes	Recorder/Alternate	US Fish and Wildlife Service
Alex Morton	Navigator/Image Processor	Ducks Unlimited Inc.

south-central region of the Northern Innoko study area. Other forested regions of the study area typically were found to contain a mix of deciduous species. These uplands were characterized by rolling hills covered with a mix of closed birch, open needleleaf, and closed mixed needleleaf/ deciduous forest types. Only a few isolated areas presented uplands that exhibited extensive non-forest types including dwarf shrub, lichen, sparse vegetation and some dry graminoid cover types.

Stands of closed canopy deciduous trees were found on steep, well-drained south-facing slopes primarily in the southeastern regions the study area. These stands were composed primarily of Birch, although occasional stands of Aspen were present. Unfortunately, no consistent spectral signature could be derived for these often scattered and smaller stands of Aspen. Closed canopy needleleaf stands also appeared to be constrained by soil conditions and were found only near major river drainages or on the very top of flat ridges; although scattered pixels of closed needleleaf are evident throughout many of the more dense open needleleaf spruce stands. Open deciduous stands were rare, occurring mainly in areas that had been recently burned or otherwise disturbed. The aquatic bed cover type, composed primarily of floating pond lilies, was a relatively rare type within the small pond and lakes in the vicinity of Nogahabara sand dunes and Inland and Selawik Lake.

Differentiating between wet and dry graminoid and areas of flooded low shrub proved to be difficult as the moisture and water level conditions visible on the 1995 and 2000 satellite imagery in many of the forb/graminoid types appeared highly variable. Generally, the 2000 imagery exhibited a much greater amount of standing water in many of the lower lying regions in the eastern portion of the study area. 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 2000 satellite imagery that appeared to be completely flooded or having a significant portion of standing water was described in the 1999 field season as having very little or no water visible. This often resulted in initial confusion between forb/graminoid regions being classified as dry when there was obvious presence of standing water visible in the satellite imagery.

Rock and sparse vegetation cover types were found mostly at the highest elevations in only a couple of fairly isolated regions, and along streambanks, riverbanks and sandbars. No areas of snow and ice were found within the study area.

The distribution of earthcover types is characterized in Table 5 and Figure 6.

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, closed canopy 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. Closed and open canopy needleleaf was found only at lower elevations within the project area, so 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. Some editing centered on ecological differences across the project area. For example, a single signature classified low shrub – tussock tundra in the lowlands throughout the central and western portions of the study area and dwarf shrub - lichen on the higher elevation ridges in the same region. Editing in this case consisted of correctly labeling and separating classes along ecological boundaries. Due to the obvious topographic positioning of these two distinct landforms that are clearly visible on the raw satellite imagery, manual editing proved to be a very efficient and effective method of classification improvement. Because the project area was relatively diverse, this kind of editing was often necessary; especially in the transitional areas from treeline into the dwarf shrub/sparse vegetation zones.

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 areas of wet sedge/graminoid and open/closed needleleaf. Editing was done to separate legitimate wet sedge/graminoid and open needleleaf pixels based on aerial photography, field notes and topography.

A final case of spectral classification confusion involved the misclassification of closed birch and tall shrub. This was a typical point of confusion in the earth cover mapping projects recently completed in the vicinity of the Northern Innoko project (e.g. Melozitna/Koyukuk and the Nowitna NWR EC Mapping projects). The spectral reflectance of these two earth cover types is very similar; especially when one considers the variety of slope and aspect combinations that these two types occupy. This confusion was corrected via manual editing utilizing photo-interpretation and review of specific field notes and photos. Fortunately, the

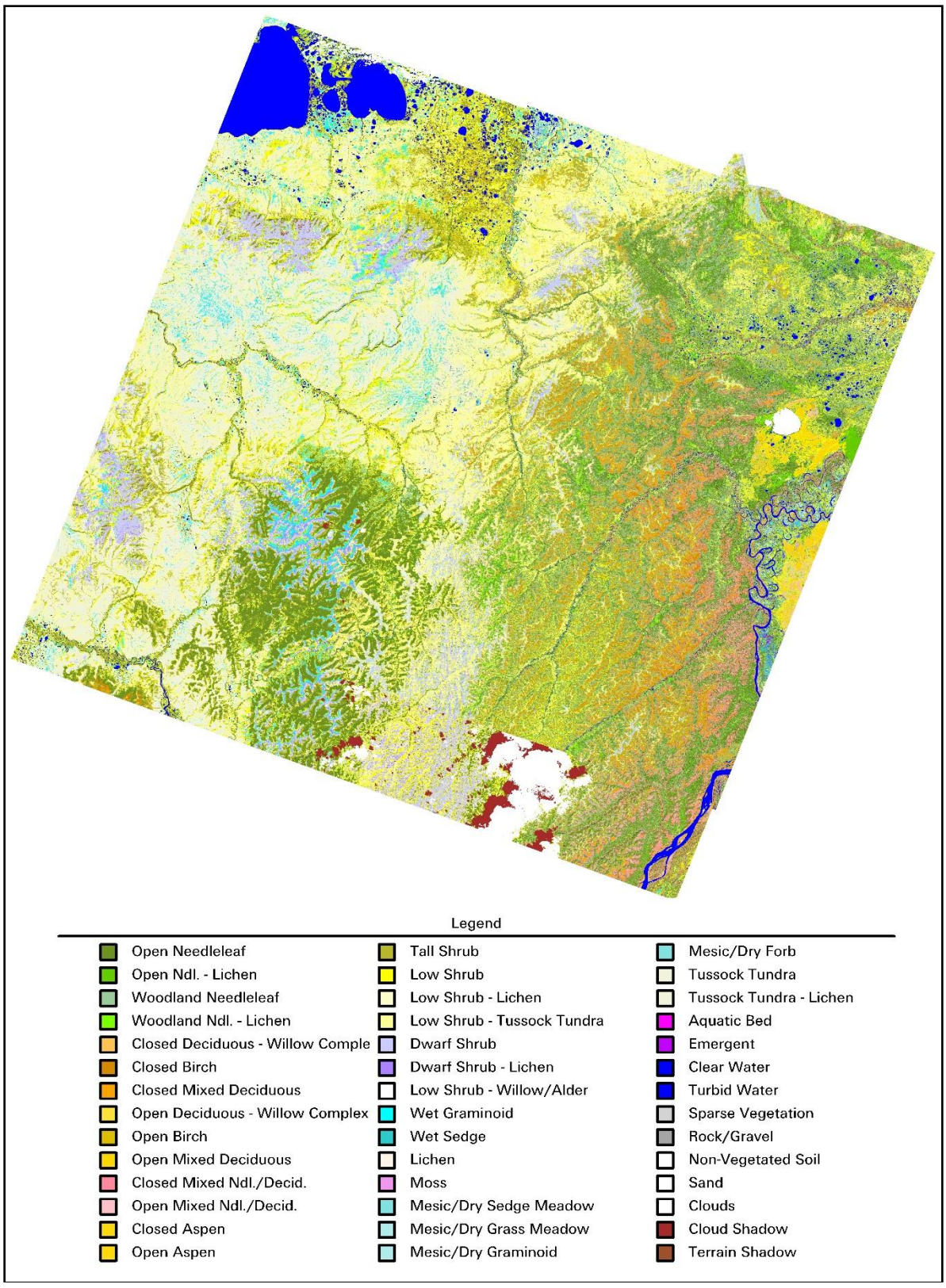


Figure 6. Northern Innoko project area final classified map.

