

SOUTHERN LAKES, YUKON TERRITORY EARTH COVER CLASSIFICATION

USER'S GUIDE



YUKON
ENERGY

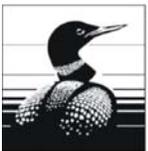


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Final Report



Ducks Unlimited Canada

Yukon
Renewable Resources



Canadian Wildlife Service
Environment Canada



Alsek Renewable
Resources Council



**Teslin Tlingit
Council**



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Abstract

Ducks Unlimited, Inc. and Ducks Unlimited Canada have been mapping wetlands in the boreal regions of Alaska since 1988 and in Canada for the past two years. The project area chosen was a 3.8 million hectare (9.4 million acre) area in the Southern Lakes region centered on Whitehorse, Yukon Territory. Portions of two cloud-free Landsat TM scenes (Path 59, Rows 17 and 18) imaged on August 1, 1999 were used to classify the project area into 31 earth cover categories. The classification scheme was based on Viereck et al. (1992) in Alaska, but was modified to represent the earth cover communities found in the Yukon. Mapped classes included open and closed canopy forests, tall, low and dwarf shrubs, herbaceous, lichen, and wetlands, as well as unvegetated and anthropogenic types. The overall accuracy of the mapped categories was 86% at the +/-5% level of variation. A change detection was performed using an August 24, 1987 Landsat TM 5 image. Changes in earth cover included those due to fires, urban expansion, conversion of arable land to agriculture, receding snow packs, and lowering of water levels. Standardized procedures were used to conduct the earth cover classification. An unsupervised clustering technique was used to determine the location of the field sites to ground truth the satellite imagery. Global positioning system (GPS) technology was used to navigate to the pre-selected sites and to record new sites selected in the field. A total of 479 sites were visited by Bell Jet Ranger helicopter during July 15-26, 2000. Field information was recorded on a custom field data form and digital database. 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.

1.0 Introduction

Ducks Unlimited Inc. and Ducks Unlimited Canada are in the second year of a multi-year program to provide regional earth cover data as part of the Western Boreal Forest Initiative (WBF). The WBF is focussed on understanding how the wetlands of the boreal forest function within the larger landscape and on finding ways to ensure that these wetlands continue to support an abundance of waterfowl and other wildlife. Earth cover mapping is an important aspect of the WBF. Some areas that have been mapped include the area around Norman Wells, Northwest Territories, and Utikuma Lake, Alberta. This project continued the mapping effort in the Yukon Territory. The Yukon portion of the western boreal region is a vast expanse of cordillera and sub-arctic woodland covering three distinct ecozones, and providing critical habitat for waterfowl and numerous other wildlife species. The Yukon Southern Lakes Project area contains highly diverse landscapes and is deemed important for its wildlife, cultural, and recreational values.

Landsat Thematic Mapper (TM) satellite imagery was chosen as the primary source for the DU WBF'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 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.

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.

2.0 Project Objective

The objective of this project was to develop a baseline earth cover inventory using Landsat TM imagery for a portion of southwestern Yukon and to provide this inventory in an integrated GIS database that can be used for improved natural resources planning. A sub-objective was to provide coverages of changes in earth cover from an earlier date. Change detection information is crucial to long term ecological monitoring of the project area.

3.0 Project Participants/Funding

Funding for this project was a multi-agency cooperative effort including the Yukon Territorial Government (YTG, Department of Renewable Resources), the Yukon Fish and Wildlife Enhancement Trust, the Yukon Energy Corporation, Environment Canada- Canadian Wildlife Service (CWS), Ducks Unlimited Canada, and Ducks Unlimited, Inc. Cooperation and support was received from the Teslin Tlingit Council, the Champagne and Aishihik First Nation and the Alsek Renewable Resources Council.

This project was administered through Ducks Unlimited Canada. Ducks Unlimited Inc. in Sacramento, California was contracted to produce the earth cover classification. Staff of YTG Dept. of Renewable Resources (now Dept. of Environment), Parks Canada, and the Canadian Wildlife Service participated in various aspects of the project.

4.0 Project Area

The Southern Lakes Earth Cover Mapping Project consisted of approximately 3.8 million hectares centered roughly on Whitehorse, YT (60.73° N, 135.098° W) and included portions of the traditional territories of the Ta'an Kwach'an, Kwanlin Dun, Champagne and Aishihik, Carcross/Tagish, and Teslin Tlingit First Nations. Figure 1 shows the location of the study area. This project area encompassed a wide variety of environments ranging from glaciated mountains to lowland black spruce muskeg. Woodland Caribou (*Rangifer tarandus caribou*), Dall's 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 are important staging/molting/production habitats for breeding ducks, geese, trumpeter swans (*Cygnus buccinator*), grebes, and other waterbirds.



Figure 1. Southern Lakes project area location.

5.0 Data Acquisition

The imagery for the earth cover classification was contributed to the project at the systematic correction level by Forest Resources of the Department of Indian and Northern Affairs, Canada. Two Landsat 7 ETM+ scenes were used in the project, and the final study area used the top 50% of row 18 and the bottom 50% of row 17 (row 17 shifted 50% south). The acquisition date for the imagery was August 1, 1999 and the field data was collected July 15-July 26, 2000, both within the peak summer season. Ducks Unlimited Canada purchased two historical TM 5 images (Path 59, rows 17 & 18) for the change detection. They were acquired on August 24, 1987, which was close to the acquisition date of the 1999 image (August 1). All imagery was cloud-free.

Ancillary data was limited for the Southern Lakes project. The data that was used was provided by YTG, and included some 1:20,000 color infrared and color photographs taken in 1978. The areas covered by these photographs were limited to the agricultural areas along the Yukon and Takhini River

valleys. Due to the long period between the dates of the photographs and the imagery, these files were used to help determine land cover in areas where there was no photo-interpreted change. A forest cover GIS layer was also used in this project. Use of the ancillary data was limited, and therefore minimally influenced the final earth cover classification.

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.

6.0 Methods

6.1 Sampling Design

The sampling design followed the following steps:

1. Determination of a Classification Scheme (# of classes)
2. Determination of the Sampling Unit
3. Calculation of the Number of Samples
4. Sample selection

The sampling design for this project was ultimately influenced by the detail of the classification (number of classes) and the overall project budget.

6.1.1 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, and 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 Southern Lakes 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 Inc. This system was developed over several years, and has been field tested on several projects. The decision to derive the Southern Lakes classification scheme from the Alaskan classification was based on the similarity of cover types between the two areas.

6.1.1.2 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 goals of this meeting were 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 was developed in order to clarify the classification. Though based largely on Level III of the Viereck et al. (1992) classification, some classes were 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 tall shrub classes, 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.

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	1.21 Open 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	
	1.6 Closed Mixed Needleleaf/Deciduous	1.53 Open Balsam Poplar/Cottonwood	
	1.7 Open Mixed Needleleaf/Deciduous	1.54 Open Mixed 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	
	2.3 Dwarf Shrub	2.24 Low Shrub Other	
		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	3.21 Wet 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

6.1.1.3 Derivation of Southern Lakes Classification Scheme

As stated earlier the final classification scheme for the Southern Lakes was based on the Alaskan classification scheme, but was adapted on several levels in an attempt to better classify the earth cover types found in the Yukon Territory. Also, the classification scheme was designed to record in the field as much variation in the vegetation as possible. For instance, in the Southern Lakes classification scheme, the open needleleaf class was broken into pine and spruce classes, and then each one of those had several understory classes. The understory classes were moss, lichen, herb, shrub, and other. This procedure greatly expanded the number of classes (Table 2). The classification decision tree is shown in Appendix A and written descriptions of the classes are in Appendix B.

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. Since there were nearly 100 classes, about 1500 or more sites would have to be recorded in the field in order to get a statistically valid sample for each class and to accurately classify all of the classes in this scheme. This level of sampling was beyond the scope of this project. The classification scheme was designed so that the higher level classes could be "rolled up" into more general classes if the inherent limits of the TM sensor to discriminate that level of vegetation were exceeded.

Table 2. Southern Lakes, Yukon Classification Scheme

Level II	Level III	Level IV	Level V
1.0 Forest	1.1 Closed Needleleaf (NL)	1.11 Closed Spruce-Fir	1.111 Closed Spruce-Fir / Shrub 1.112 Closed Spruce-Fir / Moss 1.113 Closed Spruce-Fir / Other
		1.12 Closed Pine	1.121 Closed Pine / Shrub 1.122 Closed Pine / Moss 1.123 Closed Pine / Other
		1.13 Closed Mixed Needleleaf	1.131 Closed Mixed NL / Shrub 1.132 Closed Mixed NL / Moss 1.133 Closed Mixed NL / Other
	1.2 Open Needleleaf	1.21 Open Needleleaf / Lichen 1.22 Open Needleleaf / Moss 1.23 Open Needleleaf / Herb. 1.24 Open Needleleaf / Shrub 1.25 Open Spruce-Fir	1.2111 Open Spruce-Fir / Lichen 1.2112 Open Spruce-Fir Shrub 1.2113 Open Spruce-Fir / Moss 1.2114 Open Spruce-Fir / Herb. 1.2115 Open Spruce-Fir / Other
		1.26 Open Pine	1.261 Open Pine / Lichen 1.262 Open Pine / Shrub 1.263 Open Pine / Moss 1.264 Open Pine / Herb. 1.265 Open Pine / Other
		1.27 Open Mixed Needleleaf	1.271 Open Nixed NL / Lichen 1.272 Open Nixed NL / Shrub 1.273 Open Nixed NL / Moss 1.274 Open Nixed NL / Herb. 1.275 Open Nixed NL / Other
	1.3 Woodland Needleleaf	1.31 Woodland Needleleaf / Lichen 1.32 Woodland Needleleaf / Shrub 1.33 Woodland Needleleaf / Herb.	

		1.34 Woodland Needleleaf / Other	
	1.4 Closed Deciduous	1.41 Closed Paper Birch / Poplar	1.411 Closed Birch-Poplar/ Shrub 1.412 Closed Birch -Poplar/ Herb. 1.413 Closed Birch-Poplar / Other
		1.42 Closed Aspen	1.421 Closed Aspen / Shrub 1.422 Closed Aspen / Herb. 1.423 Closed Aspen / Other
		1.44 Closed Mixed Deciduous	
	1.5 Open Deciduous	1.51 Open Paper Birch - Poplar	1.511 Open Paper Birch – Poplar / Shrub 1.512 Open Paper Birch – Poplar / Herb. 1.513 Open Paper Birch – Poplar / Other
		1.52 Open Aspen	1.521 Open Aspen / Shrub 1.522 Open Aspen / Herb. 1.523 Open Aspen / Other
		1.53 Open Mixed Deciduous	
	1.6 Closed Mixed NL/Deciduous	1.61 Closed Mixed NL/Deciduous Shrub 1.62 Closed Mixed NL/Deciduous Moss 1.63 Closed Mixed NL/Deciduous Other	
	1.7 Open Mixed NL/Deciduous		
2.0 Shrub	2.1 Tall Shrub	2.11 Closed Tall Shrub 2.12 Open Tall Shrub	2.121 Open Tall Shrub / Lichen 2.122 Open Tall Shrub / Moss 2.123 Open Tall Shrub / Herb. 2.124 Open Tall Shrub / Low Shrub 2.125 Open Tall Shrub / Other
	2.2 Low Shrub	2.21 Closed Low Shrub 2.22 Open Low Shrub	2.221 Open Low Shrub / Lichen 2.222 Open Low Shrub / Moss 2.223 Open Low Shrub / Herb. 2.224 Open Low Shrub / Other
	2.3 Dwarf Shrub	2.31 Dwarf Shrub / Lichen 2.32 Dwarf Shrub / Moss 2.33 Dwarf Shrub / Herb. 2.34 Dwarf Shrub / Other	
3.0 Herbaceous	3.1 Bryoid	3.11 Lichen 3.12 Moss	
	3.2 Wet Herbaceous	3.21 Wet Graminoid 3.22 Wet Forb	
	3.3 Mesic/Dry Herbaceous	3.31 Tussock Tundra 3.32 Tussock Tundra / Lichen 3.33 Mesic/Dry Sedge 3.34 Mesic/Dry Grass 3.35 Mesic/Dry Graminoid 3.36 Mesic/Dry Forb	
4.0 Aquatic Veg.	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 Non-Veg. Soil		
7.0 Urban			
8.0 Agriculture			
9.0 Cloud/Shadow	9.1 Cloud 9.2 Shadow		
10.0 Other			

6.1.2. Sampling Unit

The sampling unit for a project refers to the size of the field site area that will be sampled for the training of the classification and accuracy assessment. The sampling unit most useful for both techniques was determined to have the following criteria:

1. Larger than the minimum mapping unit to minimize errors of omission due to misregistration.
2. Could be located easily within the image using GPS technology.
3. Was not an arbitrary designation, i.e. formed a representative area of a cover class being mapped.

There are several potential sampling units for a project: a pixel, a group of pixels, or a polygon. For this project, the sampling unit chosen was a homogeneous polygon, since all of the other possible sampling units did not satisfy all of the above criteria desired for this project. For instance, a 3 X 3 cluster of pixels would be an arbitrary designation and would result in the sampling unit encompassing more than one earth cover type. Homogeneous polygons were selected because they directly correspond to areas within a single cover type and also provide a homogeneous spectral signature for the classification.

6.1.3 Sample Size

An adequate number of samples must be collected in the field for each earth cover class in order to determine the statistical validity of the classification, as well as to provide a representative sample of the various spectral signatures of the myriad cover types for the classification. Determination and sampling of every distinct spatial area encompassed by all of the cover types within the project area is not feasible, particularly for large, remote-access areas, so sample size is in turn influenced by logistic and economic constraints. Thus the primary objective of the sample size determination is to balance statistical recommendations with these more practical limitations.

