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Bureau of Land Management

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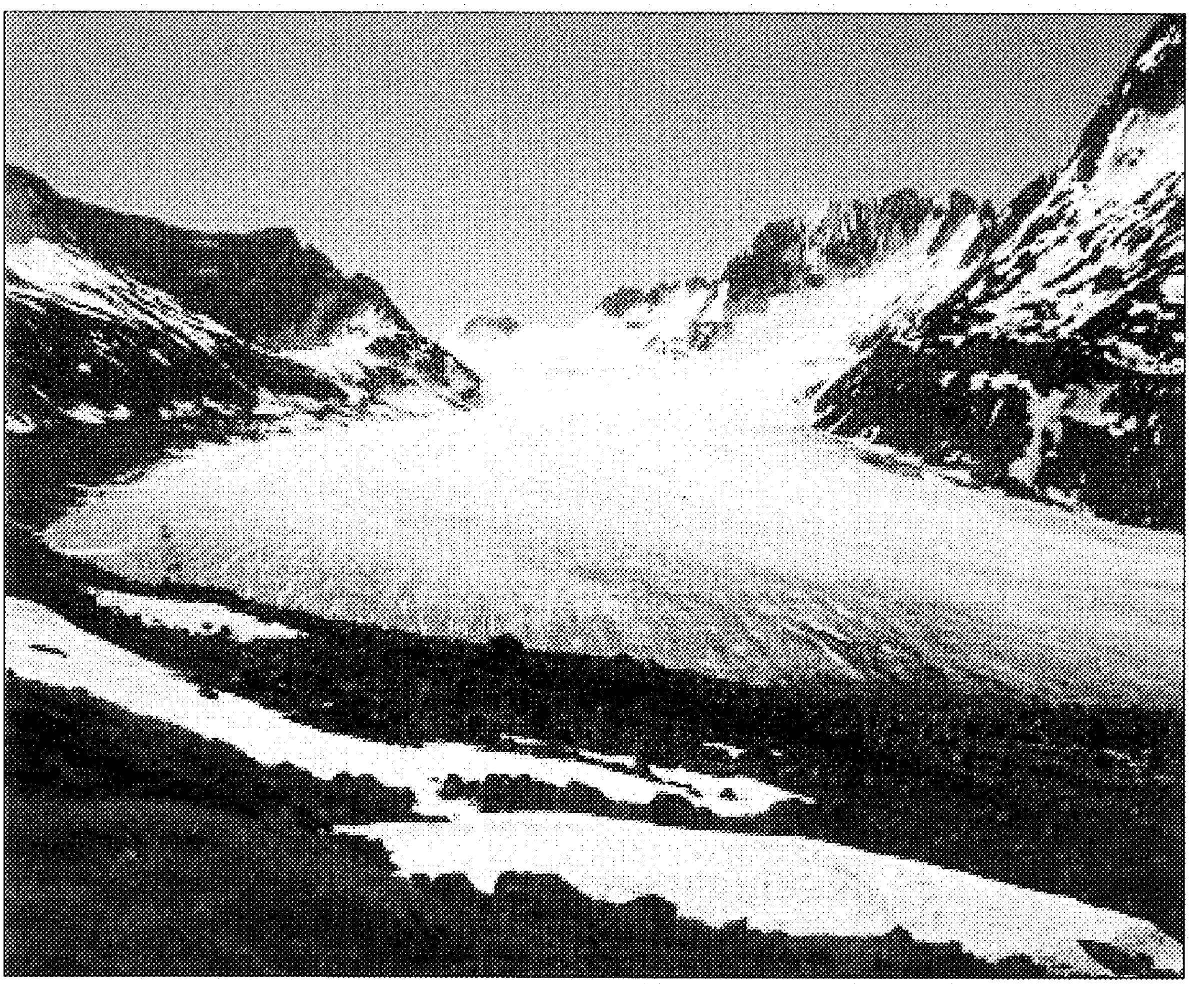
September 2002

Ducks Unlimited, Inc.

Haines, Alaska
Earth Cover Classification



Mission Statement

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

Partners

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

Cover

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

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Abstract

Ducks Unlimited, Inc. and the Bureau of Land Management have been mapping wetlands in the boreal regions of Alaska since 1988. The project area chosen was a 2.2 million acre area in the northern portion of the Alaskan panhandle centered on Haines, Alaska. Portions of two cloud-free Landsat TM images (Path 59, Rows 18 and 19) taken on August 1, 1999 were used to classify the project area into 26 earth cover categories. An unsupervised clustering technique was used to determine the location of the field sites to ground truth the satellite imagery. A custom field data form and digital database were used to record field information. A total of 178 sites were visited during July 8-13, 2000. An A-STAR helicopter was used to gain access to all of the sites. Global positioning system (GPS) technology was used to navigate to the pre-selected sites and to record new sites selected in the field. Approximately 30% of the field sites were set aside for accuracy assessment. A modified supervised/unsupervised classification technique was performed to classify the satellite imagery. The classification scheme was based on Viereck *et al.* (1992), but was modified to represent the earth cover communities found in Alaska. The overall accuracy of the mapped categories was 86%.

Introduction

The Haines Earth Cover Mapping Project area contains part of the vast expanse of cordillera and sub-arctic woodland, and provides critical habitat for waterfowl and numerous other wildlife species. Ducks Unlimited (DU) and the BLM initiated a complete earthcover inventory within a 2.2 million hectare area, centered on Haines, AK (60.73° N 135.098° W). This earthcover mapping project provides an inventory of a portion of the northern Alaskan panhandle that can be used for regional management of land, water, 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 ungulates; generate risk assessments for proposed projects; and provide baseline data to which wildlife and sociological data can be related.

Landsat Thematic Mapper (TM) satellite imagery was chosen as the primary source for the DU's earth cover mapping effort. Satellite imagery offers a number of advantages for region-wide projects. TM data is 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. In addition, TM imagery includes a mid-infrared band, which is sensitive to both vegetation and soil moisture content and is useful in identifying earth cover types. When combined with other geographic information system (GIS) data sets, (e.g., elevation, slope, aspect, shaded relief, and hydrology), Landsat TM data produces highly accurate classifications with a moderately detailed classification scheme. The Haines Earth Cover Mapping Project area contains highly diverse landscapes and is deemed important for its wildlife, cultural, and recreational values. The earth cover data will 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 a portion of southeastern Alaska. 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.

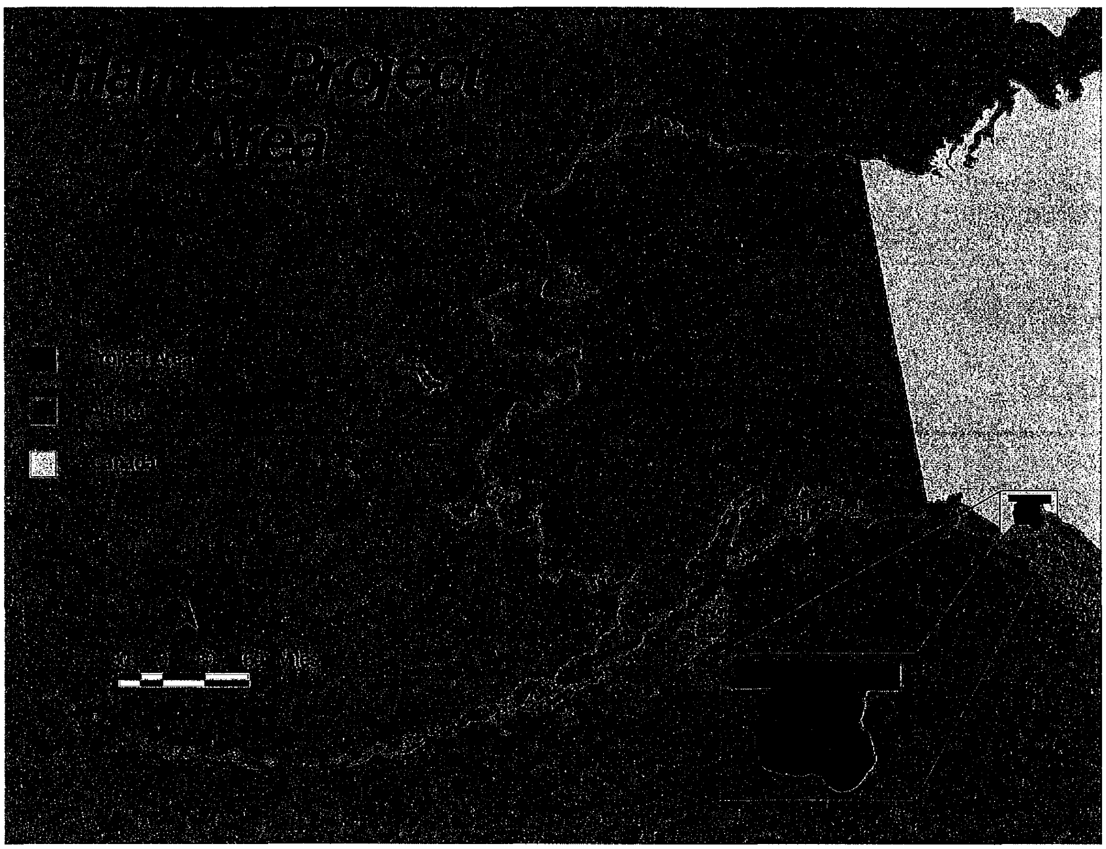
Project Participants/Funding

Funding for this project was provided by the United States Bureau of Land Management (BLM). The fieldwork was conducted by Kevin Smith (DUI), navigator; Nathan Jennings (formerly with DUI, currently with Jones and Stokes), recorder; Debbie van de Wetering (Ducks Unlimited Canada/ Canadian Wildlife Service), recorder and alternate; and Jeff Denton (BLM), vegetation caller. Kevin Smith (DUI) performed the image processing work.

Project Area

The Haines Earth Cover Mapping Project consisted of approximately 2.2 million acres centered roughly on Haines, Alaska. Figure 1 shows the location of the study area. This project area encompassed a wide variety of environments ranging from glaciated mountains to coastal Sitka Spruce (*Picea sitchensis*) forests. Caribou (*Rangifer tarandus*), Dall sheep (*Ovis dalli*), mountain goat (*Oreamnos americanus*), moose (*Alces alces*), grizzly (*Ursus arctos horribilis*) and black bear (*Ursus americanus*) are just some of the large mammalian species that can be found within the project area. The many small lakes and ponds provide important habitats for breeding ducks, geese, trumpeter swans (*Cygnus buccinator*), grebes, and a myriad of other waterbirds. The original project area was combined with the earthcover classification done for the Southern Lakes Area in the Yukon Territory. Due to ecological, political, and different classification schemes, the projects were split into two projects: Haines and Southern Lakes. The rectangular portion in the northern section of the Haines project area overlaps the southern part of the Southern Lakes project area.

Figure 1. Haines project area location.