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

CLASS NUMBER	CLASS NAME	ACRES	PERCENT COVER
1	Closed Needleleaf	14,580	0.17%
2	Open Needleleaf	1,251,468	14.95%
3	Open Ndl. - Lichen	107,467	1.28%
4	Woodland Needleleaf	783,813	9.36%
5	Woodland Ndl. - Lichen	78,364	0.94%
10	Closed Deciduous – Willow Complex	2,763	0.03%
11	Closed Deciduous – Birch	123,934	1.48%
12	Closed Mixed Deciduous	205,624	2.46%
13	Open Deciduous – Willow Complex	2,385	0.03%
14	Open Deciduous – Birch	83,704	1.00%
15	Open Mixed Deciduous	39,383	0.47%
16	Closed Mixed Ndl./Decid.	111,323	1.33%
17	Open Mixed Ndl./Decid.	148,765	1.78%
18	Closed Aspen	971	0.01%
19	Open Aspen	1,485	0.02%
20	Tall Shrub	620,318	7.41%
21	Low Shrub	939,028	11.21%
22	Low Shrub - Lichen	16,392	0.20%
23	Low Shrub - Tussock Tundra	1,203,394	14.37%
24	Dwarf Shrub	277,803	3.32%
25	Dwarf Shrub - Lichen	77,739	0.93%
32	Low Shrub – Willow/Alder	1,603	0.02%
33	Wet Graminoid	201,198	2.40%
34	Wet Sedge	36,756	0.44%
36	Lichen	1,594	0.02%
37	Moss	2,498	0.03%
41	Mesic / Dry Sedge Meadow	337	0.00%
42	Mesic / Dry Grass Meadow	3,034	0.04%
43	Mesic / Dry Graminoid	34,640	0.41%
44	Mesic / Dry Forb	5,586	0.07%
50	Tussock Tundra	1,206,516	14.41%
51	Tussock Tundra – Lichen	237,822	2.84%
60	Aquatic Bed	819	0.01%
61	Emergent Vegetation	19,712	0.24%
70	Clear Water	290,227	3.47%
71	Turbid Water	18,464	0.22%
72	Snow / Ice	0	0.00%
80	Sparse Vegetation	27,830	0.33%
81	Rock/Gravel	509	0.01%
82	Non-Vegetated Soil	15,542	0.19%
83	Sand	1,477	0.02%
92	Cloud	124,557	1.49%
93	Cloud Shadow	45,614	0.54%
94	Terrain Shadow	6,181	0.07%
Total		**8,373,227**	**100%**

areas exhibiting this vegetation composite were limited to only a few regions of the study area where typically tall shrub and closed birch communities transitioned from forested needleleaf regions to the high-elevation regions at tree-line.

Finally, at the request of U.S. Fish & Wildlife project participants, an attempt was made to further stratify the mixed deciduous classes into closed- and open deciduous classes that discriminated the willow dominated communities from other mixed deciduous types. This effort was focused on the younger willow communities found along the limited riparian corridors of the Yukon and Koyukuk Rivers in this study area. These willow communities were spectrally quite distinct from the older, more established closed birch forests that occupied portions of the riparian corridor usually just inland from the willow communities and river's edge. Therefore, a consistent and reliable stratification of willow-dominated forests from other mixed deciduous forests was achieved. Total acres of coverage of the willow-complex classes are presented in Table 4. A full characterization of these classes for the Koyukuk and Melozitna Rivers is found in the final classification of the Melozitna/Koyukuk River basins to the east of the Northern Innoko project area.

Accuracy Assessment

Most earth cover classes were not adequately represented in the field data available for training and accuracy assessment. This was due to multiple factors. First, a very limited number of field sites was collected for an 8+ million acre study area. This fact made it difficult to extract a large number of accuracy assessment sites while still maintaining enough sites for computer training in the classification process. To compensate for this circumstance, a lower than usual percentage of field sites were extracted for accuracy assessment from the pool of available field sites. This resulted in a lower than usual number of sites per class throughout the scheme of mapping classes. In addition, many classes were not adequately represented in the accuracy assessment analysis because of their scarcity within the project area, e.g., all forested classes with the exception of open needleleaf classes, mesic/dry herbaceous classes, aquatic bed, etc.

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 were 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 +/- 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 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 combined Path 76/77 matrix in Appendix D, of the nine reference sites characterized as low shrub – tussock tundra, one site was an acceptable match with low shrub - other, one was an unacceptable match with tussock tundra, and one was an unacceptable match with woodland needleleaf. The remainder of the sites (6) were diagonal matches with low shrub – tussock tundra. The off-diagonal matches indicate that at least one of those sites was just on the border between low shrub – other and low shrub – tussock tundra (prescence of 30-35% tussock species). Also, 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 74.6% with no allowance for variation in interpretation.

Overall Accuracy Assessment

The difference in classification accuracy between the +/- 0% variation in interpretation level (70%) and the +/- 5% variation in interpretation level (90%) indicates that a great 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 +/- 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 at the +/- 5% variation level), a more reliable and informative measure of accuracy and reliability is presented.

In the needleleaf classes, only open needleleaf contained any accuracy assessment sites. The accuracy measures of the open needleleaf class were acceptable with absolutely no lumping or variation of interpretation allowed (77%). Ten out of the thirteen open needleleaf reference sites were found to classify as open needleleaf. Two of the remaining three reference sites were estimated to be woodland needleleaf sites between 20 – 25% tree crown cover. Allowing +/- 5% variation in interpretation in the reference data, both of these sites would be appropriately categorized as open needleleaf; bringing the class producer's accuracy to 92%. The User's Accuracy for the same class indicates an even more reliable classification. According to the User's Accuracy for open needleleaf, when an area is classified as open needleleaf class, the user can have extreme confidence in the accuracy of that classification. Figure 7 and 8 present photos of the two accuracy assessment sites that were characterized as open needleleaf by the field observer but mapped as woodland needleleaf in the final earth cover classification.