The first step was to determine the sampling design needed to provide an adequate number of field sites used as training sites for the classification as well as enough field sites for the accuracy assessment of the earth cover map. For this project, the minimum sample size for each earth cover class was set at 15 (5 for accuracy assessment, 10 for image processing training sites) in order to perform an accuracy assessment for that class. This number was a balance between the theoretical statistical recommendations and the financial limitations of large scale mapping projects. 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 an adequate number of samples were obtained. Some earth cover classes were naturally limited in size and distribution, so a statistically valid accuracy assessment sample could not be obtained without additional field time.

For these 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. Accuracy assessment sites were selected randomly across the project area to reduce bias.

The final number of samples for each earth cover class often was a reflection of how much area that earth cover class occupied within the project area boundary. Thus, if one class covered a larger portion of the project area than another class, it should have had more samples overall. Exceptions to this rule were for classes such as clear water, shadow, ice, snow, urban, and agriculture, which, due to their inherent spectral properties, did not need to be sampled in the field. These classes were readily determined from the imagery, so more field emphasis was placed on those earth cover types with more spectral variability.

6.1.4 Sample Selection

Once the appropriate sample size for the project is determined, the samples must be allocated among the earth cover classes in the map. The primary purpose of a sampling scheme is to provide an adequate number of samples to represent the earth cover classes within a project area, for use in both the classification and the accuracy assessment. Thus the sample selection process ultimately determines the distribution of samples throughout the project. The three most common methods for selection of field sites are a random approach, a systematic approach, or a stratified approach. All of these approaches have strengths and limitations. 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. A stratified approach uses prior knowledge about the study area in order to divide the image into earth cover strata, and then each stratum is randomly sampled.

The sampling procedure used in this project was a modified stratified approach. The image was separated into strata using an unsupervised classification, which provided an unbiased grouping of strata that collectively represent the entire spectral variation found in the imagery. For this project, 30 distinct strata were determined, and a set number of samples (30) for each class were randomly selected from each of the spectral groups. Field sites are hand-digitized polygons selected from pixel clusters of sufficient size for sampling (greater than 10 pixels) of each spectral stratum. The standard deviation of the spectral variation found within each field site polygon was calculated, and typically sites over three standard deviations from the mean (in any of the bands) were thrown out. In a few cases, classes with higher standard deviations were kept due to the wide range of spectral variation found within a spectral class. In these cases, there tend to be few or no areas within the class that exhibit less than three standard deviations from the spectral mean. Thus, in order to provide samples within spectral classes with a wide range of spectral variation (such as in rocky/dwarf shrub areas), higher standard deviations were allowed.

Because earth cover classes are often arbitrary designations of a continuum of ecological variation, this sampling approach provides samples that represent the spectral variation of the project area. Since the actual ecological variation of each site is collected in the field, the sampling scheme allows the classification technique used in this project to relate spectral variation to earth cover types in a non-biased manner.

6.2 Image Preprocessing

Each image was examined for quality and consistency. Each band was examined visually and statistically by reviewing histograms. Combinations of bands were displayed to check for band to band registration and for clouds, shadows, and haze. Positional accuracy was checked by comparing the image to available ancillary data such as adjacent imagery, hydrography, and DEM's.

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%-59% crown closure, trees of varying height, and a diverse understory composition.

The image analyst individually selected training sites from the spectrally unique areas of the unsupervised classification. Whenever possible, training sites were grouped in clusters to reduce the amount of travel time between sites. The image analyst also placed training sites near landmarks that were easily recognizable in the field, such as lakes or streams. 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+ for navigational purposes. Training sites were overlain with the satellite imagery and plotted at 2.54cm = 1.6km (1 inch = 1 mile) scale. These field maps were used for recording field notes, placing additional field sample sites, and navigating to field sites.

6.3 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 are 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 used to record field information (Figure 2). A five person helicopter crew performed the field assessment. Each crew consisted of a pilot, biologist, recorder, navigator, and alternate. The navigator operated the GPS equipment, interpreted the satellite image derived field maps to guide the biologist to the pre-defined field site, and collected photos of the field sites. It was valuable for the image processor to gain first-hand knowledge of the project area, therefore the image processor filled the role of the navigator. The biologist identified plant species, estimated the percent cover of each, and determined the overall earth cover class based on the classification scheme. 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 plant species was uncertain.

camera for a close-up view of the site. The pilot then ascended to approximately 100 meters so that the biologist could estimate the percentages of each species to the recorder. The navigator then snapped an oblique angle photo and directed the pilot to the next site. On average, it took 5-8 minutes to collect all of the information for one site.

6.4 Field Data Analysis

The collected field information was entered into a digital database using a custom data entry application (DUFF), designed jointly by the BLM and DU Inc. and programmed by GeoNorth. The structure of the relational database is described in Appendix C. It 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 3). 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.

Sample Field Site – Closed Mixed Needleleaf/Deciduous



High site photo



Low site photo

DUFF INTERFACE

Ducks Unlimited

File Tools Help

2000 SLAK 1 126
 Year Project Crew Site
 (click to search) Delete New

Observation Crew Check Flag (military)
 Nav Veg Rec Observ Date Obs Level Obs Time
 KS KS MW 21-Jul-00 2 09:44 Update

Session Photo
 1 -> 1080
 1 -> 1079
 1 -> 1078

Observed Classes
 FOREST - CLOSED SPRUCE-FIR SHRUB
 FOREST - CLOSED SPRUCE-FIR MOSS
 FOREST - CLOSED SPRUCE-FIR OTHER
 FOREST - CLOSED PINE SHRUB
 FOREST - CLOSED PINE MOSS
 FOREST - CLOSED PINE OTHER
 FOREST - CLOSED MIX NEEDLELEAF
 FOREST - CLOSED MIX NEEDLELEAF
 FOREST - CLOSED MIX NEEDLELEAF
 FOREST - OPEN SPRUCE-FIR SHRUB
 FOREST - OPEN SPRUCE-FIR HERB
 FOREST - OPEN SPRUCE-FIR MOSS
 FOREST - OPEN SPRUCE-FIR LICHEN
 FOREST - OPEN SPRUCE-FIR OTHER
 FOREST - OPEN PINE SHRUB
 FOREST - OPEN PINE HERB
 FOREST - OPEN PINE MOSS
 FOREST - OPEN PINE LICHEN

Lat (degrees, decimal min) Long % Slope Elev Aspect Avg Dist Btwn Stem
 00d00.00000 000d00.00000 5 0 NE

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

Symbol	Latin	Common	% Cov	Height
LITT	LITTER	LITTER	10	(
MOXX	MOSS	MOSS	10	(
FOXX	FORB SPP	FORB SPP	5	(
ALTRE	ALNUS SPP TREE	ALDER, TREE	25	(
SAX_	SALIX SPP	WILLOW	5	(
PICO	PINUS CONTORTA	PINE, LODGE-POLE	15	1
BEPA	BETULA POPYRIFERA	BIRCH, PAPER	5	(
POTRIT	POPULUS TREMULOIDES	ASPEN, BARKING	5	(

Comments Sum of % Covers : 100

Calculated Class 1.63 CLOSED MIXED NEEDLELEAF/DECIDUOUS OTHER

Aerial Photos Flight Line Photo # Date Source
 Quad Quad
 Satellite Image Image #
 TRS Township Range Section

Figure 3. The customized database and user interface for field data entry (DUFF).

6.5 Classification

Every image is unique and presents special problems in the classification process, but we use the same basic approach in all projects (Figure 4), as it has proven successful. It is particularly valuable that the image processor was actively involved in the field data collection and had first hand knowledge of every training site.

Erdas Imagine (v. 8.4) was used to perform the classification. Arc Info (v. 7.2.1) was utilized to manage the field site polygons. Various word processing and data analysis software including MS Word, Excel and Access was also used during the image classification.

6.5.1 Generation of New Bands

The Landsat TM imagery contained 7 bands of data: 3 visible bands, 1 near-infrared band, 2 mid-infrared bands, and 1 thermal band. One new band, the NDVI (Normalized Difference Vegetation Index), 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 has 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.

6.5.2 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 1.5 ha/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.

6.5.3 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.

6.5.4 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

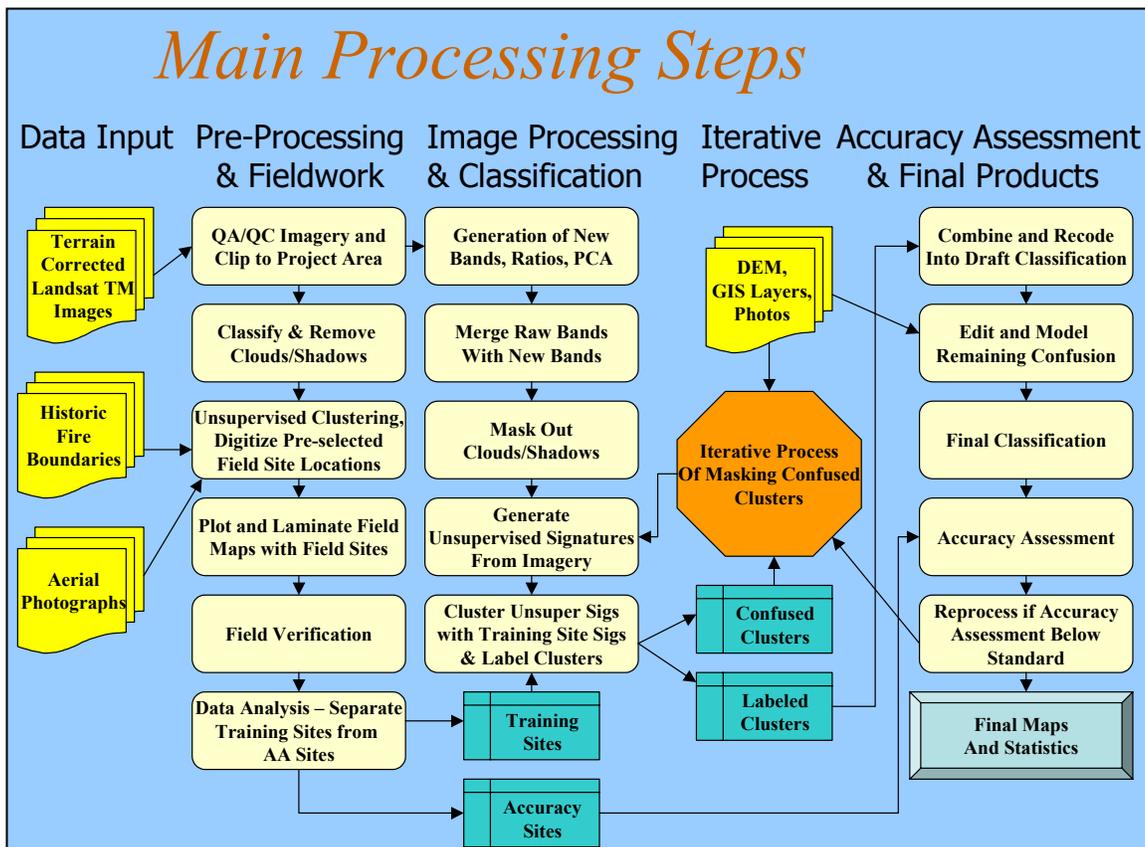


Figure 4. The image processing flow diagram.

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 iterations.

6.5.5 Editing and Modeling

The Southern Lakes project area exhibited considerable 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 DEMs. All of the relief, slope, and elevation images were created using Erdas IMAGINE. The modeling process was used primarily to identify potentially misclassified cover types (due to the influence of topography) throughout the study area.

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. The pixels that were classified in error were then corrected by manually changing the class value to their correct class value.

6.6 *Change Detection*

6.6.1 Pre-processing

Like the image classification pre-processing, change detection images must be accurately georeferenced and orthorectified in areas of significant terrain relief, typically within one-half pixel (within 15 meters) root mean squared error. Image-to-image registration quality is critical to a valid change detection analysis. Misregistration will lead directly to commission errors and will corrupt the results. For example, roads that are slightly off show up as a narrow band in change detections due to the error in registration. Commission errors are extremely difficult, or impossible in many cases, to mitigate using post-processing techniques. In addition, since image orthorectification involves pixel resampling, a nearest neighbor resampling kernel was used, as this technique alters the original pixel values the least.

The two Landsat 5 images were mosaicked for the change detection analysis for the Southern Lakes study area. The 1987 imagery covered a slightly smaller area than the 1999 imagery, with less area in the eastern portion of the image. The image was orthorectified using the same method and control points as for the 1999 imagery. Root mean squared error for the orthorectification was less than half of a pixel.

Once the earlier date image is satisfactorily orthorectified, that image must be normalized to the reference image (in this case, the image associated with the field data). Correctly normalized images ensure that changes of small magnitude can be detected and measured, and spurious changes will be minimized. Selection of anniversary dates where the spectral reflectances of most of the features on the ground are similar in both images is advisable. This is because areas that have the same unchanged cover type in both images and have different reflectance values will need to be normalized to each other, so images with similar reflectance values minimizes the need for normalization. The object of normalization is to correct for all of the differences between the images in the change analysis that are not associated with landscape change in cover or condition. These discrepancies may include atmospheric conditions, solar illumination, phenologic changes in the landscape, and sensor calibration.