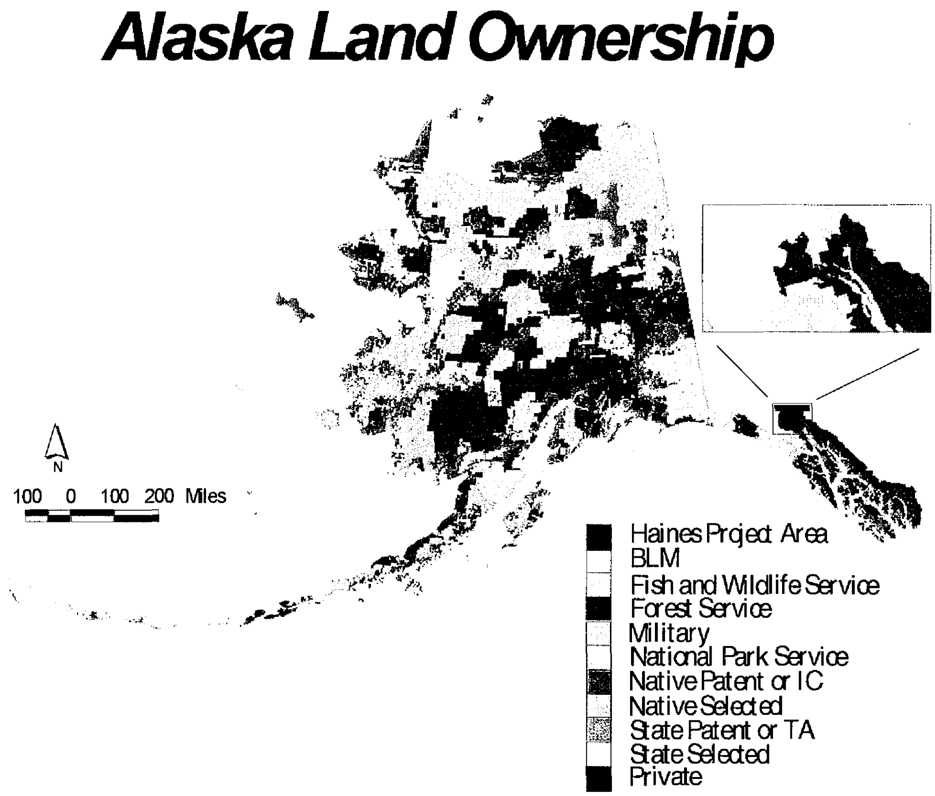


Figure 2. Land ownership within the Haines project area.

Land ownership for the Haines area was primarily state land, as well as Tongass National Forest in the southwestern portion of the image (Figure 2). BLM lands consisted of the higher elevation areas found throughout the project area.

Data Acquisition

Ducks Unlimited purchased all of the imagery for the project at the systematic correction level from the Earth Resource Observation Systems (EROS) Data Center. Two Landsat 7 ETM+ scenes were used in the project, Path 59, Rows 18 and 19. The final study area was clipped from the top 50% of row 19 and the bottom 50% of row 18 (row 18 shifted 50% south). The acquisition date for the imagery was August 1, 1999 and the fieldwork was collected July 8 - July 13, 2000, close to the anniversary date of the image. The imagery for the project area was cloud-free.

Other ancillary data used in this project included some 1:20,000 color infrared and color photographs taken in 1978. The aerial photographs covered most of the study area. Due to the long period between the dates of the photographs and the imagery date, these files were used to help determine land cover in areas where there was no photo-interpreted change.

The path images were mosaicked using the path correction information in the image header file, and then georeferenced and orthorectified to within one pixel root mean squared error.

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.

The classification system used to classify the earth cover types for the Haines project was based on an Alaskan earth cover classification system developed through a cooperative partnership between the Bureau of Land Management (BLM) and Ducks Unlimited (DU) Inc. This system was developed over several years, and has been field tested on several projects.

Derivation of Alaskan Classification Scheme

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 1) 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 this meeting. The classification scheme consisted of 10 major categories and 27 subcategories. A classification decision tree and written description (Appendix E and G) 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 the earth cover 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.

Although this classification scheme provided very detailed information for all of the sites visited in the field, the final classification did not have all of the classes listed for several reasons. In order to accurately classify all of the classes in this scheme, a significantly larger field sample size would be required. Also, some of the classes were rare or did not exist within the study area such as Tussock Tundra. Where sample sizes were not large enough to derive the more detailed classes, some of the final earthcover classes had to be "rolled up" into more general classes (ie, open poplar and open birch could be rolled into open deciduous).

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 digital elevation models (DEMs).

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. Training sites were individually selected from these spectrally unique areas by the image analyst. Whenever possible, training sites were grouped in clusters to reduce the amount of travel time between sites. The image analyst also 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 Garmin III+ global positioning system (GPS) unit for navigational purposes. Training sites were overlain with the satellite imagery and plotted at 1 inch = 1.6 kilometer 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 Canada 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

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		

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, therefore the image processor also fulfilled the role of the navigator. The navigator also had the responsibility of taking photos of each site from three different angles (high, low, oblique). The biologist identified plant species, estimated the percent cover of each cover type, and determined the overall earth cover class. The recorder wrote species percentages and other data on the field form and generally assisted the biologist. The alternate was responsible for on-ground support, 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.

These 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 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 navigator then 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, while the navigator took another picture to represent the high angle context. The navigator then directed the pilot to the next site. On average, it took approximately 5-8 minutes to collect all of the information for one site.

Field Data Analysis

The collected field information was entered into a digital database using the Ducks Unlimited Field Form (DUFF) custom data entry application, designed jointly by the BLM and DU Inc. and programmed by GeoNorth. The relational database was powered by SQL Anywhere while the user interface was programmed in Visual Basic. The user interface was organized similarly to the field form to facilitate data entry (Figure 4). The application utilized pull down menus to minimize keystrokes and checked for data integrity to minimize data entry errors. The database program also calculated an overall class name for each site based on the recorded species and its cover percentage. Digital images from each site were stored in the database and accessible from within the user interface. The number of field sites per earth cover class was tracked daily to ensure that adequate samples were being obtained within each class.

Classification

Every image is unique and presents special problems in the classification process. The approach used in this project (Figure 5) has been proven successful over many years. The image processor was actively involved in the field data collection and had first hand knowledge of every training site. The image processor's site-specific experience and knowledge in combination with high quality ancillary data overcame image problems and produced a high quality, useful product. Erdas Imagine (v. 8.4) was used to perform the classification. ArcInfo (v. 7.2.1) was

Rev 6/30/00

Haines Field Form

2000- HAIN - 1 - Yr Project Crew Site Number	___/___/___ Observers	Obs. Date: ____/____/ 00 Mo. Day Year	1 2 3 4 Obs. Level	Obs.Time:____:____ Hr Min
Digital Photo ____.____ Session # Photo #	LAT (GPS) ____.____ Decimal Degrees		LONG (GPS) ____.____ Decimal Degrees	
%Slope (Avg)	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	Closed Deciduous	Tall	Lichen	Dry Sedge	Aquatic Bed	Sparse Veg	Other
Open Needleleaf	Open Deciduous	Other Low-Lichen	Moss	Dry Graminoid	Emergent	Rock/Gravel	
Woodland Needleleaf	Closed Mixed	Tussock Low	Wet Sedge/Gr	Dry Sedge/Gr	Snow/Ice	Mud/Silt/Sand	
Wdlnd Ndllf-Lichen	Open Mixed	SA/AL Low	Wet Forb	Dry Forb	Turbid Water		
		Dwarf-Lichen	Tussock-Lichen		Clear Water		

%Cov	Height	TREES	
		White/Black Spruce	Picea glauca/mariana
		Sitka Spruce	Picea sitchensis
		Western Hemlock	Tsuga heterophylla
		Lodgepole/Shore Pine	Pinus contorta
		Aspen	Populus tremuloides
		Birch	Betula papyrifera
		Balsam Poplar	Populus balsamifera
		Red Alder	Alnus rubra

%Cov	Height	SHRUBS	
		Willow	Salix spp.
		Alder	Alnus spp.
		Dwarf Arctic Birch	Betula nana/glandulosa
		Blueberry spp	Vaccinium spp.
		Low Bush Cranberry	Vaccinium vitis-idea
		Crowberry	Empetrum nigrum
		Mountain Avens	Dryas spp.
		Mountain Bell Heather	Cassiope tetragona
		Labrador Tea	Ledum palustre
		Dwarf Willow	Salix spp. – Dwarf
		Rose	Rosa acicularis
		Shrubby Cinquefoil	Potentilla fruticosa
		Sweet Gale	Myrica gale
		Devil's Club	Echinopanax horridum
		False huckleberry	Menziesia ferruginea
		Salmonberry	Rubus spectabilis

%Cov	HERBACEOUS	
	Graminoid	
	Grass	Grass spp.
	Bluejoint Grass	Calamagrostis canadensis
	Cotton Grass	Eriophorum spp.
	Sedge	Carex spp.
	Subtotal % Cover	

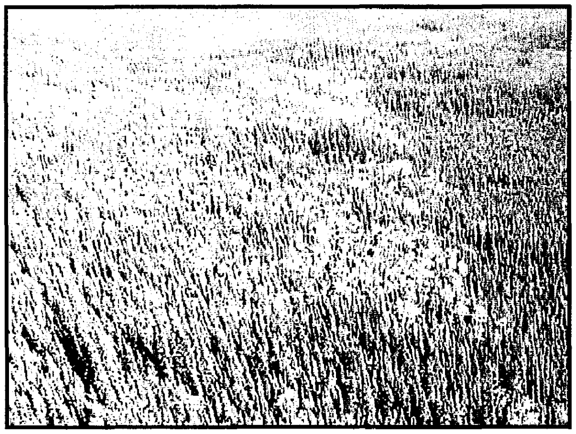
%Cov	HERBACEOUS con't	
	Forbs	
	Saxifrage	Saxifrage spp.
	Lupine	Lupinus spp.
	Horsetails	Equisetum spp.
	Fireweed	Epilobium angustifolium
	Coltsfoot	Petasites frigidus
	Bistort	Polygonum spp.
	Canada Dogwood	Cornus canadensis
	Ferns	Fern spp.
	Bryoid	
	Moss	
	Lichen	

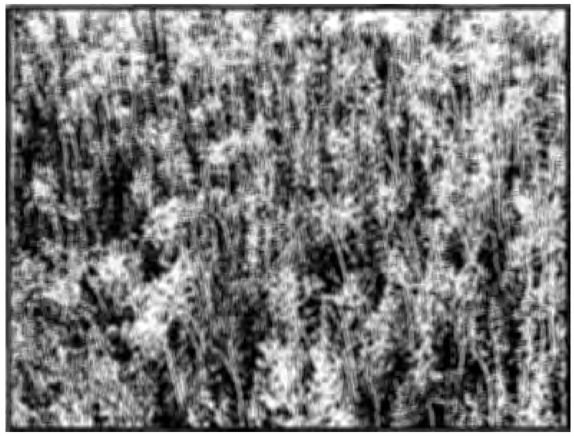
%Cov	AQUATIC	
	Water Lily	Nuphar polysepalum
	Pondweed	Potamegeton spp.
	Marsh Marigold	Calpha palustris
	Marsh Horsetails	Equisetum palustre/fluviatile
	Burreed	Sparganium spp.
	Marsh Fivefinger	Potentilla palustris
	Buckbean	Menyanthes trifoliata
	Water Sedge	Carex aquatilis

%Cov	NON-VEGETATED	
	Clear/Turbid Water	(circle one)
	Mud/Silt/Sand	(circle one)
	Gravel/Rock	(circle one)
	Litter	
	Standing Dead	
	Subtotal % Cover	
	GRAND TOTAL % COVER	

Figure 3. Custom field data collection form.