An examination of both the User's and Producer's accuracy reveals no significant trends of error in the combined path 76/77 error matrix. The errors that were present seemed to occur more-or-less equally to all mapping classes without one or two classes accounting for the majority of the error. The one potential exception seemed to be those classes associated with the presence/absence of tussock species. Vast areas of tussock tundra, low shrub – tussock tundra, and other shrub classes containing appreciable amounts of tussock species were found throughout the central and western portions of the study area. No less than seven mapping classes were characterized as, or very nearly associated with, tussock tundra cover types. These included: low shrub – tussock tundra, low shrub – other, low shrub – lichen, dwarf shrub – other, dwarf shrub – lichen, tussock tundra, and tussock tundra – lichen. With as little as a 5% variation in interpretation in the amounts of these vegetation characteristics, as many as seven different cover type labels could result. The potential number of associated classes could be as high as eight if one considers the proximity of the wet/dry graminoid classes to the tussock mapping classes. Although a total of 29 reference sites were available for evaluating these seven classes, no single class possessed more than nine accuracy assessment sites, which limits the statistical validity of any statements one can infer from the analysis. Only four of these seven mapping classes possessed any accuracy assessment sites at all. Even so, the Producer's Accuracy for these four sites were all in excess of 70% at the +/- 5% variation of interpretation level with two of the four demonstrating 100% accuracy. However, this set of classes did account for the majority of the off-diagonal "misses" in

Figure 7. Aerial view of accuracy assessment site characterized as Open Needleleaf. This site was mapped as Woodland Needleleaf.

Figure 8. Aerial view of accuracy assessment site characterized as Open Needleleaf. This site was mapped as Woodland Needleleaf.

the matrix. In fact, if the wet graminoid class is included in this mix of "potential tussocks", this group accounts for all but one of the off-diagonal misclassifications in the entire matrix at the +/- 5% variation of interpretation level.

An example of the potential in only slight variation in interpretation of one of these types of "potential tussock" sites is presented in Figure 9. This site was classified as low shrub – tussock tundra. According to the field interpretation, the site contained 25% shrub and 50% tussock cotton grass. The heights of the shrub were interpreted to be between .1 and .2 meters, resulting in a dwarf shrub – other classification. A change in height estimation of less than four inches would have resulted in a low shrub – tussock tundra designation. Similarly, an estimation of 1% less shrub cover would have resulted in an herbaceous tussock tundra designation. This site demonstrates well the impact of the variation in interpretation on the suite of sites that border on the tussock tundra characterization in this study area.

Similar results are found throughout the error matrix. When accounting for those reference sites that characterize vegetation communities at the boundary of two or more mapping classes, consistently high accuracy measures are found for both the user's and producer's accuracy. Most every measure of both the user's and producer's accuracy at the +/- 5% level of variation of interpretation in the reference data for classes containing more than four reference sites exceeded 75% with the vast majority of these sites exceeding 85% accuracy. The one obvious exception to this trend was the

Figure 9. Aerial view of borderline dwarf shrub – other / low shrub – tussock tundra / herbaceous tussock tundra site.

single site classified as low shrub – other and characterized in the field as open needleleaf. No reasonable explanation exists for this single anomaly in the classification results. Out of the thirteen open needleleaf reference sites, however, it was the sole "mis-classification" at the +/- 5% variation of interpretation level.

Despite the strong correlation between the reference data and the classified map data, one trend of potential interest to an end user is evidenced in the error matrix. From a user's perspective, the low shrub – tussock and herbaceous tussock tundra classes present a slight tendency toward being over classified. While all ten (100%) of the low shrub - tussock reference sites were found to be classified correctly at the +/- 5% variation level, four of these sites were located in an off- diagonal cell. Similarly, the herbaceous tussock tundra class presented three off-diagonal elements out of the five reference sites that fell within that mapping category in the final earth cover classification. Although all eight of the tussock tundra reference sites were found to be a match (100%) in the Producer's Accuracy at the +/- 5% variation in interpretation level, a User's Accuracy of 75% at that same interpretation variation level with three off-diagonal elements may be indicative of a slight tendency toward characterizing sites containing at least 25% low or dwarf shrub and the presence of tussock species as a herbaceous tussock tundra class in the final earth cover classification.

In summary, based on the quantitative accuracy assessment, the earth cover classification map produced for the Northern Innoko study area is very reliable. Nearly 70% of the accuracy assessment sites matched the full detailed 33 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, more than nine out of ten (90.5%) of the reference sites were found to correspond correctly with the classified map.

Discussion

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 August 28, 1995 and June 23, 2000. The aerial photographs spanned a seven-year period from 1980-87, and the field data was collected in July 1999. Differences due to environmental changes from the different sources may have affected the accuracy assessment. As discussed earlier, the significant differences in standing water in many older oxbows and other wetter sites between the image date and the field collection date contributed to inconsistencies in correctly identifying sites as wet or dry graminoid/forb, emergent, or dwarf shrub. Depending on the standing water present at any given time, each of these class labels may have been appropriate.

The other primary areas of confusion revealed in the analysis of accuracy revolves around the presence/absence of tussock species and dwarf/low shrub percentages within a given field site. With as little as a 5% variation in interpretation in the amounts of these vegetation characteristics, as many as six or eight different cover type labels could result. For instance, a site containing 25% shrub species at .2m in average height

and 30% tussock species, could easily be interpreted as a dwarf shrub, tussock tundra, low shrub – tussock tundra, or low shrub – other site. This variability is evidenced by the number of off-diagonal elements among these earth cover classes in the Appendix D matrices.

Another component impacting the quantitative accuracy assessment analysis for this project was related to the fact that many of the 63 accuracy assessment sites visited in the field contained no species specific ground cover detail. This was due to the fact that, in order to maximize the field data collection time provided, as many as 44 field sites across the entire study area were "captured" as "fly-by" sites. In these cases, only an observed class and an occasional textual note regarding general species compositions were recorded. Evaluating these sites for the impact of the variation of interpretation on the final site label was not possible.

Finally, the relatively late date of image acquisition (August 28) of the Path 77/Row 14 scene from 1995, resulted in significant terrain shadowing in much of the upland regions of the study area. This caused some degree of confusion between earth cover types; primarily in the forested classes between open and woodland needleleaf.