The first step in the normalization process was to take training samples of as much spectral variation as possible throughout the 1987 image. A total of 35 training sites were selected to normalize the 1987 image to the 1999 image. These sites were chosen to maximize spatial (image distribution) and spectral (range in brightness values) distribution in “stable” areas, or areas throughout the image that did not change between the two dates. The sites encompassed all of the major earth cover types, from water to forest to shrub to rock. Once the training sites were selected, a simple linear regression was used to determine the radiometric normalization for each band. Then the intercept and coefficient of the regression equation were applied to each band, providing the final normalized 1987 image, which was used in the change detection.

6.6.2 Change Detection Methods

After the images were correctly orthorectified and normalized, change detection procedures were run on the images. For this analysis, a simple band differencing change detection was used. All of the bands were put into a simple model and the difference (either positive or negative) was displayed as an image. Difference images were determined for each band in the image. A threshold was set where everything above the threshold was labeled as change, and everything below was labeled no change. The threshold is an arbitrary value, set by the analyst after reviewing the image. The threshold level is highly variable from image to image. Since land cover changes showed up in all of the bands, there was a lot of redundancy in the band difference images. After a review of all of the difference images, the TM Band 4 difference image was chosen to determine the vegetation and water level changes, and the TM Band 7 difference image was used to detect changes in snow cover, urban expansion, fires, and agriculture changes.

Image differencing techniques provided the difference in spectral reflectance between 1987 and 1999 for each of the bands. This final difference image exhibits a range of values from negative to positive, depending on the brightness values of each image. For this specific change detection, modeling or statistical classification of change signatures were not possible due to the overlap of difference values among change classes. For example, a fire and a clearcut might exhibit the same difference in spectral signatures between the two dates, but would belong to different change classes. In addition, some changes were nearly impossible to separate using unsupervised classification techniques, but were readily classified by an analyst using visual references. Pattern recognition, context, and other visual cues were all used to separate classes. For these reasons, a decision was made to manually classify the difference image into the different change categories. This process was done using field data, aerial photographs, and the interpretive ability of the analyst.

Because no data was collected at the time of the 1987 image overpass, no accuracies were provided for the change detection analysis. Sources of error were minimized where possible. One source of error that was present was misregistration. Although the overall pixel error for the orthorectification procedure was less than a half a pixel (<15 meters), in some areas the registration was off by more than a pixel. This typically occurred in areas where there were few control points available for the registration, for example the northwestern portion of the image. Other areas, such as around Whitehorse and along the major transportation routes, were very accurately orthorectified. A large portion of the change occurred in these areas, while very little occurred in the areas with registration errors. In areas with registration error, all changes were checked visually, and false changes were edited out of the final change coverage.

6.7 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). There is no accuracy assessment method available that would provide a precise representation of the true accuracy of the final earth cover map, due to limitations including sampling error, logistics, project funding, and the degree of complexity found within the landscape. Because sampling for every spatial unit is not economically or logistically feasible, particularly for large land areas, the sample design for this project provides an *estimate* of the accuracy of the map.

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.

For this project, an accuracy assessment was calculated for each of the designated accuracy assessment sites. The total number of earth cover classification pixels that fall within the accuracy assessment site are compared with the field site designation. For the site to be assessed as accurate, greater than 50% of the earth cover classification pixels must correspond to the earth cover class calculated by the field site. Sites with less than 50% coverage in the “correct” class are labeled as “false”.

6.7.1 Error Matrix

The standard method for assessing the accuracy of a map is to build an error matrix, also known as a confusion matrix, or contingency table. The error matrix compares the reference data (field site or photo interpreted site) with the classification. The matrix 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). In the error matrix, numbers along the main diagonal of the matrix indicate an exact match between the reference data site and the map. Sites that have been designated as “false” in the accuracy assessment are shown in the off-diagonal cells of the error matrix. Thus if an accuracy assessment site was designated in the field as open needleleaf and the majority of the image pixels were calculated as closed needleleaf, this accuracy site would be placed in the off diagonal cell that corresponds to closed needleleaf.

An error matrix was an effective way to represent accuracy in that the individual accuracy of each category was plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the classification. A commission error occurred when an area was included in a category it did not belong. An omission error was excluding that area from the category in which it did belong. Every error was an omission from the correct category and a commission to a wrong category.

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 is 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. The producer's accuracy provides an assessment of the error of omission, and is calculated by dividing the total number of correctly determined accuracy assessment sites within an earth cover type by the total number of accuracy assessment sites classified into that earth cover type (as derived from the reference data). The user's accuracy is a measure of the commission error, and is calculated by the total number of sites within an earth cover class divided by the total number of sites that were classified into that category.

An error matrix was calculated for accuracy at 0% and at +/-5% variation in interpretation within the reference data. The +/- 5% refers to adding or subtracting 5% to the cover percentages of the field sites and then recalculating the cover class. This technique gives the user an indication of the robustness of the field site vegetation calls. For instance, say a site is called in the field as 55% spruce. It would be classed as an open needleleaf, when in reality it might typify a closed needleleaf stand. By adding 5% to the cover of spruce, the value would become 60% and the site would then be correctly calculated as a closed needleleaf site. This technique compensates for human error and provides a metric of how many "borderline" sites were in the classification.

7.0 Results

7.1 Field Verification

A total of 479 sites were surveyed in the field during the period from July 15-July 26, 2000. A total of 54.2 hours of flight time were used to collect the field sites. The proportions of sites per class (Appendix D) 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. Within any cover type, there is a wide range of phenological variation (and therefore spectral variation) among cover types caused by a wide range of variables (elevation, aspect, soils, moisture regimes, etc.). Although the range of spectral variation within a spectral class is determined before the field work using an unsupervised classification, it is more difficult to determine pre-field the ecological variation within an earth cover class. For this reason, some new field sites were collected in the field. Fuel locations were spaced throughout the image, and allowed for a wide distribution of sites (Figure 5).

Southern Lakes Earth Cover Mapping Project
Field/ Fuel Site Distribution

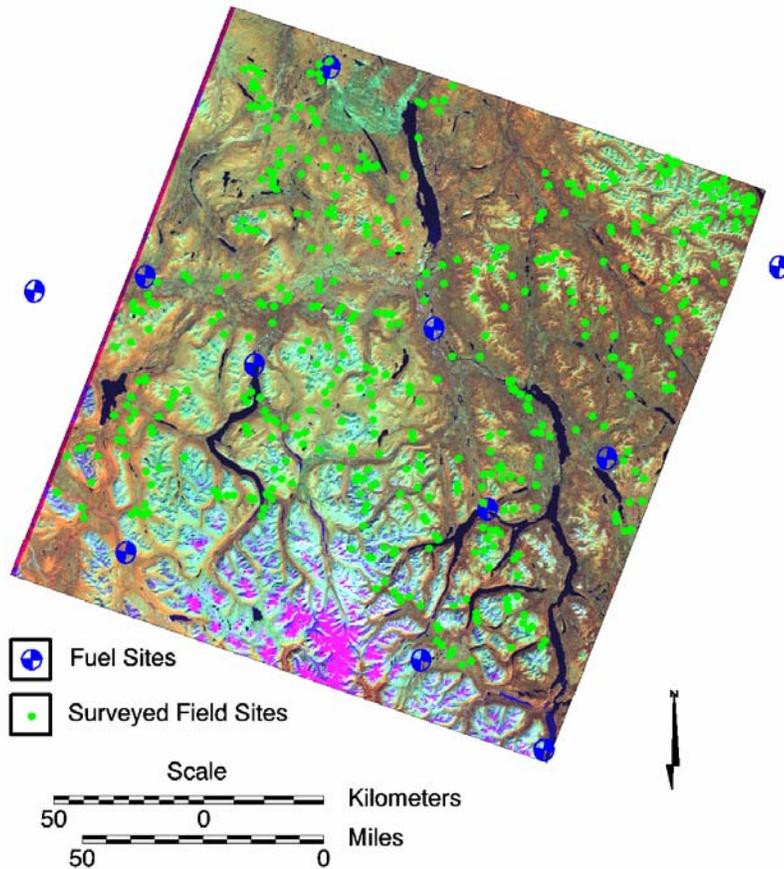


Figure 5. Fuel site locations and field site distributions for the Southern Lakes project.

7.2 Classification

A total of 31 earth cover classes were mapped in the final earth cover map (Figure 6). Appendix D shows the composition of the final map classes in relation to the field classes. Table 3 presents the total percent cover and area covered in hectares per class. The three most extensive vegetation classes were the closed needleleaf (9.9% of total area), open spruce (8.4%), and woodland needleleaf/shrub (7.9%). This agrees with observations made during the field data collection. As these summary statistics show, none of the earth cover classes were dominant (no classes were more than 10%). At over 8%, the non-vegetated rock/gravel class was one of the most dominant classes, primarily in the mountains in the south central portion of the image. The Southern Lakes project area was diverse, ranging from glacial icepack in the southern portion of the image to dwarf shrub/lowshrub highlands, to the forested river valleys. The lower elevations were characterized mainly by fire-influenced open needleleaf forests, which ranged from woodland needleleaf to closed needleleaf 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.

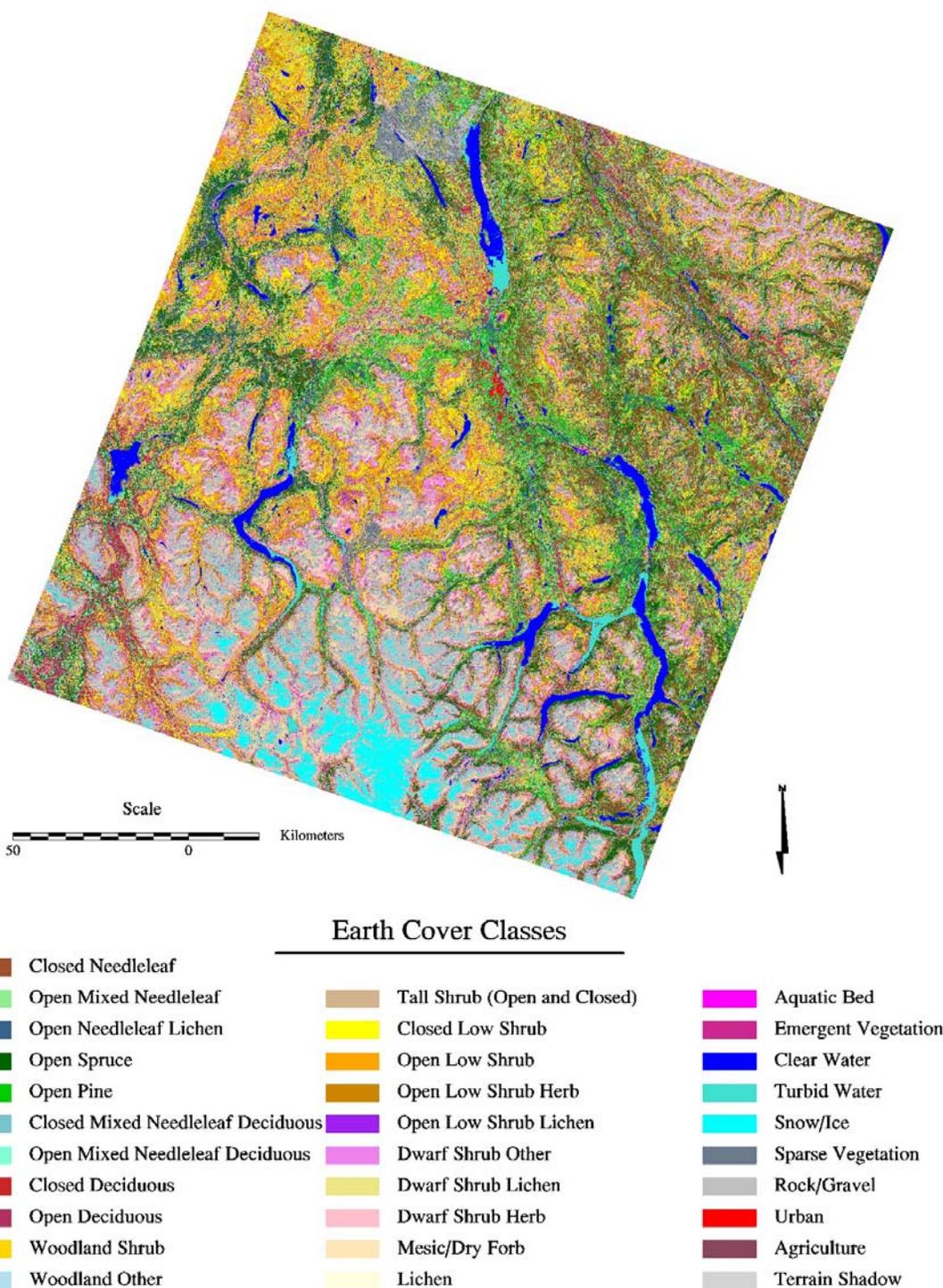


Figure 6. Southern Lakes earth cover map.

Table 3. Area and percent cover of earth cover classes within the study area.