Sample Field Site – Closed Mixed Needleleaf/Deciduous


High site photo


Low site photo

DUFF INTERFACE

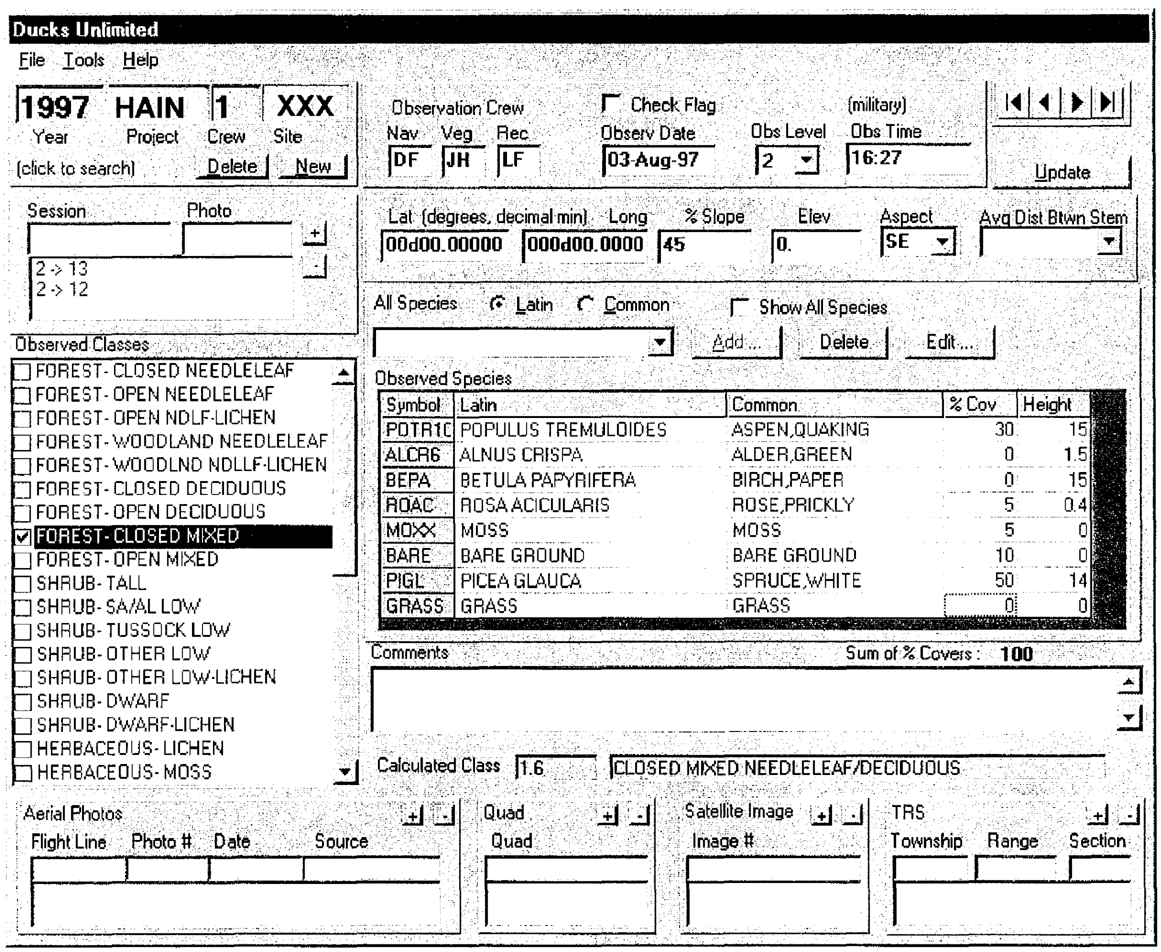


Figure 4. The customized database and user interface for field data entry (DUFF).

utilized to manage the field site polygons. Various word processing and data analysis software were also used during the image classification including Microsoft Word, Excel, and Access.

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. The thermal band, which has a different resolution at 60 meters, was not used on this project. One new band, the Normalized Difference Vegetation Index (NDVI), was generated for this project. The NDVI was highly correlated with the 4/3 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). The NDVI had been correlated with various forest and crop canopy characteristics such as biomass and leaf area index. This NDVI band replaced thermal band (band 6) to retain a 7-band image for classification.

Removal of Clouds and Shadows

Very few clouds and their associated shadows existed in the August 1, 1999 TM imagery used of the Haines study area, and consequently no cloud removal processing was done on the imagery.

Terrain shadows were identified with models using unsupervised classifications and shaded relief images as inputs. The shaded relief images were produced in Erdas Imagine using USGS 1:63,360 scale Digital Elevation Models (DEMs). Sun azimuth and sun angle values for use in the shaded relief algorithm were obtained from the header file of the path 59 Landsat TM images. This allowed the shaded relief image to most closely mimic the terrain shadows present at the time of the Landsat TM image acquisition. The terrain shadow image contains values ranging from 0.0 to 1.0 with the most shaded areas equal to 0.0 and the brightest or least shaded areas equal to 1.0. Terrain shadows were most often spectrally confused with earth cover classes that appeared very dark on the image, eg. water, closed needleleaf, closed mixed needleleaf deciduous, and open needleleaf. An unsupervised classification was used to identify four spectral classes that confused terrain shadowed areas with these spectrally "dark" classes. The model then compared the pixels from these four spectral classes to the most shaded areas in the shaded relief image. If a pixel fell within one of these four classes and had a value less than .5 in the shaded relief image, it was labeled as a terrain shadow. Some additional on-screen digitizing was used to identify terrain shadowed pixels that were not identified by the modeling procedure. All the remaining "non-shadow" pixels were put back into the image for further iterations of unsupervised classifications that were used to identify earth cover classes.

Seeding Process

Spectral signatures for the field sites to be used as training areas were extracted from the imagery using a "seeding" process in Erdas Imagine. A pixel within each training area was chosen as a "seed" and adjoining pixels were evaluated for inclusion in each training site using a threshold value based on a spectral Euclidean distance. The standard deviations of the seeded areas were kept close to or below 3 and all seeded areas were required to be over 15 pixels (approximately 3.75 acres) in size. Along with the field training areas, additional "seeds" were generated for clear water, turbid water, and snow classes. These classes were easily recognizable on the imagery and aerial photography. The output of the seeding process in Imagine was a signature file that contained 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 NDVI 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 uses a statistical program to group the spectrally unique signatures from the unsupervised classification with the signatures of the supervised training areas. In this way, the spectrally unique areas were labeled according to the supervised training areas. This 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 the process was repeated. This process was continued 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, or hydrography 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. While this process highlights some of the areas of confusion, it did not eliminate all of the problems associated with shadowing effect. Once the modeling techniques determined the areas of shadow, additional editing was required in areas influence by shadow.

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.

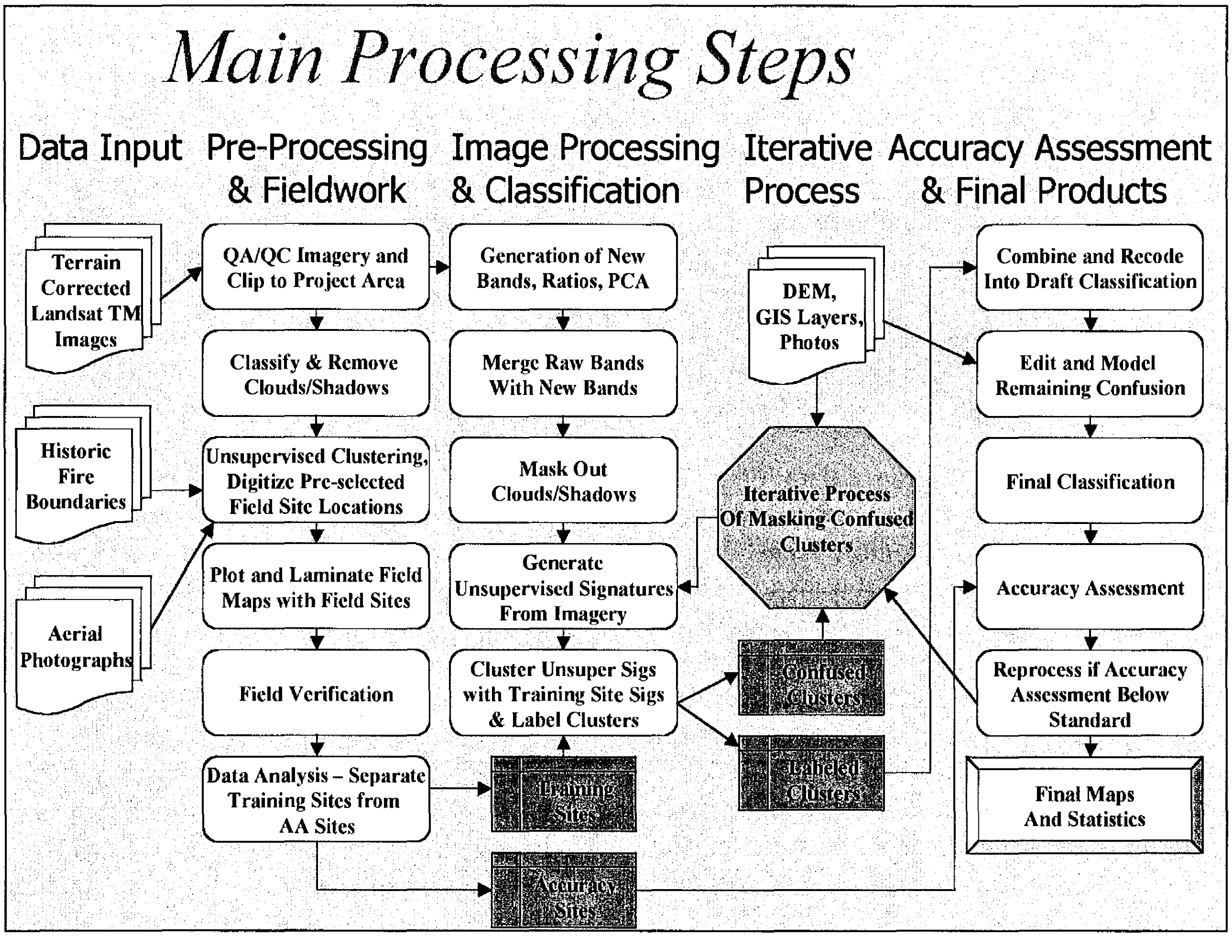


Figure 5. The image processing flow diagram

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 field site 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 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.

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 the northern regions of Canada. Aerial photographs are often not available for most of northern Canada, and those that do exist 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 the provinces and territories.

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 25-30% of the collected field sites were set aside for use in the assessment of map accuracy while the remainder 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. Because the Haines project was separated from the Southern Lakes project, the standard minimum requirement of 15 sites in an individual class (5 for accuracy assessment, 10 for image processing training sites) was not met for many of the classes. For this reason, the minimum requirement was set at 5; otherwise the accuracy assessment could not have been performed. Accuracy assessment sites were selected randomly across the project area to reduce bias.

Qualifiers

While the accuracy assessment performed in this project was not a robust test of the classification, it gives 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.

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 errors (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 earth 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 was plainly described along with both 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, especially when the reference data was derived from aerial photographs.

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

A total of 178 sites were surveyed in the field during the period from July 8-July 13, 2000. The proportions of sites per class (Appendix A) largely reflected the proportions of corresponding earth cover types within the project area. In some cases, more sites were collected for classes that exhibited greater variation in growth form and or spectral response from the satellite. Fuel locations were spaced throughout the image, and allowed for a wide distribution of sites (Figure 6). Sites were concentrated within the river valleys.