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 Northern Innoko study area.

Final Products

The project final product included a digital classification, map, and database of 44 earth cover classes within the Northern Innoko 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 ArcInfo 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 an ArcInfo point coverage. Digital photos of the field sites are stored as jpeg's. All of the delivered datasets were loaded into Arcview projects for display purposes.

Summary

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 Northern Innoko project using Landsat TM satellite scenes, Paths 77, Row 14 acquired 28 August 1995 and Path 76, Row 14 acquired on 23 June 2000. The project area was classified into 44 earth cover categories with an overall accuracy of 90.5% 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, a digital ArcInfo point coverage of wildlife sighting locations observed during the collection of field data, a complete field database including digital site photos, and an ArcView project.

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Appendices

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 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 ≥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 ≥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, ≥75% of the trees were needleleaf, and ≥ 20% of the understory was lichen.

1.3 Woodland Needleleaf

From 10-24% of the cover was trees, and ≥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, ≥75% of the trees were needleleaf, and ≥ 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 ≥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, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were Paper Birch (*Betula Papyfera).*

1.42 Closed Aspen
At least 60% of the cover was trees, ≥75% of the trees were deciduous, and ≥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, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were Cottonwood.

1.44 Closed Deciduous – Willow Complex
At least 60% of the cover was trees, ≥75% of the trees were deciduous, and ≥60% of the deciduous trees were of the Salix genera, tree form.

1.5 Open Deciduous (Mixed Deciduous Species 1.55)
From 25-59% of the cover was trees, and ≥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, ≥75% of the trees were deciduous, and ≥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, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were Aspen.

1.53 Open Cottonwood
From 25-59% of the cover was trees, ≥75% of the trees were deciduous, and ≥75% of the deciduous trees were Cottonwood.

1.54 Open Deciduous – Willow Complex
At least 25-59% of the cover was trees, ≥75% of the trees were deciduous, and ≥60% of the deciduous trees were of the Salix genera, tree form.

1.6 Closed Mixed Needleleaf/Deciduous
At least 60% of the cover was trees, but neither needleleaf nor deciduous trees made up ≥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 ≥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 ≥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 ≥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 ≥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 ≥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 ≤.25 meters, and ≥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 ≤.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 ≥40% herbaceous species, ≤25% water, and ≥ 60% lichen species.

3.12 Moss
Composed of ≥40% herbaceous species, ≤25% water, and ≥60% moss species.

3.21 Wet Graminoid
Composed of ≥40% herbaceous species, ≤25% water, and where ≥60% of the herbaceous cover was graminoid, and ≥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 ≥40% herbaceous species, ≤25% water, where ≥50% of the herbaceous cover was graminoid, and ≥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 ≥40% herbaceous species, ≤25% water, where ≥50% of the herbaceous cover was graminoid, and ≥20% of the cover was lichen, and ≥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 ≥40% herbaceous species, ≤5% water, with ≥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 ≥40% herbaceous species, ≤5% water, with <50% graminiods. 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.), Marestail (*Hippuris* spp.), and Buckbean (*Menyanthes trifoliata*).

4.1 Aquatic Bed
Aquatic vegetation made up ≥20% of the cover, and ≥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 ≥20% of the cover, and ≥20% of the vegetation was composed of plants other than pond lilies. Generally included freshwater herbs such as Horsetails, Marestail, or Buckbean.

5.1 Clear Water
Composed of ≥80% clear water.

5.2 Turbid Water
Composed of ≥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 ≥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, ≥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, ≥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.

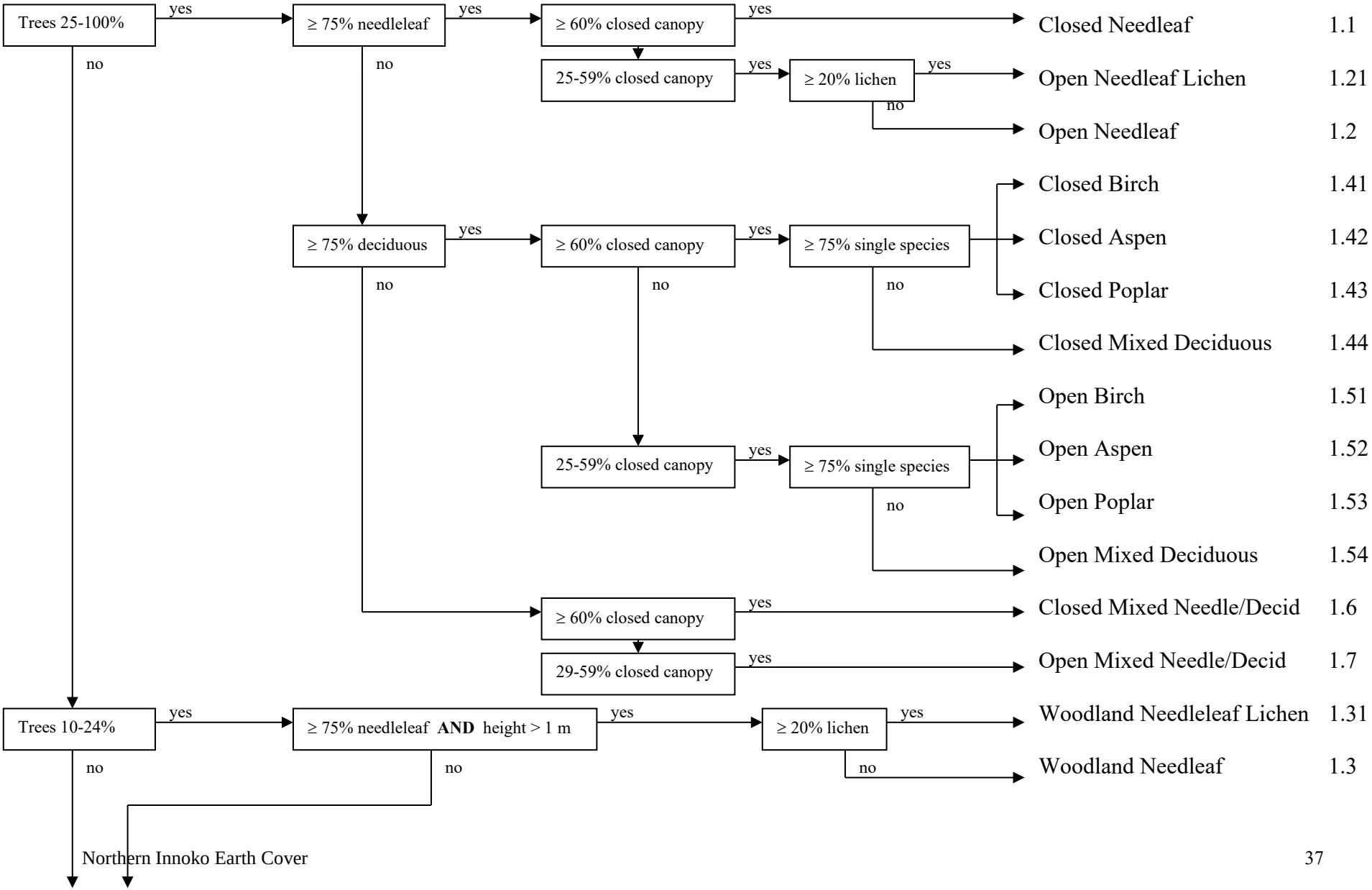
9.1 Cloud
At least 50% of the cover was made up of clouds.