Earth Cover Class	Hectares	Area Percentage
Closed Needleleaf	377862.48	9.9%
Open Mixed Needleleaf	62444.25	1.6%
Open Needleleaf Lichen	105640.29	2.8%
Open Spruce	319683.51	8.4%
Open Pine	172105.02	4.5%
Closed Mixed Needleleaf Deciduous	57867.12	1.5%
Open Mixed Needleleaf Deciduous	206270.46	5.4%
Closed Deciduous	75075.3	2.0%
Open Deciduous	130913.19	3.4%
Woodland Needleleaf Shrub	302427.27	7.9%
Woodland Needleleaf Other	86086.35	2.3%
Tall Shrub (Open and Closed)	158618.61	4.2%
Closed Low Shrub	184310.64	4.8%
Open Low Shrub Other	226440.36	5.9%
Open Low Shrub Herb	102989.52	2.7%
Open Low Shrub Lichen	165563.46	4.3%
Dwarf Shrub Other	173906.91	4.6%
Dwarf Shrub Lichen	154794.15	4.1%
Dwarf Shrub Herb	57326.31	1.5%
Mesic/Dry Forb	6145.92	0.2%
Lichen	13326.12	0.3%
Aquatic Bed	3587.31	0.1%
Emergent Vegetation	2854.71	0.1%
Clear Water	113269.23	3.0%
Turbid Water	44384.76	1.2%
Snow/Ice	88751.43	2.3%
Sparse Vegetation	93047.4	2.4%
Rock/Gravel	307574.19	8.1%
Urban	8733.87	0.2%
Agriculture	2831.58	0.1%
Terrain Shadow	12476.79	0.3%
Total Area	3817308.51	

7.2.1 Forested Cover Types

In the lower elevations with better soils and drainage, forested cover types were typically the dominant earth cover classes. Closed and open canopy needleleaf stands could be found throughout many of the river valleys and well drained hillsides along the valleys. Lodgepole Pine (*Pinus contorta* var. *latifolia*) was extensive in old burn areas in the interior influenced valleys such as the Yukon and Teslin river valleys. While deciduous trees often dominate the fire scar regeneration areas, pine regeneration in pure stands can be found along the river valleys (Figure 7).



Figure 7. Pure Lodgepole pine stands in an old burn area.

White Spruce (*Picea glauca*) was common throughout the image, whereas Black Spruce (*Picea mariana*) was more common in the eastern portion of the image. Since their growth forms were very similar in many areas, they were grouped together in the field data collection and the classification. Spruce trees were among the most widely distributed trees in the Southern Lakes project area, ranging from just below tree line to the interior and coastal influenced river bottoms. Subalpine Fir (*Abies lasiocarpa*) was often associated with the spruce trees, and also shared a wide range in distribution and growth forms, from the stunted, bush-like Krummholtz form near the treeline to the 10–20 meter tall mature trees in the eastern portion of the study area. Because fir and spruce were often mixed and the spectral signatures of each were also indistinguishable in many areas, spruce and fir were grouped into one class. In general, the spruce and fir stands dominated the forested areas of higher elevations, and pine occurred at lower elevations.

Despite the spectral similarities among 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. Where possible, every attempt was made to determine the understory component within the major earth cover type class. For instance, open needleleaf lichen was readily determined, but the other types of understory components were not readily separated from each other, so they had to be lumped into a larger category (open needleleaf). If spruce and pine had exhibited different and distinguishable understories, they would have been separated based on the understory.

The open needleleaf lichen class was comprised of open pine lichen, open spruce lichen, and open mixed needleleaf lichen earth cover classes. Since there were not enough combined field sites in these sub classes, they were grouped into the more general open needleleaf lichen mapped earth cover class. Despite the lack of an accuracy assessment on this class, this class was mapped because the spectral signature was distinct, and separable from the other open needleleaf classes.

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. Mixed Needleleaf/Deciduous classes are very difficult to separate. A wide variation of mixtures are possible, including stands where the conifers and deciduous trees are mixed tree by tree or in clumps of trees within the site.

Open and closed deciduous stands 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.*) 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 not included in the final classification.

Woodland needleleaf areas were very common throughout the study area, particularly in areas influenced by fire or with poorer soils. Woodland areas represent over 10% of the project area. These classes were among the most difficult earth cover classes to map because 80-95% of the signature was derived from the understory constituents. Transitional areas between open needleleaf and tall shrub areas, mixed pixel areas at the edge of open/closed needleleaf stands, and areas regenerating after fires were areas included within this class.

7.2.2 Wetland Cover Types

Although over 4% of the earth cover in the Southern Lakes project was water, there were relatively few large (~400ha / 1000 acres) non-forested wetland complexes. While there were some areas of black spruce muskegs throughout the image, many of these forested wetland types were classified in the woodland other or open spruce classes.

Emergent vegetation and aquatic bed classes were most common as rings of vegetation in the many small basins and lakes found throughout the image (Figure 8) and also as riparian wetlands along the rivers. 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 classes. 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 needleleaf, rock/gravel, and terrain shadow cover types.

All of the sites containing wetland pixels that were selected during the site selection process classified as "other" in the classification scheme. These sites were a mix of several different classes and were not useful as training sites for wetland types. Four emergent wetland sites were added in the field and notes were made if emergent or aquatic bed areas were encountered during the field work. This information was used to generate the classification for these types.



Figure 8. One of the many shallow depression lakes in the study area.

7.2.3 Shrub Vegetation Cover Types

Shrub-dominated cover types were very common throughout the image. They were common in burn areas, areas with poorer soils not able to support forested vegetation, 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 in the southwestern portion of the image were much more lush than many of the interior influenced shrub sites. Since these coastally influenced shrub areas exhibited a different signature than the other parts of the image, this area was processed separately, and then merged back into the final classification. This area was basically west of Kusawa Lake in the southwestern corner of the image.

7.2.4 High Elevation Cover Types

The higher elevations in the Southern Lakes 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, 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. Within a specific site, the relative percentages of each of these components will determine the cover type. For instance, a site might have dwarf shrub lichen, ice, rock, snow, etc. The final cover type determination depends on the relative proportions of these components.

7.2.5 Influences on Earth Cover Type

7.2.5.1 Fires

Most of the vegetation in the Southern Lakes project area is based on successional stages of fire regimes. Many of the field sites were in old burn areas that were spectrally similar but very different on the ground. The more recent burn areas were dominated by standing dead trees and ground litter, which caused much of the confusion between the different field sites. Most of the confusion in the old burn areas was among tall shrub, low shrub, and woodland needleleaf. The majority of these old burn areas were classified solely on field site verification.

Areas that had been burned within a close time frame of the image date left a very bright and homogenous signature because of the abundance of standing dead, litter, and burned vegetation. The standing dead trees, litter and exposed soils give a very high reflection value because the features do not absorb any IR. The actual live vegetation within the area was not represented in the signature. Therefore, it is impossible to collect any variation in signatures for classification of these areas. For this reason, very few field sites were delineated in the burned areas, and they were classified based on the spectral signatures from the imagery date. Also, areas within the fire scar are highly variable year to year. For example, the 1998 Braeburn fire was mostly bare soil during the imagery date (1999), but during the field season (2000) it had considerably more vegetation (ie., regrowth). So the image was classified based solely on remote sensing analyst interpretation – not based on field determination.

7.2.5.2 Elevation

Another factor that greatly influenced the earth cover types in this project was elevation. As can be seen in Figure 9, vegetation was clearly stratified by elevation. Pine areas, shown as forest green in the image, tended to occur in the valley bottoms. Dwarf shrub lichen sites occurred in the highest areas, just below the rock/gravel class. Interspersed between the two were the dwarf shrub, low shrub, tall shrub, deciduous (aspen), and spruce cover types.

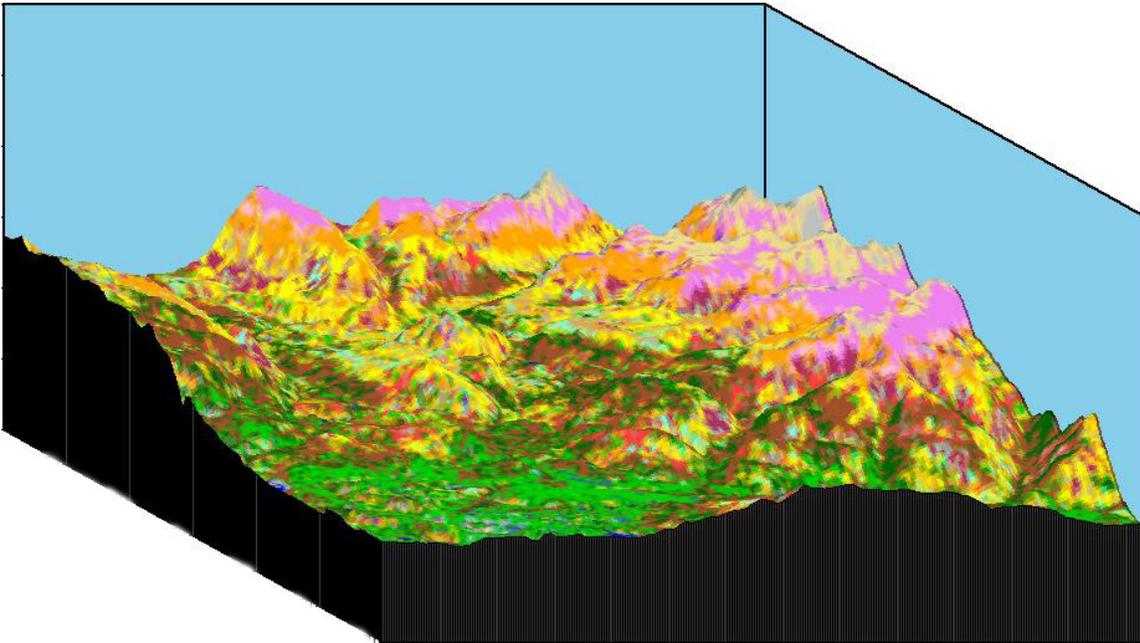


Figure 9. Surface profile of the Southern Lakes project area near the Teslin River. Refer to Figure 6 for color referencing.

7.2.6 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 highlighted some of the areas of confusion, it did not eliminate all of the problems associated with shadowing effect.

These modeling approaches identified 0.30% of the area as terrain shadow in the Southern Lakes 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.

7.2.7 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. Only a very small portion of the Southern Lakes image was manually edited, but the edits were scattered throughout the image.

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. 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. Where the differences were not able to be resolved spectrally some manual editing was needed.

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 wetland and closed deciduous signatures.

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 classes. As evidenced by the field training sites, a large number of the open and woodland needleleaf classes exhibited a crown closure between 15-25%. A classification decision was made based on the available data for these transitional areas and signatures.

A similar 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.

Detecting plant heights also proved problematical. 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.

The aquatic bed and emergent classes 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. The pixel mixing of water, mud, emergent vegetation, and upland vegetation caused much of the confusion in these small areas. 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.

Manual editing of some classes can be a more effective classification technique in some cases, because there are certain features of the image that can be “seen” by the image processor, but are not identified by the computer. Classes such as urban and agriculture were manually edited, as they are spatially distinct features of the landscape. If an analyst tried to separate these 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 (non-anthropogenic) earth cover types. Yet these areas can easily be differentiated by use of visual interpretation cues such as spatial context, and were manually separated into the appropriate classes.

7.3 Change Detection

Changes to the Southern Lakes project area and the areas changed are included in Table 4. All of the change classes were merged into one thematic raster coverage for the Southern Lakes project area, and coded by change class. Most of the anthropogenic change in the landscape occurred near the major transportation arteries, including areas around Whitehorse and the Alaska Highway. These changes included urban expansion (roads, houses, developments, mining, sewer, etc.), and conversion of arable land to agriculture. The agriculture change class was edited to remove spurious phenologic change (crop rotation, plowing), so that all of the changes in this class were alterations of the “natural” earth cover to agricultural. Aerial photographs were used where they were applicable in determining pre-existing agricultural fields. An example of some of the urban, agricultural, and fire change classes around Whitehorse is shown in Figure 10.

Some of the natural changes in the earth cover types included snow receding in the higher elevations, fires, channel shift in rivers, vegetation change, and water table changes. Fire and snow receding classes were separated as single classes, while the remaining classes were lumped into one class. This was done because many of the remaining changes were similar or related in nature, for instance, if an area dropped in water level, often in the change image it was included as vegetation change, since the exposed land often was covered by emergent, upland herbaceous, or shrub cover types.

Table 4. 1987-1999 Southern Lakes project area change.