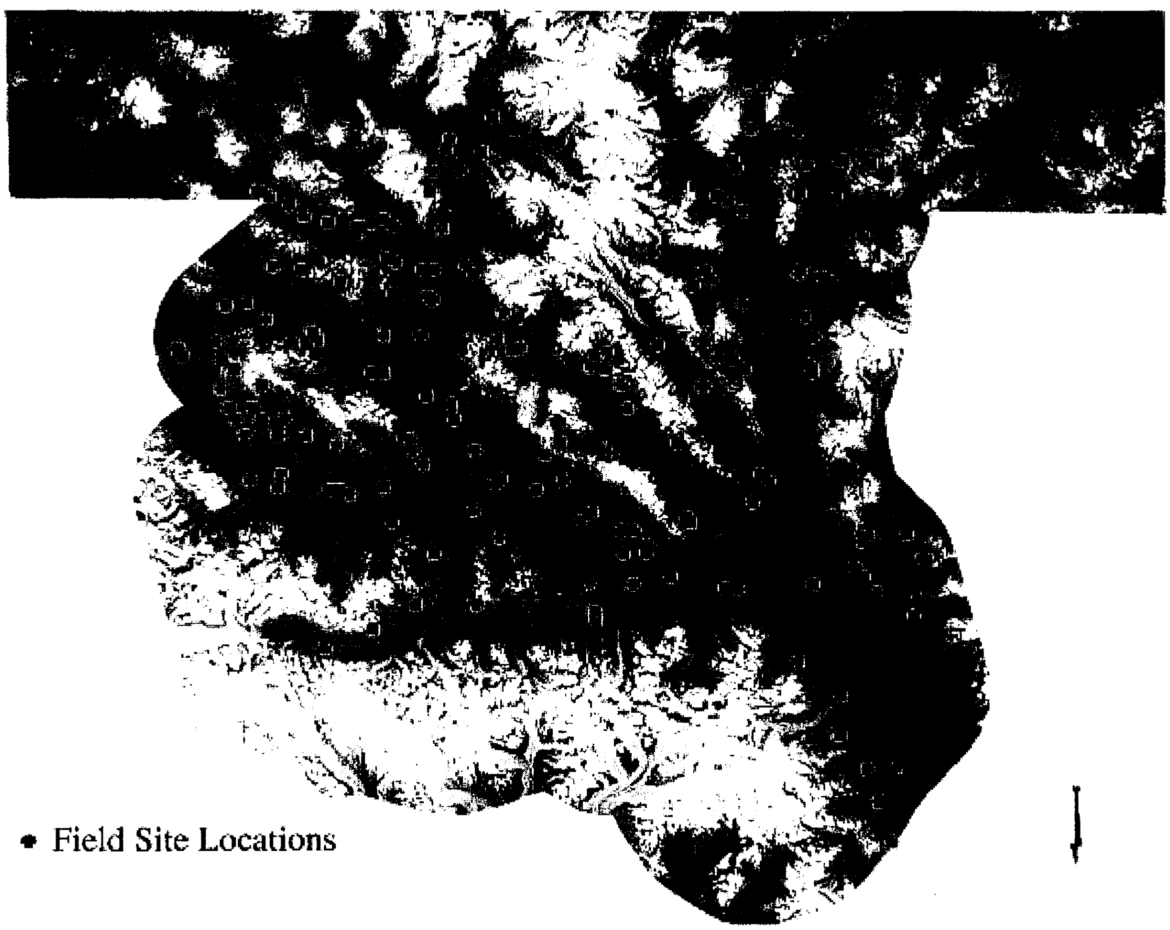


Figure 6. Field site distribution for the Haines project.

Classification

A total of 26 earth cover classes were mapped in the final earth cover map (Figure 7). Table 2 presents the total percent cover and area covered in hectares per class. The three most extensive vegetation classes were the ice (22% of total area), rock (12%) and closed needleleaf (9%). This agrees with observations made during the field data collection. As these summary statistics show, over one-third of the image was covered by areas of non-vegetated earth cover classes. The Haines project area was diverse, ranging from glacial icepack to dwarf shrub/lowshrub highlands, to the forested river valleys. The lower elevations were characterized mainly by coastal influenced closed needleleaf forests, with interspersed deciduous forests. The mountainous upland areas were characterized by dwarf shrub, low shrub, tall shrub, sparse vegetation, rock/gravel, snow, ice, and lichen cover types. Wetland earthcover classes could be found in the floodplains of the river valleys and some tidally influenced kelp beds occurred at the brackish interface of the freshwater rivers and the saltwater of the Lynn Canal.

Forested Cover Types

In the lower elevations with better soils and drainage, forested cover types were typically the dominant earth cover classes found in these areas. Closed and open canopy needleleaf could be found throughout many of the river valleys and well drained hillsides along the valleys. Sitka spruce *(Picea sitchensis)*, mountain hemlock (*Tsuga mertensiana*), white spruce (*Picea glauca*), and western hemlock (*Tsuga heterophylla*) were very common along lower elevations of the coastally influenced valleys. Lodgepole pine (*Pinus contorta* var. *latifolia*) was uncommon in the project area, but occurred in a few locations as open needleleaf stands. These stands were often located in areas of steep valley walls with shallow soils and exposed rock. While subalpine fir (*Abies lasiocarpa*) was infrequently associated with the spruce trees at lower elevations, it was more commonly found as the stunted, bush-like Crumholtz form at higher elevations. Because the hemlock stands were usually mixed with the spruce stands, and the spectral signatures were also indistinguishable in many areas, spruce and hemlock were grouped into one class. Despite the spectral similarities between all of the conifer types, the open needleleaf class was separated into open pine and open spruce categories. This separation was more difficult than expected, since several factors such as slope, aspect, stand age, understory components, and other factors caused significant confusion between the spectral classes. In areas where the two could not be distinguished, those classes were assigned back to the open needleleaf class. Insect damage to closed needleleaf forests often caused the calculated class to come out as open or woodland needleleaf (Figure 8).

The mixed needleleaf/deciduous classes occurred as mature stands, shorter stature stands in successional areas, and as sapling regrowth in recent burn scars, which resulted in a wide range of cover types being grouped into one classification class. They also occurred at the boundary between pure needleleaf and pure deciduous stands. Open and closed deciduous trees were found in association with the conifer forests throughout the image, in regenerating burn areas, along well-drained south facing slopes, and in the coastal influenced valleys. Aspen (*Populus tremuloides*) was the most common, although tree willows (*Salix sp.*)

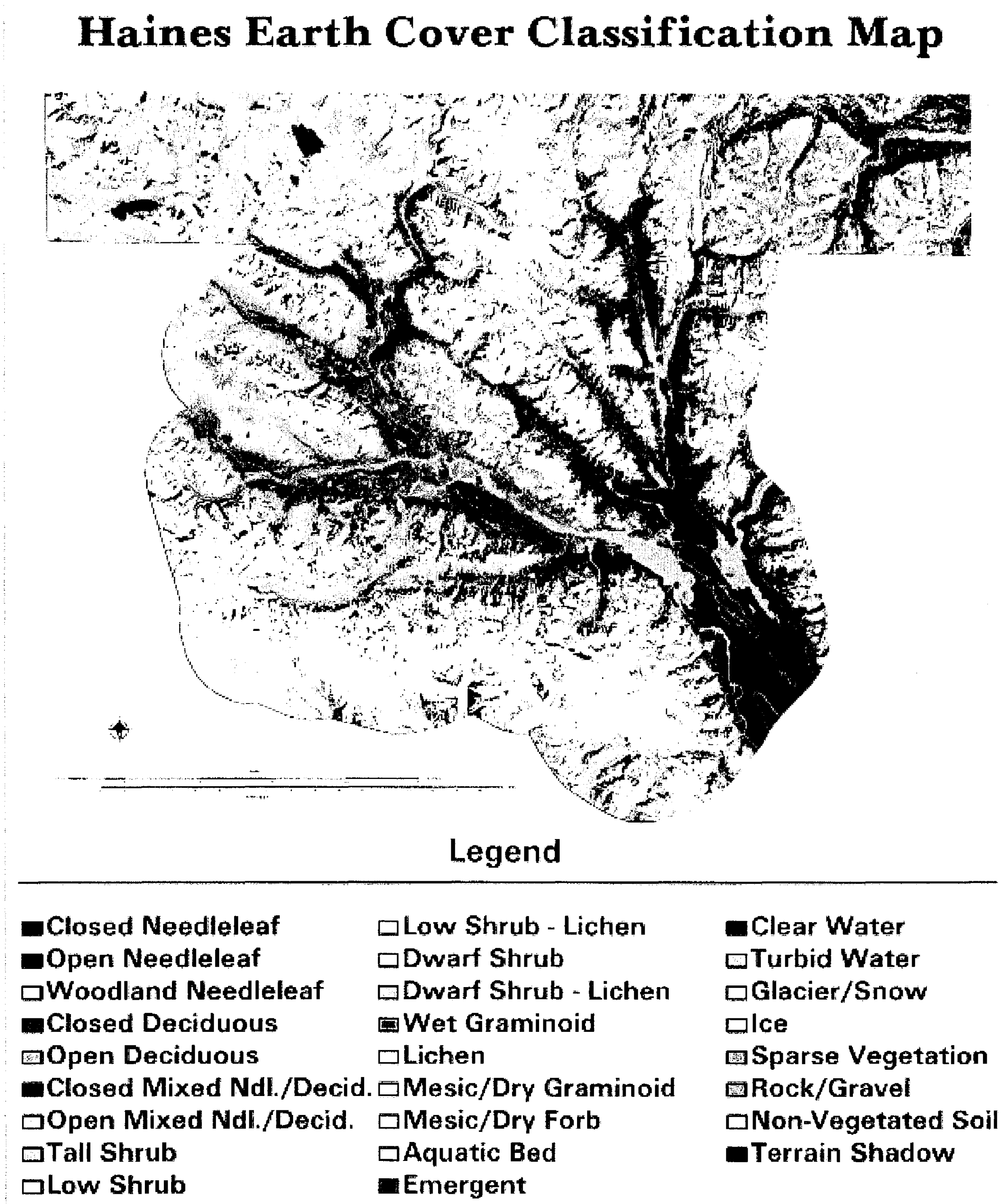


Figure 7. Haines earth cover map.

Table 2. Area covered and percent cover of earth cover classes within the study area.

Class	Acres	Percent of Total
Closed Needleleaf	191283	9%
Open Needleleaf	94287	4%
Woodland Needleleaf	78647	4%
Closed Deciduous	50094	2%
Open Deciduous	38132	2%
Closed Mixed Ndl./Decid.	3245	0%
Open Mixed Ndl./Decid.	9121	0%
Tall Shrub	137354	6%
Low Shrub	18767	1%
Low Shrub - Lichen	20985	1%
Dwarf Shrub	87153	4%
Dwarf Shrub - Lichen	66677	3%
Wet Graminoid	7926	0%
Lichen	69328	3%
Mesic/Dry Graminoid	65683	3%
Mesic/Dry Forb	40664	2%
Aquatic Bed	1584	0%
Emergent	14633	1%
Clear Water	81435	4%
Turbid Water	40660	2%
Glacier/Snow	111688	5%
Ice	498208	23%
Sparse Vegetation	65447	3%
Rock/Gravel	270183	12%
Non-Vegetated Soil	5916	0%
Terrain Shadow	100546	5%
Total	2169648	100%

Figure 8. Insect damage to needleleaf forests were common in some areas of the Haines project.

and balsam poplar (*Populus balsamifera*) were also found in abundance. Relatively few stands of paper birch *(Betula papyrifera)* were found in the study area. Due to a limited number of balsam poplar and paper birch field sites as well as to their spectral similarity to aspen, attempts to distinguish birch and balsam poplar from aspen were unsuccessful, and therefore grouped into the more general class of open or closed deciduous.

Wetland Cover Types

The majority of wetland cover types were found in the floodplains of the major river valleys (Chilkoot, Chilkat, Tsurku). These riparian wetlands occurred in slight depressional areas fringed by deciduous trees with slightly higher elevation (Figure 9). Emergent wetlands (major species include *Carex spp., Menyanthes trifoliata, Equisitum fluviatile*) occur in the shallower depressional areas, while aquatic bed wetlands (major species, *Nuphar spp.*and *Potamageton spp.*) occurred in the deeper depressional areas.

Emergent vegetation and aquatic bed classes were also found as rings of vegetation around the many depressions and lakes found throughout the image. These areas exhibited a wide range of variation in the spectral classes due to the many types of earth cover classes found within a small area. The amount of water also has a great influence on the ability of the sensor to detect wetland areas. Therefore, the value of a pixel might be the result of the mud, water, trees, and wetland plants all at once. For this reason, wetland areas often confused with closed needleleaf, open

Figure 9. One of the many shallow depressional wetlands along the Chilkat River.

needleleaf, rock/gravel, and terrain shadow cover types.