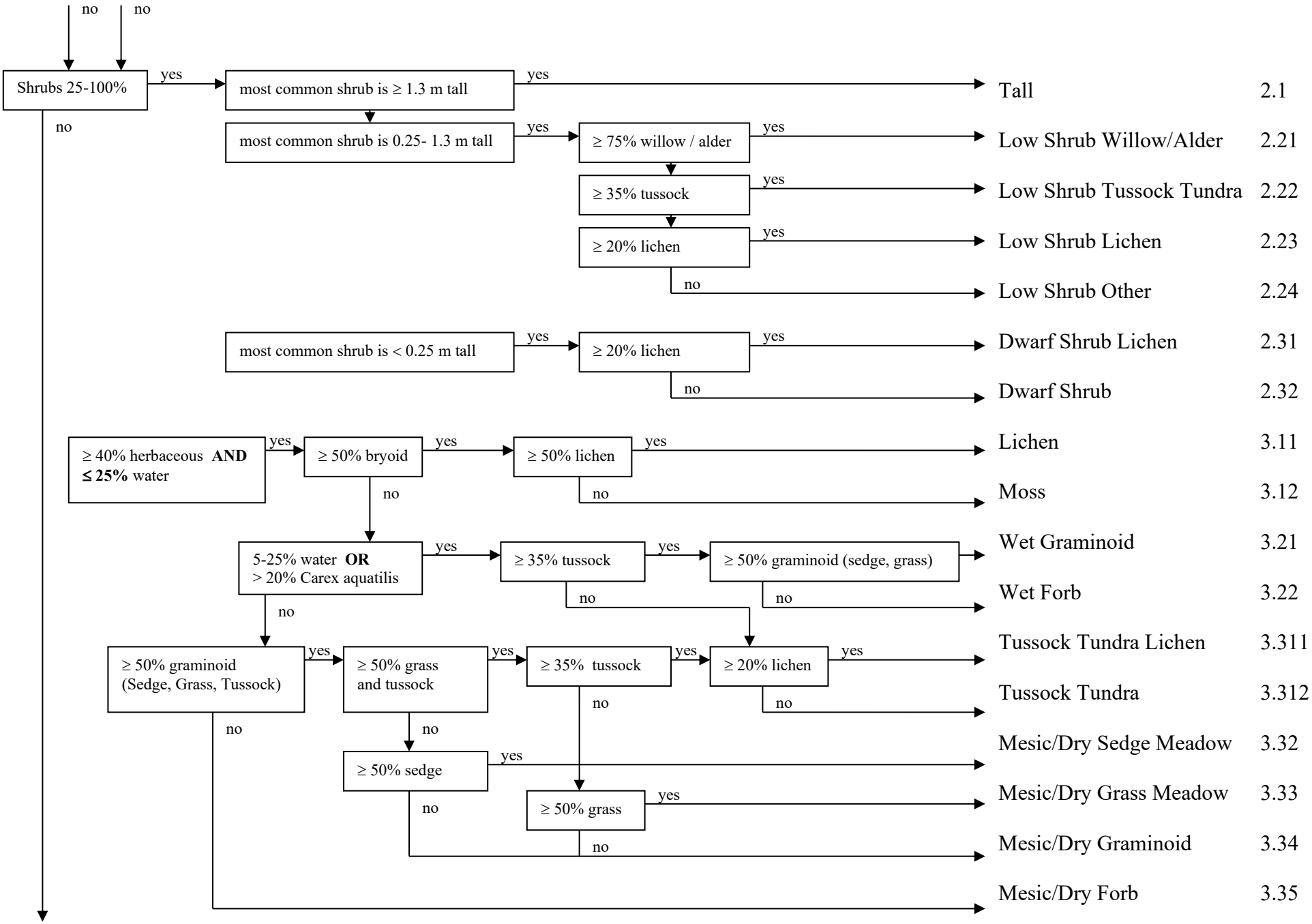
9.2 Cloud Shadow
At least 50% of the cover was made up of clouds shadows.