Change Class	Area (Acres)	Area (Hectares)
Fire	120502	48765
Agriculture Conversion	5175	2094
Urban Expansion	3039	1230
Snow Receding	59214	23963
Water table/Vegetation Change	47700	19304

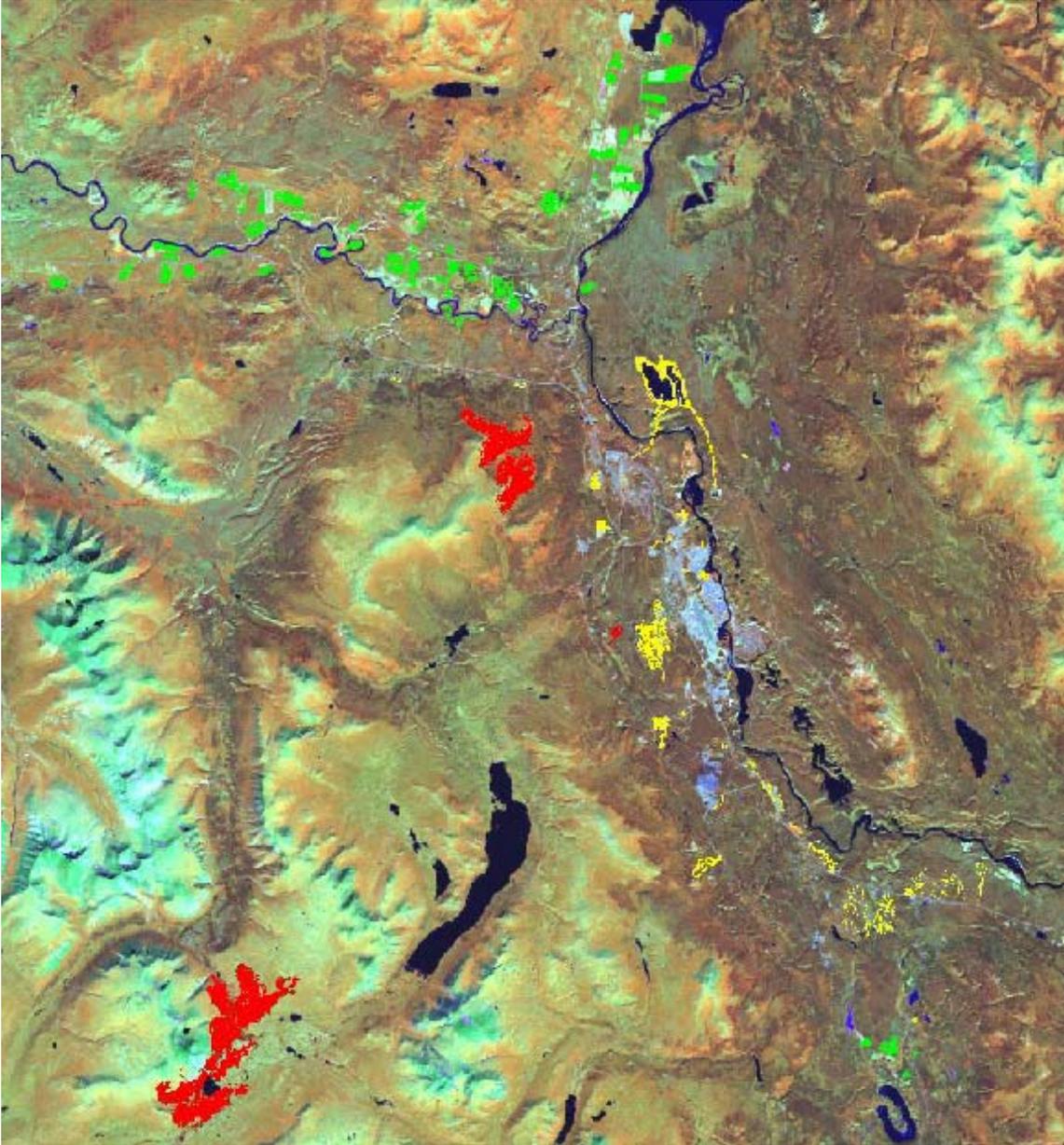


Figure 10. Change areas around Whitehorse, YT. The yellow changes are urban expansion, green changes are agriculture conversion, and red changes are fire scars. The underlying image is a 4,5,3 composite of the 1999 image.

7.4 Accuracy Assessment

The final tally of training and accuracy sites is shown in Appendix D. An assessment of the reliability/accuracy of the earth cover classification is found in the error matrix provided in Appendix E (Tables 1 and 2). The overall accuracy of the project was calculated to be 77% (86% at the +/- 5% level). In addition to the overall map accuracy, the error matrix allows the user to evaluate the performance and interrelationships of each of the mapping classes that met the minimum criteria for an accuracy assessment (highlighted in Appendix D). These classes correspond to most of the major (in terms of area extent) earth cover classes found within the final earth cover map.

An accuracy assessment was not done on all of the mapped classes. However, earth cover classes with no accuracy sites should not be interpreted as being necessarily inaccurately mapped. Some earth cover classes were not adequately represented in the field data, primarily because of their scarcity within the project area (e.g. open/closed birch, open/closed poplar). In some cases, these classes were merged together into a higher class (e.g., open/closed deciduous). Other classes did not meet the minimum requirements for accuracy assessment, but had enough training sites to be mapped. Earth cover classes were not classified if they were not represented in the field data, were not readily determinable from the ancillary data, or did not exist in the study area.

The overall map accuracy did not include classes for which no accuracy assessment was done, e.g., snow/ice, clear water, water, turbid water, urban, agriculture. 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 for the final earth cover map.

One site was discarded from the accuracy assessment where the error was not able to be reconciled (i.e., the site was labeled as closed needleleaf when it occurred in a dwarf shrub lichen area). In a few other cases, the accuracy sites were reclassified from one class to another class where they were interpreted to be incorrect. One example was a tall shrub site classified as dwarf shrub. The actual shrub height of over 4 meters was not recorded on the field form and the site was calculated as dwarf shrub. This site was reclassified to closed tall shrub from dwarf shrub other.

7.4.1 Overall and Class Accuracy

The difference in classification accuracy between the 0% variation in interpretation level (76.5%) and the +/- 5% variation in interpretation level (86.1%) indicated that characteristics of many of the reference data sites were close to the threshold of two or more mapping classes. It is generally accepted that variation in interpretation of +/- 10% is common for human interpreters, either from aerial photography or on the ground. When this natural and accepted variation is measured and accounted for (as in the case of the error matrix in Table 2, Appendix E), a more reliable and informative measure of accuracy is presented.

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 is still indicated in the matrix, a user can determine in which classes the map is least reliable and with which mapping classes the unreliable classes are confused. If lumping of classes is still desired, this can easily be accomplished through application of the techniques utilized in previous projects.

The computed accuracies for the needleleaf forested classes were the same at both the 0 and +/- 5% variation levels (i.e., Closed Needleleaf = 71.4%, open spruce = 100%, and open pine = 71.4%). The user's accuracy for the same classes was in the 83-85% range. These measures were encouraging since a large portion of the study area was mapped as one of these forested needleleaf classes. 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 difficult to map due to their high diversity of possible components. In some cases, cover types other than trees dominated the signature of woodland sites. For example, a woodland site could include 40% graminoid cover and just 10% trees, or it could contain

20% trees and 50% shrubs. A great deal of effort was expended in separating these two classes from one another as well as from other similar non-forested sites. The overall producer's error for the woodland needleleaf shrub class was 47%, while the user's error was 100%. This means that this class was "underclassified" in that it kept falling into other classes, yet none of the other classes fell into the woodland earth cover class. The error matrix indicates that only five of the 17 (accuracy = 71%) woodland needleleaf shrub reference sites were mapped incorrectly when allowing for only +/- 5% variation in interpretation of the reference data. This indicates that cover values in several of the reference sites that were not direct matches with the map sites were close to the threshold between two different mapping classes; one of which the map presented for the site. Similar results were found throughout the error matrix. When accounting for those reference sites with cover values close to these class boundaries, consistently high user's and producer's accuracy measures were found (Appendix E: Table 2).

Analysis of the off diagonal sites showed several reasons for their misclassification. In several cases, particularly the dwarf shrub and many of the needleleaf sites, terrain shadow caused these classes to fall into a different category in the classification. For instance, open needleleaf sites on north slopes generally tended to class as closed, while dwarf shrub on the north slopes tended to be sparse vegetation. This problem contributed nearly 10% of the error in the classification. Another problem was the fire regeneration sites, which had very different growth forms than the classification scheme could handle. As can be seen in Figure 11, the aspen in this picture are small, most less than 2 meters in height. This site was classed as low shrub in the image classification, but came out as open aspen shrub in the decision tree (classification scheme).



Figure 11. Short growth form of Aspen.

Three classes that are listed in Appendix D do not appear to meet the minimum requirement for accuracy assessment (at least 15 sites total, 5 for accuracy). Dwarf Shrub Herb originally had 15 sites, but one site was reclassified into another earth cover class due to errors in the field observations. Open Deciduous and Open Low Shrub Herb did have at least 15 sites, but several additional sites from each were required for training. The remote sensing analyst evaluated each class and determined that the accuracy sites would adequately represent the class and would be sufficient for the analysis.

In summary, based on the quantitative accuracy assessment, the earth cover classification map produced for the Southern Lakes project area is very reliable. Nearly 75% of the accuracy assessment sites matched the full detailed 31 mapping classes directly; even when taking no variation in interpretation into account. When as little as +/- 5% variation in interpretation was accounted for, more than eight out of ten (85.6%) of the reference sites were found to correspond correctly with the classified map.

7.4.2 Accuracy Discussion

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.

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. Since the fieldwork occurred in July 2000, only a year after the imagery was acquired on August 1, 1999 the field data was assumed to be valid.

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.

7.5 Final Products

The final products include a digital earth cover classification, a 1987-1999 change detection coverage, a hard-copy map of the entire project area, and a digital database of field data collected for the 479 field sites visited during this project. The digital map was delivered in Erdas Imagine format. Digital photographs of the field sites are stored in .jpg format and can be viewed using the DUFF Data and Photo Viewer ArcView extension (Appendix F). The site photos, field site information and vegetative species lists are stored as digital tables in Dbase IV format, described in Appendix G. 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.

8.0 Summary

The total area mapped in this project was 3.8 million hectares. Classification was performed using Landsat 7 ETM+ satellite scenes, Path 59, Rows 17 and 18 acquired on a cloudless day on August 1, 1999. The project area was classified into 31 earth cover categories with an overall accuracy of 86% at the +/- 5% level of variation in interpretation. The digital database and map of the classification were the primary products of this project along with hard copy maps of the classification, a complete field database including digital site photos, and an ArcView project.

9.0 Addendum

During the review process, a software bug was identified which caused a non-linear distortion of the original imagery used for the Southern Lakes project. The software bug was documented and confirmed by the software vendor. A bug report was filed, and the software vendor attempted a fix with no success after two months. Due to the nature of the non-linear distortion of the image, rubber sheeting could not be applied to correct the error. The remaining solution was to use the original iterative processing files and the original classification to guide a rerun of the classification.

The methods used to rerun the analysis are the same as those described in Section 6.5. The first step was to correct the image distortion by using the orthorectified imagery. This imagery was then processed with a workaround to solve the distortion problem. Then the undistorted image was used as the basis for the classification. The signature files from the old classification were used to train the new classification as part of the iterative process. In cases where the geometric distortion influenced the signature files, the old classification was used to supply additional training sites for the classification. This involved taking random clusters that represented one distinct earth cover class within the old classification. These signatures were buffered by at least five pixels to make sure that the geometric distortion would not influence the new classification. The signatures from these clusters were then combined with the signature files from the old classification to produce the new classification. The iterative process was then rerun and the classification was reassembled.

The undistorted image allowed the field sites to be more accurately registered to the image, producing better separation of spectral clusters and a more accurate classification. Differences between the original and final earth cover classifications are primarily due to the improved spatial registration. In the new classification there were the increases in open and closed mixed needleleaf/deciduous, low shrub lichen,

and aquatic bed vegetation. These classes often occurred in narrow bands between vegetation types, so the improved spatial registration allowed them to be more accurately determined during the iterative process.

After the distortion problem was solved comparison between the original and the final classification showed an improved accuracy from 84% to 86%. Although the original classification appears to be less pixilated than the final classification, this is because many of the edge classes (like low shrub lichen and needleleaf deciduous) were more difficult to isolate using the distorted image. Since these classes were readily separated in the final classification, the new classification is more accurate.

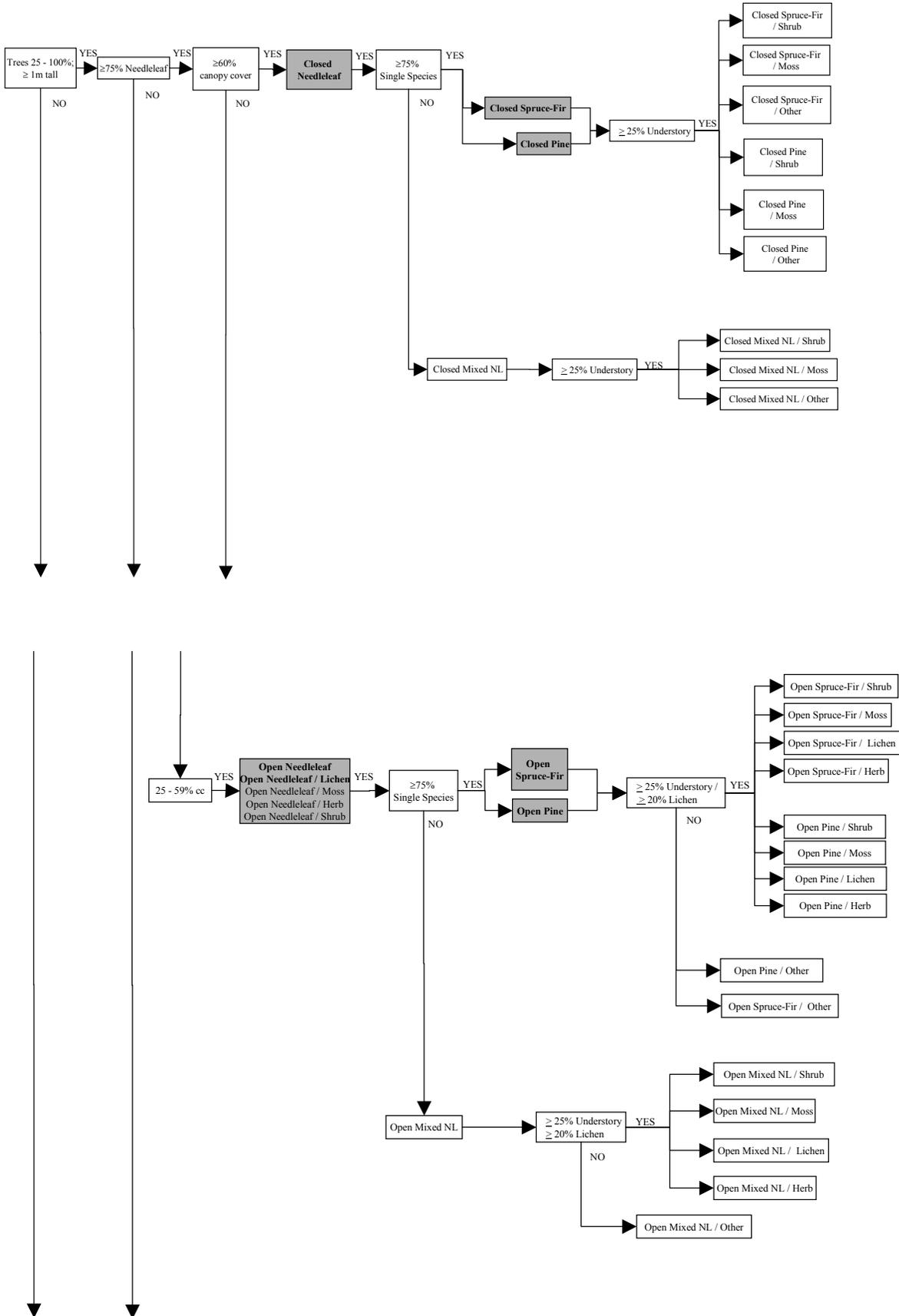
Some manual edits were done on the image for the final classification where errors were indicated by YTG staff. These areas include some of the pixels within deciduous forest classes that were mislabeled as closed low shrub, mixed pixels that occurred in wetland classes, and other minor revisions throughout the image. Also some of the classes were combined for simplicity at the request of YTG staff reviewers. This included combining snow and ice into one class, merging the deciduous classes into two classes (closed deciduous and open deciduous classes), and merging the closed pine class back into the closed needleleaf class. Thus the total number of earth cover classes were reduced from 34 to 31.