Shrub Vegetation Cover Types

Shrub-dominated cover types were very common throughout the image. They were common steep and moist valley walls, areas with poorer soils not able to accommodate forested vegetation, disturbed areas, and the areas above the treeline and below the bare rock mountaintops. The difference in shrub height was not always easily distinguishable in the imagery, as there was a wide variation in greenness in the shrub classes throughout the image. The coastal influenced valleys were much greener than many of the interior influenced sub alpine shrub sites. Since these coastally influenced shrub areas exhibited a different signature than the other parts of the image, often these areas had to be separated from the other shrub types and processed independently. Taller shrub areas were common on valley slopes from just above treeline to the more alpine zones at higher elevations (Figure 10). Low shrub areas were less common, and were found interspersed with tall shrubs, and at the high elevation boundaries of the tall shrub earthcover class.

High Elevation Cover Types

The higher elevations in the Haines project area contained a mix of non-forested vegetation communities. Rock/gravel, sparse vegetation, snow, ice, dwarf shrub lichen, dwarf shrub, low shrub, and low shrub lichen were the dominant cover types. The imagery in these areas showed a large amount of spectral variation,

Figure 10. Tall shrub vegetation typically occurred along upper part of valley slopes.

primarily due to the highly variable distribution of cover types within one field site. For example, a myriad of cover types were often found within one 30-meter area; rock, gravel, sparse vegetation, lichen, dwarf shrub, and snow were commonly associated with each other (Figure 11). The relative compositions of each of these types, when run though the decision tree classification, determined the final cover type label for the site. As a consequence, the final classification shows a "peppery" feature with many discontinuous pixels.

Influences on Earth Cover Type

Fires

Due to the cool, moist coastal climate that typifies most of the project area, fires are not a dominant disturbance regime. Very few areas, if any, areas were influenced by fire within the project area.

Elevation

Another factor that greatly influenced the earth cover types in this project was elevation. As can be seen in Figure 12, vegetation was clearly stratified by elevation. Forested areas, shown as the red and brown shades in the image, tended to occur in the valley floor and lower valley sides. Dwarf shrub, dwarf shrub lichen and lichen classes occurred in the highest areas, just below the rock/gravel class. South facing slopes had more mesic/dry forb, mesic dry graminoid, tall shrub, and other classes than more northerly facing slopes, as seen in the lower right hand portion of Figure 12.

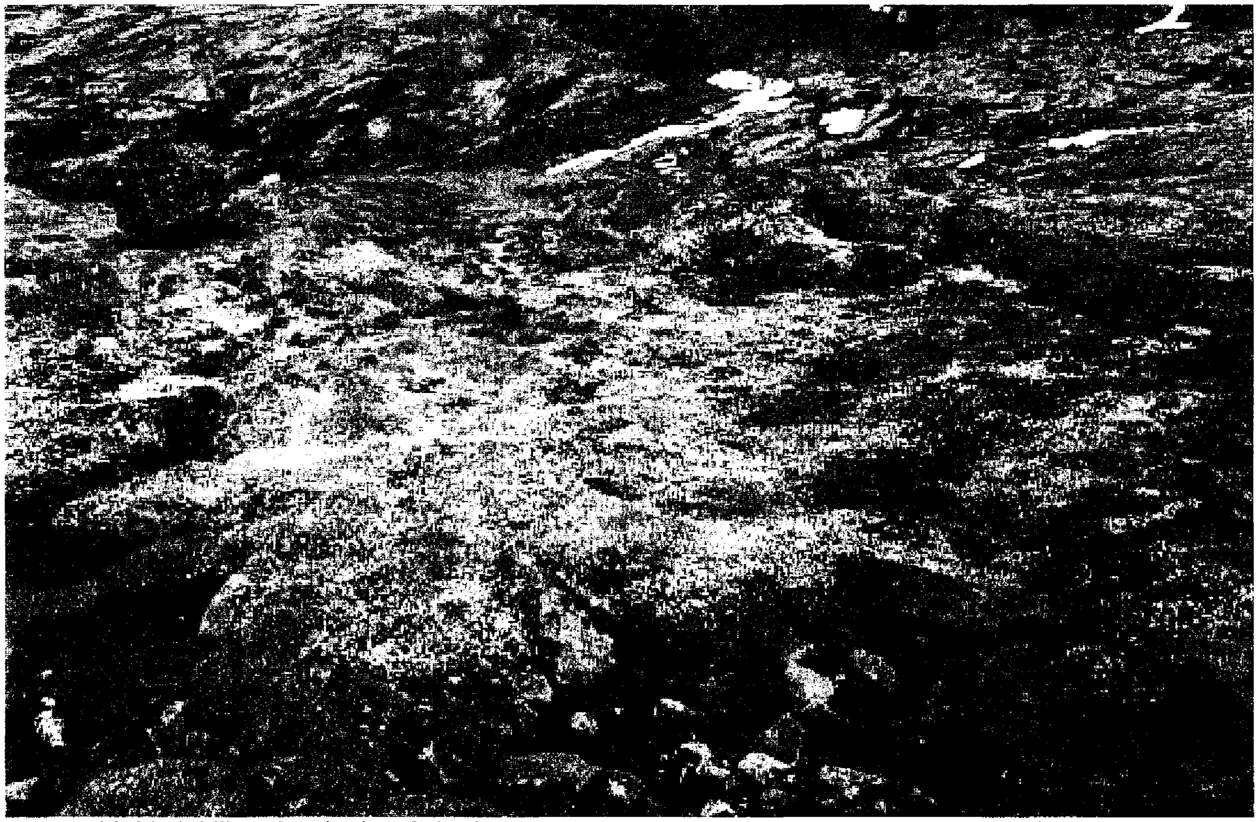


Figure 11. Variability of rock, dwarf shrub, graminoids, and lichen found in high altitude sites.

Modeling

The Haines project area exhibited a considerable amount of topographic effects on the remotely sensed imagery. To minimize the effect of this on the final classification, some modeling was done to enhance the classification. Modeling was performed using shaded relief, slope, and elevation images derived from USGS DEMs. All of the relief, slope, and elevation images were created using Erdas Imagine. It is important to note that the modeling process was used primarily to identify potentially misclassified cover types (due to the influence of topography) throughout the study area. In order to maximize the reliability and classification accuracy in this mapping effort, manual review and editing techniques were used to correct the misclassified pixels to their appropriate mapping classification.

These modeling approaches identified nearly 0.20% of the area as terrain shadow in the Haines project area. A much larger portion of the image was affected by shadows, but not completely blackened by those shadows. These in-between areas were included in the classification and an earth cover class was determined, although the shadows often influenced the signature. In some cases, the effect of the shadow on a cover type would be that it would cause it to fall into another spectral class. Attempts were made to classify any shadowed areas that showed enough spectral reflectance, but it was left up to the image processor's discretion whether or not to edit the shadowed area into the terrain class or into the appropriate earth cover class.

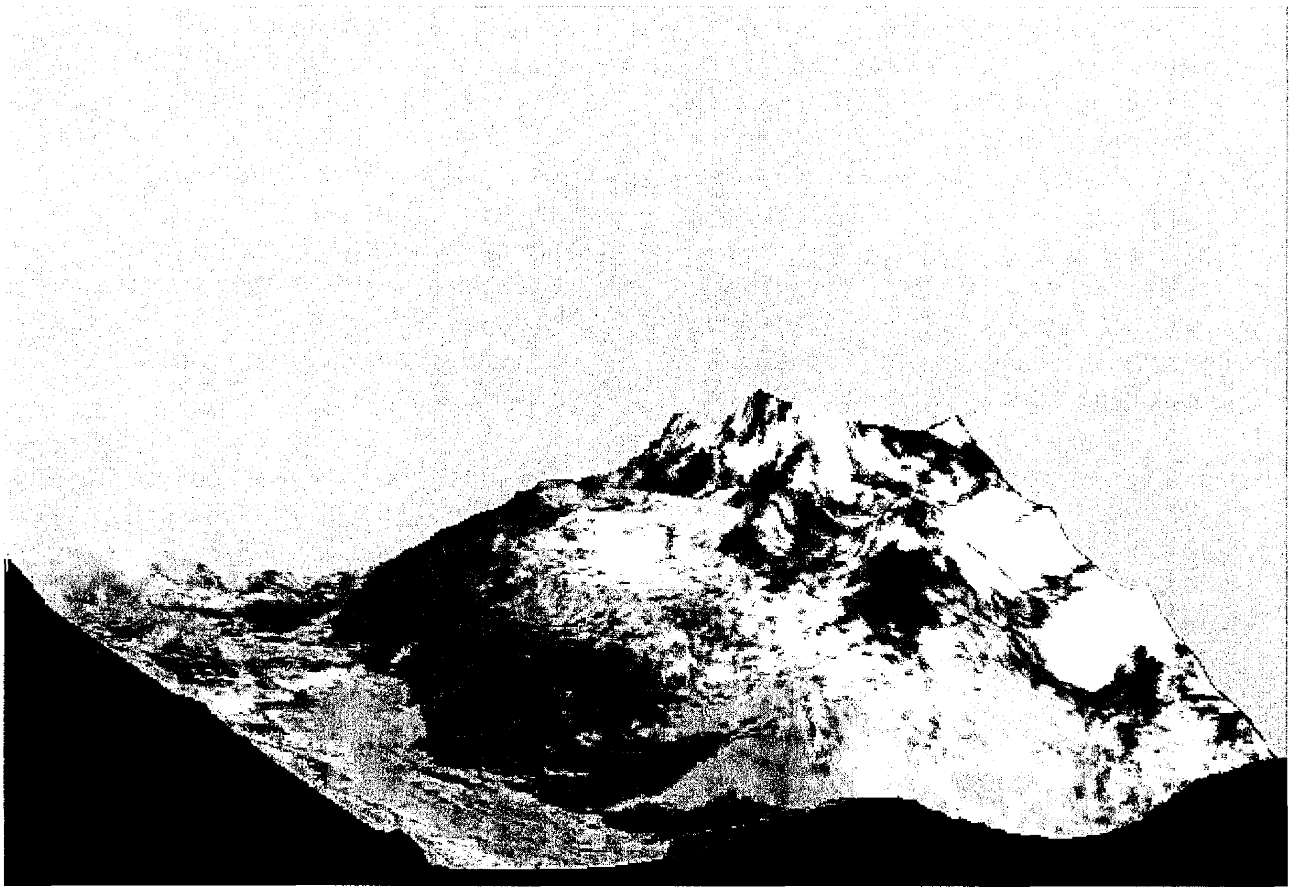


Figure 12. Surface profile of the Haines project area near the Chikat River. Refer to Figure 7 for color referencing.

Editing

Despite the extensive iterative process and modeling techniques devised to break up spectral classes into earth cover classes, there are some instances where the image analyst's ability to discern cover types visually far exceeds the computer's ability to mathematically or statistically separate classes. In some cases, different cover types can have exactly the same spectral reflectance values. For this reason, the final step in the classification is for the image analyst to check all of the assigned classes and manually edit pixels where field data, aerial photographs, or personal knowledge allows for greater accuracy. For example, if an analyst tried to separate agricultural and urban classes using the iterative process, it would be a long, involved attempt that would largely be unsuccessful due to both the wide range of spectral variation and similarity to many other "natural" earth cover types. Yet these areas can easily be differentiated by simply looking at the image, and manually separated into the appropriate classes.

Manual pixel editing was performed on all classes to a minor extent depending on how well the iterative classification and modeling processes separated the spectral classes. Any edits were verified with field sites, aerial photographs, or field notes where applicable. Some editing centered on ecological differences across the project area. For instance, the tall and low shrub classes found in the coastal influenced valleys in the southwestern portion were significantly different than the same type of class in the drier, interior influenced areas. Editing in this case consisted of separating the two areas, and re-running the classification on each type simultaneously. In some cases, the differences were not able to be resolved spectrally, and in this case some manual editing was needed.

Editing was also required to classify areas that fell in the middle of the gradient between one class and another, e.g., between woodland needleleaf and shrub. A woodland area of 10-15% trees was easily confused with a shrub area of 5-10% trees. The most prevalent example of the confusion within the gradient between classes was found between open- and woodland needleleaf class. As evidenced by the field training sites, a large number of the open and woodland needleleaf classes exhibited a crown closure between 20-20%. Similarly, low shrub areas at a height of 0.3 meters were confused with dwarf shrub areas with a height of 0.2 meters. Also, low shrub and tall shrub were confused as well for the same reason at heights near 1.5 meters. These transitional areas and signatures had to be examined and a classification decision made based on the available data.