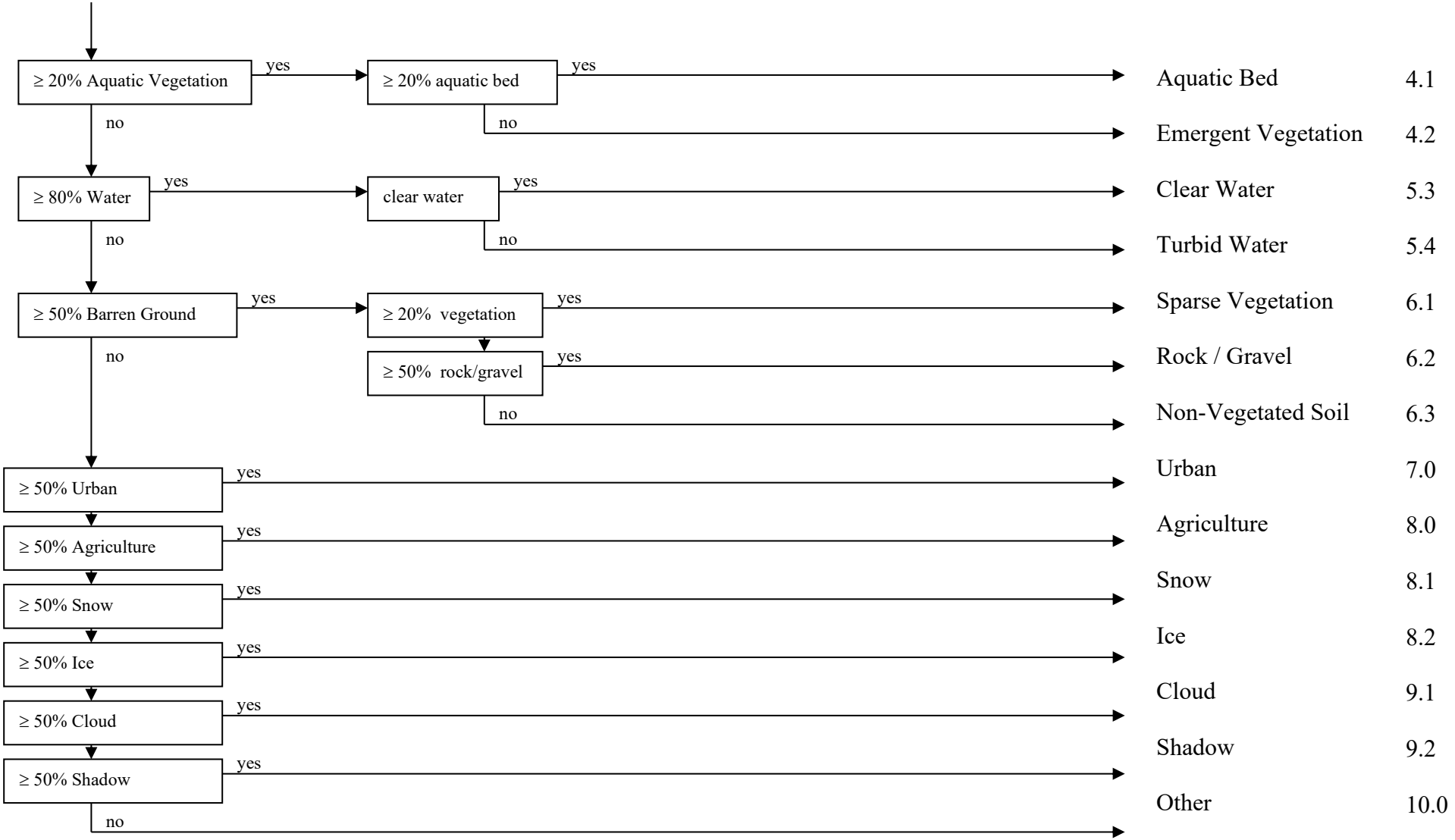
9.3 Terrain Shadow
At least 50% of the cover was made up of terrain shadows.

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.




no
no
Shrubs 25-100%
yes
most common shrub is ≥ 1.3 m tall
yes
Tall 2.1
no
most common shrub is 0.25- 1.3 m tall
yes
≥ 75% willow / alder
yes
Low Shrub Willow/Alder 2.21
≥ 35% tussock
yes
Low Shrub Tussock Tundra 2.22
≥ 20% lichen
yes
Low Shrub Lichen 2.23
no
Low Shrub Other 2.24
most common shrub is < 0.25 m tall
yes
≥ 20% lichen
yes
Dwarf Shrub Lichen 2.31
no
Dwarf Shrub 2.32
≥ 40% herbaceous AND
≤ 25% water
yes
≥ 50% bryoid
yes
≥ 50% lichen
yes
Lichen 3.11
no
no
Moss 3.12
5-25% water OR
> 20% Carex aquatilis
yes
≥ 35% tussock
yes
≥ 50% graminoid (sedge, grass)
Wet Graminoid 3.21
no
no
Wet Forb 3.22
no
≥ 50% graminoid
(Sedge, Grass, Tussock)
yes
≥ 50% grass
and tussock
yes
≥ 35% tussock
yes
≥ 20% lichen
yes
Tussock Tundra Lichen 3.311
no
no
Tussock Tundra 3.312
no
no
≥ 50% sedge
yes
Mesic/Dry Sedge Meadow 3.32
no
≥ 50% grass
yes
Mesic/Dry Grass Meadow 3.33
no
Mesic/Dry Graminoid 3.34
Mesic/Dry Forb 3.35


≥ 20% Aquatic Vegetation
yes
≥ 20% aquatic bed
yes
Aquatic Bed 4.1
no
no
Emergent Vegetation 4.2
≥ 80% Water
yes
clear water
yes
Clear Water 5.3
no
no
Turbid Water 5.4
≥ 50% Barren Ground
yes
≥ 20% vegetation
yes
Sparse Vegetation 6.1
no
≥ 50% rock/gravel
yes
Rock / Gravel 6.2
no
Non-Vegetated Soil 6.3
≥ 50% Urban
yes
Urban 7.0
≥ 50% Agriculture
yes
Agriculture 8.0
≥ 50% Snow
yes
Snow 8.1
≥ 50% Ice
yes
Ice 8.2
≥ 50% Cloud
yes
Cloud 9.1
≥ 50% Shadow
yes
Shadow 9.2
no
Other 10.0

Appendix C. Plant species and cover type list.

Site Tally	Symbol	Species	Common Name
402	MOXX	MOSS	MOSS
351	VAUL	VACCINIUM ULIGINOSUM	BLUEBERRY,BOG
335	LITT	LITTER	LITTER
321	LEPA	LEDUM PALUSTRE	LABRADOR TEA
311	LIXX	LICHEN	LICHEN
284	SAX_	SALIX SPP	WILLOW
262	BEGL	BETULA GLANDULOSA	BIRCH,DWARF ARCTIC
193	CACA4	CALAMAGROSTIS CANADENSIS	REEDGRASS,BLUE-JOINT
172	CAXX	CAREX SPP	SEDGE SPP
148	PIMA	PICEA MARIANA	SPRUCE,BLACK
129	EMNI	EMPETRUM NIGRUM	CROWBERRY,BLACK
127	ALCR6	ALNUS CRISPA	ALDER,GREEN
125	PIGL	PICEA GLAUCA	SPRUCE,WHITE
106	EQXX	EQUISETUM SPP	HORSETAILS SPP
105	BEPA	BETULA PAPYRIFERA	BIRCH,PAPER
104	PISP	PICEA SPP.	SPRUCE, MIXED WHITE AND BLACK
96	RUCH	RUBUS CHAMAEMORUS	CLOUDBERRY
88	EPAN2	EPILOBIUM ANGUSTIFOLIUM	FIREWEED
88	ERXX	ERIOPHORUM SPP	COTTON-GRASS
79	DRXX	DRYAS SPP	MOUNTAIN-AVENS
79	SPBE	SPIRAEA BEAUVERDIANA	SPIRAEA,BEAUVERED
65	CLWA	CLEAR WATER	CLEAR WATER
64	LALA	LARIX LARICINA	LARCH,AMERICAN
62	BENA	BETULA NANA	BIRCH,SWAMP
61	SADW	SALIX DW.	WILLOW, DWARF
59	ROCK	ROCK	ROCK
57	GRAV	GRAVEL	GRAVEL
56	POFR	POTENTILLA FRTICOSA	CINQUEFOIL, BUSH
49	FERN	FERN SPP	FERN
49	STDE	STANDING DEAD	STANDING DEAD
44	POBA2	POPULUS BALSAMIFERA	POPLAR,BALSAM
39	ERVA4	ERIOPHORUM VAGINATUM	COTTON-GRASS,TUSSOCK
36	CAAQ	CAREX AQUATILIS	SEDGE,WATER
36	COCA13	CORNUS CANADENSIS	BUNCHBERRY,CANADA
36	VAVI	VACCINIUM VITIS-IDAEA	CRANBERRY,MOUNTAIN
33	ROAC	ROSA ACICULARIS	ROSE,PRICKLY
30	PEFR5	PETASITES FRIGIDUS	COLTSFOOT,ARCTIC SWEET
26	POTR10	POPULUS TREMULOIDES	ASPEN,QUAKING
24	FESP	FESTUCA SPP	FESCUE
24	MYGA	MYRICA GALE	SWEETGALE