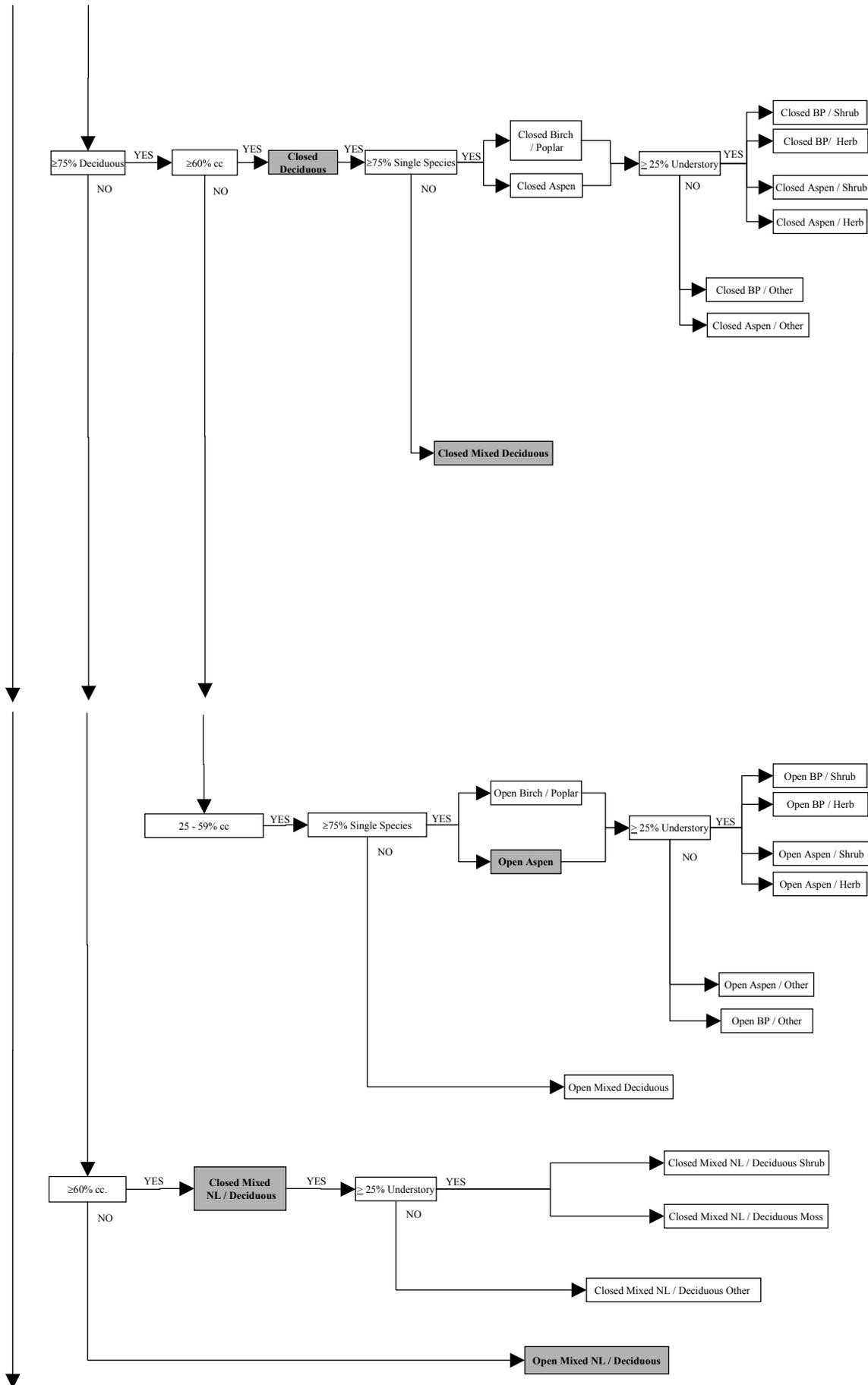
Literature Cited

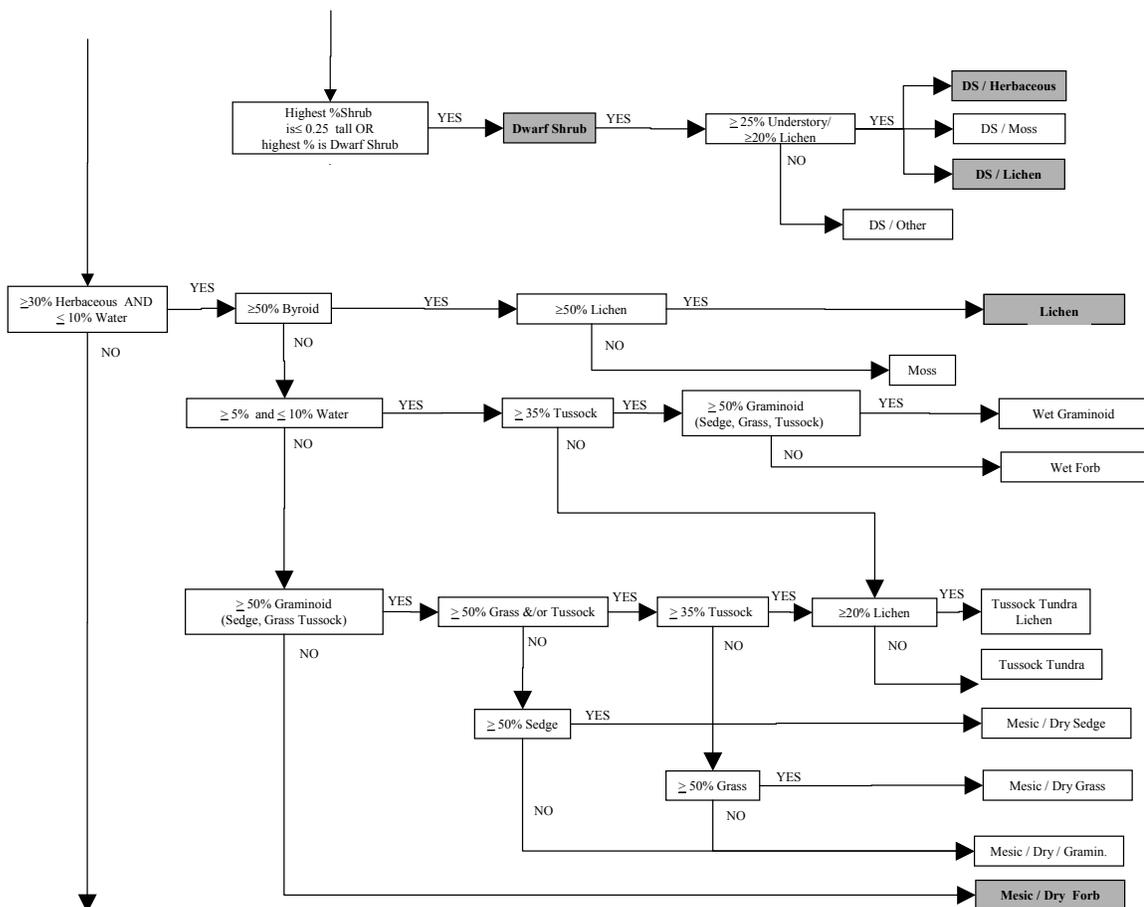
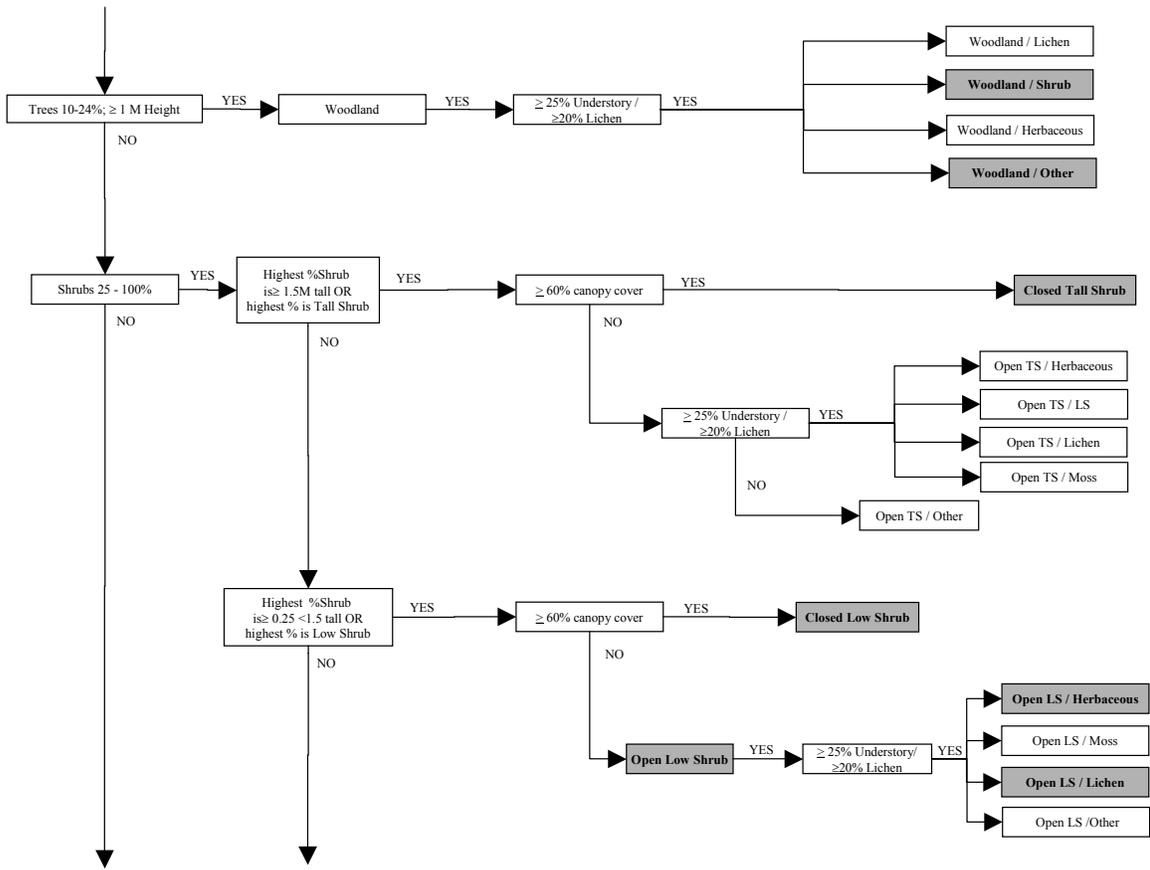
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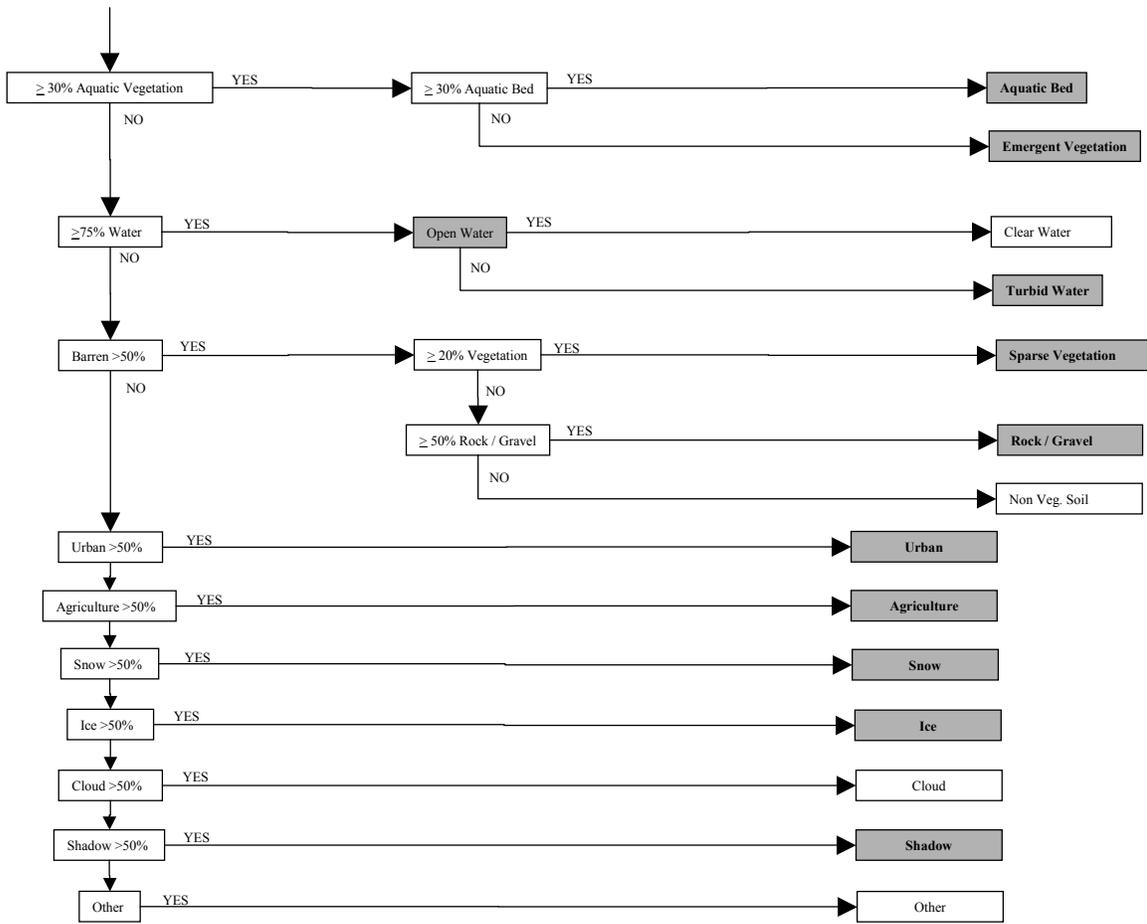
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Appendix A Classification Decision Tree