In some cases, a single pixel fell across two cover types, for example, between a lake and the forested land surrounding it. These half-water, half-land signatures were often confused with emergent and closed deciduous signatures. Many of the small lakes and depressions had a pixel wide ring of emergent vegetation, which in many cases went into open or closed needleleaf based on the pixel mixing of water, mud, emergent vegetation, and upland vegetation. Editing was done to separate legitimate emergent, deciduous or mixed forest pixels based on aerial photography, field notes and topography. Due to the number of ponds, lakes, and wetlands found throughout the image, a considerable effort went into editing these errors where possible. Undoubtedly, some of the areas around the lakes and ponds in the final classification will contain an erroneous scattering of open needleleaf pixels.

The aquatic bed and emergent classes were also heavily edited based on aerial photography and field notes. These cover types commonly required extra editing because they were generally both limited in extent and highly variable. Emergent vegetation typically occurred in narrow strips, often only a few pixels wide, making it very difficult to obtain reliable ground samples. Small differences in soil moisture content, density of vegetation, and the proportion of senescent plants drastically affected the reflectance values. Standing water created a very dark signature, while senescent plants created a very bright signature. Emergent vegetation signatures were confused with a wide variety of other cover types including open needleleaf, open and closed mixed needleleaf/deciduous, low shrub, dwarf shrub, and even open and closed deciduous. For this reason, each of these conditions was edited manually to insure consistency and reliability in the final representation of each affected class.

A final case of spectral classification confusion involved the misclassification of open mixed needleleaf/deciduous pixels in areas of woodland needleleaf that exhibited a dense low and tall shrub understory. The mix of the sparse needleleaf trees and the deciduous shrubs mimicked the spectral signatures of two open mixed needleleaf/deciduous field training sites.

This confusion was corrected via manual editing utilizing photo-interpretation and review of specific field notes and photos.

Accuracy Assessment

Some earth cover classes were not adequately represented in the field data and were not available for training and accuracy assessment, primarily because of their scarcity within the project area, e.g. open deciduous, open/closed birch, open/closed poplar. Classes with an inadequate sample size were collapsed into the hierarchical cover type above the more refined classes (ie, open aspen shrub would be collapsed into open aspen) for accuracy assessment of the classification. This grouping often resulted in 8-10 accuracy assessment classes versus the 30+ classes present in the classification. In addition, this approach grouped classes based solely on their specific mapping class labels. 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.

An informative representation of the reliability/accuracy of the earth cover classification is found in the error matrix provided in Appendix F. In this matrix, the performance and interrelationships of the final earth cover map classes are shown that had an adequate number of accuracy sites. The error matrix presents values for user's accuracy, producer's accuracy, and the overall accuracy. 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.

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. Similarly, since the number of misclassified sites are 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.

Overall Accuracy

The overall classification accuracy of the Haines project was determined to be 86%. Since a low number of accuracy assessment sites were available for the accuracy assessment (44), the results of the accuracy assessment are subject to variability. For instance, one misclassed accuracy site in a class with a low number of accuracy sites created a larger difference in the producer's and user's accuracies than one misclassed accuracy site in a class with a higher number of accuracy sites. Although the low number of accuracy sites limited the extent and direct application of the accuracy assessment, it does allow for a general assessment of the quality of the classification.

The computed accuracies for the needleleaf forested classes were: closed needleleaf = 100%, open needleleaf = 60%, and woodland needleleaf = 100%). The User's Accuracy for the closed needleleaf was 88%. This measure was encouraging since a large portion of the study area (9%) was mapped as closed needleleaf. When an area was classified as one of the forested needleleaf classes, the user can have confidence in the accuracy of that classification.

The open and woodland needleleaf classes were the most difficult class to map due to their high diversity of possible components. For example, a woodland site could include 40% graminoid cover and just 10% trees, or it could contain 20% trees and 50% shrubs. In some cases, cover types other than trees dominated the signature of woodland sites, whereas in other cases, needleleaf trees dominated. A great deal of effort was expended in separating these two classes from one another as well as from other similar non-forested sites. For the woodland needleleaf category, the overall producer's error for this class was 100%, while the user's error was 50%. This means that this class was "overclassified" in that other classes kept falling into the woodland class, yet all of the woodland sites were mapped correctly.

Most of the deciduous tree and shrub classes exhibited high accuracies (most 100%, all above 75%). One class that had less accuracy was the emergent wetland class. A couple of the emergent wetlands were misclassified as tall shrub or deciduous. These wetland sites were small areas in the center of a ring of deciduous trees or tall shrubs, so there is some possibility that pixel mixing influenced these sites. Larger wetland expanses, such as the larger emergent and aquatic bed wetlands in the river valleys were more readily and accurately classified.

In summary, although the quantitative accuracy assessment was limited due to the low number of accuracy sites, the final classification map produced for the Haines project area is very reliable. Over 86% of the accuracy assessment sites matched the full detailed 29 mapping classes directly.

Accuracy Discussion

While the accuracy assessment performed in this project was not a robust test of the classification, it gives the user some confidence in 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 1, 1999. The aerial photographs used in this project were taken in 1978. Differences due to environmental changes from the different sources may have affected the accuracy assessment. Since the fieldwork was performed in July 2000 and the imagery was recorded on August 1, 1999 the field data was assumed to be valid, and was used extensively in this project.

It should also be noted that no field sites, and therefore no accuracy assessment sites, were captured representing the snow/ice, clear water, or turbid water classes. These classes are among the most straightforward to discriminate and map from Landsat TM satellite imagery. Therefore, the limited field data collection time was focused on capturing data to assist in the discrimination and mapping of the more spectrally and ecologically complex vegetation communities throughout the study area. In terms of quantitative accuracy assessment, no assessment was conducted for mapping classes that accounted for over 10% of the ground cover within the study area. Due to their spectral distinctiveness, it is certain that both the user's and producer's accuracy for these classes would be at or very near 100%, thus only acting to improve the overall accuracy calculations for the final earth cover map.

A major assumption of quantitative accuracy assessments is that the label from the reference data 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 sometimes 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 classification map,
(2) digitizing errors,
(3) data entry errors,
(4) changes in earth cover between the date of the remotely sensed data and the date of the field collection of reference data,
(5) mistakes in interpretation of the reference data (perhaps the most significant)
(6) variation in classification and delineation of the reference data due to inconsistencies in human interpretation of vegetation.

Some of the sources of error were minimized through the planning of this project. For example, the date of the field work was very close to the one year anniversary date of the image used for this project. The error matrices included in this report attempt to capture, measure, and account for the most significant of these sources of inconsistency and error in the development of the reference dataset: 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 project area. While there were a relatively small number of sites available for the accuracy assessment, the results of quantitative assessments of accuracy performed for the Haines project should be used as a general assessment of the quality of the classification. Where possible, ancillary information, aerial photographs, field notes, extra contextual photographs were used to check the classification and refine errors.

Final Products

The final products include a digital earth cover classification, a hard-copy map of the entire project area, and a digital database of field data collected for the 178 field sites visited during this project. The digital map was delivered in Erdas Imagine format. The field site database and vegetative species list were stored as digital tables in Dbase IV format. Digital photographs of the field sites were stored in .jpg format. Hardcopy maps of the entire project area at the 1:250,000 scale, as well as 1:50,000 scale quadrangles were also produced of the classified area. All of the delivered datasets were loaded into *ArcView* projects for display purposes.

Summary

Ducks Unlimited Inc. and the Bureau of Land Management have been mapping earth cover in Alaska since 1989. This project continued the mapping effort in the Alaskan Panhandle, centered on Haines, Alaska.

total area mapped in this project was 2.2 million acres. The classification was performed using Landsat 7 ETM+ satellite scenes, Path 59, Rows 18 and 19 acquired on a cloudless day on August 1, 1999. The project area was classified into 26 earth cover categories with an overall accuracy of 86%. The digital database and map of the classification were the primary products of this project along with hard copy maps of the classification, a complete field database including digital site photos, and an ArcView project.

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Appendix A. Earth Cover Types Represented By Field Sites

Classes with accuracy are in bold.

Cover Class	Number of Sites	Training Sites	Accuracy Sites
Closed Needleleaf	24	17	7
Open Needleleaf	13	8	5
Closed Mixed Needleleaf/Deciduous	4	4	0
Open Mixed Needleleaf/Deciduous	1	1	0
Closed Mixed Deciduous	5	2	3
Open Mixed Deciduous	5	4	1
Woodland Needleleaf	6	5	1
Tall Shrub	26	18	8
Low Shrub Lichen	1	1	0
Low Shrub Other	1	1	0
Dwarf Shrub Lichen	10	6	4
Dwarf Shrub Other	12	9	3
Lichen	6	0	0
Moss	1	0	0
Wet Graminoid	2	2	0
Mesic/ Dry Graminoid	5	4	1
Wet Forb	4	4	0
Mesic/Dry Forb	9	7	2
Aquatic Bed	5	3	2
Emergent Vegetation	11	8	3
Clear Water	0	0	0
Turbid Water	0	0	0
Sparse Vegetation	4	0	0
Rock/Gravel	15	11	4
Non Vegetated Soil	1	1	0
Urban	0	0	0
Agriculture	0	0	0
Snow	0	0	0
Ice	0	0	0
Cloud	0	0	0
Shadow	0	0	0
Other	0	0	0
Totals	**178**	**134**	**44**

Appendix B. Image Metadata

Haines Earth Cover Mapping Classified Image Metadata.

Filename:Haines_earthcov
Filetype:Arc/Info Grid

Metadata:

Identification_Information
  Data_Quality_Information
  Spatial_Reference_Information
  Entity_and_Attribute_Information
  Metadata_Reference_Information

Identification_Information:
  Citation:
    Citation_Information:
      Originator:Ducks Unlimited,Inc.
      Publication_Date:032001
      Publication_Time:
      Title: hain_earthcov
      Edition:
      Geospatial_Data_Presentation_Form:map
  Description: Haines River Earth Cover Classification

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 Haines project was the first project in the panhandle of Alaska. Portions of two Landsat TM satellite scenes (Path 59, Rows 18-19 acquired 1 Aug 1999) were used to classify the project area into 26 earth cover categories. The path 59 rows 18 an 19 images were mosaiced to produce a continuous earth cover map for the entire project area. 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. Helicopters were 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 to record the locations of new sites selected in the field. The project area is approximately 9 million acres. A total of 178 field sites were visited during a 6 day field season. Approximately 30% (44) 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 86%.

Purpose:
The objective of this project was to develop a baseline earth cover inventory using Landsat TM imagery for the Haines region of Alaska. 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.