23	SESP	SENECIO SPP	SENECIO
18	VEVI	VERATRUM VIRIDE	FALSE-HELLEBORE,AMERICAN
17	ARSP	ARCTOSTAPHYLOS SPP.	BEARBERRY
17	METR3	MENYANTHES TRIFOLIATA	BUCKBEAN
16	BARE	BARE GROUND	BARE GROUND
15	CATE11	CASSIOPE TETRAGONA	BELL-HEATHER,ARCTIC
14	GELI2	GEOCAULON LIVIDUM	TOADFLAX,NORTHERN RED-FRUIT
14	SAXX	SAXIFRAGA SPP	SAXIFRAGE SPP
13	ARTSP	ARTEMISIA SPP.	SAGE, SPP.
13	CHCA2	CHAMAEDAPHNE CALYCULATA	LEATHERLEAF
12	ANPO	ANDROMEDA POLIFOLIA	ROSEMARY,BOG
12	HELA4	HERACLEUM LANATUM	COW-PARSNIP
12	MUDX	MUD	MUD
12	SACA14	SANGUISORBA CANADENSIS	BURNET,CANADA
11	ARNS	ARNICA SPP.	ARNICA
11	ASXX	ASTRAGALUS SPP	VETCH
11	GEPR4	GERANIUM PRATENSE	CRANE'S-BILL,MEADOW
11	LUPS	LUPINUS SPP.	LUPINE
11	POPA14	POTENTILLA PALUSTRIS	CINQUEFOIL,MARSH
10	ACDE2	ACONITUM DELPHINIFOLIUM	MONKSHOOD,LARKSPUR-LEAF
10	EQFL	EQUISETUM FLUVIATILE	HORSETAIL,WATER
8	SERO2	SEDUM ROSEA	STONECROP,ROSEROOT
8	SIAC	SILENE ACAULIS	CAMPION,MOSS
6	DIUN	DIAPENSIA	DIAPENSIA
6	LYSP	LYCOPODIUM SPP.	CLUBMOSS
6	PESP	PEDICULARIS SPP	LOUSEWORT
6	POBI5	POLYGONUM BISTORTA	BISTORT,MEADOW
6	SHCA	SHEPHERDIA CANADENSIS	BUFFALO-BERRY,CANADA
5	ALTRE	ALNUS SPP TREE	ALDER, TREE
5	GRASS	GRASS	GRASS
5	JUCO	JUNIPERUS COMMUNIS	JUNIPER, COMMON MOUNTAIN
5	MEPA	MERTENSIA PANICULATA	BLUEBELLS,TALL
4	BORI	BOYKINIA RICHARSONI	BEARPLANT
4	CALA7	CAMPANULA LASIOCARPA	BELLFLOWER,COMMON ALASKA
4	POAL5	POLYGONUM ALASKANUM	RHUBARB,ALASKA WILD
4	SAND	SAND	SAND
4	VIED	VIBURNUM EDULE	SQUASHBERRY
3	AGBO2	AGROSTIS BOREALIS	BENTGRASS,NORTHERN
3	ANMO	ANTENNARIA MONOCEPHALA	PUSSYTOE
3	CIDO	CICUTA DOUGLASII	WATER-HEMLOCK,WESTERN
3	COSP	CORNUS SPP.	DOGWOOD SPP.
3	COST4	CORNUS STOLONIFERA	DOGWOOD,RED-OSIER
3	GABO2	GALIUM BOREALE	BEDSTRAW,NORTHERN
3	LYAL3	LYCOPODIUM ALPINUM	CLUBMOSS,ALPINE

3	POAC	POLEMONIUM ACUTIFLORUM	JACOB'S-LADDER,STICKY TALL
3	RISP	RIBES SPP.	RASBERRY
3	SAEX2	SAXIFRAGA EXILIS	SAXIFRAGE
2	CAMS	CAMPANULA SPP.	CAMPANULA
2	CAPA5	CALTHA PALUSTRIS	MARSH-MARIGOLD,COMMON
2	CASP	CASTILLEJA	CASTILLEJA
2	DEGL3	DELPHINIUM GLAUCUM	LARKSPUR,TOWER
2	FOXX	FORB SPP	FORB SPP
2	IRSE	IRIS SETOSA	IRIS,BEACH-HEAD
2	LOPR	LOISELURIA PROCUMBENS	AZALEA, ALPINE
2	MISP	MINUARTIA SPP.	MINUARTIA
2	PALA9	PAPAVER LAPPONICUM	POPPY,ARCTIC
2	RHLA2	RHODODENDRON LAPPONICUM	AZALEA,LAPLAND
2	RUAR6	RUMEX ARCTICUS	DOCK,ARCTIC
1	ANPA	ANEMONE PARVIFLORA	THIMBLE-WEED,SMALL-FLOWER
1	ARUV	ARCTOSTAPHYLOS UVA-URSI	KINNEKINNICK
1	ASSP	ASTER SPP	ASTER
1	CAMI12	CASTILLEJA MINIATA	INDIAN-PAINTBRUSH,SCARLET
1	CARO2	CAMPANULA ROTUNDIFOLIA	BELLFLOWER,SCOTCH
1	EPAN4	EPILOBIUM ANAGALLIDIFOLIUM	WILLOW-HERB,PIMPERNEL
1	EQSP	EPILIOLIUM SPP	FIREWEED
1	HEAL	HEDYSARUM ALPINUM	SWEETVETCH,ALPINE
1	HESPP	HEDYSARUM SPP.	SWEETVETCH, SPECIES
1	LIBO3	LINNAEA BOREALIS	TWINFLOWER
1	MIAR	MINUARTIA ARCTICA	STITCHWORT, ARCTIC
1	POLS	POLYGONUM SPP.	BISTORT
1	POTS	POTENTILLA SPP.	CINQUEFOIL
1	RITR	RIBES TRISTE	CURRANT,SWAMP RED
1	RMSP	RUMEX SPP	DOCK
1	SATRE	SALIX TREE	WILLOW TREE
1	VAAL	VACCINIUM ALASKAENSE	BLUEBERRY,ALASKA
1	VISP	VIOLA SPP	VIOLET