Appendix B. Southern Lakes Earth Cover Class Descriptions

1.0 Forest

Needleleaf and Deciduous Trees-

The needleleaf species generally found were white spruce (*Picea glauca*) and black spruce (*P. mariana*). White spruce tended to occur on warmer sites with better drainage, and deeper soils while black spruce dominated poorly drained sites with poorer soils. Since the two spruce types were difficult to separate visually from a helicopter, the needleleaf classes included both white and black spruce. Lodgepole pine (*Pinus contorta* var. *latifolia*) was common throughout the interior influenced valleys throughout the project. A wide variety of understory plant groups were present, including low and tall shrubs, forbs, grasses, sedges, horsetails, mosses and lichens.

The deciduous tree species generally found were aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*), and less commonly, paper birch (*Betula papyfera*). Under some conditions willow (*Salix* spp.) and alder (*Alnus incana*) 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 south facing slopes. 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 $\geq 75\%$ of the trees were needleleaf trees. Common distribution throughout image.

1.2 Open Needleleaf

From 25-59% of the cover was trees, and $\geq 75\%$ of the trees were needleleaf. Distributed throughout study area in transitional areas.

1.21 Open Needleleaf/Lichen

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

1.3 Woodland Needleleaf

From 10-24% of the cover was trees, and $\geq 75\%$ of the trees were needleleaf. Very common, highly variable.

1.31 Woodland Needleleaf/Lichen

From 10-24% of the cover was trees, $\geq 75\%$ of the trees were needleleaf, and $\geq 20\%$ of the understory was lichen.

1.4 Closed Deciduous (Mixed Deciduous Species 1.45)

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

1.41 Closed Birch

At least 60% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Paper Birch (*Betula Papyrifera*). Extremely rare distribution.

1.42 Closed Aspen

At least 60% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Aspen. Common throughout study area.

1.43 Closed Balsam Poplar

At least 60% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Balsam Poplar. Rare in pure stands, more common mixed with other deciduous species.

Open Deciduous (Mixed Deciduous Species 1.54)

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

1.51 Open Birch

From 25-59% of the cover was trees, $\geq 75\%$ of the trees were deciduous, and $\geq 75\%$ of the deciduous trees were Paper Birch. No sites were found of this class were found in the study area.

1.52 Open Aspen

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

1.5 Closed Mixed Needleleaf-Deciduous

At least 60% of the cover was trees, but neither needleleaf nor deciduous trees made up $\geq 75\%$ of the tree cover. This class was uncommon but distributed throughout image.

1.7 Open Mixed Needleleaf-Deciduous

From 25-59% of the cover was trees, but neither needleleaf nor deciduous trees made up $\geq 75\%$ of the tree cover. Relatively common.

2.0 Shrub

The tall and low shrub classes were dominated by willow species, dwarf birch (*Betula glandulosa*) and *Vaccinium* species, with alder being somewhat less common. However, the proportions of willow to birch and the relative heights of the shrub species varied widely, which created difficulties in determining whether a site was made up of tall or low shrub. As a result, the height of the shrub species making up the largest proportion of the site dictated whether the site was called a low or tall shrub. The shrub heights were averaged within a genus, as in the case of a site with both tall and low willow shrubs. Tall shrubs generally had a major willow component that was mixed with dwarf birch and/or alder, but could also have been dominated by nearly pure stands of alder. It was found most often in wet drainages, at the head of streams, or on slopes. The low shrub class was found at mid-high elevations. The shrub species in this class were nearly always dwarf birch. 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 25-100% of the cover and shrub height was ≥ 1.5 meters. Very common just above treeline.

2.21 Closed Low Shrub

Shrubs made up 60-100% of the cover, shrub height was .25 - <1.5 meters. Common throughout study area.

2.22 Open Low Shrub/Lichen

Shrubs made up 25 - <60% of the cover, shrub height was .25-1.3 meters, and $\geq 20\%$ of the cover was made up of lichen. Fairly common throughout study area.

2.23 Open Low Shrub/Other

Shrubs made up 25 - <60% of the cover, shrub height was .25-1.3 meters. Very common throughout study area.

2.24 Open Low Shrub/Herb

Shrubs made up 25 - <60% of the cover, shrub height was 0.25 – 1.3 meters, and $\geq 20\%$ of the cover was made up of herbaceous ground cover. Uncommon distribution throughout study area, mainly in coastally influenced alpine regions.

2.31 Dwarf Shrub/Lichen

Dwarf Shrubs made up $\geq 25\%$ of the cover, shrub height was <.25 meters, and $\geq 20\%$ of the cover was made up of lichen. Very common at higher elevations.

2.31 Dwarf Shrub/Other

Dwarf shrubs made up $\geq 25\%$ of the cover, the shrub height is <.25 meters, ground cover is variable. Very common at higher elevations.

3.0 Herbaceous

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

3.11 Lichen

Composed of $\geq 30\%$ herbaceous species, $\leq 10\%$ water, and $\geq 50\%$ lichen species. Not common to find areas dominated by lichen in study area.

3.12 Moss

Composed of $\geq 30\%$ herbaceous species, $\leq 10\%$ water, and $\geq 50\%$ moss species. No sites found of this type in study area.

3.21 Wet Graminoid

Composed of $\geq 30\%$ herbaceous species, $\geq 5\%$ and $\leq 10\%$ water, and where $\geq 35\%$ was tussock forming graminoids and where $\geq 50\%$ of the total was graminoid. Moderately well distributed throughout study area; areas were typically very small sites.

3.34 Mesic/Dry Graminoid

Composed of $\geq 30\%$ herbaceous species, <5% water, with $\geq 50\%$ graminoids, but <35% tussock forming cotton grass. This class was not common and was found generally only at high elevations.

3.35 Mesic/Dry Forb

Composed of $\geq 30\%$ herbaceous species, $< 5\%$ water, with $< 50\%$ graminoids. This class was very rare in the Southern Lakes project area, and many of the areas were reclassified into agriculture, for example.

4.0 Aquatic Vegetation

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

4.1 Aquatic Bed

There was $> 10\%$ water and aquatic vegetation made up $\geq 30\%$ of the cover, and $\geq 30\%$ of the vegetation was composed of plants with floating leaves. This class was uncommon, and spatially limited in distribution. Generally dominated by pond lilies.

4.2 Emergent Vegetation

There was $> 10\%$ water and aquatic vegetation made up $\geq 30\%$ of the cover, and $\geq 30\%$ of the vegetation was composed of hydrophilic plants. Common around ponds, but areas usually very small.

5.1 Clear Water

Composed of $\geq 75\%$ clear water. Common.

5.2 Turbid Water

Composed of $\geq 75\%$ turbid water. Moderately common.

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.

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. Common.

6.3 Non-vegetated Soil

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

7.0 Urban

At least 50% of the area was urban. Included areas of human habitation, e.g. Whitehorse.

8.0 Agriculture

At least 50% of the area was agriculture. This was an uncommon type.

9.0 Cloud/Shadow

At least 50% of the cover was cloud or shadow. The imagery was cloud-free.

9.1 Cloud

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

9.2 Cloud Shadow

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

9.3 Terrain Shadow

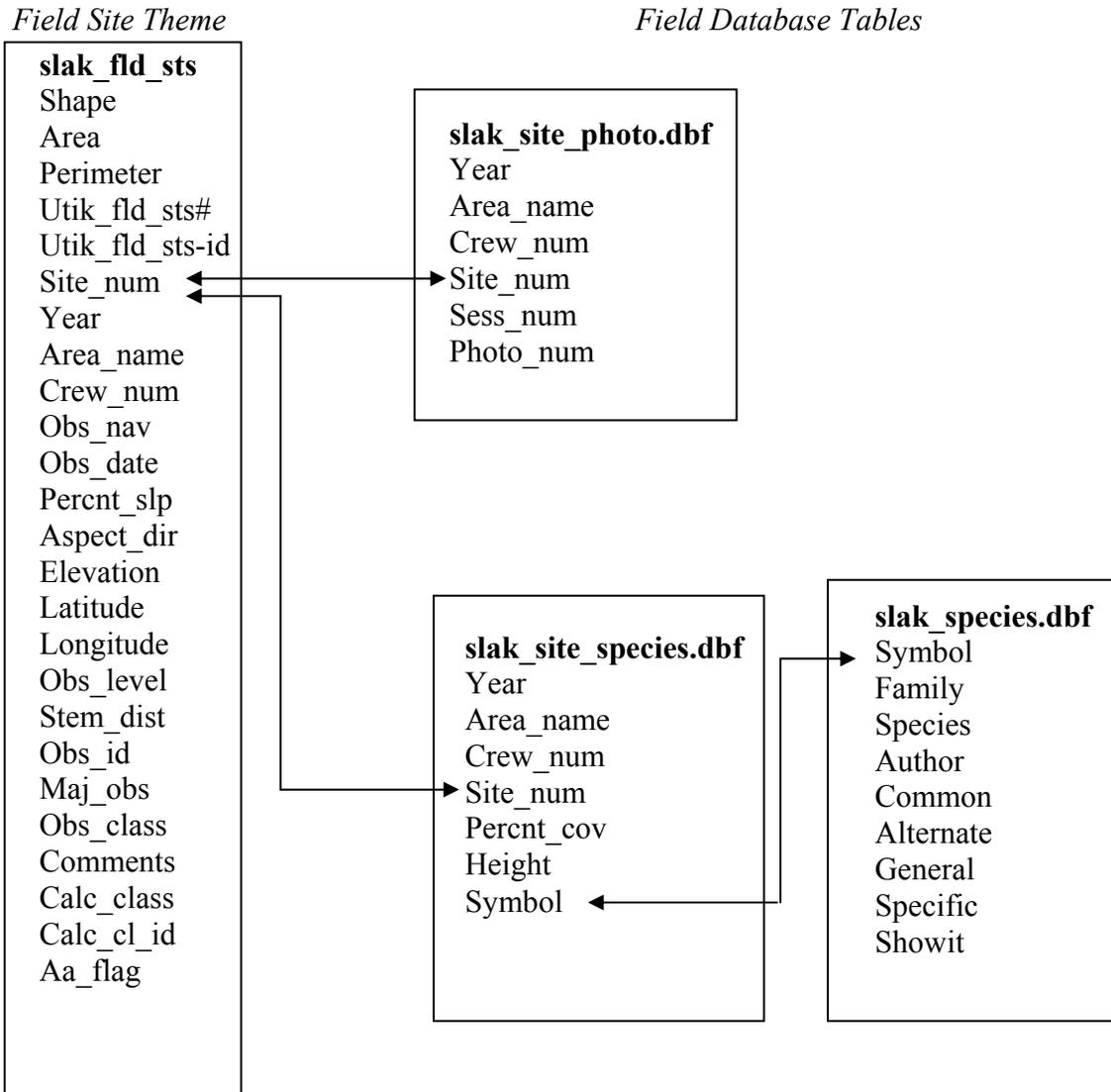
At least 50% of the cover was made up of terrain shadows. Terrain shadows were important in the mountainous areas.

10.0 Other

Sites that did not fall into any other category were assigned to Other. For example, sites with mixed pixels from several different types such as, 25%-80% water, <25% shrub and <30% aquatic vegetation were classed as Other. Sites classed as Other may have also included extensive areas of vegetative litter, such as downed wood.

Appendix C. Structure of the DUFF Field Database

The field database is delivered as a field site polygon coverage and three related .dbf tables. The structure of the related tables is diagrammed below. These tables can be linked in MS Access or linked/joined in ArcView where they can also be related to the field site polygon coverage.



SLAK_FLD_STS (polygon coverage) - ArcInfo coverage of the field sites.