Time_Period_of_Content:
Time_Period_Information:
Multiple_Dates/Times:
Single_Date/Time:
Calendar_Date:08011999
Currentness_Reference:102001
Status:
Progress:complete
Maintenance_and_Update_Frequency:none
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate:-136.0693
East_Bounding_Coordinate:-134.9082
North_Bounding_Coordinate:59.9873
South_Bounding_Coordinate:58.7659
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Theme_Keyword:Earth Cover Classification
Theme_Keyword:Landsat TM
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Place_Keyword:Haines
Place_Keyword:Alaska
Temporal:
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Temporal_Keyword:1999
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Contact_Information:
Contact_Organization:Ducks Unlimited, Inc.
Contact_Person:
Contact_Position:GIS Manager
Contact_Address:
Address_Type:
Address:3074 Gold Canal Drive
City:Rancho Cordova
State_or_Province:California
Postal_Code:95670

Country:U.S.A
Contact_Voice_Telephone:(916)852-2000
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Attribute_Accuracy:
Attribute_Accuracy_Report:See Final Report
Quantitative_Attribute_Accuracy_Assessment:
Attribute_Accuracy_Value:
Attribute_Accuracy_Explanation:
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Source_Citation:
Citation_Information:
Originator:EROS Data Center
Publication_Date:1999
Publication_Time:
Title:Landsat7 ETM Imagery From Path 59, Rows 18-19 acquired 8/01/99
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Source_Time_Period_of_Content:
Time_Period_Information:
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Single_Date/Time:
Calendar_Date:1999
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Process_Discription:See "Haines Earth Cover Classification" report
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Process_Date:2000/2001
Process_Time:
Source_Produced_Citation_Abbreviation:
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Latitude_Resolution:
Longitude_Resolution:
Geographic_Coordinate_Units:
Planar:

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        Contact_Person:
      Contact_Position:GIS Manager
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        City:Rancho Cordova
        State_or_Province:California
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        Country:U.S.A
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      Contact_TDD/TTY_Telephone:
      Contact_Facsimile_Telephone:
      Contact_Electronic_Mail_Address:
      Hours_of_Service:
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  Metadata_Time_Convention:
  Metadata_Access_Constraints:
  Metadata_Use_Constraints:
  Metadata_Security_Information:
```

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Online_Linkage:
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Appendix C. Field Site Metadata

Haines Earth Cover Mapping Field Sites Metadata

Filename:karh_fld_sts
Filetype:Arc/Info coverage

Metadata:

Identification_Information
Data_Quality_Information
Spatial_Reference_Information
Entity_and_Attribute_Information
Metadata_Reference_Information

Identification_Information:
Citation:
Citation_Information:
Originator:Ducks Unlimited, Inc.
Publication_Date:03/2001
Publication_Time:
Title:karh_fld_sts
Edition:
Geospatial_Data_Presentation_Form:map
Description:
Abstract:
The field data collected for the Haines Earth Cover Mapping Project is included on the final products CD's. hain_fld_sts is an ArcInfo coverage of all sites that were visited in the field. hain_fld_sts includes site information about each polygon. Three DBASE files (hain_photo.dbf, hain_site_species.dbf, and hain_species.dbf) are also included on the final products CD's. All three of these files can be linked to the ArcInfo polygon coverage to provide the complete database of information collected for each fieldsite. The links are made by the duff.avx *ArcView* extension included on the final products CD's.
Purpose:
The objective of this project was to develop a baseline earth cover inventory using Landsat TM imagery for the Haines 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.
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Time_Period_Information:
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Maintenance_and_Update_Frequency:none
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East_Bounding_Coordinate:-134.9082
North_Bounding_Coordinate:59.9873
South_Bounding_Coordinate:58.7659
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Theme_Keyword:ArcInfo Coverages
Theme_Keyword:Land Cover Classification
Theme_Keyword:Earth Cover Classification
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Place_Keyword:Skagway
Place_Keyword:Alaska
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Contact_Person:
Contact_Position:GIS Manager
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City:Rancho Cordova
State_or_Province:California
Postal_Code:95670
Country:U.S.A.
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Contact_TDD/TTY_Telephone:

Contact_Facsimile_Telephone:
Contact_Electronic_Mail_Address:
Hours_of_Service:
Contact_Instructions:
Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:See Final Report
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Publication_Date:2001
Publication_Time:
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Edition:
Geospatial_Data_Presentation_Form:ArcInfo polygon coverage. DBASE files.
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State_or_Province:California
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Hours_of_Service:
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Cloud_Cover:

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See “Haines Earth Cover Classification Final Report"
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City:Anchorage
State_or_Province:Alaska
Postal_Code:99513

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Metadata_Extensions:
Online_Linkage:
Profile_Name:

Appendix D. Attribute Descriptions

Attribute Descriptions for Field Site Coverage and Dbase Files.

Field Site Polygon Coverage Attribute Table

HAIN_fld_sts.pat:

Field	Width	Output	Type	#Decimals	Description
AREA	4	12	F	-	ArcInfo internal fields
PERIMETER	4	12	F	-	ArcInfo internal fields
coverage#	4	5	B	-	ArcInfo internal fields
coverage-ID	4	5	B	-	ArcInfo internal fields
SITE_NUM	4	4	I	-	Field site number
YEAR	4	4	I	-	Year of field data collection.
AREA_NAME	10	10	C	-	Name of project area.
CREW_NUM	1	1	I	-	Id number of crew that collected data
OBS_NAV	2	2	C	-	Navigator for field data collection
OBS_VEG	2	2	C	-	Vegetation caller for field data collection
OBS_REC	2	2	C	-	Recorder for field data collection
OBS_DATE	8	8	D	-	Date of field data collection
PERCNT_SLP	3	3	I	-	Percent slope of site
ASPECT_DIR	2	2	C	-	Aspect of site (8 compass points – N,NE,E,etc., FL=Flat)
LATITUDE	10	10	N	5	Latitude of polygon labelpoint – Decimal Degrees
LONGITUDE	11	11	N	5	Longitude of polygon labelpoint – Decimal Degrees
OBS_LEVEL	1	1	I	-	Observation level, where: 1 = site visited on the ground, 2 = viewed from above (ie from helicopter),

3 = viewed from a distance,
4 = viewed on air photos.

STEM_DIST 2 2 I - Distance between tree stems(applies to Open or Woodland Needleaf only).

OBS_ID 2 2 I - Id of site class as observed by the vegetation caller.

MAJ_OBS 20 20 C - Level 1 class of classification hierarchy.

OBS_CLASS 25 25 C - Vegetation caller's observed class for site.

COMMENTS 200 200 C - Notes made by vegetation caller while at the site.

CALC_CLASS 50 50 C - Classification of site as calculated using the project decision tree

CALC_CL_ID 6 6 N 3 ID number of calculated class

AA_FLAG 1 1 I - Indicates if site was used as accuracy assessment or training data. 0 = site used for training. 1 = site used for accuracy assessment.

Data exported from Ducks Unlimited Field Form Software.

HAIN_SITE_PHOTO.dbf Dbase IV file containing site photo information.

YEAR Year of field data collection

AREA_NAME Name of project area

CREW_NUM Id number of crew that collected data

SITE_NUM Field site number; relates to SITE_NUM of field site polygon coverage in a one-to-many relationship (i.e. each site may have multiple photos).

SESS_NUM Session number for field data collection. Photos are uniquely numbered within each session.

PHOTO_NUM Photo number. Photos are numbered consecutively within each session.

HAIN_SITE_SPECIES.dbf. Dbase IV file containing species composition information for each site. Each record describes an individual species observed at a site. Each site can have multiple records in this table, depending on how many different species were observed within the site.

YEAR Year of field data collection

AREA_NAME Name of project area

CREW_NUM Id number of crew that collected data

SITE_NUM Field site number; relates to SITE_NUM of field site polygon coverage in a one-to-manyrelationships. Each site may have multiple species records in this table.

PCT_COVER Percent cover of the species at site observed by the vegetation caller.

HEIGHT Height of tree or shrub species at site as observed by the vegetation caller.

NOTE: The data in site_species Dbase IV file are based on the PLANTS National Database developed by the National Resource Conservation Service. Edits have been made to some species codes to facilitate use of the data with the DUFF data entry program. Also species have been added to the list as necessary when compiling field data. Non-vegetated identifiers (Rock, Sand, Litter, etc.) have also been added.

HAIN_SPECIES.dbf

SYMBOL Species code - usually a combination of the first two letters of the genus and first two letters of the species.

FAMILY Plant family.

SPECIES Plant genus and species.

AUTHOR Author citation for species information.

COMMON Common name.

ALT_NAME Alternate name.

GENERAL General plant type; used to pipe information correctly through the decision tree.

SPECIFIC Specific plant type; used to pipe information correctly through the decision tree.

Appendix E. Haines Earth Cover Classification Class Descriptions

Forest

Needleleaf and Deciduous Trees-

The needleleaf species generally found were sitka spruce *(Picea sitchensis)*, mountain hemlock (*Tsuga mertensiana*), white spruce (*Picea glauca*), and western hemlock (*Tsuga heterophylla*). Most of these trees occurred in the coastally influenced forests. Pine (*Pinus contorta* var. *latifolia*) was uncommon in the project area, but occurred in a few locations as open needleleaf stands in sites with poor soils.

The deciduous tree species generally found were paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*). 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.

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 river valleys.

1.2 Open Needleleaf

From 25-59% of the cover was trees, and ≥75% of the trees were needleleaf. A wide variety of understory plant groups were present, including low and tall shrubs, forbs, grasses, sedges, horsetails, mosses and lichens.

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. In higher elevations, woodland communities of subalpine fir (*Abies lasiocarpa*) were common.

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 fairly large size, generally on the floodplains of the major river valleys, but occasionally on hillsides, riparian gravel bars, or bordering small lakes. This class included paper birch, aspen, or willow.

Open Deciduous (Mixed Deciduous Species 1.54)

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 common class.

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.

Shrub
The tall and low shrub classes were dominated by alder and willow species, dwarf birch (*Betula nana* and *B. 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 very common throughout the image, typically above the treeline in the river valleys and would extend to the subalpine zones.

2.22 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 was dwarf birch, willow, or alder.

2.23 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.

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

3.21 Wet Graminoid
Composed of $\geq$40% herbaceous species, $\leq$25% water, and where $\geq$60% of the herbaceous cover was graminoid. This class represented wet or seasonally flooded sites that occurred in the higher elevation areas.

3.34 Mesic/Dry Graminoid
Composed of $\geq$40% herbaceous species, $\leq$5% water, with $\geq$50% graminoids excluding tussock forming cotton grass and *Carex aquatilis*. This class was fairly common and was found generally only at high elevations.

3.35 Mesic/Dry Forb
Composed of $\geq$40% herbaceous species, $\leq$5% water, with <50% graminiods. This class was fairly common in the Haines project area on the south facing, moist slopes above the shrub-dominated slopes.

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 $\geq$20% of the cover, and $\geq$20% of the vegetation was composed of plants with floating leaves. This class was generally dominated by pond lilies (*Nuphar spp.*).

4.2 Emergent Vegetation
Aquatic vegetation made up $\geq$20% of the cover, and $\geq$20% of the vegetation was composed of plants other than pond lilies. Generally included freshwater herbs such as horsetails, marestail, or buckbean.

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

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

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

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

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

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

Urban
At least 50% of the area was urban. This class was not classified in the study area, although the towns of Skagway and Haines

were present, along with smaller settlements.

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

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

Cloud
At least 50% of the cover was made up of clouds. This class was not applicable

Cloud Shadow
At least 50% of the cover was made up of cloud shadows. This class was not applicable.

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.

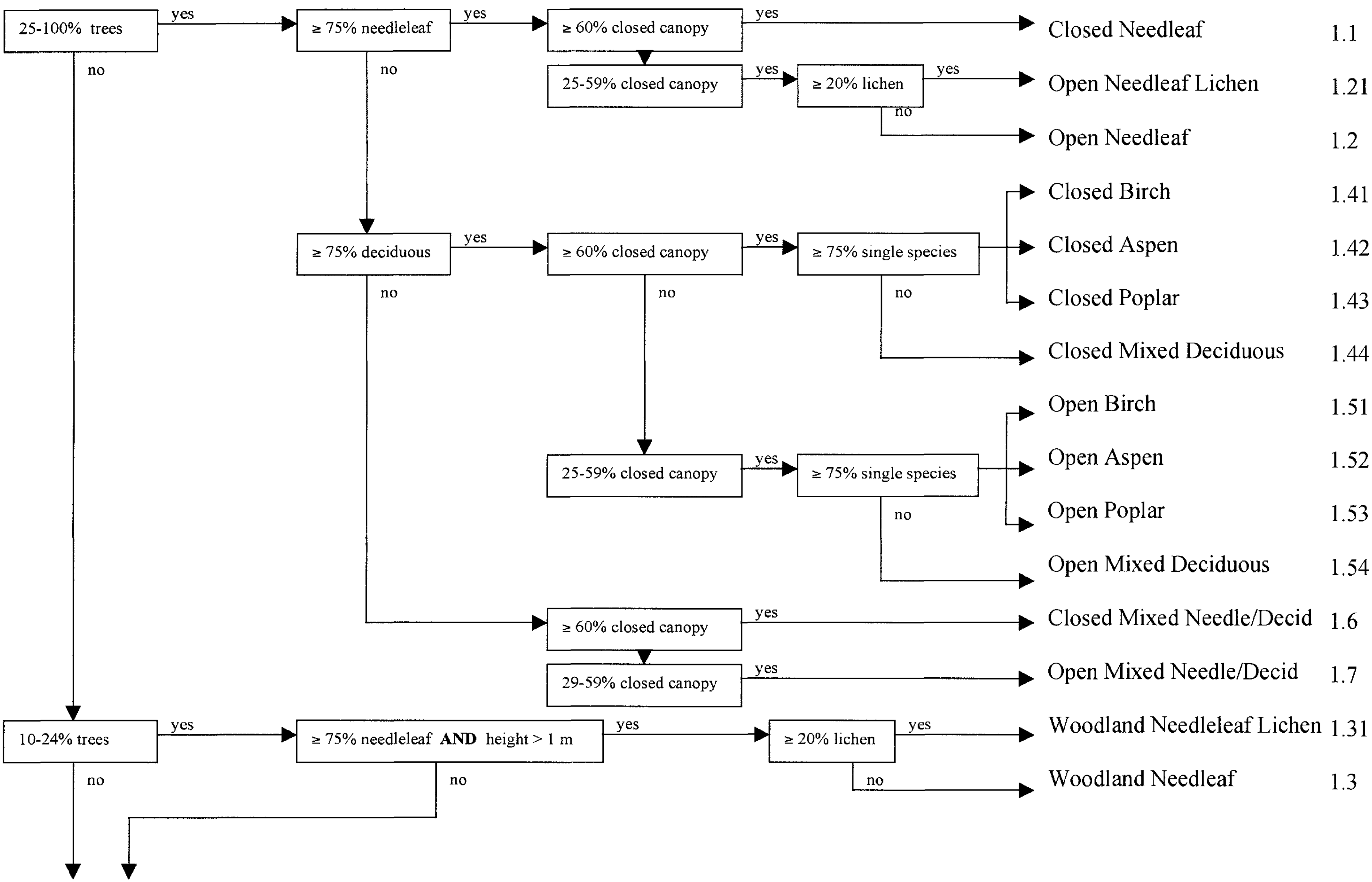
Appendix F. Accuracy Assessment Error Matrix

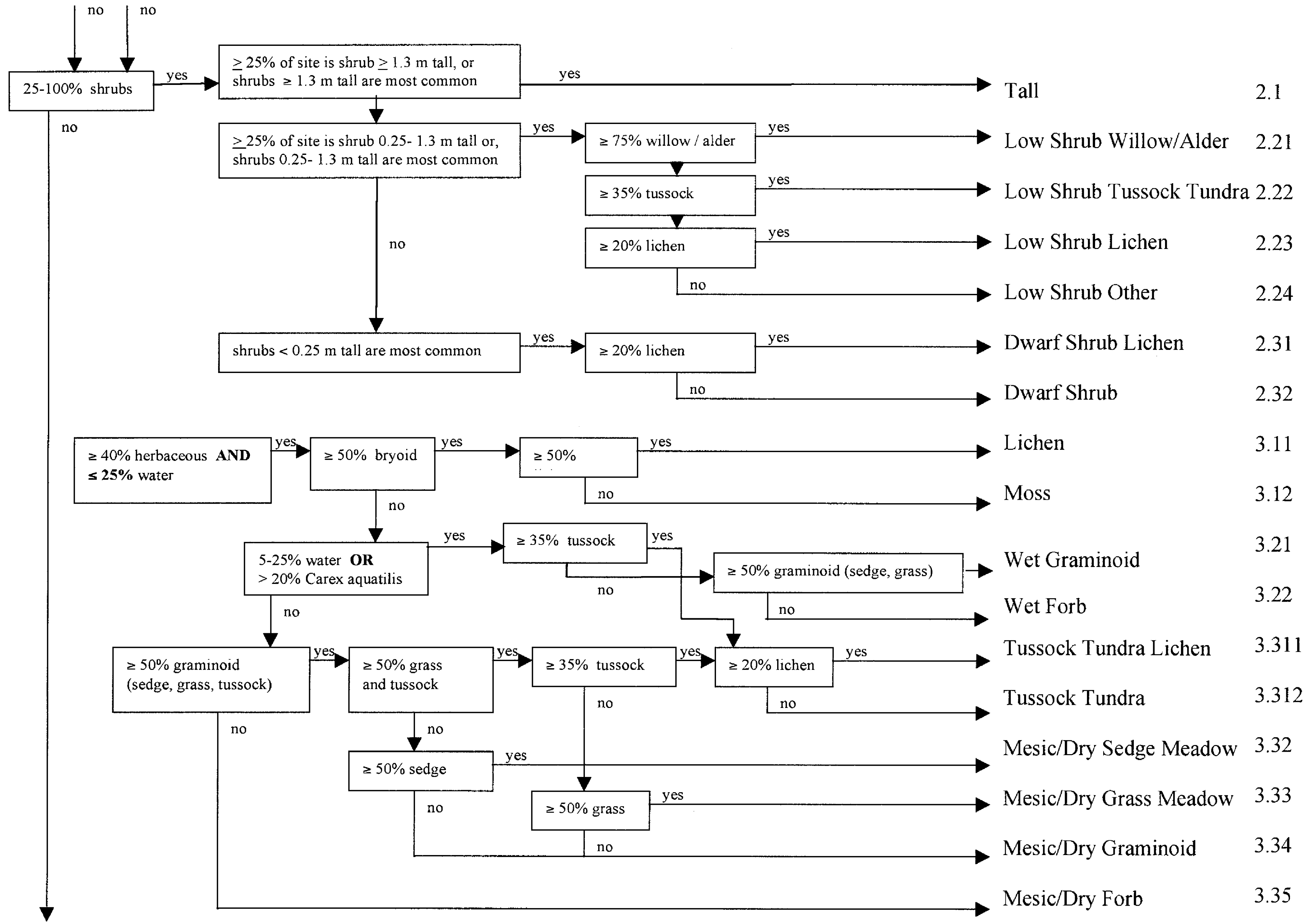
Class	Closed Needleleaf	Open Needleleaf	Woodland Needleleaf	Closed Deciduous	Open Deciduous	Tall Shrub	Dwarf Shrub	Dwarf Shrub - Lichen	Graminoid	Forb	Emergent	Aquatic Bed	Rock/Gravel	Total	User's Accuracy
Closed Needleleaf	7	1												8	88%
Open Needleleaf		3					1							4	75%
Woodland Needleleaf		1	1											2	50%
Closed Deciduous				3										3	100%
Open Deciduous					1						1			2	50%
Tall Shrub						8					1			9	89%
Dwarf Shrub							3							3	100%
Dwarf Shrub - Lichen								3						3	100%
Graminoid									1					1	100%
Forb										1				1	100%
Emergent										1	1			2	50%
Aquatic Bed												2		2	100%
Rock/Gravel													4	4	100%
Total	7	5	1	3	1	8	4	3	1	2	3	2	4	44	
Producer's Accuracy	100%	60%	100%	100%	100%	100%	75%	100%	100%	50%	33%	100%	100%		**86%**

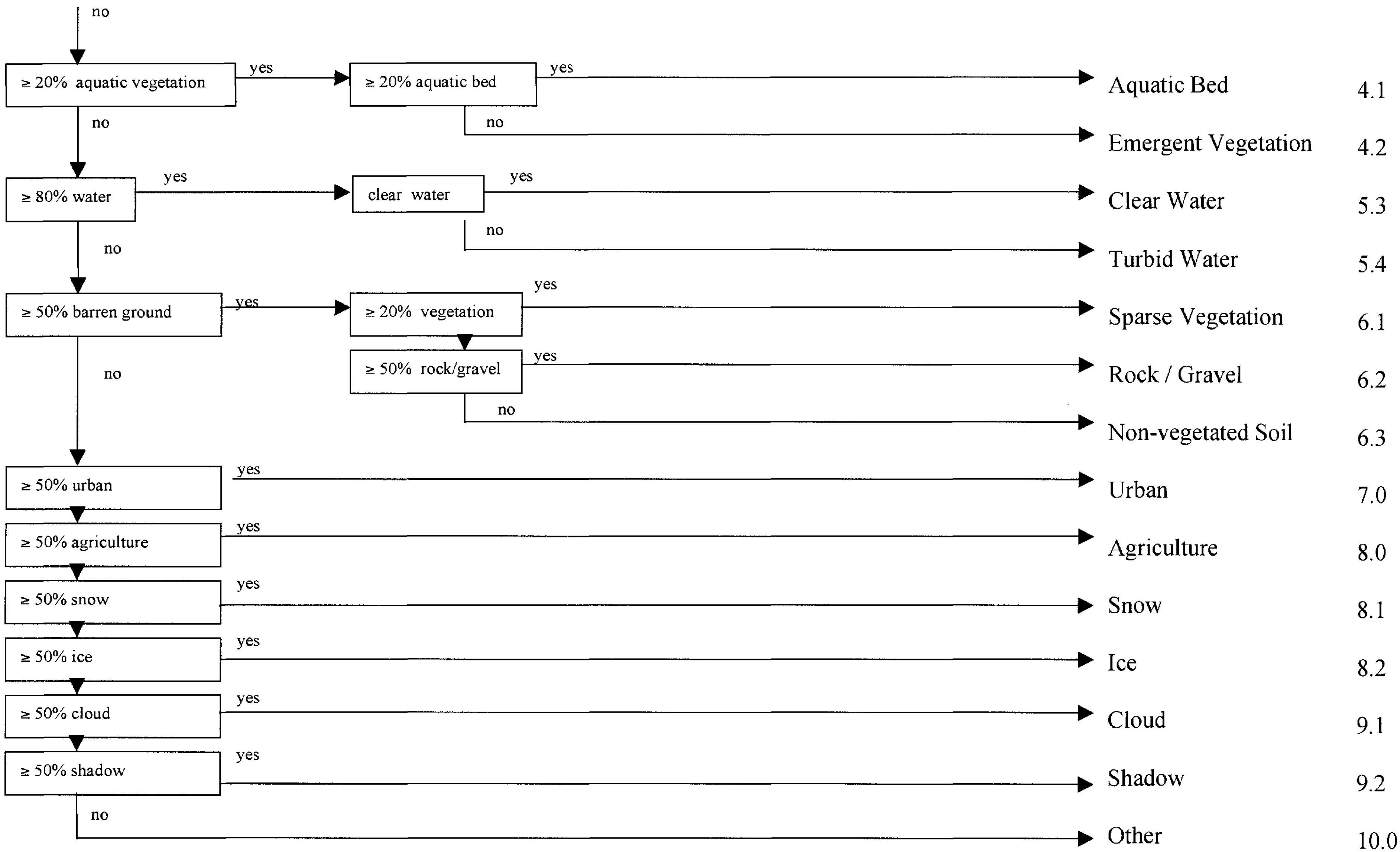
Total Number of Training Sites	44
Diagonal Total	37
Off-diagonal Total	7
Overall Accuracy	86.4%

Appendix G. Decision Tree

Alaska earth cover classification decision tree.




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



no
≥ 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
≥ 50% rock/gravel
yes
Rock / Gravel
6.2
no
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 H. Contact Information

The following additional data is available:

ARC/INFO coverages
Final map classification in ERDAS Imagine format
Final map compositions in Imagine 8.2 format
Raw Landsat TM and DEM imagery
Field database files and FoxPro data entry program
ARC/INFO coverage of aerial photogragh flight lines

For more information please contact:

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