Appendix D. Northern Innoko Accuracy Assessment Error Matrices

N. Innoko (Path 76 & 77)

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	User's Accuracy
1) Closed Needleleaf																																		
2) Open Needleleaf		10																																100%
3) Open Needleleaf - Lichen																																		
4) Woodland Needleleaf		2,0													0,1																			67%
5) Woodland Needleleaf - Lichen																																		
6) Closed Deciduous						1																												100%
7) Closed Birch							3																											100%
8) Open Decidiuous																																		
9) Open Birch																																		
10) Closed Mixed						1,0																												100%
11) Open Mixed																																		
12) Tall Shrub												9	1,0																					100%
13) Low Shrub - Other		0,1											4		1,0			0,1																75%
14) Low Shrub - Lichen																																		
15) Low Shrub - Tussock Tundra															6	2,0									2,0									100%
16) Dwarf Shrub - Other																2									1,0									100%
17) Dwaft Shrub - Lichen																																		
18) Wet Graminoid																		4																100%
19) Wet Sedge																																		
20) Lichen																																		
21) Moss																																		
22) Mesic/Dry Grass Meadow																																		
23) Mesic/Dry Graminoid																																		
24) Mesic/Dry Forb																																		
25) Tussock Tundra													0,1		0,1	1,0									5									75%
26) Tussock Tundra - Lichen																																		
27) Aquatic Bed																																		
28) Emergent													0,1					2,0																67%
29) Clear Water																																		
30) Turbid Water																																		
31) Snow/Ice																																		
32) Sparse Vegetation																																		
33) Rock/Gravel																																		
Reference Site Totals:	0	13	0	0	0	2	3	0	0	0	0	9	7	0	9	5	0	7	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	**63**
Producer's Accuracy (+/-5%):		92%				100%	100%					100%	71%		78%	100%		86%							100%									

Total = **63**

Diagonal = **44**

Off-Diagonal = **13**

Overall Accuracy (0% var) = **69.84%**

Overall Accuracy (+/- 5% var) = **90.48%**

N. Innoko (Path 76)

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	User's Accuracy
1) Closed Needleleaf																																		
2) Open Needleleaf		6																																100%
3) Open Needleleaf - Lichen																																		
4) Woodland Needleleaf		2,0													0,1																			67%
5) Woodland Needleleaf - Lichen																																		
6) Closed Deciduous						1																												100%
7) Closed Birch							2																											100%
8) Open Deciduous																																		
9) Open Birch																																		
10) Closed Mixed						1,0																												100%
11) Open Mixed																																		
12) Tall Shrub												3																						100%
13) Low Shrub - Other													1																					100%
14) Low Shrub - Lichen																																		
15) Low Shrub - Tussock Tundra															4	1,0									1,0									100%
16) Dwarf Shrub - Other																2									1,0									100%
17) Dwaft Shrub - Lichen																																		
18) Wet Graminoid																		1																100%
19) Wet Sedge																																		
20) Lichen																																		
21) Moss																																		
22) Mesic/Dry Grass Meadow																																		
23) Mesic/Dry Graminoid																																		
24) Mesic/Dry Forb																																		
25) Tussock Tundra													0,1												1									50%
26) Tussock Tundra - Lichen																																		
27) Aquatic Bed																																		
28) Emergent													0,1					2,0																67%
29) Clear Water																																		
30) Turbid Water																																		
31) Snow/Ice																																		
32) Sparse Vegetation																																		
33) Rock/Gravel																																		
Reference Site Totals:	0	8	0	0	0	2	2	0	0	0	0	3	3	0	5	3	0	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	**32**
Producer's Accuracy (+/-5%):		100%				100%	100%					100%	60%		80%	100%		100%							100%									

Total =	**32**
Diagonal =	**21**
Off-Diagonal =	**8**
Overall Accuracy (0% var) =	**65.63%**
Overall Accuracy (+/- 5% var) =	**90.63%**

N. Innoko (Path 77)

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	User's Accuracy
1) Closed Needleleaf																																		
2) Open Needleleaf		4																																100%
3) Open Needleleaf - Lichen																																		
4) Woodland Needleleaf																																		
5) Woodland Needleleaf - Lichen																																		
6) Closed Deciduous																																		
7) Closed Birch							1																											100%
8) Open Decidiuous																																		
9) Open Birch																																		
10) Closed Mixed																																		
11) Open Mixed																																		
12) Tall Shrub												6	1,0																					100%
13) Low Shrub - Other		0,1											3		1,0			0,1																67%
14) Low Shrub - Lichen																																		
15) Low Shrub - Tussock Tundra															2	1,0									1,0									100%
16) Dwarf Shrub - Other																																		
17) Dwaft Shrub - Lichen																																		
18) Wet Graminoid																		3																100%
19) Wet Sedge																																		
20) Lichen																																		
21) Moss																																		
22) Mesic/Dry Grass Meadow																																		
23) Mesic/Dry Graminoid																																		
24) Mesic/Dry Forb																																		
25) Tussock Tundra															0,1	1,0									4									83%
26) Tussock Tundra - Lichen																																		
27) Aquatic Bed																																		
28) Emergent																																		
29) Clear Water																																		
30) Turbid Water																																		
31) Snow/Ice																																		
32) Sparse Vegetation																																		
33) Rock/Gravel																																		
Reference Site Totals:	0	5	0	0	0	0	1	0	0	0	0	6	4	0	4	2	0	4	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	**31**
Producer's Accuracy (+/-5%):		80%					100%					100%	100%		75%	100%		75%							100%									

Total = **31**

Diagonal = **23**

Off-Diagonal = **6**

Overall Accuracy (0% var) = **73.33%**

Overall Accuracy (+/- 5% var) = **93.55%**