Field	Description
AREA	ArcInfo internal field; area in coverage units
PERIMETER	ArcInfo internal field
COVERAGE	ArcInfo internal field
COVERAGE-ID	ArcInfo internal field
SITE_NUM	Field site number
YEAR	Year of field data collection
AREA_NAME	4 letter code for project area
CREW_NUM	ID number of crew that collected data
OBS_NAV	Navigator for field data collection
OBS_VEG	Vegetation caller for field data collection
OBS_REC	Recorder for field data collection
OBS_DATE	Date of field data collection
PERCNT_SLP	Percent slope of site
ASPECT_DIR	Aspect of site
LATITUDE	Latitude of site (only entered for non-preselected sites)
LONGITUDE	Longitude of site (only entered for non-preselected sites)
OBS_LEVEL	Observation level, where 1 = Observation made from within site, on the ground 2 = Observation made from above site (ie from helicopter) 3 = Observation made from a distance, outside of site 4 = Observation made from aerial photographs
STEM_DIST	Distance between tree stems (applies to Open or Woodland Needleleaf only)
OBS_ID	ID of observed class (ie classification assigned by vegetation caller)
MAJ_OBS	Level 1 class of classification hierarchy (ie forest, shrub, herbaceous, etc)

OBS_CLASS	Classification label assigned by vegetation caller
COMMENTS	Notes made by vegetation caller while observing the site
CALC_CLASS	Classification of site as calculated using the project decision tree
CALC_CL_ID	ID number of calculated class
AA_FLAG	Indicates if site was used as an accuracy assessment site or training data. 0 = site used for training 1 = site used for accuracy assessment

Appendix D. Summary of Final Map Classes

Shows Field Classes that comprise them and the number of Training and Accuracy Sites for each (shaded map classes are included in accuracy assessment, Appendix E).

Final Map (roll-up) Class ¹	Field or Modeled Class ²	Field Sites		
		Training	Accuracy	Total
Closed Needleleaf	Closed Spruce/Fir	16	7	23
	Closed Pine	6	0	6
	Sub-Total	22	7	29
Open Pine	Open Pine Herb	3	0	3
	Open Pine Shrub	7	4	11
	Open Pine Other	8	3	11
	Sub-Total	18	7	25
Open Spruce-Fir	Open Spruce/Fir Herb	5	0	5
	Open Spruce/Fir Moss	11	5	16
	Open Spruce/Fir Shrub	17	7	24
	Open Spruce/Fir Other	2	0	2
	Sub-Total	35	12	47
Open Needleleaf Lichen	Open Needleleaf Lichen	1	0	1
	Open Spruce/Fir Lichen	4	0	4
	Open Pine Lichen	9	0	9
	Sub-Total	14	0	14
Open Needleleaf	Open Needleleaf Herb	3	0	3
	Open Needleleaf Shrub	2	0	2
	Open Needleleaf Other	1	0	1
	Sub-Total	6	0	6
Closed Mixed Needleleaf/Deciduous	Closed Mixed Needleleaf/Deciduous	1	0	1
Open Mixed Needleleaf/Deciduous	Open Mixed Needleleaf/Deciduous	13	0	13
Open Deciduous	Open Aspen Shrub	8	2	10
	Open Aspen Other	1	1	2
	Open Birch/Poplar Shrub	0	1	1
	Open Birch/Poplar Herb	1	0	1
	Open Mixed Deciduous	2	0	2
	Sub-Total	12	4	16
Closed Deciduous	Closed Aspen	6	0	6
	Closed Mixed Deciduous	4	0	4
	Sub-Total	10	0	10
Woodland Needleleaf Shrub	Woodland Needleleaf Shrub	36	17	53
Woodland Needleleaf Other	Woodland Needleleaf Lichen	5	0	5
	Woodland Needleleaf Herb	1	0	1
	Woodland Needleleaf Other	3	0	3
	Sub-Total	9	0	9

Appendix D cont.

Final Map (roll-up) Class	Field or Modeled Class	Field Sites		
		Training	Accuracy	Total
Tall Shrub	Closed Tall Shrub	15	4	19
	Open Tall Shrub Herb	3	1	4
	Open Tall Shrub/ Low Shrub	3	1	4
	Open Tall Shrub Lichen	2	0	2
	Open Tall Shrub Other	9	3	12
	Sub-Total	32	9	41
Closed Low Shrub	Closed Low Shrub	13	6	19
Open Low Shrub	Open Low Shrub Other	18	11	29
Open Low Shrub Herb	Open Low Shrub Herb	12	3	15
Open Low Shrub Lichen	Open Low Shrub Lichen	12	0	12
Dwarf Shrub Other	Dwarf Shrub Other	24	13	37
Dwarf Shrub Herb	Dwarf Shrub Herb	10	4	14
Dwarf Shrub Lichen	Dwarf Shrub Lichen	19	8	27
Lichen	Lichen	2	0	2
Mesic/Dry Forb	Mesic/Dry Forb	2	0	2
Aquatic Bed	Aquatic Bed	0	0	0
Emergent Vegetation	Emergent Vegetation	4	0	4
Clear Water	Clear Water	4	0	4
Turbid Water	Turbid Water	0	0	0
Sparse Vegetation	Sparse Vegetation	10	5	15
Rock/Gravel	Rock/Gravel	19	9	28
Urban	Urban	0	0	0
Agriculture	Agriculture	0	0	0
Snow/Ice	Snow/Ice	0	0	0
Shadow	Shadow	0	0	0
	Non Vegetated Soil	1	0	1
	Other	6	0	6
	TOTAL	364	115	479

1. Map classes are often comprised of (i.e. a roll-up of) more than one field class, where confusion between field classes was significant.
2. Field classes are those identified in the field, but also includes those readily mapped through modeling.

Appendix E. Accuracy Assessment

Table 1. Error Matrix at 0% Variation

Classified Data		Reference Data																Sum	User's Accuracy (error of commission)
		1	3	4	5	7	9	10	12	13	14	15	17	18	19	27	28		
Closed Needleleaf	1	5						1										6	83.3%
Open Needleleaf Lichen*	3		0		1			1										2	N/A
Open Spruce	4			12				1					1					14	85.7%
Open Pine	5	1			5													6	83.3%
Open Mixed N/D*	7	1				0			1									2	N/A
Open Deciduous	9				1		4											5	80.0%
Woodland Ndlf. Shrub	10							8										8	100.0%
Tall Shrub	12							4	7		1							12	58.3%
Closed Low Shrub	13							1		6								7	85.7%
Open Low Shrub	14								1		9		1	2				13	69.2%
Open Low Shrub Herb	15											3						3	100.0%
Dwarf Shrub Other	17												7		1			8	87.5%
Dwarf Shrub Lichen	18										1			6				7	85.7%
Dwarf Shrub Herb	19														3			3	100.0%
Sparse Vegetation	27												4				4	8	50.0%
Rock/Gravel	28							1									1	9	81.8%
	Sum	7	0	12	7	0	4	17	9	6	11	3	13	8	4	5	9	115	
Producer's Accuracy (error of omission)		71.4%	N/A	100.0%	71.4%	N/A	100.0%	47.1%	77.8%	100.0%	81.8%	100.0%	53.8%	75.0%	75.0%	80.0%	100.0%		Overall Accuracy: 76.5%
Total Number of Sites	115																		
Diagonal Sum	88																		
Off-diagonal Sum	27																		
Overall Accuracy	76.5%																		

* Denotes mapped classes that accuracy sites from other mapped classes fell into due to error of commission. These classes were therefore included in the error matrix, but no accuracy assessment was done for these two classes.

Table 2. Error Matrix at +/- 5% Level of Variation

Classified Data		Reference Data															Sum	User's Accuracy (error of commission)	
		1	3	4	5	7	9	10	12	13	14	15	17	18	19	27			28
ClosedNeedleleaf	1	5						1										6	83.3%
Open Needleleaf Lichen*	3		0		0			0										0	N/A
Open Spruce	4			12				1					0					13	92.3%
Open Pine	5	1			6													7	85.7%
Open Mixed N/D*	7	1				0			1									2	N/A
Open Deciduous	9				1		4											5	80.0%
Woodland Ndlf. Shrub	10							12										12	100.0%
Tall Shrub	12							2	7		1							10	70.0%
Closed Low Shrub	13							1		6								7	85.7%
Open Low Shrub	14								1		9		1	1				12	75.0%
Open Low Shrub Herb	15											3						3	100.0%
Dwarf Shrub Other	17												11		1			12	91.7%
Dwarf Shrub Lichen	18										1			7				8	87.5%
Dwarf Shrub Herb	19														3			3	100.0%
Sparse Vegetation	27												1			5		6	83.3%
Rock/Gravel	28							0									0	9	100.0%
Sum		7	0	12	7	0	4	17	9	6	11	3	13	8	4	5	9	115	
Producer's Accuracy (error of omission)		71.4%	N/A	100.0%	85.7%	N/A	100.0%	70.6%	77.8%	100.0%	81.8%	100.0%	84.6%	87.5%	75.0%	100.0%	100.0%		Overall Accuracy: 86.1%
Total Number of Sites	115																		
Diagonal Sum	99																		
Off-diagonal Sum	16																		
Overall Accuracy	86.1%																		

* Denotes mapped classes that accuracy sites from other mapped classes fell into due to error of commission. These classes were therefore included in the error matrix, but no accuracy assessment was done for these two classes.

Appendix F. DUFF Data and Photo Viewer Extension

Installation and “How to Run” the Extension, Version 1.0
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Installation and Requirements

Requirements:

1. ArcView 3.1 or 3.2 with the Dialog Designer extension. (NOTE: The Dialog Designer extension comes with ArcView 3.1 and 3.2.)
2. It is assumed that the machine on which the extension is to be run has the environmental variable \$AVHOME set to the directory where ArcView is located. The environmental variable \$AVEXT should also be set to the Ext32 directory where ArcView is located.
3. The structure of the field data is important. The following directories must be at the same directory level:

.\arccovs
\photos

where the photos are set up under the photos directory as shown in the following example:

.\photos\2000-SLAK-1\0806\sess1\0806_001.jpg
(where SLAK is the 4 letter project code, 0806 is the month/day, and 001 is the photo number)

Installation:

1. Copy the duff.avx file to the ArcView extension directory (Ext32). Generally this directory is located at c:\esri31\AV_gis30\Arcview\Ext32. If the user has set the \$USEREXT variable to another location, the extension can be placed there since ArcView will look in that directory for all extensions.
2. Open a new ArcView session, go to File -> Extensions, and turn on the DUFF Data and Photo Viewer extension.

Using the DUFF Data and Photo Extension:

1. As described under Installation, make sure the DUFF Data and Photo Viewer extension is turned on in ArcView.
2. Load the slak_fld_sts coverage from the /arccovs directory into a view, where slak is the project abbreviation (Ex: SLAK for Southern Lakes).
3. Load the three .dbf files from /arccovs into the ArcView project. To do this, click on the Tables icon in the Project Menu and then click Add. You will be prompted to enter the .dbf files to be loaded. The three .dbf files are slak_site_species.dbf, slak_species.dbf, and slak_site_photo.dbf.
4. Once the DUFF Data and Photo Viewer extension is turned on, the following buttons/tools will appear on the ArcView menu bars:



the DUFF Info Tool can be used to access the field info from a selected site.



the DUFF Photo tool can be used to view the field photos related to a selected field site.



the DUFF Inquiry button can be used to query the field database according to user specified criteria.

Steps to run the Inquiry Button:

NOTE: Due to a bug in the program, you must deselect all sites before using the Inquiry Button. If you have sites selected when you use the Inquiry Button, no sites will be returned in response to your inquiry. We hope to correct this error in the near future. –Ducks Unlimited, Inc.

1. Select a way of identifying up to 3 species: 4 letter code (Symbol), Common Name, or Scientific Name.
2. Select the type of physical parameter(s) to examine for a single species: either percent cover or height or both.
3. Select a mathematical operator for the physical parameter to examine. Note this is specific to each species selected.
4. Determine if specific sites are to be compared. If only certain sites are to be examined, select yes. Next, select a field with which the DUFF field site theme will be queried. Finally, select a value to use as a limiter. This inquiry may run a long time due to large numbers of records being chosen.

Limitations of the DUFF Data and Photo Viewer Extension

1. If there is more than one view in the ArcView Project, the user will have to identify which view contains the field site theme.
2. The field site theme must be named with the same project name as the tables. (ie for the Southern Lakes project: slak_fld_sts, slak_species.dbf, slak_site_species.dbf, slak_site_photo.dbf.)
3. To sort the species box, the user needs to click on the column which they want sorted.
4. DUFF Photo tool looks specifically for .jpg files, not .jgw files.
5. If sites are currently selected when you use the Inquiry Button, no sites will be returned in response to your query regardless of the query. This is due to a bug in the program. To avoid this problem, deselect all sites before using the Inquiry Button. – added by Ducks Unlimited, Inc.

Appendix G. Field Site Attribute Tables and Field Descriptions

SLAK_SITE_PHOTO.dbf Dbase file containing site photo information

YEAR	Year of field data collection
AREA_NAME	4 letter code for 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 (ie each site may have multiple photos).
SESS_NUM	Session number for field data collection.
PHOTO_NUM	Photo number. Photos are numbered consecutively within each session.

SLAK_SPECIES.dbf - The data in the following table are based on the PLANTS National Database developed by the National Resource Conservation Service. Edits have been made to some species codes to facilitate the use of the data with the DUFF data entry program. Also species have been added to the list (and a species code created) as necessary when compiling field data.

SYMBOL	Species code. Most of these are from the PLANTS National Database. When new species were added to the field database, a code was created to represent it.
FAMILY	Plant family.
SPECIES	Plant genus and species (or in some cases genus only)
AUTHOR	Author citation for species information.
COMMON	Common name.
ALTERNATE	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.
SHOWIT	Internal field used by the DUFF program.

SLAK_SITE_SPECIES.dbf - Dbase table 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	4 letter code for 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. Each site may have multiple species records in this table.
PERCNT_COV	Percent coverage of the species as observed at site by vegetation caller.
HEIGHT	Height of tree or shrub species at site as observed by vegetation caller.